



EWB-USA Energy Standing Content Committee

Recommendations for Solar PV Projects

Scope and Purpose:

The primary purpose and use of this document is to provide a framework for solar photovoltaic (PV) documentation packages (such as the 525 Form) submitted to the EWB-USA Technical Advisory Committee (TAC). Such packages are developed by EWB-USA chapters for TAC approval prior to implementation. The TAC has a responsibility to review, and ultimately clear or reject, each project submitted to it. As such, this document provides the guidance to achieve a successful review of solar PV electrical systems.

The EWB-USA Standing Content Committee for Energy (Energy SCC) expects electrical engineering (EE) students and EE mentors to lead the work on electrical projects. The EWB-USA chapter's technical team, and the team's EE mentor, will benefit greatly by following the recommendations herein. Each chapter needs an electrical engineering mentor and each package should be rigorously reviewed and approved by chapter members along with their mentor prior to submitting to the TAC. The TAC is encouraged to look favorably on packages that conform to the framework presented herein.

Generally speaking, energy projects require a “Level 2” Mentor, defined as a professional with at least 5 years of direct professional experience (post bachelor’s degree) in design and construction of infrastructure similar to that proposed in the project. Complete mentorship guidelines can be found in 405 Form – EWB-USA Mentor Qualifications.

These guidelines are intended to promote best practices. They recommend a uniform framework and an electrical engineering outline for evaluating and documenting solar PV submission to the TAC. Specific requirements for electrical design are found, for example, in the National Electrical Code, or Code of Record where the project is to be located. The Energy SCC recognizes that some non-safety aspects of standards may need modification in developing countries. But it is established practice at EWB-USA that the intent of the NEC (or equivalent) is to be followed for safety as well as reliability of both standalone and grid-tied energy systems. Deviations from relevant industry codes and standards should be acknowledged and addressed in project submittals and design documentation such as the 525-Pre-Implementation Report.

By defining this baseline standard of uniformity and thoroughness, the Energy SCC intends to offer a foundation for design reviews by EWB-USA chapters, mentors, and TACs. The document covers the important considerations of load forecasting, design, installation, start-up, maintenance, training during installation, and documentation of any solar PV project. It covers the system calculations and drawings to be produced, measurements to be made, and also offers some best practices. Presenting only results, without detailed analyses and drawings, does not allow the TAC reviewer to understand how the design team reached the results being presented to the TAC.

Currently, this document applies only to DC systems and to AC single phase, 50 and 60 Hz, 120 and 240 volt systems, which should capture most, if not all, of the designs for EWB-USA installations. Solar PV projects are analyzed as five subsystems, listed below, beginning with an assessment of electrical loads and calculating the necessary energy to be supplied by the sun. If each of these subsystems is analyzed individually, the evaluation of the entire system by the TAC is simplified.



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Key Subsystems of solar PV Projects:

- A. Load Sizing and Electrical Distribution (Cabling, Panels, Grounding) Subsystem
- B. Inverter Subsystem
- C. Charge Controller Subsystem
- D. Battery Subsystem
- E. Solar Panel Subsystem

The guidelines presented in this document are an expansion of the previously established minimum requirements for EWB-USA solar PV projects, which are listed below:

1. Project team has performed and documented alternatives analysis of potential energy sources and explained which is most appropriate for the community.
2. Equipment, materials, and components are locally sourced.
3. Final designs account for the physical security of the installation.
4. Project implementation and community engagement is consistent with EWB-USA sustainable development model.

The EWB-USA Project Management team developed these requirements as minimum criteria for chapters to consider when deciding to proceed with solar PV. These minimum requirements were never intended to cover all aspects of a solar PV design.

Furthermore, the team is encouraged to assess project risk in terms of likelihood and risk impact on the project. An important part of the EWB-USA project process is for chapters to report "as-built" and outcome information from the implementation trips so that the organization can learn and build on successful implementation and/or lessons learned. Archiving the final notebook, bills of materials, and comments are considered.

This document was written and is maintained by the Energy SCC. The Energy SCC hopes this document will facilitate increased participation of EE's in EWB-USA projects, and facilitate the interfacing required with mechanical and civil engineering representatives on project teams.

Discussion:

Electrical Power Projects for EWB typically consist of one or more of the following subsystems. If each of these subsystems is analyzed individually, the evaluation of the entire system is simplified.

1. Subsystem DESIGN

Each Subsystem Design should include a diagram(s) in sufficient detail to allow the reviewer a complete picture of the design. If for example a number of houses have the same wiring, a diagram showing that wiring detail can be included and then the higher level diagram can reference that sheet as a single block on the higher level drawing. Spreadsheets, etc. can replace more detailed drawing to the extent that it is clear how the spreadsheet data and a higher level drawing link.

A. Electrical Distribution Load Calculations & Analysis (assumes AC power distribution)

The electrical distribution system needs to consider sizing of the distribution wiring, disconnect and circuit protection devices. The design team should prepare a design documentation package that demonstrates a



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complete design of the electrical load portion of the system including service panels, along with the total square footage and facility type (i.e. hospital, school, dwelling unit, etc.).

Below is a checklist of items that should be included in the design package:

1. Load determination including timing, duration and starting surge requirements.
2. Calculate peak power requirement for sizing of the AC inverter.
3. Calculate voltage drops for the entire distribution system. The voltage drop calculations need to consider the entire distribution system including feeder circuits, branch circuits and sub-branch circuits.
4. Conductors, circuit protection devices (fuses, circuit breakers, etc.) and disconnect devices (switches, etc.) need to be sized for the operating voltage and current, and conductors have to be rated for conditions of use such as temperature and conduit fill.

B. Inverter Sizing Calculations & Analysis

The inverter provides the AC electricity for the Electrical Distribution System above. The inverter needs to be sized to handle the worst case loads. The inverter or a controller associated with it needs to protect the batteries that the inverter is drawing energy from. Ideally it should never discharge the batteries below 80% of their capacity or 80% State of Charge (SOC), 20% Depth of Discharge (DOD). Project teams are encouraged to install some sort of visual display of battery state of charge to be monitored by system operators. Logging of the amount of energy consumed each day would help in future planning of the system capacity of the site. The EWB chapter should consider presenting the following data:

1. Programming and Data Monitoring for controller and inverter.
2. Maximum Inverter input current at the lowest operating voltage for sizing.
3. Fuse, disconnect and Overcurrent Protective Device (OCPD) i.e. breaker sizing and circuit location and Ampere Interrupting Capacity (AIC).

C. Charge Controller Sizing Calculations & Analysis

The charge controller takes the power from the solar panels and charges the batteries. The charge controller ensures that the batteries are never over charged. Logging the amount of energy put into the batteries each day will help in future planning of the system capacity of the site. The amount of energy put into the batteries each day will be significantly different than the amount of energy taken out (see discussion on inverter analysis above). Knowing both pieces of information would help track the performance of the batteries and can predict battery failures long before the failure occurs.

D. Battery Sizing Calculations and Analysis

The batteries need to be sized to provide the amount of energy needed by the electrical distribution system. If the system needs to support providing power during several days of inclement weather when the solar panels do not perform very well, that needs to be included in the analysis. Charging sources must be sufficient to regularly charge batteries to a full state of charge.

The analysis needs to account for the inefficiencies of the batteries at various discharge rates. At higher discharge rates the batteries are much less efficient at delivering power than at lower rates. Sizing also needs to account for discharge rate, charging or re-charge losses from the solar panels/charge controller. In general, it is not recommended to use starting, lighting and ignition (SLI) batteries for solar application. All systems should use “deep cycle” or batteries designed for solar applications (other terms referring to these types of batteries maybe be better than “deep cycle” and should be chosen by the



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Energy SCC).

Battery maintenance needs to be addressed. Some batteries require water level monitoring and replenishment. Most batteries require equalization maintenance on a periodic basis. In off-grid applications, this is done by use of a generator. Equalization of batteries using solar arrays is difficult to complete since all loads must be stripped and the weather conditions must be ideal.

E. Solar Panel Power and Energy Calculations

Solar Panels power output specs are specified at standard test conditions. NASA and other websites provide irradiance data for most locations on the planet. The Solar panel power calculations should account for the difference in output between the standard test conditions and the actual operating environment at the installed location. Common derates have to be considered such as temperature, shading, soiling and cell degradation.

If multiple models of solar panels are being used at a site, then the analysis and design needs to account for the different operating voltages of each panel model and how power from the different models are routed into the batteries (i.e. different charge controllers in parallel, derating of some panels, etc.). (Solar panel power output should be derated to account for expected operating temperature during the day). The following list of items needs to be considered in the solar panel sub system design package:

1. Irradiance at location to determine minimum sun hours per day.
2. Cold temperature maximum voltage for PV array.
3. Hot temperature minimum voltage for PV array.
4. Ampacity for conductor sizing, fuse sizing, and disconnect sizing (including 1.25% continuous duty factor as well as irradiance factor, as applicable).
5. Fuse, disconnect and Overcurrent Protective Device (OCPD) i.e. breaker sizing and circuit location. DC breakers are necessary in the DC circuits.

F. Additional recommended Design Documentation:

1. 3-wire Schematic showing circuit grounding, both DC and AC single-phase systems.
2. Sketch showing equipment grounding and earth ground.
3. Physical sketch of size and location of all equipment used, including NEC layout requirements. These are the requirements of NEC 110, including dedicated space, working space, and accessibility. Labels and Markings should also comply with the NEC requirements, as appropriate. If there are country specific requirements for electrical systems these should take precedence over NEC requirement if they require a higher standard of design or safety. In all other cases the NEC should be followed to standardize design and review of systems.
4. Table of cables to be used and explanation why each cable was chosen. Sustainability should be taken into account when sizing cable not maximum efficiency. If locally available materials can provide acceptable efficiency they should be used. Materials available in country but not easily accessible or affordable to the .system users should be avoided unless necessary
5. A short summary stating which portions of the National Electrical Code (NEC) NFPA 70 – 2008 or 2011 or later were used in the design and why these portions were selected. For countries that use other electrical codes and/or wiring configurations that don't correlate to



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NEC standards, alternative appropriate codes should be identified and summarized.

G. Mounting details for the array

The solar panel array should be mounted in a manner that protects the array from damage due to winds and debris. As appropriate, the panels should be protected from theft and vandalism. Mechanical design calculations for the mounting should be provided as appropriate.

H. Structural Engineering

Civil/structural calculations including wind loading as determined by a structural engineer must be provided. Materials selected should be suitable for the intended use and local conditions.

2. INSTALLATION

The following is a checklist of items that should be considered before the actual installation is done:

- A. Logic of installation steps and why such logic was chosen.
- B. Tools to be used during installation. To the extent possible, teams should consider using tools that are locally available and familiar to maintenance personnel. Using US sourced battery powered drill while easier give the impression these kinds of tools are needed for these projects. Include locals for the installation and training whenever possible.
- C. Estimation of duration of installation and basis for this estimation.
- D. Personal Protection Equipment (PPE) to be worn during installation and electrical and physical safety practices to be followed.
- E. Health and Safety Plan (HASP) should address electrical safety principles and hazard identification for all end users, operators, and maintenance personnel. Project teams should be trained on electrical safety prior to traveling and conduct on-site training for project partners prior to energizing electrical equipment.
- F. Document each step of the installation process with digital photos to be included in Installation, Operations, and Maintenance Manual (see section 4a).

3. START-UP and TESTING

The following is a checklist of items that should be considered before placing the system into service:

- A. It is recommended that wiring diagrams be generated based on the schematic and vendor drawings. These drawings are to be marked with suitable test points and expected values. Both voltage and current have to be obtained from each PV array, from the combined input to the controller, at the battery bank, and at the input to each individual load breaker. Voltage can be taken using a multimeter. Current must be determined using a DC/AC Clamp-On Ammeter or use of 50 millivolt shunts. For Solar (DC) and A/C D/C Clamp-On Ammeter is required with the ability to zero out any background flux. Independent instrumentation is strongly recommended during the initial start-up troubleshooting. Do not rely on values generated by the components themselves.
- B. Each parameter tested is to be marked next to the expected values on the wiring diagrams. Any deviations from the expected values must be analyzed and explained as to why the installation is correctly constructed.
- C. Trip itinerary should include 24-48 hours of monitoring and testing after installation is complete and before the project team leaves the community. This will allow for troubleshooting and training of local technicians for operation of the system.
- D. To the extent possible, local technicians and system operators should be on-site and participating in the entire installation process to facilitate knowledge transfer. Chapters may need to compensate these skilled individuals for their time during installation, testing, and start-up.



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4. DOCUMENTATION for Long Term Maintenance and Sustainability

A documentation package (wiring diagrams, bill of material, and operating manual) should be provided and available for local in country support and may be a part of the Memorandum of Understanding (MOU) with the community. The documentation package should be in a language that is common for the support personnel expected to provide ongoing technical support.

- a. An Installation and Operations and Maintenance (IOM) manual consisting of a cut sheet for each component must be obtained and placed in logical order in an overall system notebook. The manual should include plenty of photographs of each step of the installation process and common troubleshooting procedures to overcome language and literacy barriers.
- b. Any vendor information or safety warnings should also be included. Vendor information includes operating manuals, repair manuals and any relevant correspondence with the vendor.
- c. An as-built schematic of the entire electrical design has to be added to the design document package.
- d. Wiring diagrams with marked up test points and values, expected and obtained, during start-up testing must also be added to the documentation package.
- e. A complete listing of all components provided in the system as well as expected maintenance supplies and a schedule or replacement intervals for major components. The Bill of Materials (BOM) should include sourcing information for local suppliers where replacement parts can be obtained. Consumable spare parts, such as fuses, should also be identified in the BOM and spare parts stored securely at the project site.
- f. Start-up instrumentation data such as model number, range used and most recent calibration date must be added to the notebook.
- g. Setup information such as voltage setpoints, cutoff voltage, equalizing schedule, etc. for all installed equipment as well as any vendor programming used to establish settings.
- h. Partner community should be encouraged to establish a Field Log to document any settings changes, modifications, repairs, or malfunctions. This can be kept in a secure location at the project site as a maintenance record for local technicians and EWB-USA Monitoring & Evaluation (M&E) teams.
- i. The EWB-USA 526 Post Implementation report should be submitted to document lessons learned and project outcomes to the Project Managers, Technical Advisory Committee, and Energy SCC for the benefit of the EWB-USA community at-large.



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Appendix I

DESCRIPTION OF ELECTRICAL DESIGN PARAMETERS

Electrical Design Parameters	Description
Peak Power (Pmax or Pmp)	The specified maximum wattage of a module, the maximum power point (Pmax), sits at the “knee” of the I-V curve, and represents the product of the maximum power voltage (Vmp) and the maximum power current (Imp).
Vmp (Voltage at Max Power)	At STC and tested under load, voltage at maximum power (Vmp) is the highest operating voltage a module will produce. Vmp, adjusted for highest operating cell temperature, is used to calculate the minimum number of modules in series.
Voc (Open-Circuit Voltage)	Open-circuit voltage (Voc) occurs when the module is not connected to a load. No current can flow in an open circuit and, as a result, Voc occurs at the point on the I-V curve when current is zero, and voltage is at its highest.
Imp (Current at Max Power)	At STC and tested under load, the maximum power current (Imp) is the highest amperage a module will produce. Imp is used in voltage drop calculations when determining wire gauge for PV circuits. This is a design consideration rather than a NEC ampacity calculation, for minimizing voltage drop and maximizing array output.
Isc (Short-Circuit Current)	Short-circuit current (Isc) is the maximum amperage that the module can produce at STC. There is no voltage when a module is short-circuited and thus no power. Isc is the measurement used to size conductors and overcurrent protection with safety factors as required by the NEC.
Voc Temperature Coefficient	The change in module open-circuit voltage (Voc) at temperatures other than 25°C. This value is typically given in (%/°C) . It is most commonly used to calculate maximum system voltage (per NEC Article 690.7) for system design and labeling purposes.
Maximum System Voltage	Maximum System Voltage is calculated using the Voc at coldest expected temperatures so as not to exceed the NEC limit and any limits imposed by the ratings of inverters, disconnects, or conductors. For example, consider a single panel with a Voc of 36V, installed at a site with a record low of -10°C with a Voc temperature coefficient of -0.35%/deg C. The Maximum System Voltage would be calculated to be: $Voc (1 + (-0.0035) * (-10 - 25))$ or 40.4V.
Maximum Series Fuse Rating	This is the maximum current a module is designed to carry through the cells and conductors without damage. While modules themselves are current-limited, excess current can come from other sources in parallel, or from other equipment in the system such as some inverters or charge controllers. A fuse or breaker for a series string must be no larger than the maximum series fuse specification.
STC	Standard Test Conditions: irradiance of 1000 W/m ² , cell temperature of 25°C and air mass of 1.5.



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Appendix II

Frequently used NEC Codes for PV Design (2011 or Latest Edition)

NEC Article 690	Solar Photovoltaic Systems
NEC Article 110*	Requirements for Electrical Installations
NEC Article 200	Use and Identification of Grounded Conductors
NEC Article 210*	Branch Circuits
NEC Article 220	Feeder & Service Calculations
NEC Article 230*	Services
NEC Article 240*	Overcurrent Protection
NEC Article 250*	Grounding & Bonding
NEC Article 280	Surge Arrestors, Over 1kv
NEC Article 285	Surge-Protection Devices (SPDs), 1kv or less
NEC Article 300	Wiring Methods
NEC Article 310*	Conductors for General Wiring
NEC Table 310.17	Conductor Ampacity
NEC Article 334	Nonmetallic-Sheathed Cable: Types NM,NMC, and NMS
NEC Article 338	Service-Entrance Cables: Types SE and USE
NEC Article 400*	Flexible Cords and Cables
NEC Article 422	Appliances
NEC Article 445	Generators
NEC Article 450*	Transformers and Transformer Vaults
NEC Article 480*	Storage Batteries
NEC Article 490*	Equipment over 600 Volts, Nominal
NEC Article 702	Optional Standby Systems
NEC Article 705*	Interconnected Electric Power Production Sources
NEC Article 720	Circuits and Equipment Operating at Less Than 50 Volts

*Articles directly referenced in Article 690
From NFPA-70-2008 or NEC 2008



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Appendix III

Checklist of key elements of a solar photovoltaic (PV) system design

The following checklist summarizes the Recommendations for Solar PV Projects issued by the EWB-USA Energy Standing Content Committee and is to be used in conjunction with this report. Fulfillment of these checklist items will help ensure a successful PV project, aid in swift TAC approval, and ensure a more effective in-country implementation process.

Part 1, Project Design

A. Electrical Distribution Load Calculations & Analysis

- ☐ Loads determined, including timing, duration and starting surge requirements
- ☐ Peak power requirements calculated (to be used in the AC inverter size determination)
- ☐ Distribution system voltage drops calculated
- ☐ Size of conductors, circuit protection devices (fuses, circuit breakers, etc.) determined, as based on operating voltage and current
- ☐ Rating of conductors determined for site conditions, such as temperature and conduit fill
- ☐ Design documentation package issued, covering the complete design of the electrical load portion of the system
- ☐ Drawing(s)/Diagram(s) of the Electrical Distribution subsystem prepared in sufficient detail to depict a complete picture of the subsystem design

B. Inverter Sizing Calculations & Analysis

- ☐ Inverter size determined using the calculated peak power requirements
- ☐ Visual display of battery state of charge to be monitored by system operators designed and documented (Strongly recommended, not a requirement)
- ☐ Chapter has defined and documented the following data:
 - Programming and data monitoring for controller and inverter
 - Maximum Inverter input current at the lowest operating voltage for sizing
 - Disconnect sizing and circuit location
 - Overcurrent Protective Device (OCPD) sizing, circuit location, and Ampere Interrupting Capacity (AIC)
- ☐ Design documentation package issued, covering the complete design of the inverter portion of the system
- ☐ Drawing(s)/Diagram(s) of the Inverter subsystem prepared in sufficient detail to depict a complete picture of the subsystem design

C. Charge Controller Sizing Calculations & Analysis

- ☐ Daily energy input into batteries calculated
- ☐ Daily energy taken out of the batteries calculated
- ☐ A data plan to track the electrical energy put into and taken out of the fielded batteries each day is defined and documented (Strongly recommended, not a requirement)
- ☐ Design documentation package issued, covering the complete design of the controller portion of the system
- ☐ Drawing(s)/Diagram(s) of the Controller subsystem prepared in sufficient detail to depict a complete picture of the subsystem design



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D. Battery Sizing Calculations and Analysis

- ☐ The energy needed to be supplied to the electrical distribution system has been calculated and used to size the battery bank
- ☐ An analysis to the prevailing weather conditions, in order to determine the worst case energy input situation, has been made and documented
- ☐ Design documentation package issued, covering the complete design of the battery portion of the system
- ☐ Drawing(s)/Diagram(s) of the Battery subsystem prepared in sufficient detail to depict a complete picture of the subsystem design

E. Solar Panel Power and Energy Calculations

- ☐ Solar Panels power output calculations are documented and they show adequate energy output to meeting the needs of the electrical distribution system and to account for site specific considerations, to include:
 - Irradiance at location to determine minimum sun hours per day
 - Cold temperature maximum voltage for PV array
 - Hot temperature minimum voltage for PV array
 - Ampacity for conductor sizing, fuse sizing, and disconnect sizing (including 1.25% continuous duty factor as well as irradiance factor, as applicable)
 - Disconnect and Overcurrent Protective Device (OCPD) sizes and locations
- ☐ If multiple panel types are used, the differences in operating parameters have been analyzed and documented
- ☐ Design documentation package issued, covering the complete design of the Solar Panel portion of the system
- ☐ Drawing(s)/Diagram(s) of the Solar Panel subsystem prepared in sufficient detail to depict a complete picture of the subsystem design

F. Additional recommended Design Documentation:

- ☐ A 3-wire schematic drawn to show the circuit grounding, both DC and AC single-phase systems
- ☐ Sketch showing equipment grounding and earth ground
- ☐ Physical sketch of size and location of all equipment used, including NEC layout requirements
- ☐ Table of conductors to be used and explanation of why each conductor was chosen.
- ☐ A short summary stating which portions of the National Electrical Code (NEC) NFPA 70 – 2008 or 2011 or later were used in the design and why these portions were selected
- ☐ A Bill of Material (BOM) showing all items needed to implement the project. Identify material sources and country of procurement.

G. Mounting details for the array mechanical design

- ☐ Document mechanical design calculations for the array mounting structure
- ☐ Describe how the panel structure is to be protected from wind and debris damage
- ☐ Describe how the Solar PV installation is to be protected from theft and vandalism

H. Structural Engineering

- ☐ Document Civil/structural calculations including wind loading as determined by a structural engineer
- ☐ Document the materials of construction and explain their suitability for the intended use and local conditions



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Part 2, Project Implementation

A. Installation

- ☐ A site implementation plan has been written and includes:
 - The logic of the installation steps and why this logic was selected
 - Tools need for installation
 - Estimation of the duration of the installation and the human resources required (skills and quantity)
 - Personal Protection Equipment (PPE) required
 - A Health and Safety Plan (HASP)
 - Documentation of on-site activities, minutes, photographs, videos, etc.

B. Start-up and Testing

- ☐ A site start-up and test plan has been written and includes:
 - A site wiring diagram is drawn and shows suitable test points and expected values
 - A template devised to show test data to be taken and compared to the expected values; a comments section that allows for a discussion of why any measured values do not agree with expected values
 - A test agenda showing period of monitoring and testing while on-site, with an appropriate data logging methods defined
 - Discuss a technology hand-over plan to local technicians and operators, highlighting duties and responsibilities

C. Documentation for Long-term Maintenance and Sustainability

- ☐ A documentation package is prepared and is available to local country support and maybe a part of the Memorandum of Understanding (MOU) with the Community. The package should be in a language that is common for the support personnel expected to provide ongoing, in-country technical support. The package is to include:
 - An Installation and Operation and Maintenance (IOM) manual
 - Vendor technical and safety information
 - An as-built schematic of the entire electrical design
 - Wiring diagrams showing suitable test points and expected values
 - A complete Bill of Material (BOM) including the source of procurement
 - A complete list of Recommended Spare Parts and their source of procurement
 - Start-up instrumentation data (model number, range required, calibration requirements, etc.)
 - Set-up information, such as voltage set points, cutoff voltage, equalization schedule, etc.)
 - A draft of a Field Log to be used by the local community partners to help them document all recommended maintenance activities and any setting changes, modifications, repairs or modification
 - The EWB-USA 526 Post Implementation report written and submitted



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REVISION HISTORY

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001	Art White, Initial Creation of Document, March 8 th , 2012.
002	Comments from EWB-USA Energy Standing Content Committee incorporated
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004	Peer-Review by EWB-USA National Office
005	Final version after peer-review
006	Addition of Appendix III, July 2014