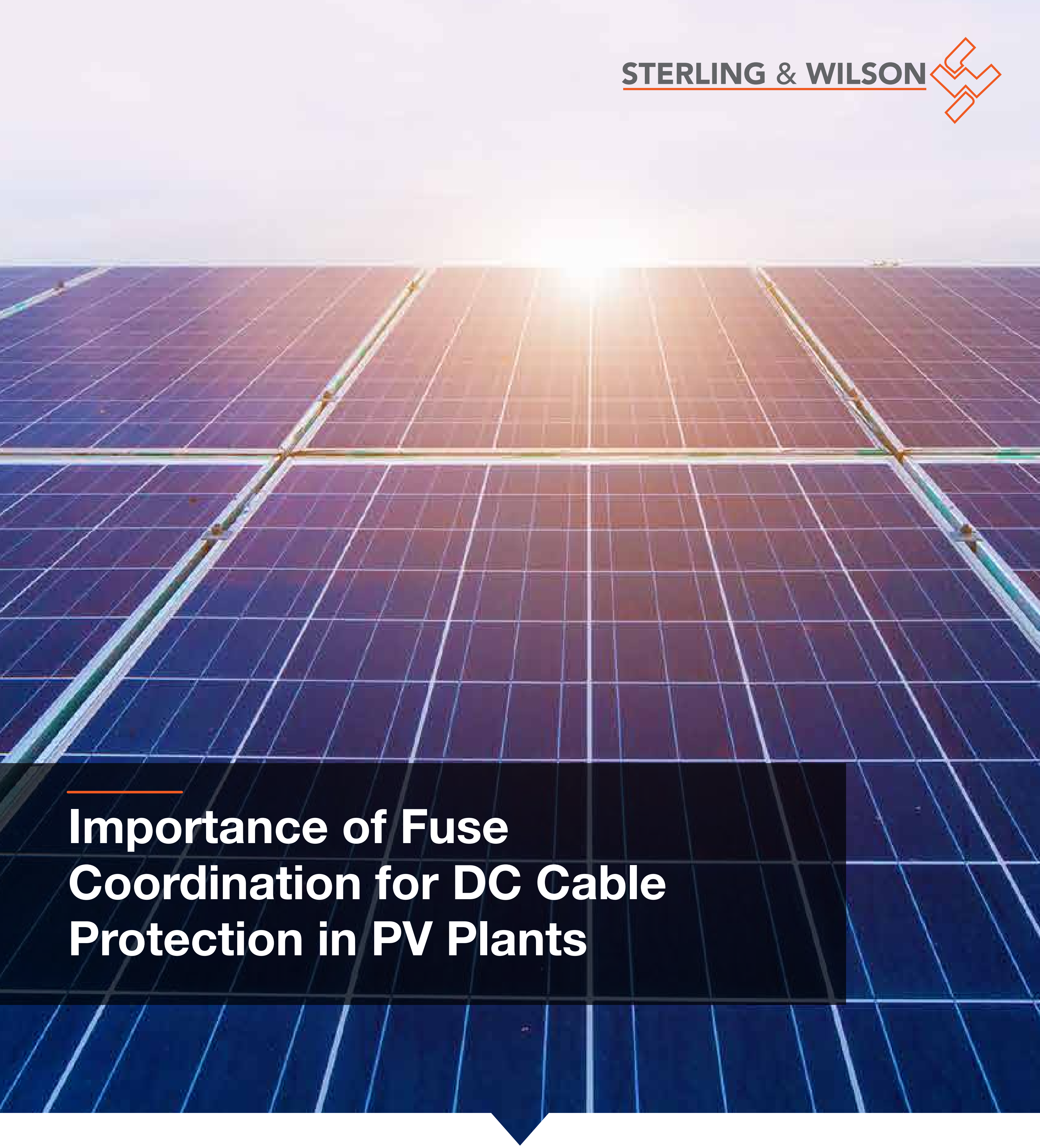

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Importance of Fuse Coordination for DC Cable Protection in PV Plants

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Abstract:

As photovoltaic plants generate DC at first with the help of modules, the size of the DC cable is of utmost importance due to its huge scope and importance in delivering DC power from module to PV inverter level. As far as safety is concerned, an electrical engineer need not only consider short circuit analysis and cable deration in his design, he should know how to coordinate overcurrent protection device (OCPD) with DC cable in the electrical system that will ensure that during fault condition the fuse will clear the system before the DC cable starts burning, triggering an arc flash or fire. Coordination study is very critical since the interval of the clearing the fault and the start of the burning of the cable is just a matter of a second. This paper provides guidance, on the methodology and importance of OCPD fuse coordination with DC cable that will help in proper selection of DC cable sizes for photovoltaic projects.

Introduction:

Solar power is the conversion of energy from sunlight into electricity using PV Panels. PV Panels used in solar plants generate DC that is than converter to AC with the help of PV inverters. DC cables are lifelines of the Solar Power Plant and interconnect modules to combiner boxes and then combiner boxes to inverters.

As far DC cable sizing in PV projects is concerned, PV engineers consider DC cable sizing based on cable derating factors such as – depth of cable laying, ground/air temperature, thermal resistivity of soil and grouping of cable that are important criteria for cable sizing. However, the coordination of DC cable with OCPD is neglected by PV engineers and may cause severe damage to DC cable during fault conditions at extreme environment i.e. – high irradiance and higher temperature as the PV module can generate more short circuit current with respect to rise in temperature and irradiance.

Methodology for fuse and DC cable coordination:

A fuse is the simplest overcurrent protection device (OCPD) in electrical circuits, yet it is very important. A fuse is a two-terminal device that is placed in series with the circuit it is supposed to protect. It performs its function by melting out when the current tries to exceed the specified level, thus breaking the circuit open. Once operated (fused) it must be replaced. Replacing is not a problem because fuses are relatively inexpensive. In solar PV plants gPV fuses are used to protect string / DC cable from overcurrent within a PV array that can be result from earth faults in array wiring or from fault currents due to short circuits in modules, in junction boxes, combiner boxes or in module wiring. Coordination of fuse with DC cable needs to be done in such a way that the nearest fuse electrically closest to the fault will blow (clear) and open the circuit far before the DC cable melting point, so that the DC cable can be protected from overcurrent. For this, the time-current characteristics of DC cable and fuse to be plotted on a common current basis i.e. – maximum short-circuit current (Isc) produced by PV panel or array. Below mentioned example can provide better understanding on the methodology.

Example:

Let us consider one example of fuse (used at combiner box input) and DC cable (used in between PV module and combiner box) coordination while validating the DC cable and fuse size.

In this example a 370Wp module has been considered. Module I_{sc} rating of 9.61A, I_{mp} rating of 9.23A, V_{mp} rating of 40.1V and V_{oc} rating of 48.5V. String size of 20 module per string has been considered based on 1000V system. 1Cx4Sqmm solar DC cable is used to connect string to combiner box. 20 input combiner box has been considered with fuse on positive pole only. String cable is laid in HDPE conduit containing 6 number of strings in single HDPE conduit that buried at 800mm depth inside the DC trench. Ground temperature of 40°C is considered as mentioned in the example below. Please refer to the diagram below that shows the connection of PV module string to combiner box with the help of DC cable and placement of fuse at incoming of combiner box.

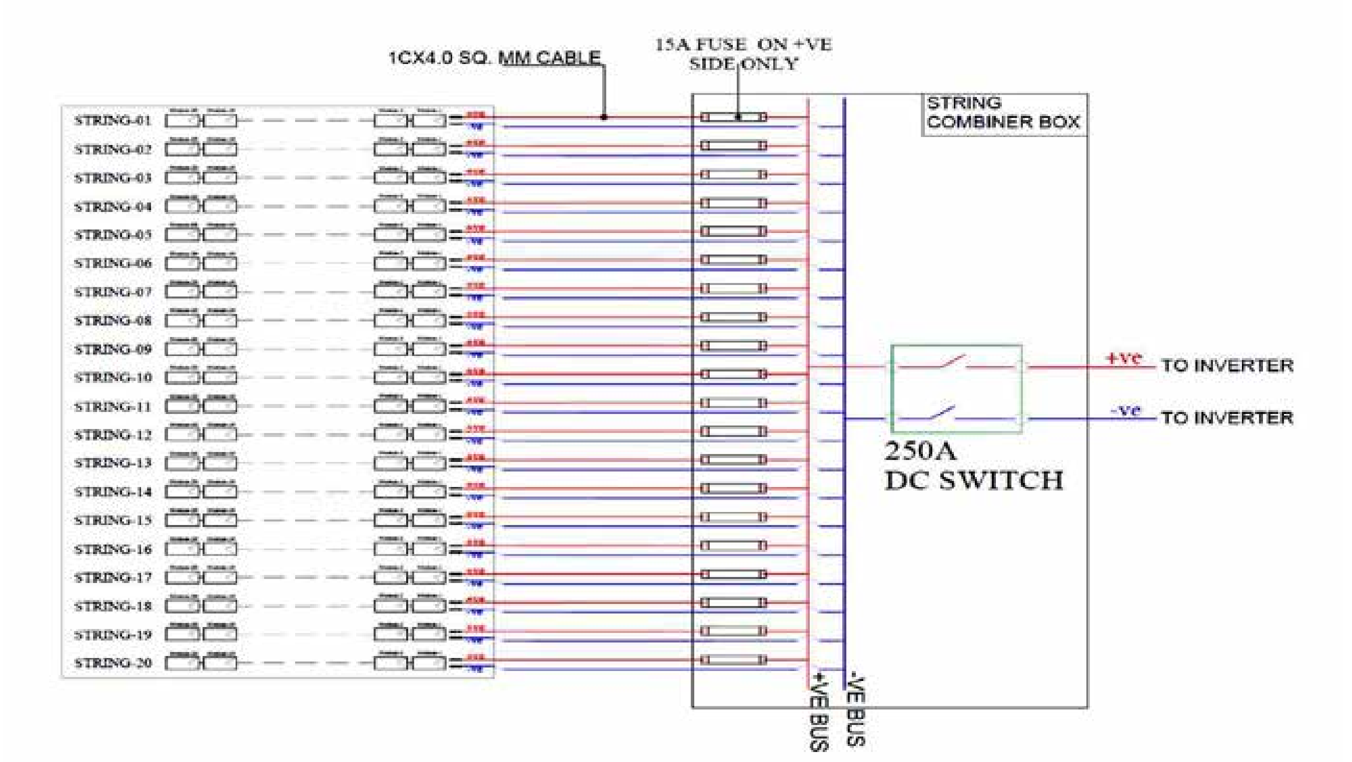

Figure – 1(Typical arrangement of string connection to combiner box)

The solution can be divided in three steps for easy computation.

Step -1: Maximum allowed continuous current of the cable

The cable cross section is sized in accordance with the maximum current. The maximum current that may flow through the string cable is the maximum generated PV short-circuit current minus the short-circuit current of one string:

$I_{max} = I_{sc}$ PV – I_{sc} String

The cable is either designed for this current or string fuses must be used to protect the cables from overloading. In our case, the string cable is protected by means of fuses installed on the String Combiner Box (SCB). The current-carrying capacity of the cables is influenced by the ambient temperature, the bunching with other cables and the method of installation. Hence, the corresponding formula to calculate maximum allowed continuous current for solar cables is as follows:

I_z cable = In x K1 x K2 x K3

Where,

I_z cable : Maximum allowed continuous current of the solar cable for continuous operation under service conditions

In : Current rating for continuous operations under standard conditions (to be provided by vendor)

K1 : Reduction factor for ambient temperature

K2 : Reduction factor for depth of laying

K3 : Reduction factor for bundled cables (group of circuits)

Let us consider the worst case when group of string cables laid underground in HDPE conduit and ground temperature is 40°C.

Hence, the values of de-rating factors shall be:

K1 = 0.85 (at ground temperature of 40°C as per IEC 60364-5-52)

K2 = 1 (depth of laying @ 800mm as per IEC 60364-5-52)

K3 = 0.6 (for 6 circuits laid in HDPE conduit as per IEC 60364-5-52)

Thus,

I_z cable = 55 x 0.85 x 1 x 0.6, wherein = 55A (current rating of 1C x 4Sqmm. Cu. XLPO cable defined by cable manufacturer) I_z cable = **28.05 A**

In accordance with IEC 60364-7-712, the string cable must be able to carry 1.25 times the generator short-circuit current: I_z cable required > 1.25 x I_{sc} String.

Let us consider string size of 20 module with module having Isc value of 9.61 A, and Isc value of module is equal to I_{sc} of string, as the modules are connected in series.

Hence, the minimum required cable ampacity shall be -

I_z cable required = 1.25 x 9.61 A

I_z cable required = 12.01 A

Hence,

I_z cable (28.05 A) > I_z cable required (12.01 A)

Conclusively the ampacity of the chosen 1C x 4Sqmm. Cu. XLPO cable is higher than 125% of the maximum current calculated for each module, that means the cable meets the requirements.

Step -2: Fuse rating selection

The cable will be protected by means of fuses inside the DC combiner boxes. The string fuse must be rated for DC operation and selected considering the conditions as follows:

- ✓ According to IEC 62738, it's recommended that the fuses must be chosen as follows:
  Fuse rating $\geq$ 1.25 x I_{sc}
- ✓ According to IEC 60269-6 states that:
  Fuse rating $\geq$ 1.4 x I_{sc}
- ✓ According to IEC 62548 states that:
  Fuse rating $\geq$ 1.5 x N_G x I_{sc}
- ✓ Where, N_G is the number of strings in a group under the protection of the one overcurrent device.

Hence, considering the worst case as per IEC 62548 as mentioned above -

Fuse rating > 1.5 x 1 x 9.61

Fuse rating > 14.415 A

Therefore, selected fuse rating should be higher than 14.415 A. As per standard rating of fuse next higher rating shall be 15A. Selected fuse rating = 15A

Step -3: Fuse coordination with DC cable

The permitted current-carrying capacity of the cable (Iz cable) must be same as or greater than the trigger current of the string fuse.

I_z cable (28.05 A) > Fuse rating (15A)

Time-current characteristics of the fuse:

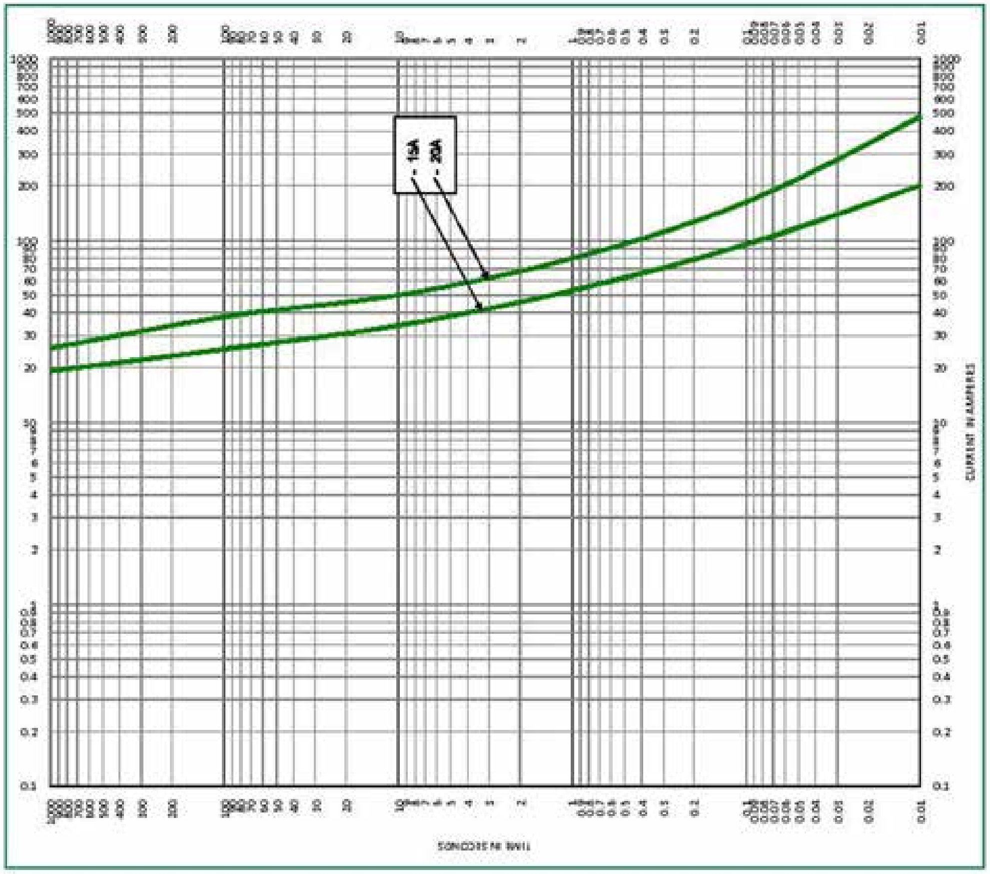

Figure – 2 (reference fuse characteristics from Little Fuse catalogue)

As previously mentioned, the maximum current that may flow through the string cable is the maximum generated PV short-circuit current minus the short-circuit current of one string:

$I_{max} = I_{sc}$ PV – Isc String

Thus, the maximum generated short-circuit current at 20 input combiner box DC bus is calculated as –

I_{sc} string = 9.61 A

I_{sc} at 20 input combiner box DC bus = 19 x 9.61 A = **182.6 A**

(Fault will be contributed by 19 inputs of 20 input combiner box as 1 input is having earth fault that will not contribute)

DC cable can withstand a short-circuit current during a determinate time until the temperature reaches the maximum conductor temperature. This may be calculated by means of the following expression:

$$\sqrt{t} = k \cdot \frac{S}{i}$$

Where,

t = duration of the short-circuit in seconds.

S = cross section of the cable.

i = effective short-circuit current.

k = factor which is 143 for Copper cable (from IEC 60364-4-43).

Hence, from the above equation melting time of DC cable is –

$$t = \left(143 \text{ x } \frac{4}{182.6}\right)^2$$

t_c (cable melting time) = **9.8 sec.**

According to Fuse time-current values (refer figure -2), the fuse melting times for the calculated short circuit currents is:

t_f (fuse melting time) = **0.015 sec.**

Thus, comparing the melting time of the fuse and the short-circuit time of the cable for coordination, the results are as follows:

t_c (cable melting time) > t_f (fuse melting time)

Therefore, during the maximum short-circuit current OCPD device (Fuse) will below or open the circuit before any damage to DC cable. The 15A fuse size is coordinated properly with DC cable in the electrical system.

*Above mentioned example and methodology can also be used as a reference for coordination of fuse (placed at PV inverter DC bus) and DC cable (between combiner box and PV Inverter).

Conclusion:

From the above discussion and worked out examples it can be concluded that while selecting the fuse size, in solar PV plant, it should be properly coordinated with DC cable such that the OCPD (Fuse) will below or open the circuit before any damage to DC cable that will ensure that during fault condition the fuse will clear the system fault before the DC cable start burning that would trigger an arc flash or fire that would further result in loss of human life, generation loss and increase in PV plant maintenance cost.

Reference:

1 IEC 60364-4-43: Low-voltage electrical installations - Part 4-43: Protection for safety - Protection against overcurrent.

2 IEC 60364-5-52: Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment – Wiring systems

3 IEC 62738: Ground-mounted photovoltaic power plants - Design guidelines and recommendations.

4 IEC 60269-6: Low-voltage fuses - Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems.

5 IEC 62548: Photovoltaic (PV) arrays - Design requirements

6 IEC 60364-7-712: Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems

7 Little Fuse catalogue for 15A gPV Fuse characteristics.

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