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Making Plug & Play PV Systems A Reality:

A framework for driving down the cost of residential solar installations in the United States

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1 Introduction

This white paper describes a framework to enable the broad-based adoption of Plug & Play PV Systems. This Plug & Play PV Framework is built around a standardized set of electronic permitting, inspection and interconnection (PI&I) processes, data exchange protocols, and self-test capabilities that, in combination, can significantly reduce the cost and time associated with the installation and commissioning of residential PV systems. The initial scope of the Plug and Play PV Framework applies to residential, rooftop mounted, grid-connected systems rated up to 10kW AC. The intended audience for this paper is key decision makers within the PV community, such as PV component vendors, jurisdictional authorities, utilities, installers, code inspectors, and policy makers, with a goal of communicating the vision for the Plug & Play PV framework, and generating support for the formation of a collaborative industry alliance focused on realizing this vision.

The body of this paper is organized as follows: Section 2 defines the key elements of the electronic PI&I process that forms the heart of the Plug & Play PV framework, and identifies two critical enablers for scalable deployment of Plug & Play PV Systems – (1) a means for electronically verifying that a PV System installation is code compliant, and (2) a set of standardized protocols for electronically communicating key information in the PI&I process. The next two sections detail how these two enabling elements are implemented, with Section 3 introducing a Plug & Play PV System Standard that enables electronic proof of compliance, and Section 4 introducing the Plug & Play Data Exchange Protocol.

2 From Factory to Rooftop: An Electronic Process for Permitting, Inspection, and Interconnecting Residential PV Systems

The *Plug & Play Electronic Permitting, Inspection, and Interconnection (ePI&I) Process*, outlined in Figure 2-1, uses modern data models and electronic information exchanges to address the key shortcomings of traditional PI&I processes – notably cost, delays, uncertainty, and limited scalability. This proposed framework builds on an existing body of work that has been developed in a number of jurisdictions and utilities, most notably in California, to expedite permitting and interconnection applications in several key respects: (1) it is designed to be flexible enough to scale broadly across AHJs and utilities with varying regulatory requirements and acceptance of electronic workflows; (2) it integrates data from all Actors (I.e., AHJs, Utilities, Installers, Manufacturers, Homeowners, etc) within a common framework; (3) it implements electronic self-verification of PV systems (an "electronic code inspection"); and (4) it uses structured data to facilitate communication and integration with client workflow packages. A detailed comparison of a traditional PI&I process to the ePI&I process is included in Appendix B.

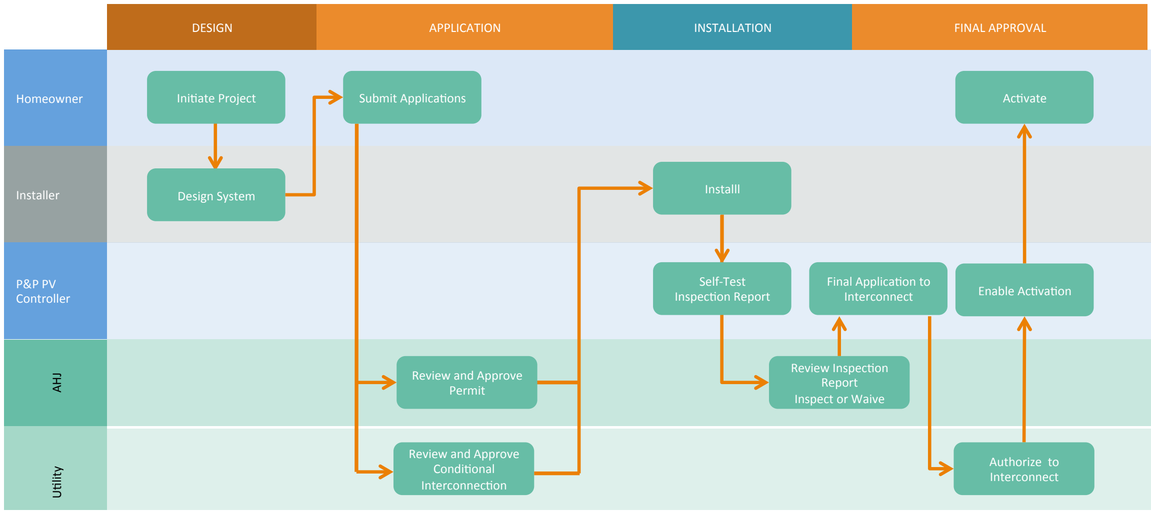

Figure 2-1: The Plug & Play Electronic Permitting, Inspection, and Interconnection (ePI&I) Process

Relative to a traditional PI&I process, as commonly adopted in the US, the ePI&I process is enabled by two key innovations:

(1) **An electronic "proof of compliance" framework:** As shown in Figure 2-1, onsite inspection and communication of an installed Plug & Play PV System is executed by a "Plug & Play PV System Controller" – a supervisory controller that provides an interface between an installed system and the outside world, and that has the ability to conduct an "electronic code inspection". The electronic proof of compliance framework enables a field-installed PV System to conduct such a self-verification, supported by limiting the complexity of Plug & Play PV Systems through pre-defined constraints defined within a Plug & Play System certification standard. This combination of authenticated self-verification coupled with limitations on the complexity of system design and installation enables approval authorities to remotely review and issue approvals. This electronic proof of compliance framework is outlined in Section 3.

(2) **A standardized Data Exchange Protocol.** The Data Exchange Protocol defines the actual data content and network infrastructure for transacting data between Actors at each stage in the ePI&I process. It is outlined in detail in Section 4.

3 Proof of Compliance

3.1 Introduction: A Framework For Electronic "Proof of Compliance"

Conceptually, an electronic protocol for assessing code compliance of an installed PV system has two key requirements - the first is that it have the ability to *self-verify* that it complies with applicable code (i.e., it must have the ability to perform an "electronic code inspection"), and the second is that it have the ability to *communicate remotely with the external Approval Authority*, both to provide self-test results, and to secure appropriate approvals prior to energizing.

In more concrete terms, these electronic proof of compliance requirements are defined in a Plug and Play PV System Standard, which enables a methodology whereby (1) Plug & Play PV Systems are designed and certified *as a system* to comply with the Plug & Play PV System Standard – and in particular, to verify that the System can reliably detect and communicate compliance with NEC; and (2) a PV System executes a standardized "electronic code inspection" when first commissioned to verify that the system has been properly assembled and approved by relevant Approval Authorities prior to energizing. This framework for proof of compliance is summarized in Figure 3-1.

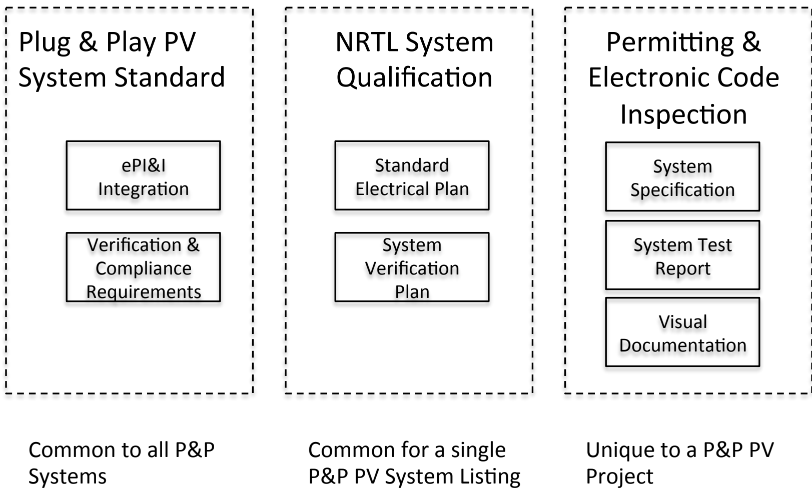

Figure 3-1: A framework for electronic proof of compliance

3.2 Standardizing Requirements: What is a Plug & Play PV System?

The requirements for certifying a PV System as a Plug & Play PV System are defined by the Plug & Play PV System Standard.[1] The Plug & Play PV Standard defines two broad categories of requirements: (1) compliance and verification requirements; and (2) ePI&I integration requirements. Development of these requirements was based on a comprehensive review of the National Electric Code,[2] as well as code inspection and permitting best practices.[3]

Compliance & Verification Requirements: The compliance and verification requirements are defined by the *Master Inspection Checklist* – a standardized, comprehensive list of requirements that a Plug & Play PV System must both satisfy *AND* verify that it satisfies prior to energizing. A snapshot of the Master Inspection Checklist is included in Appendix D. The individual requirements within the Master Inspection Checklist reflect a number of considerations, including:

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[1] Please contact Fraunhofer CSE for a draft of the Plug & Play PV Standard documentation

[2] NFPA 70, NEC 2014.

[3] For example, the California Solar Permitting Guidebook provides AHJs a standardized framework for expediting the permitting process. We have attempted to leverage these types of initiatives to inform (1) constraints on Plug & Play PV System Design, and (2) standardized information exchanges and review requirements. http://opr.ca.gov/docs/California_Solar_Permitting_Guidebook.pdf

- **Compliance with the NEC:** The Master Inspection Checklist is structured as a checklist of component- and system-level requirements that collectively constitute a sufficient set of conditions for a PV system to be NEC-compliant.
- **Limitations on PV System complexity to facilitate Proof of Compliance:** For example, a Plug & Play PV System is expected to use listed connectors to complete all field-assembled electrical connections within a system, and is limited to a maximum of three strings (for DC-bus/string inverter systems), or three branch circuits (for microinverter systems).
- **Constraints on the size and application of Plug & Play PV Systems to residential PV systems:** The Plug & Play PV Standard is constrained to apply to grid-Interactive PV Systems, rated to less than 10kW AC, with a nominal output voltage of 120/240VAC split-phase, and a maximum DC Voltage rating of 600VDC, as defined in NEC Article 690.
- **Verification of Approved Plans:** The Master Inspection Checklist requires a PV System to verify that its “as-built” configuration matches the “as-designed” configuration specified in the initial Permitting and Interconnection Application Submittals.

Integration into the Plug & Play ePI&I Process: The second portion of the Plug & Play PV System Standard defines requirements for how a Plug & Play PV System integrates into the Plug & Play ePI&I process. These requirements include implementation of a Plug & Play PV System Controller[4] that:

- Executes the ePI&I Data Exchange Protocol, discussed in Section 4.
- Performs a standardized commissioning protocol with the rules for how and when a Plug & Play PV System secures approvals and energizes itself. The commissioning protocol is described in detail in Section 3.4.

3.3 NRTL Certification of a Plug & Play PV System Design

Compliance with the Plug & Play PV System Standard is ensured through a certification testing process for a PV System *as a system* by a Nationally Recognized Test Laboratory (NRTL). From the perspective of the PV system design, qualifying “as a system” requires that a Plug & Play PV system be designed to work only with specific components arranged in a pre-specified set of valid configurations. In addition, it requires the incorporation of a supervisory controller (the Plug & Play PV System Controller) that integrates within the ePI&I process per the requirements of the Plug & Play PV System Standard. These requirements are formalized through the definition of two pieces of documentation, submitted as part of the certification process: a PV System Standard Electrical Plan, and a PV System Verification Plan.

PV System Standard Electrical Plan: The PV System Standard Electrical Plan is an annotated description of the electrical system, including a Reference Single Line diagram, that fully specifies the range of valid system configurations for the specific PV System to be certified. The

[4] The Plug & Play PV System Controller will typically be implemented as a software stack running on an inverter controller, or monitoring hardware.

requirements for the Standard Electrical Plan are defined within the Data Exchange Protocol data model. The Standard Electrical Plan is one of several data models that is used to characterize a PV System in a standardized, structured, electronic format. A more detailed description of these PV System data models is included in Appendix C.

PV System Verification Plan: The PV System Verification Plan is a system-specific proposal that identifies *how* each requirement in the Master Inspection Checklist is met and verified. While the Plug & Play PV System Standard does not specify how a requirement is met, three different verification *approaches* are recognized:

1. **Verification by Design** relies on an intrinsic design characteristic of the PV System to ensure that a specified Master Inspection Checklist requirement is satisfied. *Verification by design* includes, for example, elimination of exposed metal from electrical system components to eliminate the need for equipment grounding conductors, or use of a keyed connector that implies a specific type of cable assembly has been used.
2. **Verification by Electrical Self-Test** relies on an electrical self-test during the commissioning process – i.e., after installation, and prior to submission of an Inspection Submittal Package. *Verification by electrical self-test* includes, for example, mapping of an as-built array to determine that the number of PV modules in a DC string or AC Modules in a branch circuit are within specified limits (e.g., max string voltage or max branch circuit current).
3. **Verification by Visual Inspection** relies on either (i) remotely submitted visual documentation (e.g., photographs) or (ii) onsite inspection to demonstrate compliance.
    a. A requirement met by remotely submitted visual documentation requires a Plug & Play PV System to provide, as part of its Inspection Submittal package, time and location-stamped photographs to provide evidence that the system has been installed correctly from a mechanical perspective. As a guiding principle, visual documentation is expected primarily to validate factors such as workmanship.
    b. Depending on the particulars of both the PV System and the AHJ, certain requirements within the Master Inspection Checklist may require verification through onsite inspection[5] – for example, connection to the premises electrical wiring if no standardized method has been used.[6]

Broadly speaking, the NRTL certification process then verifies that the system to be certified meets the following criteria:

- It satisfies the compliance and verification requirements defined by the Master Inspection Checklist
- It is compatible with the ePI&I Data Exchange Protocol

[5] While the ultimate ambition for Plug & Play PV Systems is to eliminate the need for such onsite inspections, substantial simplification of the ePI&I process is achievable by vastly reducing the scope of the onsite inspection – even if it is not fully eliminated.

[6] For additional discussion of premises wiring in general, and the Solar Connection Device (SCD) in particular, refer to the Plug & Play PV Standard.

- It implements the commissioning protocol requirements associated with the electronic code inspection process
- As applicable, it is compatible with a qualified Solar Connection Device (SCD) for connection to premises wiring.[6]

The actual qualification test protocol consists of first conducting a comprehensive audit of the design submittals to ascertain consistency and completeness. This is followed by an assessment of a field-installed system to ascertain that the system performs as specified. The field assessment consists of a comprehensive set of experiments to ascertain the system's ability to function properly across the system's full design envelope, and, conversely, to verify that the system does not function if this design envelope is violated.

3.4 Electronic Code Inspection

The final part of the framework for electronic proof of compliance is the electronic code inspection. The role of the electronic code inspection within this framework is to validate that a Plug & Play PV System has in fact been installed correctly, and to verify that proper approvals are in place prior to energizing.

The first time a Plug & Play PV System starts up, it executes a commissioning protocol that navigates a defined sequence of steps prior to energizing:

- On initial startup, the system enters an idle state in which DC conductors are not energized and the system does not export any power.
- The system begins the commissioning process by connecting with the Plug & Play Server network (discussed in Section 4), which links the installed system to a pending Project submittal (i.e., permitting and interconnection submittal package);
- Following successful registration, the PV System conducts a code-compliance self-test and functional self-test according to the PV System Verification Plan.[7] As part of the self-test, the PV System may temporarily energize conductors to verify component functionality.
- Following successful completion of the self-test, the results are assembled along with other applicable documentation (e.g., visual documentation) into a Final Submittal Package and routed to the relevant AHJ and Utility.
- When the system receives both its approved Inspection Certificate and Final Approval to Interconnect, it prompts the Installer for permission to energize the system. With the Installer's acknowledgement, the PV System completes the commissioning protocol by energizing and beginning to export power.

[7] A "functional self-test" is a system-specific set of tests intended to verify that system components are functioning correctly (e.g., checking that PV module or string voltages are within a defined tolerance). In contrast, the "code compliance self-test" is intended to verify that system components have been installed in a code-compliant fashion.

Each step in the commissioning process is associated with rules as to whether conductors are energized, and whether the system can export power, as summarized in Table 3-1.

Table 3-1: Commissioning Protocol States

System State	P&P Controller Actions	AC V	DC V	Pwr Out
Initial Startup	System registration	240V	0V	0W
System Registered	Initiate self-test	240V	600V	0W
Functional Self-Test Complete	Transmit inspection results	240V	0V	0W
Regulatory Approvals Received	Prompt Installer for final activation	240V	0V	0W
Installer Approval Received	Energize system	240V	600V	Up to 10,000W

4 Data Exchange Protocol

4.1 Introduction

This section outlines the Data Exchange Protocol for exchanging information between Actors within the Plug & Play ePI&I process. The Data Exchange Protocol defines (1) the high-level network architecture used to transmit data between Actors with the purpose of processing an ePI&I Project, and (2) the structure and content of these data exchanges. These two components of the Data Exchange Protocol facilitate widespread adoption of the ePI&I framework by addressing key requirements:

Integration: It integrates information exchanges with all relevant stakeholders, including Installers, AHJs, utilities, Homeowners, and certification agencies.
Completeness: It is designed to fully capture the suite of information that is commonly required by approval authorities – Utilities and AHJs – and users throughout a Project lifecycle.
Flexibility: It is robust and configurable enough to capture a range of use cases, including different processes, different types of PV systems, varying levels of integration with electronic workflow tools, and varying requirements regarding scope and presentation of the information.
Security: It segments and restricts access to sensitive data, and minimizes exposure should a security breach occur.
Simplicity: It (1) shields Actors from the complexity of interfacing with multiple Actors and varying requirements; (2) provides transparency to Actors, both with respect to Project status and Project information; (3) clearly communicates requirements for and verifies the completeness of information exchanges; and (4) standardizes, authenticates, and reuses information that is common across Projects, thereby eliminating redundancy.

4.2 Data Exchange Protocol - Network Architecture

A block diagram of the Data Exchange Protocol network architecture is shown in Figure 4-1. As shown, information exchanges are transacted between Actors using the public internet or VPN channels with a cloud-based Plug & Play PV Server. The Plug & Play PV Server serves three key functions: (1) It routes information between Actors; (2) It maintains a database of information relevant to the ePI&I process – e.g., Project Information, System Certification information, and user profiles for different Actors; and (3) It implements the security layers required to restrict access to data.

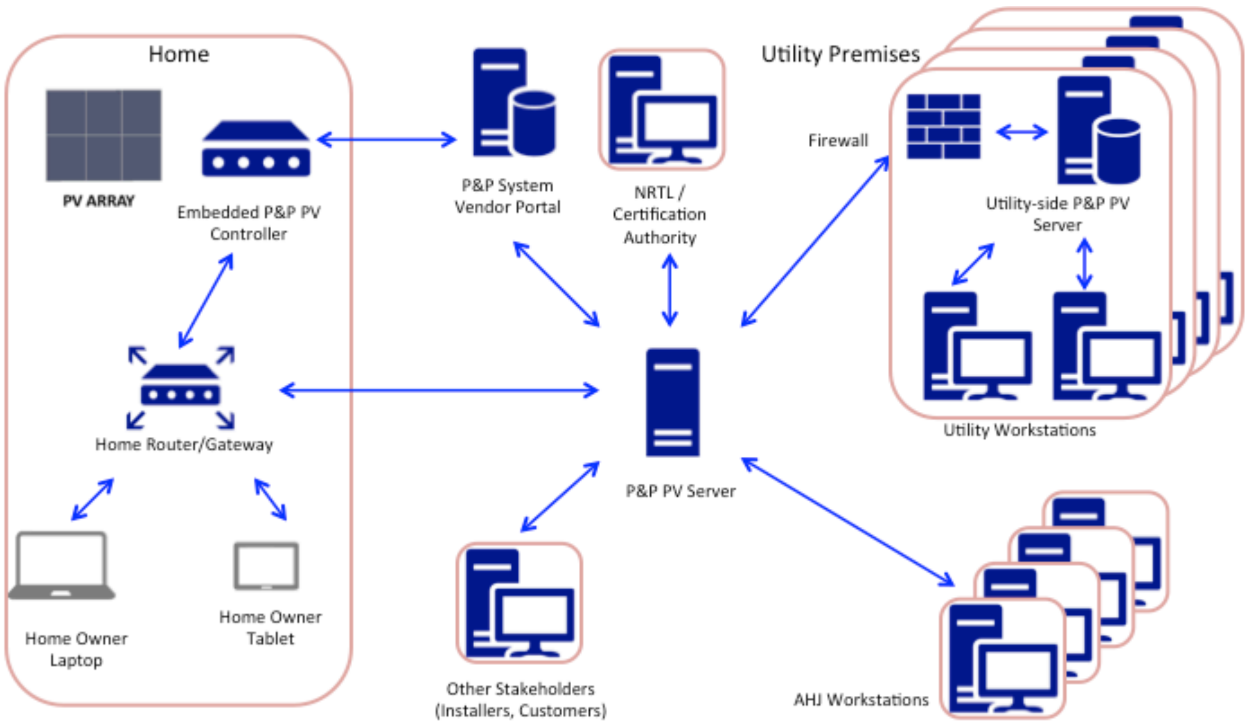


Figure 4-1: Plug & Play PV Network Infrastructure

Routing of Information: The Server's routing function serves multiple purposes. First, by centralizing the routing function of the electronic information exchanges, the Plug & Play Server enables each Actor within the Plug & Play eco-system to only interface with a single entity. In so doing, the Server handles the complexity of interfacing between thousands of AHJs, Utilities, and OEMs. For example, an OEM need only design software to interact with Server, which can then serve this information to other Actors according to their particular requirements. Also, a Utility or AHJ user can establish a profile on the server at the time of a Plug & Play PV program rollout that defines the parameters for their specific approval process: i.e., the specific process steps, data requirements, and presentation format.
Another key aspect of this routing function is that the Plug & Play PV Server can interface with Actors in multiple ways:

- **3rd-party software integration:** the Data Exchange Protocol and network architecture are designed to readily integrate with utility workflow packages, AHJ workflow packages, PV System supervisory control software, and OEM- or Installer-oriented system design tools through the use of structured, standardized data schemas.[8]

[8] The baseline implementation uses a JSON-based schema that follows the REST protocol, but it is configurable to interface with multiple industry-standard protocols.

- **Web-based interface:** the Plug & Play Server offers an interface from which users can retrieve or provide Project information, or create/modify user Profiles. This web-based interface is critical for facilitating adoption with users that do not use 3rd party software. For Utility and AHJ users, this web-based interface is, within certain constraints, configurable.
- **Email-based notifications**: Finally, the Plug & Play PV Server is designed to provide email notifications to keep Actors apprised of changes in Project status.

Finally, the Plug & Play Server provides an initial validation layer between Actors insofar as it: (1) verifies messages validity at the protocol layer; (2) verifies that all required information has been submitted prior to notifying stakeholders; and (3) authenticates credentials of Actors. That said, it should be emphasized that the function of the Server specifically does not extend to validating *the content* of message payload.[9]

Plug & Play Data Repository: The second core function of the Plug & Play PV Server is to maintain a relational database of core information relevant to the Plug & Play ePI&I Process. This core information falls into three broad categories, as shown in Figure 4-2: (1) Project Information – i.e., information that is specific to Plug & Play PV Installations (either in process or completed); (2) User Profiles – i.e., account information for specific Actors who are involved in one or more Projects; and (3) Certification Information – i.e., authenticated information regarding Plug & Play PV System certifications. The database is designed to manage data access permissions by classes of Actors. The motivation for this database structure is that it provides a mechanism for Actors to store and access authenticated information throughout the ePI&I process for a particular Project (i.e., Project information), and to reuse authenticated information that is common across Projects (i.e., Actor profiles and system certification information) – thereby both increasing transparency and simplifying the process.

[9] While the Server is designed to have limited ability to check that a submittal meets basic PV System constraints (i.e., "range checks"), validating code compliance is performed primarily by the combination of (1) NRTL certification process; (2) PV System startup tests; and (3) AHJ-review of permitting and inspection submittal packages

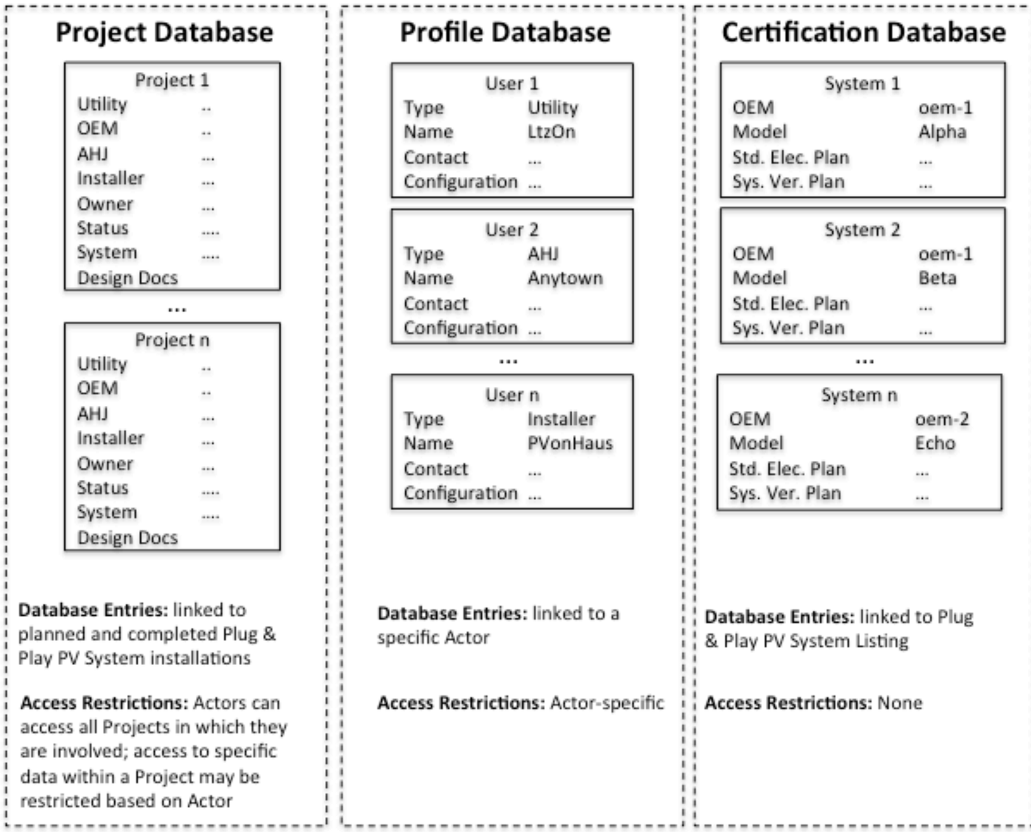


Figure 4-2: Plug & Play Server database architecture

Security Model: The third core function of the Plug & Play PV Server is to maintain the integrity of data as it is stored on the Server and transacted between Actors. This security model is implemented using a portfolio of techniques that are designed to (1) minimize the likelihood that a security breach compromises data; and (2) limit the impact of a security breach if data is comprised:

- **Secure Transactions:** Information is transacted between Actors over the public internet or VPN using industry-standard encryption and authentication protocols to maintain integrity of transactions.
- **Data Restrictions:** Both the database structure and Data Exchange Protocols are designed to restrict access to data only to authenticated users who have authorization and reason to access the data.
- **Limitations on Data Residence:** The Server limits what data is actually stored within its repositories. Because the ePI&I Process extends only through the completion of the installation process, following Interconnection, there is limited need to maintain the full suite of Project data in perpetuity. After AHJs and Utilities have archived the Project information for their internal purposes, sensitive Project information can be purged from the Plug and Play PV Server.
- **Limitations on Data Types**: In addition, the Server explicitly does not maintain a repository of certain types of information such as credit card information or sensitive

Utility customer data. If access to Utility customer data is required – e.g., to tie in to billing information or GIS systems - the Utility has the option to replicate Utility-specific Project information on a server behind the Utility firewall.

- **Functional Restrictions:** Finally, the Plug & Play data transport model in general, and the Plug & Play PV Server in particular, has the ability to interact with (and control) PV Systems in only a very limited sense. In particular, the Data Exchange Protocol incorporates the ability to *authorize a Plug & Play PV System to interconnect* to the power distribution system. It does not, however, have the ability to command a PV System to *disconnect* from the power distribution system; nor can it directly *command a Plug & Play PV System to interconnect.* Interconnection is actuated only by the Installer, not by a remote command from the cloud, and information exchanges with the Server can only be initiated by Actors – not by the Server. These restrictions on the functionality of the transport model limit the scope of a potential cyber-attack.[10]

4.3 Data Exchange Protocol – Data Model

The Data Exchange Protocol's data model has two key functions – the first is that it links *steps* in the ePI&I process to *specific, pre-defined information exchanges*; the second is that it specifies the *structure and content* of these information exchanges. A representation of the ePI&I process is shown in Figure 4-3. Conceptually, each *step* of the ePI&I process, represented by a rectangular box in Figure 4-3, is associated with an exchange of information between an Actor and the Plug & Play PV Server. [11] Note that this representation of the ePI&I process is, in part, defined in terms of abstract "Approval Steps". The specific set of "Approval Steps" required to receive regulatory approval, as well as the requirements for completing a given Approval Step, is defined by the AHJ and Utiltiy.

Within this framework, a Project lifecycle consists of the following phases:

- **Pre-Project:** Prior to Project creation, it is required that accounts exist for each of the relevant Actors, and that certification information exist for the PV System to be installed. Within certain broad constraints, AHJs and Utilities may configure the requirements for their approvals within the ePI&I process.
- **Project Creation:** A Project is created by linking a specific combination of Actors (i.e., Utility, AHJ, Installer, and Homeowner) together. Project Instantiation creates a unique Project identifier and associated database entry, which is used to track Project status and store Project-specific information. In addition, the combination of AHJ and Utility defines the specific requirements for completing the Project Review phase.
- **Project Review:** The Project Review phase consists of one of more "Approval Steps". An "Approval Step" is a requirement specified by an Approval Authority (i.e., a Utility or an

[10] For example, a cyber-attack could theoretically modify the "authorization" status of pending applications, but can not change the status of already commissioned PV systems

[11] Notably, with the exception of notification messages indicating a change in status, the Plug & Play Server passively serves or accepts data from Actors; conversely, Actors are responsible for pushing data to the Server, or pulling data from the Server.

AHJ) that requires formal approval, and acts as a gating item for the ePI&I process.[12] The Project Review Phase is completed when either (1) All applicable Approval Steps have been completed; or (2) The Project is cancelled or an Approval Step is rejected.

- **Project Completion:** Following successful completion of Project Review, the Installer completes the interconnection of the PV System and communicates this information to the P&P Server, thereby completing the Project.

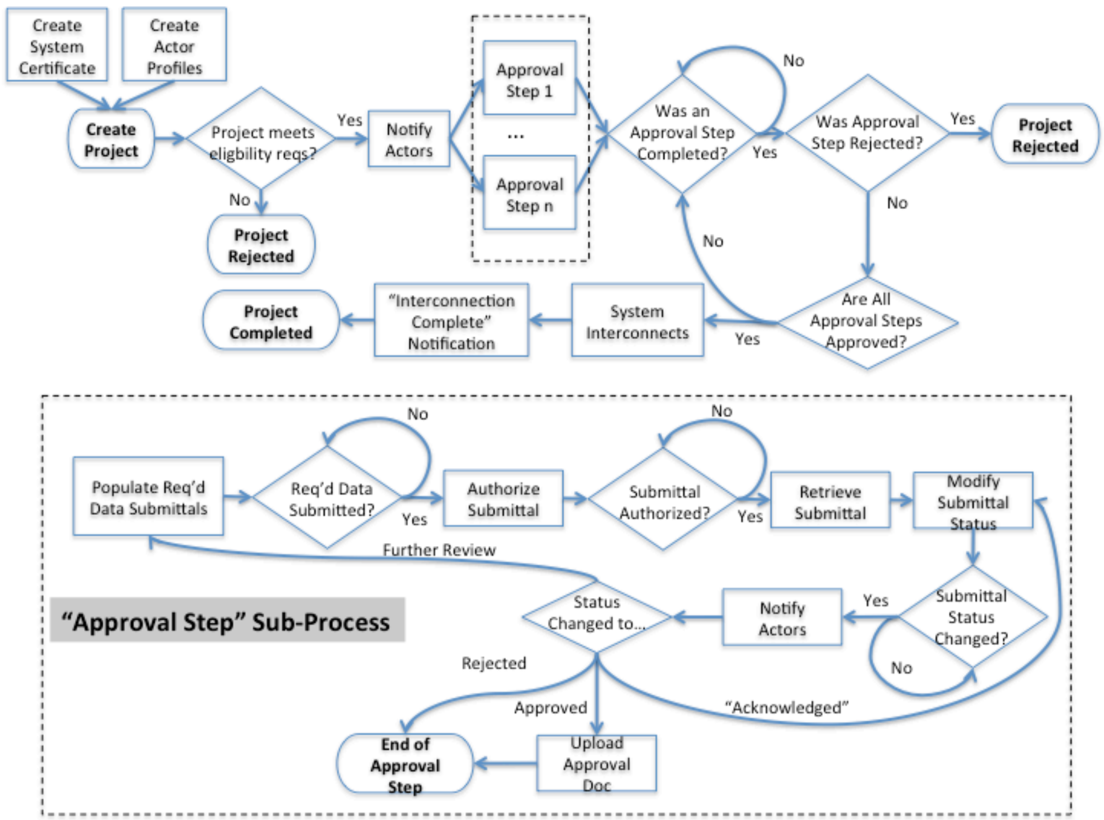


Figure 4-3: Generalized Plug & Play PV ePI&I Project Lifecycle

The data *content* of a Project is organized around standardized, logically grouped "Datasets" that contain the information payload of the Data Exchange Protocol,[13] as summarized in Table 4-1. While a Dataset can include both structured and unstructured data,[14] to the extent possible, information is organized primarily as structured data for a variety of reasons – e.g., to facilitate integration with electronic workflow packages, to enable the use of configurable tools

[12] Examples of typical Approval Steps include "permitting" and "Inspection" by an AHJ, or "Provisional Approval to Interconnect", and "Final Approval to Interconnect" by a Utility.

[13] Typically, the information content of a Dataset is: (1) generated from a common source; (2) has a common set of access restrictions (i.e., be consumable by a common set of Actors); and (3) comprises a related set of information.

[14] "Structured data" refers to data that is stored in a standardized, machine-interpretable data schema, e.g., relational database schemas, such as JSON or XML. "Unstructured data" refers to data that is stored as free-form content, such as pdfs, text files, or jpgs.

for displaying and manipulating data, and to enable varying degrees of machine-interpretation and validation.

Table 4-1: **Data Exchange Protocol – Example Datasets for a typical AHJ/Utility workflow**

Category	Datasets
Project	Project ID
Actor Profiles	Installer, Homeowner, Utility, AHJ
Site Profiles	Site Address, Premises Electrical, Premises Structural, Utility Account Information, Project Details
PV System Profile	Controller ID, Standard Electrical Plan, System Layout, Visual Documentation, Inspection Report
Project Status	approval process step #1
	approval process step #2
	…
	approval process step #n
Formal Authorizations	Permit, Inspection Certificate, Provisional Approval to Interconnect, Final Approval to Interconnect, eSignatures, Payment information[15]

5 Conclusion

This white paper has provided a broad introduction to the key technical requirements that will enable the deployment and adoption of Plug & Play PV Systems. The core of the Plug & Play framework is an electronic permitting, inspection, and interconnection process that standardizes the communication of project submittals and approvals between key stakeholders. In turn, the ePI&I process is enabled first by a standardized methodology for electrically verifying that PV systems are code compliant, and second, by a Data Exchange Protocol that defines the infrastructure, process, and content for participating in the ePI&I framework. Taken in combination, these elements have the potential to drive down the cost of residential PV by simplifying the uncertainty and cost associated with installing PV systems, while reducing the qualification requirements for PV installations.

[15] Payments for AHJ and Utility fees as required will be processed by the Installer. Proof of payment information will be transmitted as part of the Authorizations.

Appendix A Dictionary of Terms

Actors: Participants in the ePI&I process. They include:

Manufacturer: Manufacturers make system components (e.g., modules, racking, inverter, and electrical balance of system) that, when assembled, comprise a PV system

NRTL: Nationally recognized test laboratories, or NRTLs, acts as a certification authority to provide validation testing of components or systems supplied by Manufacturers against nationally recognized standards

Installers The entity responsible for installing a PV system, including managing the PI&I process, designing the system, sourcing components, and performing onsite installation. The Installer is typically a trained, licensed, 3rd party contractor, but also may be the same entity as the Homeowner.

AHJ: The Authority Having Jurisdiction (AHJ) is the Approval Authority responsible for reviewing and approving PV systems for safety and code compliance, typically through the permitting review and code inspection processes.

Utility: The Approval Authority responsible for reviewing and approving PV Systems interconnection requests to ensure compliance with Utility business and operational requirements.

Homeowner: The entity who owns the premises at which the planned PV system is to be installed.

Plug & Play System Supplier: A supplier of a complete, NRTL-certified Plug & Play PV System

Plug & Play PV System Controller: A supervisory controller that provides an interface between an installed Plug & Play PV system and the outside world, and that has the ability to conduct an "electronic code inspection" in compliance with the Plug & Play PV System Standard.

Approval Authority: An entity, such as a Utility or AHJ, that plays a formal, legal role in approving a rooftop PV system for interconnection.

Approval Step: A requirement specified by an Approval Authority that requires formal approval, and acts as a gating item for the ePI&I process.

Datasets: standardized data schemas of structured or unstructured data that contain the information payload of the Data Exchange Protocol. Typically, information content within a Dataset is: (1) generated from a common source; (2) has a common set of access restrictions (i.e., be consumable by a common set of Actors); and (3) comprises a related set of information.

Data Exchange Protocol: The data standard for transacting information exchanges between Actors in the ePI&I process. It defines both the data transport architecture used to transmit data between Actors with the purpose of processing an ePI&I Project, and the structure and content of these data exchanges.

Master Inspection Checklist: A standardized, comprehensive list of requirements that a Plug & Play PV System must both satisfy *AND* verify that it satisfies prior to energizing.

Plug & Play PV Server: The central, cloud-based server that (1) routes information between Actors; (2) maintains a database of information relevant to the ePI&I process; and (3) manages security and access restrictions.

Plug & Play PV Project: A proposed installation of a Plug & Play PV System. A Project is initiated when an Installer first registers a new proposed system with the Plug & Play Server, and is completed when the Project is interconnected or cancelled.
Plug & Play PV System: A PV System that has been NRTL-qualified as complying with the Plug & Play PV System Standard.
Plug & Play PV System Standard: The standard that defines the requirements for certifying a PV System as a Plug & Play PV System. It consists of requirements for (1) self-verifying that an installed PV system complies with applicable code, and (2) integration within the Plug & Play ePI&I process.
PV System Verification Plan: A system-specific proposal, submitted during the system certification process, that identifies *how* each requirement in the Master Inspection Checklist is met and verified by the system under test.
PV System Standard Electrical Plan: An annotated description of the electrical system that fully specifies the range of valid system configurations for a PV System under test for certification as a Plug & Play PV System. It consists of a Reference Single Line Diagram and a system specification dataset.
Reference Single Line Diagram: A single line diagram template that defines the PV System topology. It characterizes the PV System as an assembly of functional blocks that connect together in a specific way, thereby constraining the design envelope of the PV System to within pre-defined constraints.
Solar Connection Device: A standardized, pre-installed solar-ready connector receptacle that connects to the premises electrical wiring to enable a connectorized interface between a PV system and the premises wiring. SCD requirements are specified as part of the Plug & Play Standards portfolio.

Appendix B Comparison of ePI&I to tradition PI&I Processes

Table B-1: Differences between a typical traditional PI&I and ePI&I process

Process Step	Change Relative to Current State of the Art PI&I Process
Listing of Components	No Change
Certification of PV System	New process step to verify a Plug & Play PV System meets electronic Proof of Compliance and electronic data exchange requirements
Permitting	Submittal package presented electronically; Permit issued electronically to Plug & Play Controller
Interconnection Application	Application presented electronically; Provisional Approval to Interconnect issued electronically to Plug & Play Controller
Electrical Inspection	Proof of Compliance assessed electronically by the Plug & Play Controller as part of a standardized electronic system commissioning protocol; Inspection Submittal package assembled and presented electronically to the AHJ by the Plug & Play Controller; Inspection Certificate issued electronically to Plug & Play Controller
Interconnection	Final Interconnection Request assembled and presented electronically by the Plug & Play Controller to the Utility; Final Approval to Interconnect issued electronically to Plug & Play Controller; Final Interconnection actuated by Plug & Play Controller after authorization from Installer

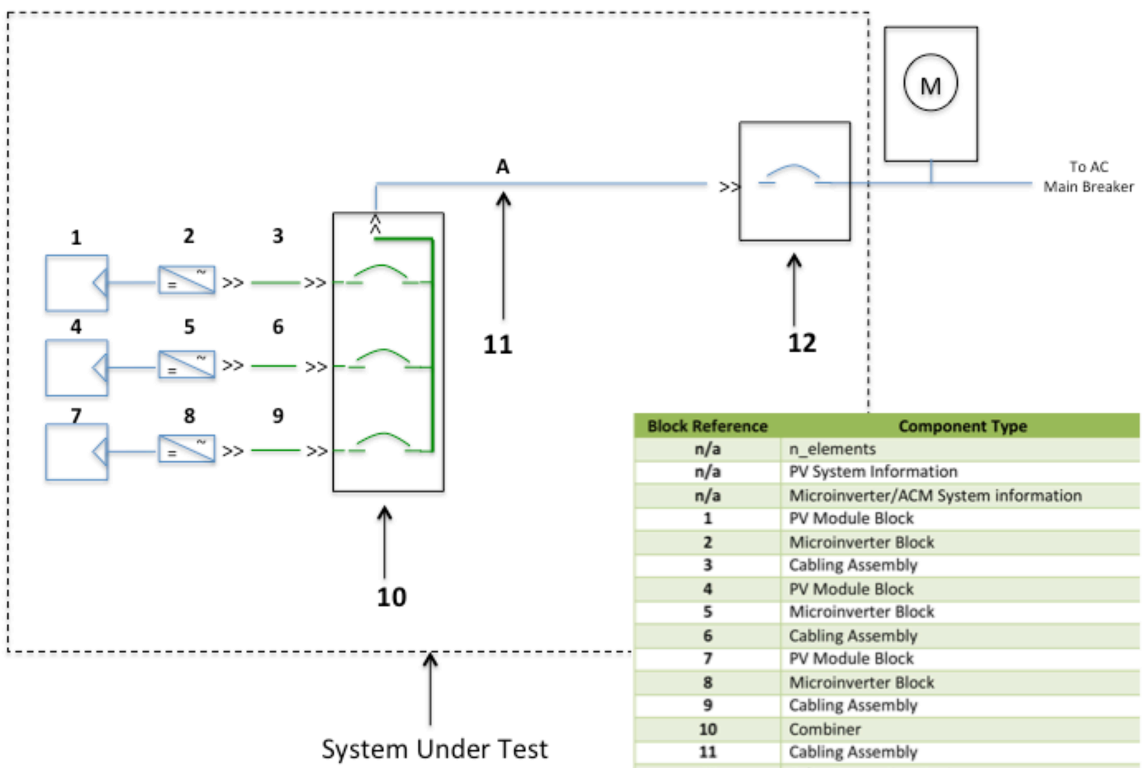
Table B-2: Description of the Roles of all Actors involved in PI&I processes

Actor	Role, State of the Art PI&I Process	Role ePI&I Process
OEM	Presents: components to an NRTL for certification, receives component certification	
Plug & Play System Manufacturer	n/a	Presents: Plug & Play PV System to an NRTL for certification, receives: Plug & Play product certification.
NRTL	Performs product certification	Performs product *and* Plug & Play PV System certification
Installer	Presents: permitting submittal to AHJ and interconnection application to Utility Requests: Inspection Certificate from AHJ Receives: permit from AHJ, Provisional Approval to Interconnect and Final Approval to Interconnect from Utility, Inspection Certificate from AHJ	Presents: permitting submittal to AHJ, presents Interconnection Application to Utility, Receives: permit from AHJ, Provisional Approval to Interconnect from Utility, Authorizes: Plug & Play Controller to present Inspection Submittal, to present Final Interconnection Request, and to Interconnect PV System
AHJ	Receives: Permitting submittal and Inspection submittal packages Issues: electrical permits, building permits (as needed), and Inspection Certificates Assesses: compliance of PV system with applicable Code	
Utility	Receives: Interconnection Application, Final Interconnection request, Issues: Provisional and Final Approvals to Interconnect Assesses: Compliance with Utility operations and business practices	
Homeowner	Provides legal authorization to the Installer to submit Permitting Submittal, Interconnection Application, Inspection Submittal, and Final Interconnection Request	
Plug & Play Controller	n/a	Receives: Permits from AHJ and Provisional Approval to Interconnect from Utility Presents: Inspection submittal to AHJ, Presents Final Request to Interconnect to Utility Receives: authorization from Installer to present Inspection Submittal, to present Final Request to Interconnect, and to Interconnect PV System, Inspection Certificate from AHJ, Final Approval to Interconnect from Utility

Appendix C PV System Data Model Library

The purpose of the PV System data models is to provide a structured, standardized format for communicating information (such as would typically be included on a single line diagram and code inspection results/documentation of the “as built” PV system), while maintaining sufficient flexibility to communicate the full range of system design and configurations for residential PV systems.

A PV System is represented electronically by several different sets of structured data – a System Specification Dataset, a Self-Test Dataset, and a Visual Documentation Dataset – whose structure is defined by, and maps to, a Reference Single Line Diagram that is uniquely specified for a PV System during the certification process.



Block Reference	Component Type
n/a	n_elements
n/a	PV System Information
n/a	Microinverter/ACM System information
1	PV Module Block
2	Microinverter Block
3	Cabling Assembly
4	PV Module Block
5	Microinverter Block
6	Cabling Assembly
7	PV Module Block
8	Microinverter Block
9	Cabling Assembly
10	Combiner
11	Cabling Assembly
12	Solar Connection Device

Figure C-1: Example reference single line diagram for a microinverter-based system rated for up to three branch circuits. The System Specification data model for this system is assembled by compiling relevant information for each of the “functional blocks” outlined in the accompanying table.

The Reference Single Line Diagram is an electrical representation of the PV system that defines the system topology. It characterizes the PV System as an assembly of functional blocks that connect together in a specific way, thereby constraining the design envelope of the PV System to within pre-defined constraints. An example is shown in Figure C-1. Each functional block corresponds to a specific instance of one of a pre-defined set of standard PV System component data types (Table C-1).

Table C-1: Standardized PV Component Library data types

PV Component Name	Description
PV System Information	Overview information about the PV System
Microinverter System Information	System-level information about a MI/AC Module (ACM) PV System
String Inverter System Information	System-level information about a string-inverter PV System
PV Module Block	Represents a block of one or more PV modules.
Microinverter Block	A block of one or more microinverters in a branch circuit
Inverter	A string inverter
Converter Block	A block of one or more dc-dc power converters.[16]
Cabling Assembly	A cable or wiring system, including cable management, that is field installed as a discrete component.
Production Meter	A PV production meter that is field-installed as a discrete component
Disconnect	A disconnect that is field-installed as a discrete component
Solar Connection Device	A Plug & Play-compatible premises-side solar connection device.[17]
Main Service Panel	A "stub" for a main service panel specification.[17]

Each PV System component data type then has three associated data schemas:

- Component Specification data schema – defines "datasheet" type information for each instance of the PV Component in question.
  - *Example:* For a "PV Module Block" component type (#1, #4, and #7 in the Reference Single Line Diagram) would include information such as Manufacturer, Model, Isc, Imp, etc;
- Component Self-Test data schema – defines the specific set of self-tests required for each instance of the PV component.
  - *Example:* Required self-tests for each of the "Microinverter block" component types (#2, #5, and #8 in the Reference Single Line Diagram) include:
    - Does the number of microinverters detected in the branch circuit match the permitting submittal?
    - Is the overcurrent protection on the branch circuit sufficient for the maximum current?
- Component Visual Inspection Report data schema – defines the specific visual documentation requirements for the PV Component.

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[16] "DC-DC Power Converter" includes multiple types of devices that process power from a PV module or group of PV modules - including DC optimizers, module-level shutdown devices, and Class 2 power supplies.
[17] Because the Solar Connection Device and Main Service Panel are both premises-side devices that may be installed and sold separately from a PV System, these represent placeholders for the actual data payload, which resides in a dataset that is separately specified and communicated.

- *Example:* For cabling assembly component types (#3, #6, #9, and # 11), photos would be required demonstrating continuous conduit runs installed in a workmanlike manner.

Appendix D Master Inspection Checklist

A snapshot of the Master Inspection Checklist is shown below. A certified Plug & Play PV System is required to have the ability to verify that each *instance* of a sub-system defined in the "Sub-System" column satisfies the requirement shown in the "Description" column.

Sub-System	Description	Reference(s)
PV System	Total number of PV modules match the approved plans	P&P Standard
PV System	Total number of power converters match the approved plans	P&P Standard
PV System	Systems with DC voltage > 80V, shall incorporate listed Arc Fault detection	690.11
PV System	Systems with DC voltage > 80V, shall incorporate an annunciator to identify if an arc fault has occurred	690.11
PV System	With the exception of AC module systems, ungrounded conductors shall be protected by a listed ground fault detector	690.5, 690.6, 690.35
PV System	GFCI, if required, properly isolates the faulted circuit	690.5, 690.6, 690.35
PV System	System is equipped with an approved rapid shutdown device	690.12
PV System	Total system power rating matches the approved plans	P&P Standard
PV System	Site layout drawings match the approved plans	P&P Standard
PV System	DC voltage <80V during installation	P&P Standard
PV System	PV System has an approved AC disconnecting means. For microinverter/AC-module systems, disconnecting means is in a readily accessible location outside the building	690.15
PV System	PV System includes a means to disconnect all ungrounded DC conductors from all other conductors in a readily accessible location, outside the building	690.15, 690.17, 690.54, 690.13
PV System	Grounded two-wire DC systems have one conductor grounded or impedance grounded; Grounded bipolar systems have the reference (center tap) conductor grounded	690.41
PV System	DC circuit grounding conductor connects at a single point to grounding electrode conductor through accepted means of bonding	690.42
PV System	Equipment ground conductor connects at a single point to grounding electrode conductor through accepted means of bonding	690.43(B)
PV System	Grounded conductor in grounded DC systems has continuous connection to grounding electrode conductor	690.49, 690.31(J)
PV System	Equipment grounding conductors have continuous connection to grounding electrode conductor	690.48
PV System	SCD Specifications identified/verified per P&P Data Model	P&P Standard
PV System	Solar Connection Device installed by qualified installer	P&P Standard
PV System	# of DC Strings matches plans	P&P Standard
PV System	# of AC branch circuits matches plans	P&P Standard
PV System	# of paralleled AC sources per branch circuit matches plans	P&P Standard
PV System	# of series connected DC sources per circuit matches plans	P&P Standard
PV System	Total system power rating is less than applicable P&P limits	P&P Standard
PV Module	PV Modules are Listed to UL1703	690.4(B)
PV Module	PV Modules are labeled in accordance with NEC 690.51	690.51
PV Module	Module manufacturer and model # match the approved plans	P&P Standard
PV Module	Panel OCV is within specification (tbd - does this belong here?, >2V, < 1.25 x OCV)	P&P Standard
PV Module	Modules are mounted in compliance with manufacturer specifications	Oregon, Wisc, IREC, EERE
PV Module	Roof penetrations are secure and weather tight	EERE, Santa

		Clara, IREC
PV Module	PV Modules are protected by over current protection device per 690.9	690.9
PV Module	PV Module specifications identified per P&P Data Model	P&P Standard
Connections	All electrical connections between discrete (non-factory assembled) components use connectors listed to UL6703. Connectors are guarded (690.33(C)), polarized (690.33(B)), Have FMLB Grounding member 690.33(D))	690.33
Connections	If not rated for interrupting current, module connectors are labeled with ""Do Not Disconnect Under Load" or "Not for Current Interrupting."	690.33(E)
Connections	Current Rating of Connector is sufficient to handle max current of the connected circuit as defined by 690.8	690.33(A)-(E)
Connections	Voltage Rating of Connector is sufficient to handle max voltage of the connected circuit as defined by 690.7	690.33(A)-(E)
Connections	Connections are properly terminated and weather tight	110.3(B), 110.12(A)
Connections	Connections are fully and properly engaged	110.3(B), 112
Connections	Connector Specifications identified per P&P Data Model	P&P Standard
Converter	Converter manufacturer and model # is in accordance with plans	690.4, 690.13
Converter	Converter is Listed to UL1741	690.4, 690.13
Converter	Converter is labeled in accordance with 690.13, 690.53, 690.56	690.13, 690.53, 690.56
Converter	Max current per input circuit is less than <1.25 max input rating per string input	690.8
Converter	Max combined current of paralleled sources is <1.25X max input rating of converter	690.8
Converter	Input Voltage rating is sufficient for the maximum DC voltage per 690.7	690.7
Converter	Inverters have an approved means to disconnect from ungrounded conductors of all sources, within or in sight of inverter.	690.13, 690.15
Converter	AC output voltage is 240VAC split phase	P&P Standard
Converter	Converter input & output is protected by over current protection device per 690.9	690.9
Converter	Converter specifications identified per P&P Data Model	P&P Standard
Cabling Assembly	Conductor ampacity is sufficient for the max current of the connected source(s) per 690.8	690.8
Cabling Assembly	Conductor voltage rating is sufficient for the connected source(s) per 690.7	690.7
Cabling Assembly	Conductors are protected by over current protection device per 690.9	690.9
Cabling Assembly	System is wired in accordance with NEC-approved wiring methods (e.g., 690.33, Chapter 3 / Article 300(	690.33, 300, 110.8
Cabling Assembly	Conductors are color coded in accordance with industry convention, Conductors of various PV source & output circuits grouped, identified	690.31(B)
Cabling Assembly	Conductors are listed and specified for the application	690.31
Cabling Assembly	Conductors are undamaged	110.12(B)
Cabling Assembly	Conductor bend radius is within specification, sufficient clearance around connectors	336.24, IREC
Cabling Assembly	Wiring is installed in a neat & workmanlike manner; Conductor follows the surface of the building	110.12, IREC
Cabling Assembly	Cable or Raceway is adequately supported at 6' intervals (10 ft?)	334.30
Cabling Assembly	Raceways terminated by adequate fittings or other means	300.12
Cabling Assembly	Raceways are mechanically continiuous	300.12
Cabling Assembly	Raceway is properly sized for conductors	300.17
Cabling Assembly	PV Source & Output circuits in readily accessible location are suitably guarded 150+VDC in an accessible location	690.31(A), 690.7(D)
Cabling Assembly	Cable protected from physical damage by approved means: protected from touching roof or other abrasive surfaces exposing them to physical damage.	334.12, IREC
Cabling Assembly	PV Source & Output circuit conductors routed in a raceway that does not include conductors from other systems	690.31(B)
Cabling Assembly	Equip ground conductor routed in the same raceway as other conductors	690.43, IREC
Cabling Assembly	Equipment Ground is suitably sized and specified	690.45, 690.46, 250.120(c), EERE, 250.120,

		250.122
Cabling Assembly	Max DC bus voltage of series connected sources <600V	690.7C
Cabling Assembly	Wiring Assembly Specifications identified per P&P Data Model	P&P Standard
Cabling Assembly	Raceways, conduit, etc inside building shall be marked in accordance with 690.31(G)(3)	690.31(G)(3)
OCPD	Overcurrent protection device voltage rating is sufficient for the source	690.9
OCPD	Overcurrent protection device current rating is sufficient for the source	690.9
OCPD	Overcurrent protection device interruption rating is sufficient for the source	690.9
OCPD	Overcurrent protection is accessible in PV Source & Output Circuits	690.9(D)
OCPD	Overcurrent protection device is listed	690.9
OCPD	There is a disconnecting means to disconnect OCPD from all sources of supply. For source circuits, it shall be capable of being disconnected independently of other source circuits	690.16
OCPD	OCPD Specifications identified per P&P Data Model	P&P Standard
Enclosure	Boxes mounted behind modules are accessible, per 690.34	690.34, Oregon
Enclosure	Enclosures are firmly secured to the mounting surface, and mounted in compliance with manufacturer specifications	110.3(B), 110.13
Enclosure	For any user-serviceable compartments: verify that the cover is closed and secured correctly	110.12(A)
Enclosure	Exposed metal is bonded to equipment ground conductor though approved means	690.43, 250.110, 690.50
Disconnect	Interrupting current rating is sized for max circuit current rating per 690.8	690.15, 690.17
Disconnect	Voltage rating is sized for max voltage per 690.7	690.15, 690.17
Disconnect	Disconnect is identified and listed for the specified purpose	690.15, 690.17
Disconnect	<6 disconnects in a single enclosure; Disconnects from more than one source shall be grouped and identified	690.31
Disconnect	Disconnect Specifications identified per P&P Data Model	P&P Standard
Combiner	Combiners have a disconnect in the combiner	690.15(C)
Combiner	Combiner is listed to UL1741	690.4
Combiner	Combiner Specifications identified per P&P Data Model	P&P Standard
SCD	SCD Specifications identified per P&P Data Model	P&P Standard
SCD	Sum of PV breaker and panel main breaker less than 120% of panel rating	690.17