

Electrical Design
and Performance
Calculations Manual
for *UNI-SOLAR*[®]
PowerBond[™] ePVL

UNI-SOLAR[®]

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This document must be read and understood before attempting to handle, install, wire, operate, and/or perform maintenance to the laminates and ePVL system. The laminates produce DC electricity when exposed to sunlight or other light sources. Contact with electrically active parts of the laminates can cause injury or death, whether they are connected to other laminates or individually. The installer assumes any risk of personal injury or property damage that might occur during the installation and handling of laminates or the ePVL system.



To avoid product damage, personal injury, or even possible death, anyone installing or handling the laminates and/or ePVL system must carefully read, understand, and follow all the installation and safety instructions in this document before attempting to install, wire, operate the array, and/or perform maintenance on the laminates.



Observe all electrical safety precautions to prevent electrical shock while installing laminates, and while wiring, testing, and/or performing maintenance of the PV array. Use insulated tools and proper personal protective equipment to reduce the risk of electric shock.

The following references can help you determine the appropriate bonding and installation approach for your system:

References

IEC 61140	Protection against electric shock, common aspects for installation and equipment
IEC 62548	Installation and safety requirements for photovoltaic (PV) generators
NFPA70 Article 690	Solar photovoltaic systems National Electric Code in the U.S.
CSA 22.1	Safety standard for electrical standards, Part 1 of the Canadian Electrical Code

Introduction

Overview

The installation of a roof photovoltaic (PV) system varies from site to site depending on environment and complexity. This manual will:

- Explain the precautions that should be taken when working with this product
- Explain the electrical design of *UNI-SOLAR* PowerBond ePVL laminates
- Provide performance calculations for *UNI-SOLAR* PowerBond ePVL laminates
- Explain proper electrical installation procedures

Please ensure that you have the most recent version of this manual by visiting:

www.uni-solar.com/resource-center/installation-guides/

Tested and Certified

These *UNI-SOLAR*® PowerBond™ ePVL laminates are certified to comply with IEC 61646:2008 and IEC 61730:2007 for Class A installations up to 1000 Vdc, fulfilling the requirements of Safety Class II.



- Qualified, IEC 61646
- Safety Tested, IEC 61730
- Periodic Inspection

These laminates are also certified to meet the requirements of UL 1703 for a maximum system voltage of 600 Vdc and Class C fire classification.

Disclaimer of Liability

The information contained in this document is based on United Solar Ovonic's knowledge and experience, but such information and suggestions do not constitute a warranty expressed or implied. The methods of installation, use, and maintenance of roofing surfaces are beyond the control of USO.

USO assumes no responsibility and expressly disclaims liability for any loss, damage, or expense associated with the use, installation, and/or operation of its solar systems. Any liability of USO is strictly limited to the Limited Warranty.

USO reserves the right to make changes to product specifications and this document without notice. The content of this document was current to the time of publication.

Limited Warranty

Product limited warranties are described in full in the USO Limited Warranty, obtainable at www.uni-solar.com. In summary, the Limited Warranty does not apply to any of the following: damage, malfunctions, or failures of PV product that, in the judgment of USO, has been subject to misuse, abuse, neglect, alteration, accident, vandalism, excessive wear and tear, improper or inadequate installation, and/or application. The Limited Warranty also does NOT apply to installations not in conformance with USO specifications, installation manuals/documents, operation manuals, and maintenance instruction.

Contact

For further information about United Solar Ovonic, LLC (USO) products, email USO at info@uni-solar.com.

If you have questions or need support for specific roof PV system applications, contact your local *UNI-SOLAR* office, referring to the contact information on page 2 of this document.

Safety Warnings and Cautions

General

- Installation of *UNI-SOLAR* products must be in accordance with NFPA 70, Article 650, Solar Photovoltaic Systems, of the National Electric Code of the United States, or CSA 22.1 Safety Standard for Electrical Installations, Part 1 of the Canadian Electrical Code
- Potentially lethal DC voltages can be generated whenever laminates are exposed to a light source, therefore, avoid contact with electrically active parts and be sure to isolate live circuits before attempting to make or break any connections
- Do NOT proceed if any doubt arises about the correct or safe method of performing any of the procedures found in this document
- Always wear appropriate safety and protective equipment, such as:
 - Rubber soled shoes
 - Cut resistant and chemical resistant gloves
 - Safety glasses
 - Hard hat
- When working on electrical connections, remove all metallic jewelry, and use insulated tools
- Wear cut resistant gloves whenever handling laminates
- *UNI-SOLAR* laminates contain electrical components enclosed and protected within. Do NOT cut or trim or alter them in any way. Do NOT drive screws into any part of the photovoltaic laminate. Altering the laminate or improper installation could cause electric shock, may result in fire, and will void the product Limited Warranty. In extreme cases where additional fixation of the laminate to the substrate is required, consult your USO representative to learn about approved options

Work Site

- Follow all appropriate safety practices for the site
- Do NOT handle PV laminate assemblies in high wind conditions
- Do NOT install or perform maintenance on this product when laminates are wet or are in standing water
- Ensure that the work area is clear of trip hazards. Personal injury can result from tripping over power cords, tools, electrical conduit, natural gas lines, and/or installation materials
- Provide clear warning signage at each access point to the installation. This signage should clearly state the dangers associated with a high voltage solar system, the personal protection equipment that should be worn, and emergency telephone numbers for fire and emergency medical service

Additional

- Scratches to the front surface of PV laminates that may occur during transportation and installation are NOT covered by the USO Limited Warranty
- Try NOT to walk or kneel on the laminates. Wear clean (free from small stones) soft soled shoes to avoid possible scratching of the front surface of the laminates
- Avoid dropping sharp objects or placing objects on the laminates, and do NOT wheel carts or drag items across them
- PV laminates contain electrical components, and cannot be trimmed or altered in any way
- Do NOT connect or disconnect quick connect cables under load
- To reduce the risk of electric shock or arc flash, cover laminates with an opaque material before making wiring connections
- All test equipment, leads, and probes must be rated for maximum system voltage
- Observe proper polarity when connecting laminates into an electrical circuit, as reverse connections may damage the laminates and will void the product Limited Warranty
- Do NOT attempt to concentrate sunlight (via lenses, mirrors, etc.) on the laminates to increase output, as damage may occur, which will void the product Limited Warranty
- Follow all roof manufacturer and material safety data sheet (MSDS) instructions for the safe use of any chemicals
- Do NOT use any chemical agents on or around laminates that are NOT approved by USO
- Do NOT use the laminate cables to lift or maneuver the laminate



UNI-SOLAR PowerBond ePVL Specifications

Product	ePVL-64	ePVL-68	ePVL-72	ePVL-128	ePVL-136	ePVL-144
Maximum Power (P_{max}) ($\pm 5\%$)	64 W	68 W	72 W	128 W	136 W	144 W
Voltage at P_{max} (V_{mpp})	16.5 V	16.5 V	16.5 V	33.0 V	33.0 V	33.0 V
Current at P_{max} (I_{mpp})	3.9 A	4.1 A	4.4 A	3.9 A	4.1 A	4.4 A
Open-Circuit Current (V_{oc})	23.1 V	23.1 V	23.1 V	46.2 V	46.2 V	46.2 V
Short-Circuit Current (I_{sc})	4.8 A	5.1 A	5.3 A	4.8 A	5.1 A	5.3 A
Max. Series Fuse Rating	10 A	10 A	10 A	10 A	10 A	10 A
Length mm (in) (± 5 mm)	2771 (109.1)	2771 (109.1)	2771 (109.1)	5412 (213.1)	5412 (213.1)	5412 (213.1)
Width mm (in) (± 5 mm)	373 (14.7)	373 (14.7)	373 (14.7)	373 (14.7)	373 (14.7)	373 (14.7)
Laminate Thickness cm (in)	3.0 (.12)	3.0 (.12)	3.0 (.12)	3.0 (.12)	3.0 (.12)	3.0 (.12)
Laminate Thickness cm (in) including adhesive and strain relief assembly	21.0 (.83)	21.0 (.83)	21.0 (.83)	21.0 (.83)	21.0 (.83)	21.0 (.83)
Weight kg (lb)	3.9 (8.5)	3.9 (8.5)	3.9 (8.5)	7.4 (16.2)	7.4 (16.2)	7.4 (16.2)

The above electrical specifications are based on measurements performed at Standard Test Conditions (STC) of 1000 W/m² irradiance, air mass 1.5, and a cell temperature of 25°C (77°F) per ASTM E892, after stabilization.

Production tolerance for P_{max} at STC is $\pm 5\%$, while for other electrical parameters it is $\pm 10\%$.

During the first 8-10 weeks of operation, modules have higher electrical output than rated output. The output power may be higher by 15%, the operating voltage (V_{mpp}) may be higher by 8%, and operating current (I_{mpp}) may be higher by 7%, open-circuit voltage (V_{oc}) may be higher by 4% and the I_{sc} may be higher by 2%.

Module performance will vary depending on irradiance and temperature. Use the appropriate Temperature Coefficient to determine performance at different temperatures:

Temperature Coefficient (TC) of I_{sc} : 0.0010°/K (0.10%/°C)

Temperature Coefficient (TC) of V_{oc} : -0.0038°/K (-0.38%/°C)

Temperature Coefficient (TC) of P_{max} : -0.0021°/K (-0.21%/°C)

Temperature Coefficient (TC) of I_{mpp} : 0.0010°/K (0.10%/°C)

Temperature Coefficient (TC) of V_{mpp} : -0.0031°/K (-0.31%/°C)

$$y = y_{reference} \cdot [1 + TC \cdot (T - T_{reference})]$$

Additional Electrical Specifications

In contrast to many other module manufacturers, United Solar builds an initial degradation factor into our module classification to ensure that all products will be within specification at the end of the initial light induced degradation process.

This means that each *UNI-SOLAR* module has a significantly greater power when installed than the minimum power of any product within our factory, resulting in Rated Power * (1-Tolerance) / (1-% LID degradation factor).

Therefore, *UNI-SOLAR* products can have significantly higher output than their data sheet values when first installed:

- Rated Power (P_{max}) may be higher by 15%
- Operating Voltage (V_{mpp}) may be higher by 8%
- Operating Current (I_{mpp}) may be higher by 7%
- Open circuit voltage may be higher by 4%

Planning Your Installation

When planning an installation with *UNI-SOLAR* PowerBond ePVL laminates, keep in mind the following:

Laminate Orientation

- Laminates should be installed so that the length of the laminate is parallel to the roof slope
- There needs to be a minimum separation of 2 mm (0.1 in) between laminates, but 20 mm (0.8 in) is recommended to accommodate variations in laminate positioning

Pooling Water

- Identify any areas which are prone to pooling water, which is defined as standing water one hour after a rain, and avoid installing laminates in these areas
- Drainage areas are prone to water pooling if drains become blocked

Roofs with a Slope of >60°

- Additional procedures may be required, contact your USO representative for specific advice for your application

High Snow Areas

- Additional edge protection or sealing may be needed to prevent snow and ice from collecting on the laminates
- Contact your USO representative for specific advice for your application
- Refer to the *UNI-SOLAR* Operation and Maintenance manual for snow removal guidance

Hurricane Areas

- *UNI-SOLAR* products have been certified by Miami-Dade county to be suitable for installation in hurricane areas
- Special installation instructions may be required for your particular substrate
- Contact your USO representative for specific advice for your application

High Temperature Areas

- If the surface temperature of the substrate is likely to exceed 85°C (185°F), contact your USO representative for specific advice for your application

Shaded Areas

- System performance will be impaired if laminates are shaded
- Shading can normally be minimized by ensuring that the distance between the obstruction and laminate is greater than three times the obstruction's height

Electrical Installation

How Grid Connected PV Systems Work

With today's technology, a photovoltaic (electric) system operates automatically and requires very little day-to-day supervision.

The solar array generates DC electricity whenever it is subjected to light. The inverter turns ON automatically whenever sufficient energy is produced to convert the DC power from the solar array into grid quality AC power.

Similarly, when there is little or no DC energy coming from the solar modules (for example, at sunset), the inverter will go into a "sleep" mode until it detects that the solar array is again generating energy.

The inverter also continuously monitors the quality of the utility line and automatically switches itself OFF if it detects that utility power is outside acceptable limits. The inverter will reconnect itself when this irregular condition has been corrected.

System Wiring

- PowerBond ePVL laminates come factory equipped with a polarized MC4 plug and sockets
 - This provides for fast and reliable connection of groups or strings of modules
 - These components are NOT designed for use as a disconnect switch
 - MC4 connectors are not load-break rated, and should not be disconnected while exposed to sunlight and under load
- If the wiring system cannot be completed at the time of laminate installation, leave the laminate connectors short circuited together (as factory shipped) to avoid connector corrosion
- Cover the laminate with an opaque material before disconnecting when exposed to sunlight

Connections of Laminates in Series

- Laminates can be connected in series to increase operating voltage by plugging the positive plug of one laminate into the negative socket of the next laminate
- You can minimize system losses through module mismatch by only connecting modules with the same I_{mpp} rating in series
- The maximum open voltage of the system, in a worst case ambient temperature scenario, must not exceed either the maximum system voltage as governed by the IEC/UL rating (as applicable) of the modules, or the maximum input voltage of the inverter and of the other electronic devices installed in the system

$$\text{System voltage} = N * V_{oc} * [1 + TC_{voc} * (25 - T_{min})]$$

- N No laminates in series
- V_{oc} Open circuit voltage of each laminate
- TC_{voc} Thermal coefficient of open circuit voltage (-0.38%/°C)
- T_{min} Minimum ambient temperature

Selection of Inverters

For optimal system performance, use galvanically isolated inverters (with transformer) with *UNI-SOLAR* laminate systems. Using inverters without a transformer can result in lower energy production due to the inverter misinterpreting capacitive currents as ground leakage (fault) currents and then switching OFF.

UNI-SOLAR laminates can exceed rated power by up to 15% during the first few months of operation. This is a temporary effect and does NOT affect inverter selection.

When choosing an appropriate inverter, take into account the rated power of the PV laminate (P_{max}). It is also necessary to take both the open circuit voltage and operating voltage (V_{mpp}) into consideration, verifying that maximum input current is not exceeded.

Exceeding maximum rated voltage can cause component damage. When determining the number of laminates in a series, increase the open circuit voltage by a 4% degradation factor, while taking expected ambient temperature or -10°C (14°F), whichever is lower, into consideration.

The open circuit voltage for the series string can be calculated using the formula:

$$V_{string} = N \times V_{oc} \times (1 + 4\%) \times [1 + TC_{voc} \times (T_{actual} - T_{stc})]$$

- TC_{voc} Thermal coefficient of open circuit voltage ($-0.38\%/^{\circ}\text{C}$)
- V_{oc} Nominal (data sheet) value for open circuit voltage
- T_{stc} Cell temperature at standard test conditions ($25^{\circ}\text{C}/77^{\circ}\text{F}$)
- T_{actual} Lowest minimum temperature at time of installation or $-10^{\circ}\text{C}/14^{\circ}\text{F}$
- N Number of laminates in series

Strings connected to the same mpp ingress of the inverter need to have similar open circuit voltage, within +/- 5V of each other.

Maximum string voltage should be less than both the maximum input voltage of the inverter and the maximum system voltage as defined by applicable regulations 1000V (IEC) and 600V (UL).

For a system installed in accordance with IEC ratings, and an inverter with a maximum input voltage of 1000V, up to eighteen ePVL-128/136/144 laminates can be connected in series where minimum temperatures are approximately $-10^{\circ}\text{C}/14^{\circ}\text{F}$. If minimum temperatures can reach $-20^{\circ}\text{C}/-4^{\circ}\text{F}$, the total number of laminates in series would need to be reduced by one, to seventeen laminates.

The following table shows the maximum number of laminates that can be connected in series for ePVL-128/136/144 laminates and ePVL-64/68/72 laminates, without exceeding maximum system voltage for various minimum temperatures.

ePVL-128/136/144 (22-L)	500V	600V	850V	1000V
$-10^{\circ}\text{C}/14^{\circ}\text{F}$	9	11	15	18
$-15^{\circ}\text{C}/5^{\circ}\text{F}$	9	10	15	18
$-20^{\circ}\text{C}/-4^{\circ}\text{F}$	8	10	15	17
$-25^{\circ}\text{C}/-13^{\circ}\text{F}$	8	10	14	17

ePVL-64/68/72 (11-L)	500V	600V	850V	1000V
$-10^{\circ}\text{C}/14^{\circ}\text{F}$	18	22	31	36
$-15^{\circ}\text{C}/5^{\circ}\text{F}$	18	21	30	36
$-20^{\circ}\text{C}/-4^{\circ}\text{F}$	17	21	30	35
$-25^{\circ}\text{C}/-13^{\circ}\text{F}$	17	20	29	34

Connections of Laminates and Strings in Parallel

- Fuses (max. 10A rated) should be connected in series with each series string
- If the DC system is not grounded, then fuses should be connected in both the positive and negative poles (terminals)
- After series connecting (positive to negative) individual *UNI-SOLAR* laminates together into a string of modules, sub-array cables with MC4 connectors can be connected to the rest of the PV system
- Sub-array cables should be rated for use with the maximum system voltage, have a temperature rating of 90°C/194°F, and be suitable for long-term outdoor use
- The minimum current rating of the cables is determined by multiplying the number of parallel strings by the short circuit current of the laminate and applying a 125% safety factor
- For improved system performance, determine the voltage drop in the array cables, to ensure that power loss is minimized. Average power loss in the string to inverter connecting cables should be less than approximately 2%

Grounding

- *UNI-SOLAR PowerBond ePVL* laminates do NOT contain a metallic frame, so they do NOT have to be grounded
- Metallic substrates do need to be grounded in accordance with local regulations

NEC Compliance

For the most current NEC requirements, access www.nfpa.org.

The following is a partial list of some of these requirements:

- Maximum system voltage is limited 600 Vdc
- An additional multiplying factor of 1.25 may be applicable to determine the rating ($I_{sc} * 1.25 * 1.25$) of fuses and protection devices
- PV source circuits must be terminated in a terminal box and then run in a metal conduit prior to entering dwellings
- The negative terminal of the solar array should be grounded
- The Safety Lock Slip from Multi-Contact (Type: PV-SSH4, Order Number: 32.5280), which is NOT supplied, must be installed on each coupled connector pair per Multi-Contact MA-252 instructions
- Systems with PV modules on the roof of a dwelling must have ground fault protection equipment
- The grounding of metal parts where the PV laminate or PV source wire are passing under or over (either direct contact or close proximity) should be performed using approved grounding clamps that meet KDER and NEC requirements
- The equipment ground conductor needs to be bonded to a ground rod, with the conductor being:
 - Bare copper or green-colored insulated
 - Sized according to NEC Table 250-122

Pre-Commissioning Tests

Prior to a full test by local electrical authorities, the installer should conduct a pre-test to verify that the system is correctly installed and suitable for connection.

This pre-test should include the following three tasks:

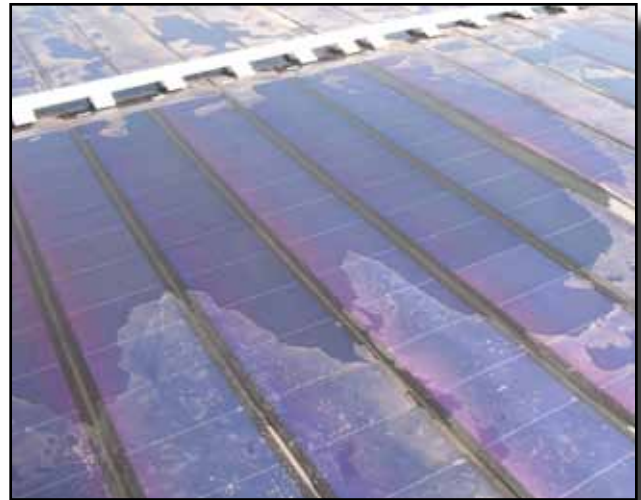
- A visual audit of the installation
- Verification of electrical connections
- Verification of system performance once the system has been connected

Visual Audit

Performing a visual audit of the solar array at the completion of installation is important, as this will provide a good baseline for future operation and maintenance visits.

- Ensure that appropriate safety signs are in place at each access point to the installation
- Record the serial number of each laminate, its location on the roof, and to which combiner box and inverter each laminate is connected
- Check that each laminate is bonded perfectly to the substrate. If any areas of the laminate are NOT perfectly bonded, mark the product with a permanent marker or crayon to flag an area to be repaired or monitored during subsequent maintenance
- Check the front surface of the laminate for any scratches or surface damage that may have occurred during installation. Contact your USO representative immediately for repair guidelines
- Clean any laminates which are particularly dirty before performing electrical checks. Excessive dirt, debris, or film on the laminates will limit performance and create false test results
- Verify that all laminates are located in areas that will not be shaded
- Verify that all laminates are located in areas which are not subject to water pooling

Commissioning procedures outlined by this document are provided as reference only and reflect United Solar experience in the PV industry. Any additional tests or procedures required by local permitting jurisdiction, utilities, or other authorities may also be required.



Water pooling:
laminates should not be subjected to water pooling

- Verify that the cables are appropriate for outdoor use, fit properly in a cable duct, and are NOT in standing water. Inspect cables to verify that the connections are tight
- If the DC system is floating (not earthed or grounded), then fuses should be connected in both the positive and negative poles
- Verify that appropriate string fuses (max. 10A) are in place and that these are located in each non-earthed pole
- When the laminates are mounted on conducting substrates which require grounding, verify that there is continuity between all substrates and that the ground connection is appropriate
- Fill in the warranty registration form and attach a list of laminate serial numbers

Electrical Connections Verification

The following tests should only be performed by qualified personnel who are familiar with working on high voltage solar power systems and understand local electrical code requirements.

The best weather conditions that will provide the most accurate system verification tests are cloudless days with strong sun conditions.

Before performing any of the following tests, ensure that:

- All DC isolation switches are open (OFF)
- All string fuses have been removed
- All test equipment, leads, and probes are rated for maximum system voltage
- The inverter is switched OFF

Tag each box with a warning sign to signify that work on the PV system is in progress, locking OFF switches, if possible.

Record the total number of PowerBond ePVL laminates connected to each array combiner box, and note how the system is configured.

- Verify that the number of laminates in series does NOT exceed the maximum system voltage as dictated by local codes (NEC/IEC) or the maximum input voltage of the inverter
- Measure and record the open circuit voltage of each series string, verifying that all strings that are feeding the inverter's mpp tracker have the same polarity and a similar open circuit voltage. It is easier to perform this test in the array combiner box or fuse box
- If the variation in string voltages is significant, or if the string delivers 0V, there is either a short or an open circuit within the string, requiring a check of each individual module
- Differences in string voltage can be due to a misconnection of the laminates. Check that the correct number of laminates is connected in series and that each laminate is providing correct voltage. To test for the latter, laminates need to be disconnected and the voltage checked directly across the module

- Verify that the polarity of each string is the same. A reversed string or module can result in damage to the product or protection circuits
 - Reversed polarity on an inverter can cause damage that is NOT covered by the USO product Limited Warranty

In addition to checking voltage across the series string, it is important to verify insulation resistance (R_{iso}) from both positive and negative poles of the string to ground. This can be accomplished with a megger meter.

- Close fuse switches in the DC disconnect switch combiner box
- Check open circuit voltage at the DC disconnect switch to ensure it is within proper limits, per the manufacturer's installation manual
- Close each switch after each test, except for the final switch before the inverter
- Follow the proper inverter startup procedure from the inverter manufacturer's installation manual

System Performance Verification

Once you have validated that the solar array has been correctly wired and configured, the final step is to verify that the system is performing properly.

The following tests can only be performed once the inverter has been connected into the circuit and commissioned in accordance with manufacturer instructions.

These tests, together with the majority of the checks included in the visual audit, should be performed every time there is an operation and maintenance visit.

- Measure and record the operating voltage of each series string and verify that all strings feeding the same inverter have a similar operating voltage. Any significant difference between strings needs to be investigated
- Measure and record the operating current of each series string and verify that all strings with the same number of laminates, have a similar operating current within 10% of each other. A variation in operating current can indicate areas of the array which are shaded or need cleaning
- Check the alarm status of each inverter
- Record DC and AC power at the input and output of the inverter, and determine inverter operating efficiency
- Perform and record insulation resistance (R_{iso}) on the input to each inverter

