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REVIEW OF LIGHTNING PROTECTION STANDARDS FOR PHOTOVOLTAIC SYSTEMS

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SUMMARY

In areas of modest solar resources, one key to obtaining a positive overall contribution to the ecology rests in obtaining reliable and long-term service from photovoltaic systems. This means that lightning protection systems, normally regulated to make buildings safe from fire, should also give an effective degree of electromagnetic pulse protection to photovoltaic panels and components.

In photovoltaic (PV) systems, modules are grounded to reduce shock and fire hazards. The Canadian Electrical Code (CE) and National Electric Code (NEC) require that any exposed metal surface be grounded if it could be energized. Any failure of insulating materials in a PV module could allow its frame to become energized at up to 600 V. The NEC and UL Standard 1703 require that the module frame be grounded where a designated grounding provision has been made, using the hardware and instructions supplied by the module manufacturer.

Normally copper conductors are used for electrical connections and the module frames are generally anodized, milled or coated aluminum. Aluminum oxidizes quickly, so bimetallic (copper and tin) connections rated for outdoor direct-buried application should be used.

When retrofitting a PV system to an existing structure, so that it also functions as a Lightning Protection System (LPS), installers should provide additional ground rods as shown in Option 3 of Figure 7. Generally, each #2 AWG downlead should have its own ground rod or ground wire of 50-mm² cross section and there should be at least two downleads. It is recommended that these be bonded to existing ground electrodes as in Option (3), especially in areas of high resistivity. The minimum suitable wire size for downleads and for bonds between PV modules in the same LPS is #2 AWG.

Where practical, it is better to move the PV modules to the interior volume of a separate LPS and to place sensitive inverters, batteries and monitoring equipment in a less sensitive area, using equipotential bonding and appropriately-rated surge arresters on every conductor that passes through an interface boundary.

The electrodes described in CE Code Rule 10-700 and 10-702 have a wide range of resistance values, depending on local soil resistivity, electrode shape and size. With its large surface area, The “Ufer” ground described in 10-702(2) is most appropriate in many areas of Canada.

The CE Code Rule 10-706 allows for interconnection of lightning protection systems and the grounding of the electrical system if they are “closer than 2 m”. In a wide range of practical situations, with a thin layer of soil over poorly conducting rock, this rule should be changed to allow or require bonding below grade using the recommended 0 AWG conductor, or to endorse the use of a Bonding Bar and #5 AWG bonds and downleads as described in IEC 61024.

The CE Code Rule 10-710 expresses a desire for a separation between lightning protection system ground electrodes and power system grounding unless they share a common water piping system. Generally, this decreases the effectiveness of the lightning protection system without materially reducing the risk of lightning damage to the electrical system. Selection of appropriately rated bonding or surge arresters at each lightning protection zone for all traversing systems represents relatively modern practice that mitigates much of the electromagnetic pulse effects of lightning on PV and other enclosed electronic systems.

SOMMAIRE

Dans les régions où les ressources solaires sont limitées, un des facteurs clés pour obtenir une contribution globale positive à l'égard de l'écologie consiste à garantir un service fiable et durable des systèmes photovoltaïques. Cela veut dire que les systèmes de protection contre la foudre, normalement prescrits pour protéger les bâtiments contre les incendies, devraient également assurer un degré efficace de protection des panneaux photovoltaïques et leurs éléments contre les impulsions électromagnétiques.

Dans les systèmes photovoltaïques (PV), les modules sont mis à la terre pour réduire les risques de choc électrique et d'incendie. Le Code canadien de l'électricité (CCE) et le National Electric Code (NEC) des États-Unis exigent que toute surface métallique exposée soit mise à la terre si elle risque d'être mise sous tension. Or, tout claquage de l'isolation d'un module PV risque d'appliquer au cadre une tension allant jusqu'à 600 V. Le NEC et la norme UL 1703 exigent que le cadre de module soit mis à la terre lorsque des dispositions de mise à la terre ont été prises, au moyen du matériel et des instructions fournis par le fabricant des modules.

Normalement, des conducteurs de cuivre sont utilisés pour des connexions électriques, et les cadres de module sont généralement en aluminium anodisé, laminé ou enduit. L'aluminium s'oxyde rapidement, de sorte qu'il faudrait utiliser des connexions bimétalliques (cuivre et étain) cotées pour les applications extérieures à pose en pleine terre.

Lorsqu'un système PV est connecté à une structure existante, l'installateur devrait prévoir des prises de terre à tige supplémentaires d'après l'option 3 de la figure 7, de façon à constituer un système de protection contre la foudre (SPF). En règle générale, chaque conducteur de mise à la terre de grosseur 2 AWG devrait avoir sa propre prise de terre à tige ou son propre fil de mise à la terre d'une section de 50 mm², et il devrait y avoir au moins deux conducteurs de mise à la terre. Il est recommandé de relier celles-ci aux prises de terre existantes d'après l'option 3, en particulier dans les aires à grande résistivité. La grosseur minimale appropriée des fils pour les descentes de paratonnerre et pour les liaisons de continuité des masses entre les modules PV d'un même SPF est de 2 AWG.

Dans la mesure du possible, il vaut mieux déplacer les modules PV vers l'intérieur de l'espace de protection d'un SPF distinct et placer les équipements sensibles tels les onduleurs, les batteries et l'équipement de surveillance dans une zone moins sensible, tout en utilisant des connexions équipotentielle de continuité des masses et des parafoudres de valeur nominale appropriée sur chaque conducteur qui traverse une interface.

Les prises de terre (de type « Ufer ») décrites aux articles 10-700 et 10-702 du CCE ont une vaste gamme de valeurs de résistance, selon la résistivité locale du sol et la forme et la taille de la prise de terre. Vue sa grande superficie, la prise de terre décrite à l'article 10-702(2) convient le mieux dans bien des régions du Canada.

L'article 10-706 du CCE prévoit l'interconnexion de systèmes de protection contre la foudre et du circuit de mise à la terre du réseau électrique s'ils sont écartés de moins de 2 m. Dans un grand nombre de situations pratiques, où il y a une mince couche de terre sur de la roche de mauvaise conductivité, cet article devrait être modifié afin de permettre ou d'exiger la continuité des masses au-dessous de la surface au moyen du conducteur 0 AWG recommandé ou d'autoriser l'utilisation d'une barre de continuité des masses et des liaisons de continuité des masses et des conducteurs d'une grosseur de 5 AWG conformément à la publication 61024 de la CEI.

L'article 10-710 du CCE préconise la séparation entre les prises de terre du système de protection contre la foudre et le circuit de mise à la terre du réseau électrique, à moins qu'ils ne partagent une tuyauterie de distribution d'eau. En règle générale, cela réduit l'efficacité du système de protection contre la foudre sans réduire véritablement le risque de dommages causés par la foudre aux équipements électriques. La sélection de liaisons de continuité des masses ou de parafoudres de valeur nominale appropriée dans chaque zone de protection contre la foudre pour tous les systèmes traversants correspond à une pratique relativement moderne qui atténue une bonne partie des effets de l'impulsion électromagnétique de la foudre sur les systèmes PV et d'autres systèmes électroniques protégés.

INTRODUCTION

In areas of modest solar resources, one key to obtaining a positive overall contribution to the ecology rests in obtaining reliable and long-term service from photovoltaic systems. This means that lightning protection systems, normally regulated to make buildings safe from fire, should also give an effective degree of electromagnetic pulse protection to photovoltaic panels and components.

In Canada, the average lightning ground flash density is $N_g = 1.0$ flashes per km^2 per year. A photovoltaic array with a perimeter of $p = 40$ m, mounted on a freestanding 10-m house, will have an attractive radius $r_a = 54$ m and an exposed area of $\pi r_a^2 + pr_a$. This “average” domestic array will be struck every 90 years with a surge current I of median (30 kA) with subsequent strokes having a median rate of current rise dl/dt in excess of 40 kA/ μs . Both parameters cause over-voltage stress on the photovoltaic modules and on their associated electronic equipment.

The lightning exposure across Canada varies widely, as do the conditions for grounding of electrical and lightning protection systems. Regional variations in risk mitigation, possibly on a province basis, may represent good engineering practice.

SCOPE

Review clauses 10-700, 10-706, 10-710 and associated notes in Appendix B of the Canadian Electrical Code 2002. Review proposed changes (as provided by NRC) to USA National Electric Code regarding grounding requirements for photovoltaic systems. Clauses will be reviewed against modern practice for mitigation of lightning, including comparison with current versions of IEC 61024 and 61312, provided by Kinectrics. Provide input to CE Code Section 50 Technical Subcommittee Subject 3055 on how PV arrays and electronic components should be grounded and bonded to minimize failure rates and fire hazards.

LIGHTNING PROTECTION OF STRUCTURES

Lightning protection is achieved in structures by an external lightning protection system (LPS), sized to carry the anticipated currents without damage. Electrical continuity among metallic services (water lines, coaxial cable shields, power system neutrals) is mandated [7,8]. The IEC model can lead to very large surge currents in relatively small conductors.

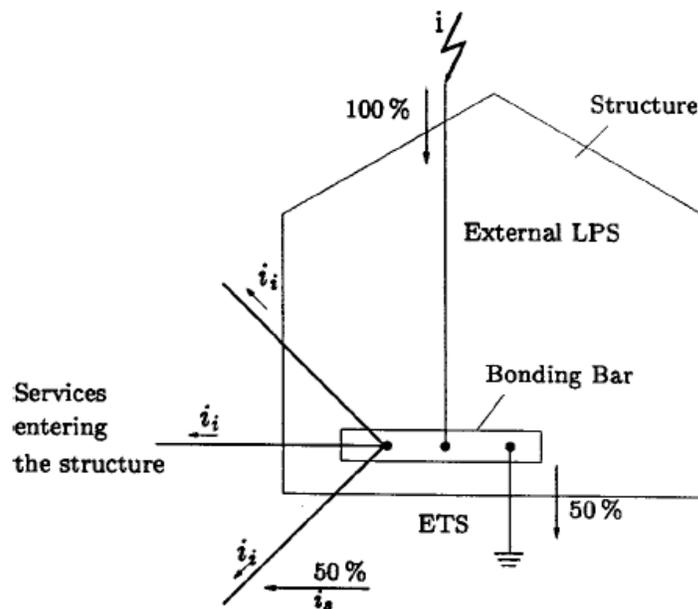


Figure 1: Division of Lightning Current among a Structure's Earth Termination System (ETS) (grounding) and other services entering the structure, per IEC 61312-1 (1995) [8]

The lightning surge entering the air termination in Figure 1 is typically a fast-rising, slow-falling unipolar impulse current with a rise time of $1 \mu\text{s}$, a peak of $2 \text{ kA} < i < 200 \text{ kA}$ and a time to half value of $50 \mu\text{s}$. Figure 1 also shows how this current splits up at the ground, and suggests that a building with only a three-wire electrical service will carry $(50\%/3=16.7\%)$ of the lightning surge current in each wire. The lightning flash will cause such a large voltage rise on the

Bonding Bar (typical 50-100 kA into ETS $\times 20 \Omega = 1000-2000$ kV) that typical low-voltage wiring would puncture without protection. The IEC recommends instead that the current be managed through the use of suitably rated lightning current arresters (LCA) that will conduct at about 1 kV, with each LCA carrying away 16.7% of the 100-to-200 kA current from Table 1.

Rakov (3) carried out tests using triggered lightning to measure current splits between the building ground and its interconnected, surge-protected electrical system. Triggered lightning in this case had about 1- μ s rise time and 60- μ s time to half value. Half of the leading-edge fast-front surge current did indeed flow into local grounding systems, but at later time the greatest fraction of current exited into the service. Between 81 and 100% of the current eventually found its way into the house and 28-50% went out to the transformer secondary neutral ground. Generally, these results strengthen the IEC view that interconnected services play an important role in mitigating lightning surges. Thus, all interfaces should be engineered with adequate surface area and material thickness to ensure that the lightning surge currents will flow without damaging the services.

As outlined in the Introduction, the occurrence of a lightning flash to a structure is calculated with the use of an “attractive radius” that is positioned all around the perimeter of the structure. This attractive radius is a function of height, with one recommended expression being $r_a = 19h^{0.45}$ where r_a and h are in meters [5].

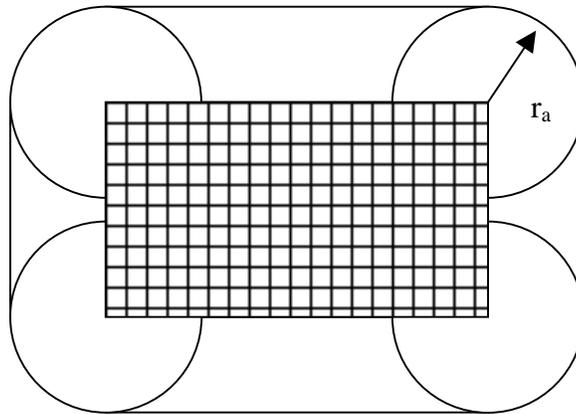


Figure 2: Exposed Area of Large Rooftop

A mesh pattern is shown on the roof of the building in Figure 2. The mesh size is selected, for example using IEC 61024-1, according to the degree of protection needed for the contents.

Table I: Minimum Values for Rolling Sphere Radius and Mesh Size

Lightning Protection Level	Probability Level	Rolling Sphere Radius	Mesh Size	Peak Current	Peak Rate of Current Rise
I	99% (3 kA)	20 m	5x5 m	200 kA	200 kA/ μ s
II	97% (5 kA)	30 m	10x10 m	150 kA	150 kA/ μ s
III	91% (10 kA)	45 m	15x15 m	100 kA	100 kA/ μ s
IV	84% (16 kA)	60 m	20x20 m	100 kA	100 kA/ μ s

All lightning protection systems (LPS) follow the same construction rules with regard to material and cross section, and greater protection is afforded by closer spacing of downloads and grids.

- Generally, small detached houses with a perimeter of less than 40 m should have two, rather than one, down conductors on opposite corners.
- Internationally, 35-mm² copper (#2 AWG) for interception conductors, 16-mm² copper (#5 AWG) for each download and buried 50 mm² (1/0 AWG) are recommended by IEC [7]
- The current CSA B72-M87 standard recommends #2 AWG copper or 1/0 AWG aluminum wire for both interception conductors and downloads.
- Aluminum frames of PV modules used as intercepting conductors in the absence of a separate LPS should be at least 25 mm wide and 2 mm thick [10] with IEC recommending a minimum thickness of 7 mm [7]. Interconnections in this case should use 35-mm² (#2 AWG) copper or equivalent.
- Drain pipes should not in general be used since they are easily damaged, corroded or replaced with plastic.

The risk of lightning damage is linearly scaled by ground flash density. The ground flash density in Canada has been measured using remote radiated fields, giving the map in Figure 3.

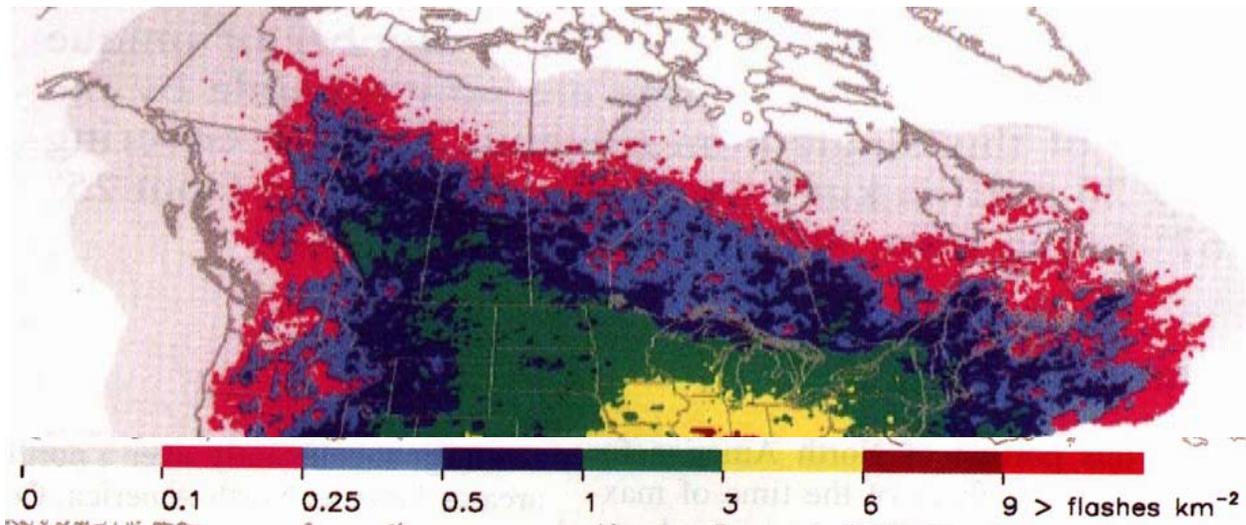


Figure 3: Observed Ground Flash Density in Canada [6]

Some areas of British Columbia, Quebec and Newfoundland have a ground flash density of less than 0.1 per km² per year, compared to a peak value of 3/(km²-year) near Windsor, Ontario.

Central Canada is, unfortunately, part of a region that has an exceptionally high level of positive flash incidence. In this region, there is a greater risk of thermal damage to lightning interception conductors and downloads. In areas where the fraction of positive flashes exceeds 10%, 35 mm² (#2 AWG) conductors may need to be upgraded to at least 50 mm² 1/0 AWG, based on the increased I²t and charge levels in positive flashes compared to the “ordinary” negative flashes.

One of the most difficult aspects of lightning protection is the design of the Earth Termination System (ETS). In new structures, the use of a foundation ground electrode (also referred to as “Ufer”) is preferred in IEC standards, similar to that described in CE Code Rule 10-702(2), and partly illustrated in Figure 4.

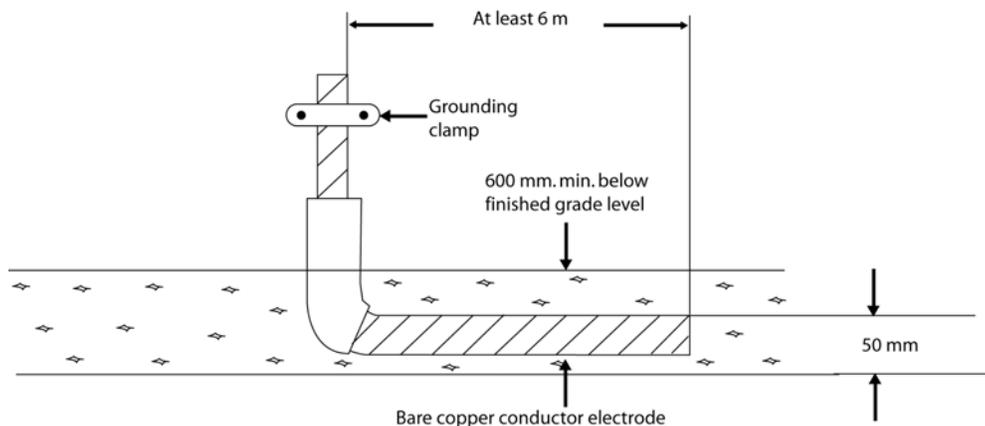


Figure 4: Electrode in a Concrete Footing

Metallic conductors of sufficient ampacity (such as reinforcing steel) are bonded electrically and an external connection above the concrete surface is made before concrete is poured. This gives a large surface area and low inductance, both minimizing the potential rise resulting from a lightning flash.

“Made” electrodes have a resistance that is calculated from the length of the electrode, its exposed surface area and the local resistivity of the soil ρ , in Ωm . One excellent equation, covering a wide range of shapes from buried pipes through to flat surfaces, is:

$$R = \frac{\rho}{2\pi g} \ln\left(\frac{11.8g^2}{A}\right) + \frac{\rho}{l}$$

$$g = \sqrt{r_x^2 + r_y^2 + r_z^2}$$

Where A is the surface area of the electrode in contact with the soil, g is the geometric radius and l is the total length of wire in contact with the soil, a correction factor between a solid plate and a wire grid of the same shape.

Soil resistivity can be estimated from maps of conductivity (σ in $\text{mS/m} = 1000 / \rho$) for Canada:

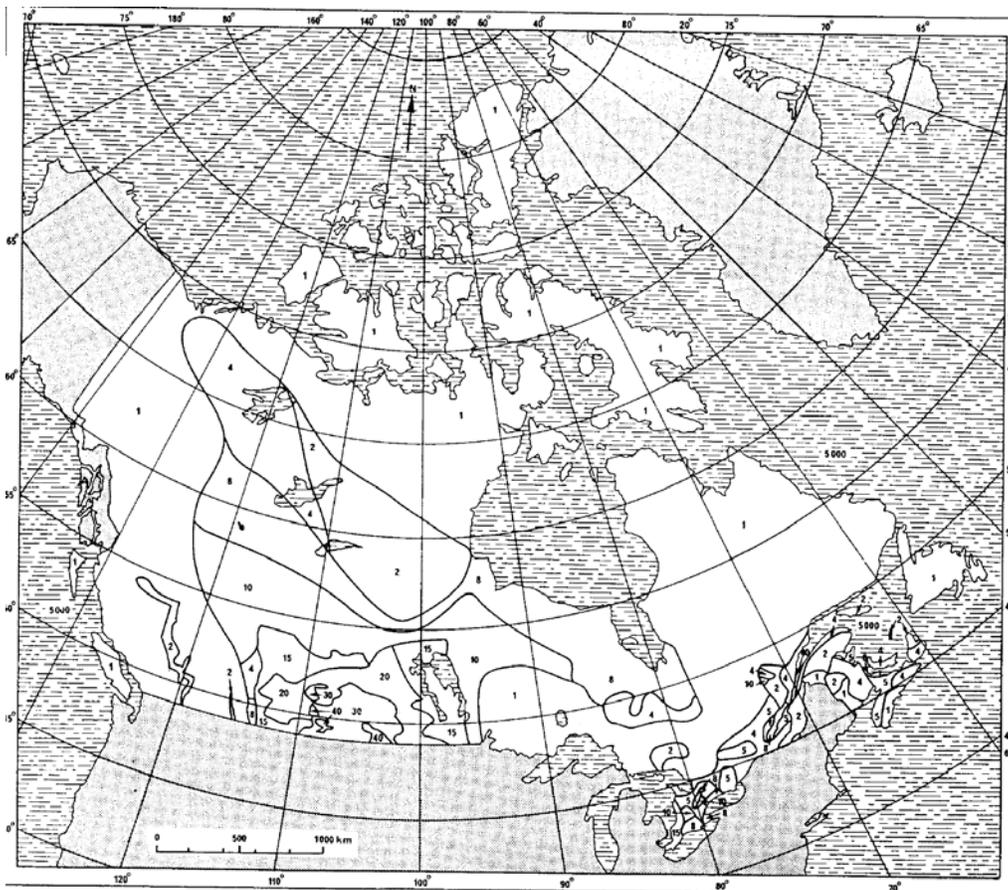


Figure 5: Observed Conductivity in Canada, units mS/m [9]

1 = 1000 Ωm ; 2 = 500 Ωm ; 4 = 250 Ωm ; 10 = 100 Ωm ; 20 = 50 Ωm ; 40 = 25 Ωm

As in the case of ground flash density, there is a wide variation in resistivity across Canada. The Prairie Provinces have low soil resistivity in the range of 50 to 100 Ωm , with BC, Newfoundland, Quebec and northern Ontario having difficult 1000 Ωm conditions.

The electrodes illustrated in the CSA CE Code Handbook, Rule 10-700, can be used to show how ground resistance varies across Canada.

Table 2: Low-Current Resistance of CSA CE Code Electrodes in Rule 10-700

RULE	DESCRIPTION	R_x M	R_y M	R_z M	G M	A M ²	L M	R FOR $\rho=100 \Omega\text{M}$	R FOR $\rho=$ 1000 ΩM
10-700(1)(a)	3-m water line, 0.6m deep	3	0.01	.6	3.06	3.6	3	52 Ω	520 Ω
10-700(1)(b)	15 m well casing	.038	.038	15	15	3.53	n/a	7.0 Ω	70 Ω
10-702(2)	10 m x 10 m foundation	5	5	3	7.7	160	n/a	3.0 Ω	30 Ω
10-702(3)	Two rods, 3 m apart	1.5	.01	3	3.35	18	6	26 Ω	260 Ω
10-702(4)	0.2m plate, 0.6m deep	0.1	0.1	0.6	0.62	0.44	n/a	49 Ω	490 Ω

In many parts of Canada, the option of 10-702(2) is recommended as the only practical configuration to achieve a suitably low (20-30 Ω) resistance.

The intent for CE Code Rule 10-700 notes that, when more than one grounding electrode exists, they are all to be bonded together using a minimum of #6 AWG copper conductor to optimize the overall electrode effect and to prevent voltage differences. This is feasible for DC and 60-Hz systems but is not practical for long-distance bonds not under lightning surge conditions. The series inductance of a wire is approximately 1 μH per meter of wire length. With the specified rates of current rise (dI/dt) in Table 1, Class IV of 100 $\text{kA}/\mu\text{s}$, the potential rise at the input end of a 30-m connection to a 25- Ω ground would be ($L dI/dt = 30 \mu\text{H} \times 100 \text{kA}/\mu\text{s} = 3000 \text{kV}$) and this would be superimposed on the ($RI = 100 \text{kA} \times 25 \Omega = 2500 \text{kV}$). The use of multiple bond wires is preferred to reduce the inductive effect, since wire diameter has only a minor effect on inductance. If a single wire is to be used for lightning protection purposes below grade, it should be copper, #2 AWG or larger.

LIGHTNING PROTECTION OF ELECTRONIC EQUIPMENT

Under lightning surge conditions, the potential on the independent ground rod (ETS) for the LPS is likely to be higher than 1000 kV. This will puncture through 2.5 m of average soil (400 kV/m) or flash across 6 m of wet soil surface (150 kV/m) in an uncontrolled manner to any nearby object at ground potential. Also, the mutual inductance of the LPS to nearby wiring will couple energy into victim circuits.

The IEC [8] recommend four “Lightning Protection Zones” (LPZ) for engineering the protection of sensitive equipment against lightning. These are:

- LPZ 0A, the area exposed to direct strokes, full lightning current and full magnetic field. The frame of a PV module with no other lightning protection is in Zone 0A.
- LPZ 0B, the area shielded from direct strokes, but carrying partial lightning current or induced current, and exposed to full magnetic field. If there is a horizontal wire running across the peak of a roof to down-conductors, and the PV modules are located on the slope of the roof, then the modules are in Zone 0B. Similarly, if the flashing around the perimeter of a flat roof on a high-rise building and an air termination system provides direct stroke protection, the modules are in Zone 0B.
- LPZ 1, the area with no direct strokes, partial or induced current and damped magnetic field. This is the region inside a “Faraday cage” that respects a safety distance to every downlead.
- LPZ 2, the area within a “Faraday cage” constructed inside LPZ 1, having no direct strokes, partial or induced current and further damped magnetic field. Again, the protected volume inside LPZ 2 must respect a safety distance to the conductors that form the cage.

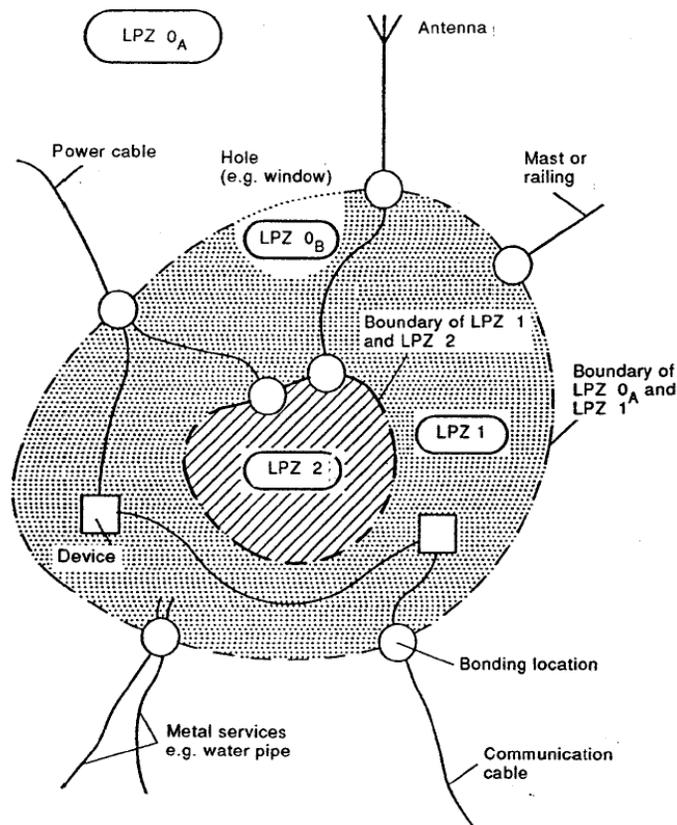


Figure 6: Principle of the Division of a Volume to be Protected into Different Lightning Protection Zones (LPZ) [8]

The IEC standard describes the various interfaces needed for services passing from one zone to another. For example, a water pipe entering a building as one of three services in Figure 3 should have connection to the Bonding Bar that is capable of carrying 17% of the anticipated lightning surge current. A lightning current arrester to a power conductor should be rated for the same duty.

Generally, there is no practical way to construct electronic equipment that will withstand the potential rise to remote earth under direct lightning flashes. It is only practical to equalize the potentials within a volume (building) using bonding and surge arresters, and to rely on reduced magnetic fields inside this volume, to reduce the relative potentials across PV system terminals and increase its chances of survival.

SUBJECT 3055 [1]

This subject raised an important issue/controversy since PV structures are often the highest point of a building, thus playing the role of a lightning rod. Consequently there are three ways one could approach bonding as shown in Table 3. Nevertheless, the group agreed that the proposal in Subject 3055 can move forward even though the lightning consideration is pending.

Minor editorial changes in 3055 is required in Sub-rule 3 proposed for the second round where elements mentioned in the text are also found in points a), b) and c). Proposed wording (by the minute taker):

(3) Where a non-metallic or insulated array structure is used, individual photovoltaic module frames shall be bonded together using one of the following means:

- a) Individual bonding conductors; or
- b) Bonding jumpers used in accordance with 10-614; or
- c) A screw in a bonding bus behind the frame; or
- d) Any other acceptable mean defined in 10-610.

Figure 7 shows the Table 3 mentioned in the text.

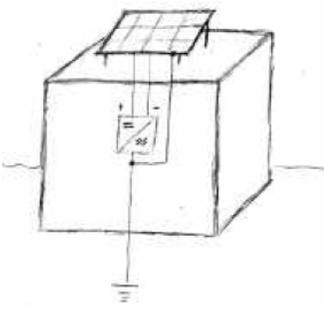
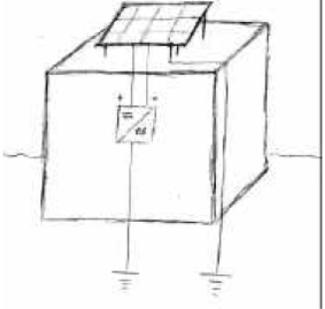
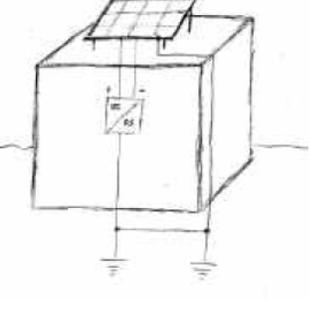
Option 1	Option 2	Option 3
Bonding the PV structure with the bonding conductor of the electrical system.	Considering the PV structure as a lightning rod.	Using a separate electrode and connecting both electrodes at ground level (10-700 / 10-706)
		
<p>Pros:</p> <ul style="list-style-type: none"> • Simple. • As mandated by current rules of the code. • Same rules as for roof equipment such as HVAC. <p>Cons:</p> <ul style="list-style-type: none"> • In case of lightning, all current will flow through the building. • Ampacity of the bonding conductor not set according to lightning requirements. 	<p>Pros:</p> <ul style="list-style-type: none"> • Divert safely all lightning energy to the ground. <p>Cons:</p> <ul style="list-style-type: none"> • Does not follow the code in term of bonding of electrical equipment. 	<p>Pros:</p> <ul style="list-style-type: none"> • Divert safely all lightning energy to the ground. • Does not contradict the intent of the code for a proper bonding of electrical equipment. <p>Cons:</p> <ul style="list-style-type: none"> • More complex but could be mandated only when PV is the highest structure. • Different from rules applied to other roof equipment such as HVAC.

Figure 7: Options listed in [1] for Bonding a PV System to Ground.

Option 1

Electrical code requirements for the equipment-grounding conductors on PV source and output circuits call for an ampacity of 125% of the short-circuit current at those points. While this can allow #14 AWG conductor between modules, a conductor this small would not be suitable for carrying lightning surge currents. A cross-section of 35 to 50 mm² of copper (2 to 0 AWG) or 50-80 mm² of aluminum is recommended for round conductor or the equivalent rectangular strip. This would apply to the frames of PV modules if they are installed in the absence of an external LPS. Sheet metal to carry lightning surge currents should be a minimum of 0.3 mm thickness (for copper), 0.5 mm (for galvanized steel) or 0.7 mm (for aluminum). Also, the basic inductance of the wire (1 μH per meter) will, under 100 kA/μs conditions, make the potential at a 10-m roof 1000 kV higher than at the base, even if the wire has adequate cross-section for ampacity purposes. Parallel downloads, such as those in Options 2 and 3, reduce this effect.

In Option (1), the lightning current is carried in a wire that runs near to PV system wiring. In addition to the ampacity concerns addressed above, the mutual inductance between the bonding

conductor and nearby wires will allow the high dI/dt of the surge to generate intense overvoltages, leading to insulation damage and risk of fire.

Option 2

The isolation between ground rods suggested in Figure (2) is somewhat fallacious. The mutual resistance between the two ground electrodes is likely to be low enough relative to the resistance to remote earth that a significant current flow will occur into the power system even if the ionization envelope around the ETS does not encounter the electrical service ground. However, this current flow will still produce a large potential difference between the LPS ground and the local power system, leading to flashover from the PV module frames to nearby supply terminals. Thus, the absence of bonding will not perform either of its desired isolating functions.

Option 3

This option is closest to the recommended practice in IEC. It may be appropriate that different rules apply to air conditioners and ventilators, compared to electronic equipment associated with solar panels. The electrical strength of motor insulation is typically at least four times rated peak running voltage (680 V impulse for a 120-V motor), and they are located inside a grounded metal case (IEC Zone 1) and sometimes under a metal cover (IEC Zone 2). Commercial PV modules typically bypass 12 or 24 cell blocks with 600V diodes, located at the end of the string of cells in a junction box so that the inductance of the diode path is low compared to the PV cell path. In this way, the modules have similar electrical strength to electric motors. However, they are not enclosed in a metal structure of any sort and are thus located in IEC Zone 0.

CONCLUSIONS AND RECOMMENDATIONS

Photovoltaic (PV) modules are grounded to reduce shock and fire hazards. The Canadian Electrical Code (CE) and National Electric Code (NEC) require that any exposed metal surface be grounded if it could be energized. Any failure of insulating materials in a PV module could allow its frame to become energized at up to 600 V. The NEC and UL Standard 1703 require that the module frame be grounded where a designated grounding provision has been made, using the hardware and instructions supplied by the module manufacturer.

Normally copper conductors are used for electrical connections and the module frames are generally anodized, milled or coated aluminum. Aluminum oxidizes quickly, so bimetallic (copper and tin) connections rated for outdoor direct-buried application should be used.

When retrofitting a PV system to an existing structure, so that it also functions as a Lightning Protection System (LPS), installers should provide additional ground rods as shown in Option 3 of Figure 7. Generally, each #2 AWG download should have its own ground rod or ground wire of 50-mm² cross section and there should be at least two downloads. It is recommended that these be bonded to existing ground electrodes as in Option (3), especially in areas of high resistivity. The minimum suitable wire size for downloads and for bonds between PV modules in the same LPS is #2 AWG.

Where practical, it is better to move the PV modules to the interior volume of a separate LPS (Zone 0_B or Zone 1) and to place sensitive inverters, batteries and monitoring equipment in Zone 2, using equipotential bonding and appropriately-rated surge arresters on every conductor that passes through an interface boundary.

The electrodes described in CE Code Rule 10-700 and 10-702 have a wide range of resistance values, depending on local soil resistivity, electrode shape and size. With its large surface area, The “Ufer” ground described in 10-702(2) is most appropriate in many areas of Canada.

The CE Code Rule 10-706 allows for interconnection of lightning protection systems and the grounding of the electrical system if they are “closer than 2 m”. In a wide range of practical situations, with a thin layer of soil over poorly conducting rock, this rule should be changed to allow or require bonding below grade using the recommended 0 AWG conductor, or to endorse the use of a Bonding Bar and #5 AWG bonds and downloads as described in IEC 61024.

The CE Code Rule 10-710 expresses a desire for a separation between lightning protection system ground electrodes and power system grounding unless they share a common water piping system. Generally, this decreases the effectiveness of the lightning protection system without materially reducing the risk of lightning damage to the electrical system. Selection of appropriately rated bonding or surge arresters at each lightning protection zone for all traversing systems represents

relatively modern practice that mitigates much of the electromagnetic pulse effects of lightning on PV and other enclosed electronic systems.

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