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UL 2703

OUTLINE OF INVESTIGATION
FOR
MOUNTING SYSTEMS, MOUNTING DEVICES, CLAMPING/RETENTION
DEVICES, AND GROUND LUGS FOR USE WITH FLAT-PLATE
PHOTOVOLTAIC MODULES AND PANELS

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Summary of Topics

This is the second issue of the Outline of Investigation for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels, UL 2703.

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INTRODUCTION

1 Scope

1.1 These requirements cover rack mounting systems, mounting grounding/bonding components, and clamping/retention devices for specific (manufacturer/model designation) flat-plate photovoltaic modules and panels that comply with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, intended for installation on or integral with buildings, or to be freestanding (i.e., not attached to buildings), in accordance with the National Electrical Code, ANSI/NFPA 70 and Model Building Codes.

1.2 These requirements cover rack mounting systems and clamping devices intended for use with photovoltaic module systems with a maximum system voltage of 1000 V.

1.3 These requirements cover rack mounting systems and clamping, retention devices pertaining to ground/bonding paths, mechanical strength, and suitability of materials only.

1.4 These requirements do not cover:

- a) Equipment intended to accept the electrical output from the array, such as power conditioning units (inverters) and batteries.
- b) Any tracking mechanism (except as specifically directed by other standards).
- c) Cell assemblies intended to operate under concentrated sunlight.
- d) Optical concentrators.
- e) Combination photovoltaic-thermal modules or panels.
- f) Equipment intended to carry current as a normal function of that component, such as combiner boxes, connection boxes (other than connection box for grounding), wireways and enclosures housing live parts. See the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703 or the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741.
- g) Ground rods and ground rod accessories.

2 Glossary

2.1 For the purpose of this Outline of Investigation, the following definitions apply.

2.2 AC MODULE – The smallest complete unit that includes solar cells, optics, inverters, and other components, excluding tracking devices, intended to generate ac power from sunlight.

2.3 ABOVE ROOF MOUNTING (including rack-mounted style installations) – Mounting that is spaced away from the building's roof member.

2.4 ARRAY – A mechanically-integrated assembly of modules or panels with a support structure and foundation, tracking, thermal control, and other components, if used, to form a dc power-producing unit.

2.5 BOLT – See cap screw, 2.10.

2.6 BONDING – Electrically connecting all metal components to the point of the ground conductor.

2.7 BONDING DEVICE – A device for bonding and may include a function to pierce non-conductive coatings such as but not limited to; anodization, paint, vitrious enamel, and may be a separate piercing device or integral to the component to perform the bonding function.

2.8 BONDING STRAP – A solid, multistrand or braided copper, copper-clad aluminum or aluminum conductor (and may be tin or zinc plated) with factory crimped terminations to allow bonding of components.

2.9 CELL – The basic photovoltaic device that generates electricity when exposed to sunlight.

2.10 CAP SCREW – A threaded fastener which is utilized with a threaded nut or internal threads in a material, to provide a clamp load on the mechanical joint being fastened. Cap screws are most typically hex head, but include socket head, button head, and other types. See ANSI/ASME B18.2.1 and ANSI/ASME B18.3 for illustrations of these and other types of cap screws.

2.11 CLAMP LOAD – The force exerted on a fastened joint by a fastener, such as a cap screw. To minimize fatigue failures, the clamp load of a fastener, such as a cap screw and hex nut, must exceed the force exerted on the fastener by the fastened joint.

2.12 CLAMPING DEVICE(S) – A mechanical means to secure a PV module to the rack mounting system which does not rely upon the mounting holes in the PV module's frame. These clamping devices are typically, but not limited to, top-down clamps. The clamping device may also function as a bonding device where specified. Also see Retention Device.

2.13 CYCLIC LOADING – The non-static (changing) forces that act upon a body; for the purposes of this Outline of Investigation, the changing loads that act upon the fastened joint (i.e., changing wind loads that will force a PV module to act against the clamping device which is securing the PV module in place).

2.14 DIRECT ROOF MOUNTING – PV modules which are direct-mounted to a roof and in direct contact with the roof. For example, modules mounted directly upon the building's waterproof membrane/shingles or the like.

2.15 ELECTRIC SHOCK – A risk of electric shock is considered to exist at a part if the potential between the part and earth ground or any other accessible part is more than 30 Vdc and the leakage current exceeds the values specified in the following table:

Surface or part from which measurement is made	Maximum current (dc)
Accessible conductive frame, pan, or the like	10 μ A

2.16 **FACTORY INSTALLED** – The connection of a device under controlled factory conditions at the manufacturer's location(s).

2.17 **FASTENER** (threaded fastener) – See cap screw or machine screw.

2.18 **FIELD INSTALLED** – The connection of a device, which is made in the field by an installer.

2.19 **GROUNDING DEVICE** – The device, which may be a grounding lug, attached to the racking system which accepts the grounding electrode conductor for the purpose of grounding the system that contains equipotentially bonded connections.

2.20 **INTERCONNECT** – A conductor within a module that provides a mechanism for conducting electricity between cells.

2.21 **MACHINE SCREW** – A threaded fastener which is utilized with a threaded nut or internal threads in a material, to provide a clamp load on the mechanical joint being fastened. See ANSI/ASME B18.6.3 for illustrations of the various types of machine screws.

2.22 **MAXIMUM POWER** (P_{max}) – The point on the current-versus-voltage curve of a module, at standard test conditions (STC), where the product of current and voltage is maximum.

2.23 **MAXIMUM SYSTEM VOLTAGE** – The sum of the maximum open-circuit voltages of the maximum number of modules or panels to be connected in series in a system.

2.24 **MODULE (FLAT-PLATE)** – The smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts, such as interconnects and terminals, intended to generate dc power under unconcentrated sunlight. The structural (load-carrying) member of a module can either be the top layer (superstrate), or the back layer (substrate), in which:

- a) The superstrate is the transparent material forming the top (light-facing) outer surface of the module. If load-carrying, this constitutes a structural superstrate.
- b) The substrate is the material forming the back outer surface of a module. If load-carrying, this constitutes a structural substrate.

2.25 **PROOF STRESS** – The highest stress at which a material strain remains elastic (where it is not permanently deformed).

2.26 **PANEL (FLAT-PLATE)** – A collection of modules mechanically fastened together, wired, and designed to provide a field-installable unit.

2.27 **RATED OPERATING VOLTAGE** – The voltage, ± 10 percent, at which maximum power is available from the module or panel under standard test conditions (STC).

2.28 **PANEL MOUNTING CLIP** (framed modules) – A mechanical means to secure a PV module to the rack mounting system which does not necessarily rely upon the mounting holes in the PV modules frame (but may use such for alignment) and may not be secured with a threaded fastener and may include a bonding function.

2.29 **PANEL MOUNTING CLIP** (un-framed modules) – A mechanical means to secure a PV module to the rack mounting system and may not be secured with a threaded fastener, and may include a bonding function.

2.30 **RETENTION DEVICE** – A device which retains a PV module, such as, but not limited to a U-channel rail and where applicable the requirements pertaining to clamping devices may also apply to the retention devices.

2.31 **SHEAR LOADING** – A load applied parallel to the cross-section of the material.

2.32 **STAINLESS STEEL (300 SERIES)** – Stainless steel in the AISI 300 series, which typically contains roughly 18% chrome and 8% nickel.

2.33 **STANDARD TEST CONDITIONS (STC)** – Test conditions consisting of:

- a) 100 mW/cm² irradiance,
- b) AM 1.5 spectrum, and
- c) 25°C cell temperature.

2.34 **TENSILE STRENGTH (RATING)/ULTIMATE** – The minimum ultimate tensile strength of a material, per cross-sectional area, that it can withstand, independent of deformation. Although therefore a stress, many engineering handbooks head the reference tables as tensile strength.

2.35 **TERMINAL CONNECTOR** – Establishes a connection between one or more conductors to a terminal plate or stud, or to any similar device, by means of mechanical pressure.

2.36 **TORQUE** – Rotational force, for the purposes of this Outline of Investigation, refers to the rotational force applied to a threaded fastener to obtain a desired clamp load.

2.37 **UNCONDITIONED MODULES OR SAMPLES** – Modules or samples that have not been previously subjected to tests or environmental exposures.

2.38 **YIELD STRESS** – The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently, or the offset yield point at 0.2% strain for 300-series stainless steel.

3 Units of measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

4 Components

4.1 Except as indicated in 4.2, a component of a product covered by this Outline of Investigation shall comply with the requirements for that component. Also see Appendix A for a list of standards covering components generally used in the products covered by this Outline of Investigation.

4.2 A component need not comply with a specific requirement that:

- a) Involves a feature or characteristic not needed in the application of the component in the product covered by this Outline of Investigation, or
- b) Is superseded by a requirement in this Outline of Investigation.

4.3 A component shall be used in accordance with its recognized rating established for the intended conditions of use.

4.4 Specific components are recognized as being incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions for which they have been recognized.

5 Undated References

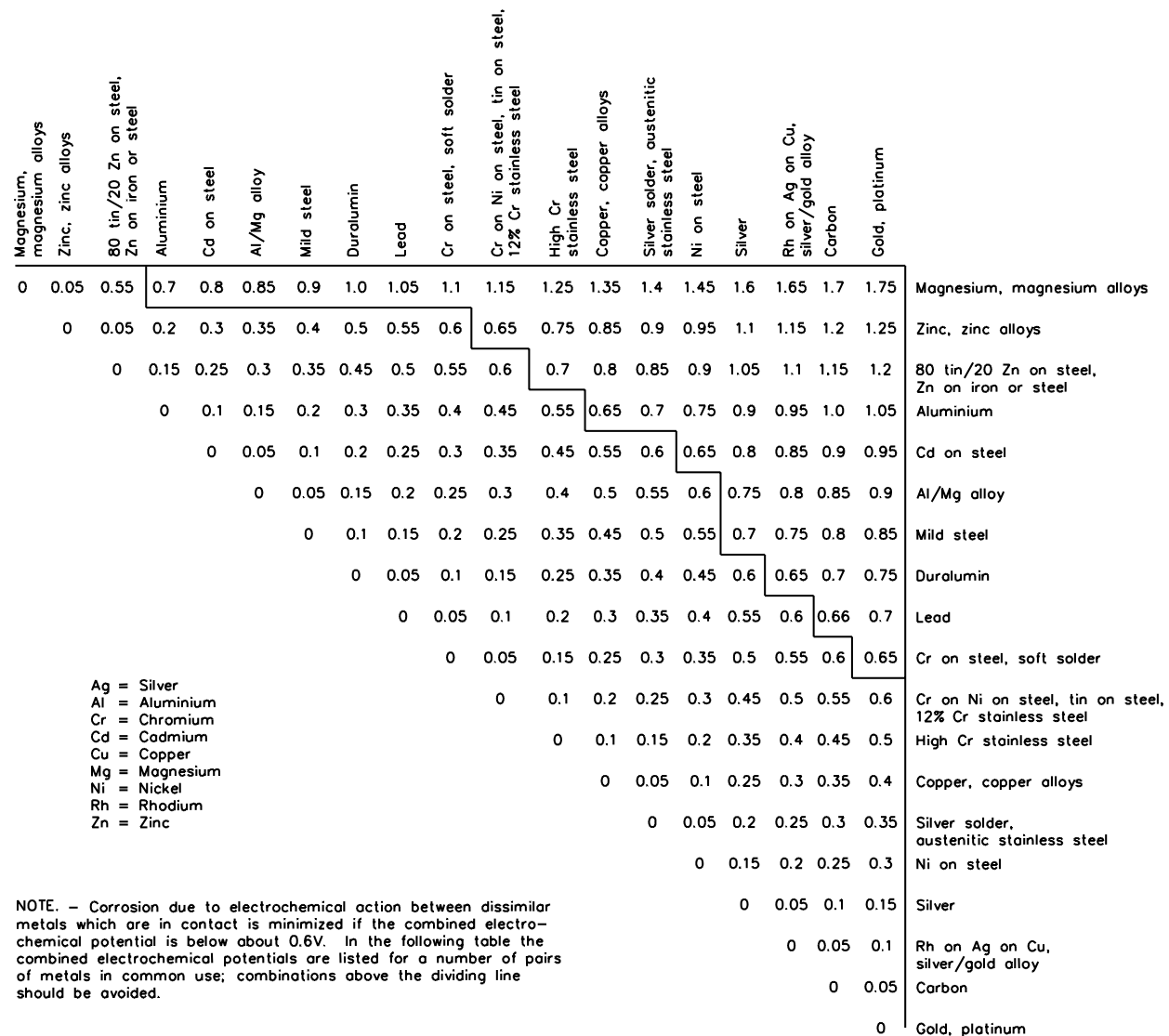
5.1 Any undated reference to a code or standard appearing in the requirements of this Outline of Investigation shall be interpreted as referring to the latest edition of that code or standard.

CONSTRUCTION

6 General

6.1 The rack mounting system and all components shall be designed with suitable materials and at sufficient material thickness for structural integrity under the loads the rack system will be subjected to. Materials shall also have suitable corrosion resistance. Any dissimilar metals that significantly contribute to galvanic corrosion shall not be utilized. The electrochemical potentials table of Figure 6.1 shows various common metal combinations. Combinations below the table cutoff line are considered to be acceptable.

Figure 6.1
Electrochemical potentials



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6.2 The rack mounting system shall be designed with suitable corrosion resistant materials to ensure that the rack system, through all connection points, is a suitable bond/ground path.

6.3 Clamping devices shall be evaluated with their mounting hardware designed with suitable corrosion resistant materials to ensure structural integrity to suitably retain the PV modules for loading, cyclic loading and, where applicable, to maintain a bond/ground path. The clamping devices for bonding, where intended to be utilized with aluminum framed PV modules, must have a means to pierce the PV module's frame anodization, paint or other non-conductive coatings.

6.4 Threaded fasteners used to secure clamping devices and other components shall be utilized at their recommended clamp load and shall not incorporate sheet metal threads. The tensile strength of the cap screw shall match the proof load of the female threads. Threaded fasteners are to be of suitable tensile strength and corrosion resistance and are to be tightened to the recommended torque for the fastener type and size as specified by the mounting system manufacturer. The tightening torque specification shall result in a clamp load on the fastened joint that exceeds the force that the joint can exert against the threaded fastener. Threaded fasteners without suitable clamp load are subject to loosening and/or fatigue failure.

6.5 It is necessary to consider cyclic loading, that if a PV module's uplift potential, in accordance with Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, exceeds the fasteners clamp load, a fatigue potential exists. It will be necessary to calculate the fastener's clamp load, using the clamping device manufacturer's recommended torque for the fastener size and threads per inch, the number of fasteners per PV Module and compare to the potential upload, utilizing the 45 lb/ft² up-loading (or greater based upon the PV module load rating) from UL 1703. A minimum safety factor of 4:1 must be utilized, where the clamp load exceeds potential uplift, based upon UL 1703 test values.

To determine clamp load, based upon the fastener torque specification provided by the manufacturer, the following formula is to be used:

$$W = 12T/(rD)$$

where:

W = Clamp Load (lbs)

T = Torque (ft-lbs)

r = Friction Coefficient (use 0.25 for 300 series stainless steel, or use 0.20 if antiseize compound is required to be used and is specified in the installation instructions)

D = Major diameter of the threaded fastener (inches)

Example: The manufacturer is using 3/8 inch-16 thread/inch cap screws to secure each of the 4 clamping devices securing each PV Module to the rack mounting system. Each cap screw is tightened to 20ft-lbs to secure each clamping device, and anti-seize compound is not specified to be used on the threads:

Using $W = 12T/rD$; $W = 20 \times 12/0.25 \times 0.375$; $W = 2560$ lbs

Then compare to the module's dimensions; for example 3 ft x 5 ft = 15 sq-ft. 15 sq-ft $\times$ 45 lbs/ft² = 675 lbs (calculated UL 1703 minimum uploading).

Compare the combined fastener's clamp loads:

4 fasteners $\times$ 2560 lb clamp force = 10,240 lbs of total clamp force vs 675 lb upload test value. Applying the 4:1 safety factor; compare the ratio of 10,240 lbs (total clamp force) to: 675 lbs (uplift test value) = 15.2:1, exceeding the 4:1 safety factor and therefore in this example; the total clamp load (or clamping force on the fastened joint) does comply with 6.5.

6.6 For threaded fasteners utilized in shear, a slip factor (where joint movement could occur) between the surfaces clamped shall be 2:1 when compared to the test load upforce (which is based upon the PV module's load rating and therefore may be greater than 45 lbs/ft²). The same calculation in 6.5 is to be utilized, however the coefficient of friction (not the same as threaded fastener "friction coefficient" in 6.5) is also to be considered between the joint mating surfaces.

For example, a galvanized steel racking system is secured with 4 vertical posts each with three 1/2 inch -13 300 series stainless cap screws and hex nuts (total of 12 cap screws/nuts) and the torque specification on the 1/2 inch -13 cap screws is 40 ft-lbs and the installation instructions require antiseize compound to be used on the fastener threads (therefore utilize 0.20 as the friction coefficient) and the array of PV Modules to be attached is 420 ft².

Utilizing the formula from 6.5, $W = 12T/rD$; $W = 12 \times 40/0.20 \times 0.5$; $W = 4800$ lbs of clamp force for each of the 300-series 1/2 inch -13 threads per inch cap screws and hex nuts, multiplied times 12 cap screws = 57,600 lbs of clamp force. Using the steel on steel coefficient of friction for the support structure mating surfaces from Table 6.1 of 0.74, we have 57,600 lbs $\times$ 0.74 = 42,624 lbs in total, before the bolted joints could slip and act against the clamp load of the fasteners. Compare this to the array of 420 ft² of PV modules $\times$ 45 lbs/ft² = 18,900 lbs and we have 42,624 lbs/18,900 lbs and the ratio is 2.25:1 complying with the 2:1 requirement.