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WHITE PAPER:

Fusing For Photovoltaic Solar Power Applications

SIBA fuses for solar energy systems

Our Protection. Your Benefit.

SIBA

Fusing For Photovoltaic Solar Power Applications

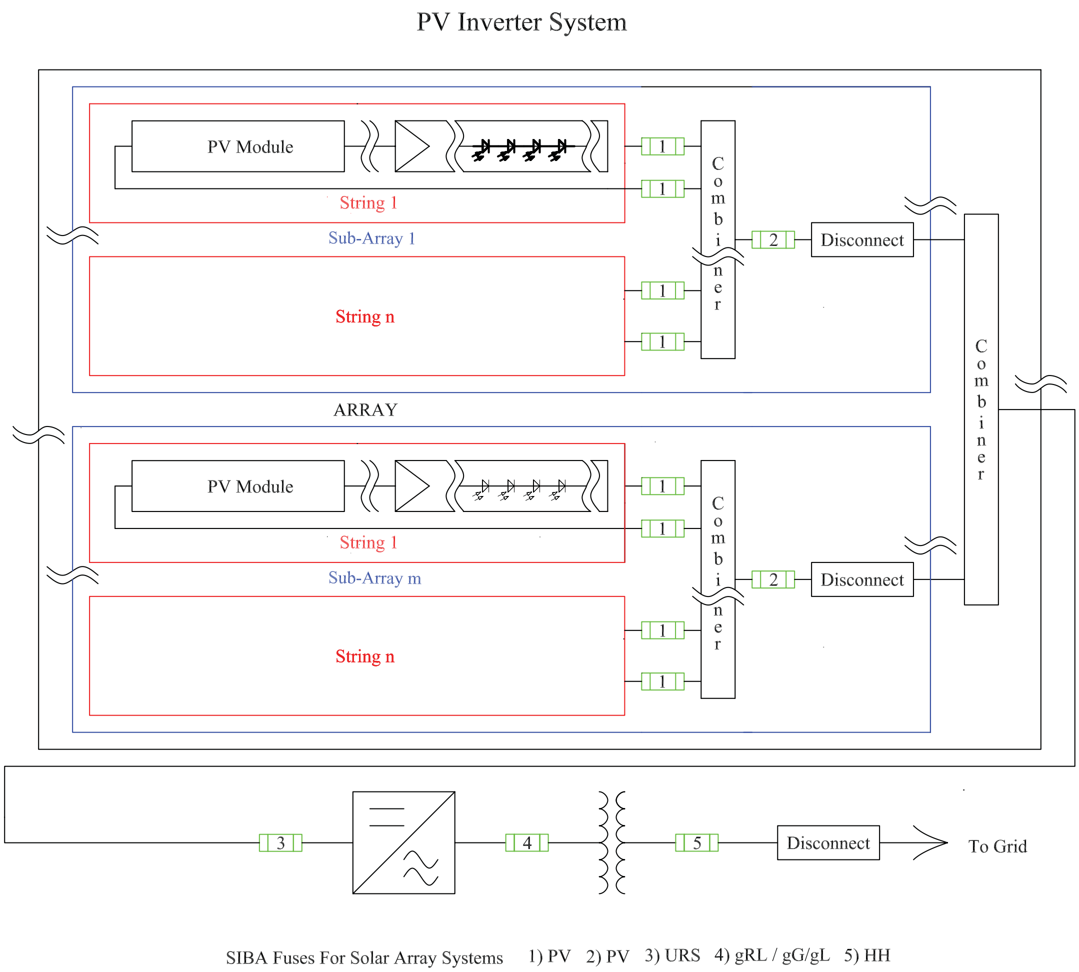
SIBA Fuses, the world leader in photovoltaic(PV) fusing protection by far. SIBA Fuses R&D Engineering group in cooperation with the major PV system manufacturers of the world is in the forefront of introducing the newest technology specifically dedicated to PV applications on a regular basis. Using a standard fast acting, dual element or slow acting fuses would NOT be the proper protection. The selection of the proper fusing requires knowledge of the total system fundamentals and understanding of all its parameters.

Power generation by means of solar photovoltaic modules is growing at an exponential rate. The rapid increase in energy cost and decrease in the cost of PV modules and inverters is making this a practical means of lowering energy cost of the end user and a means of cogeneration if power generated exceeds the usage.

As with all electrical generating equipment safety is a priority in all stages of operation. Figure 1is a simplified diagram of a typical large PV array with inverter.

The diagram shows a PV array that is composed of photovoltaic cells that converts light to a direct current. The photovoltaic cell is the smallest unit of the system that provides voltage and current. The PV cell is a two terminal device that can be connected in parallel to increase current, or in series to increase voltage. The voltage output of a PV cell is on the order of 0.3V -1.2V and is dependent on the semiconductor materials.

Figure 1



The current is dependent upon the semiconductor efficiency and surface area(theoretically one photon will generate 1 free electron), the dielectric constant of the semiconductor material and the angle of incidence of sunlight upon the panel. Normal incidence to the sun providing maximum highest density of photons/area, thus maximum current output. Current will decrease as the angle incidence deviates further from the normal.

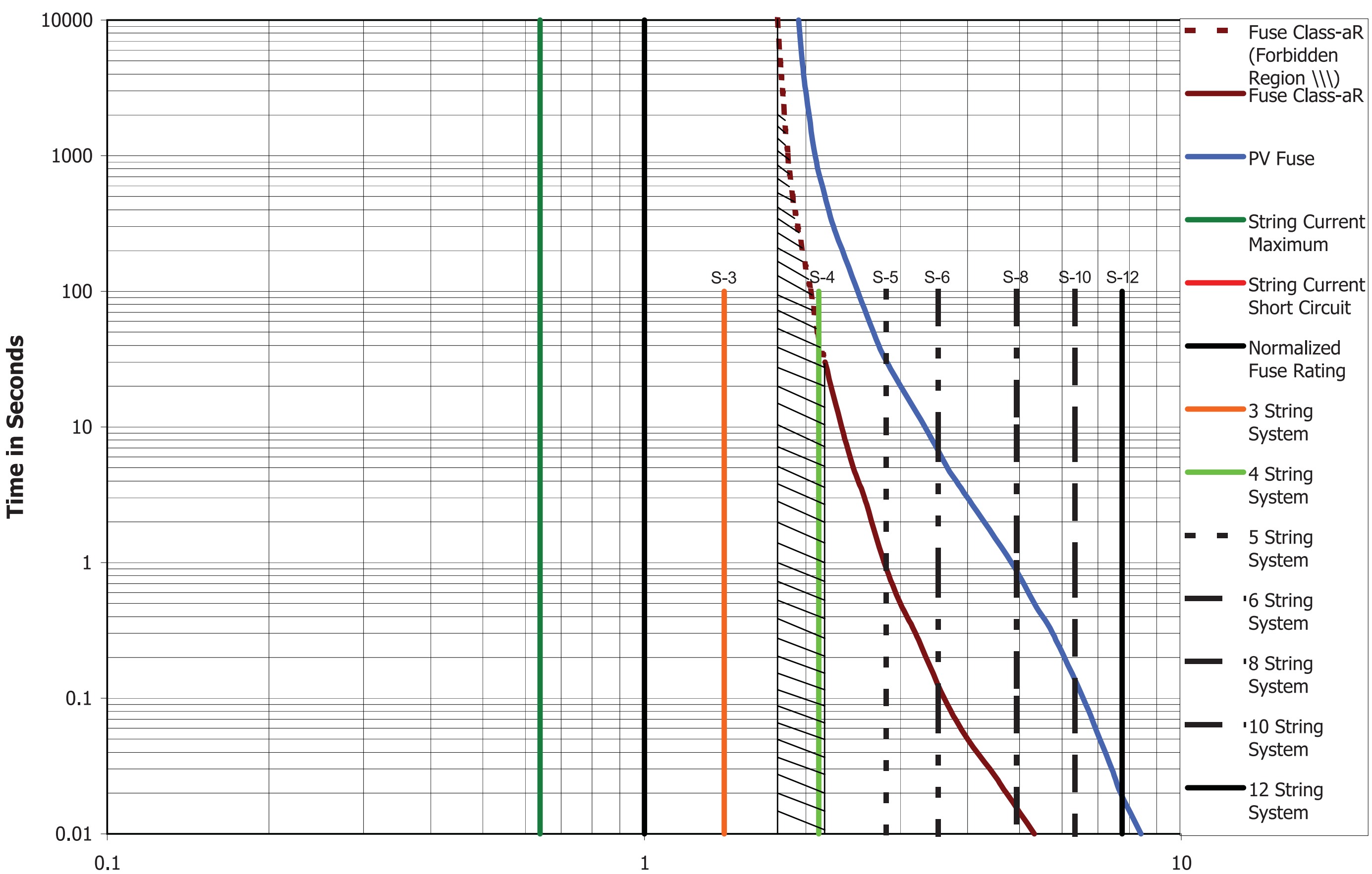
PV cells can be connected in a planar array to form a PV module in the form of a panel. The PV module is the smallest integrated package and is the basic unit for delivery of usable power. The PV module is constructed from PV cells that are series connected that forms a string. The current in the string is independent of the number of cells that are series connected and is equal to the output of a single cell, while the output voltage is equal to the output of a single cell times the number of cells that are series connected that forms the string.

Current can be increased by paralleling stings of PV modules and will be equal to a single string's current times the number of strings paralleled.

PV modules and PV strings are of such a size as to be readily manufactured cost effectively and to be manageable for assembly at the point of use. This is primarily due to the low current conversion efficiencies of less than 20%. This means that with a maximum available solar power of 1000W/m^2 the output power would be less than 200W/m^2 of panel area. State of the art limits the PV module's output power to about 250Watts.

The module has a label designating the output power rating (Watts), rated current (Amps), short circuit current (Amps), open circuit voltage (Volts), rated voltage (Volts) with load and maximum system Voltage (Volts), output terminals polarity, and fuse rating to protect the PV module.

Figure 2 **Array Short Circuit Current Normalized to Fuse Rating**



Normalized Current

Maximum available short circuit current from n-panel syetem with one panel shorted

To provide more power, strings are paralleled to form an array. For large power output systems, the array is subdivided into smaller units called sub-arrays. This allows maximum system protection and minimum degradation in performance in the case of failure of a PV string due to a short circuit fault.

For example a 500kW system with 600Vdc output would have about 360 PV strings, with each PV string delivering 600Vdc at 2.3A. Each PV string would be fused individually. 12 PV strings would be paralleled into a junction box to form the sub-array. The out put of the sub-array junction box would also be fused. The 30 sub-arrays would be summed into an array junction box, which is also fused, to form the PV array to provide an output current of 833A.

Fusing to protect solar panel in an array and cable assembly.

Basically a PV string is capable of delivering about 110% of its rated current into a short circuit at maximum light intensity(normal incidence of light). This is one of the major parameters in determining the proper fuse current rating.

Once the fuse has cleared the fault current, it must now withstand the voltage applied to it from the other PV strings. The voltage rating of the fuse must be equal to or greater than the no load voltage at that part of the system at which it is utilized.

If a PV string develops a short circuit, all PV strings that are connected in parallel to it will deliver their short circuit to the faulted PV string. This means that for n-paralleled PV strings with one PV string shorted the maximum available short circuit current is 1.1 x (n-1)x available rated current of one PV string.

The other major factor is the maximum ambient temperature that the fuse will be subjected to as this will lower the current capability of the fuse.

As an example in one application it was determined from the maximum available string operating current and maximum ambient temperature that the minimum fusing required per PV string was 1.56x(string max operating current).

The maximum available short circuit current (remember this is at "High Noon") is 1.1(PV string maximum operating current) x (n-1) where n is the number of PV strings connected in parallel. Figure 2 shows the normalized fuse rating melt characteristics of a PV full range fuse and partial range class aR fuse. Also plotted are the available fault currents available from (n-1) panels base upon the fault current of one PV string being 0.64x of the fuse rating.

As can be seen from the fuse melt curves the larger the available fault current the faster the fuse melts and clears. The only way to increase the fault current is to increase the number of PV strings paralleled. The plot in Figure 2 indicates that a 4 string system is the minimum for the PV fuse, and seems to indicate that a 5 string system is minimum for the class partial range aR fuse with these characteristics.

There is an advantage to the increasing the number of paralleled PV strings, as the incidence angle of light is constantly changing during the day, the output current of the panel changes correspondingly.

Kelley Cosine values of the photocurrent in Si-cells, gives the correction factor of the available current current at incidence from normal.

Incidence from normal	Kelley cosine value
30°	0.866
50°	0.635
60°	0.450
80°	0.100
85°	0.0

Figure 3a

5 Panel Array Short Circuit Current Normalized to Fuse Rating vs incidence angle - Kelley Cosine

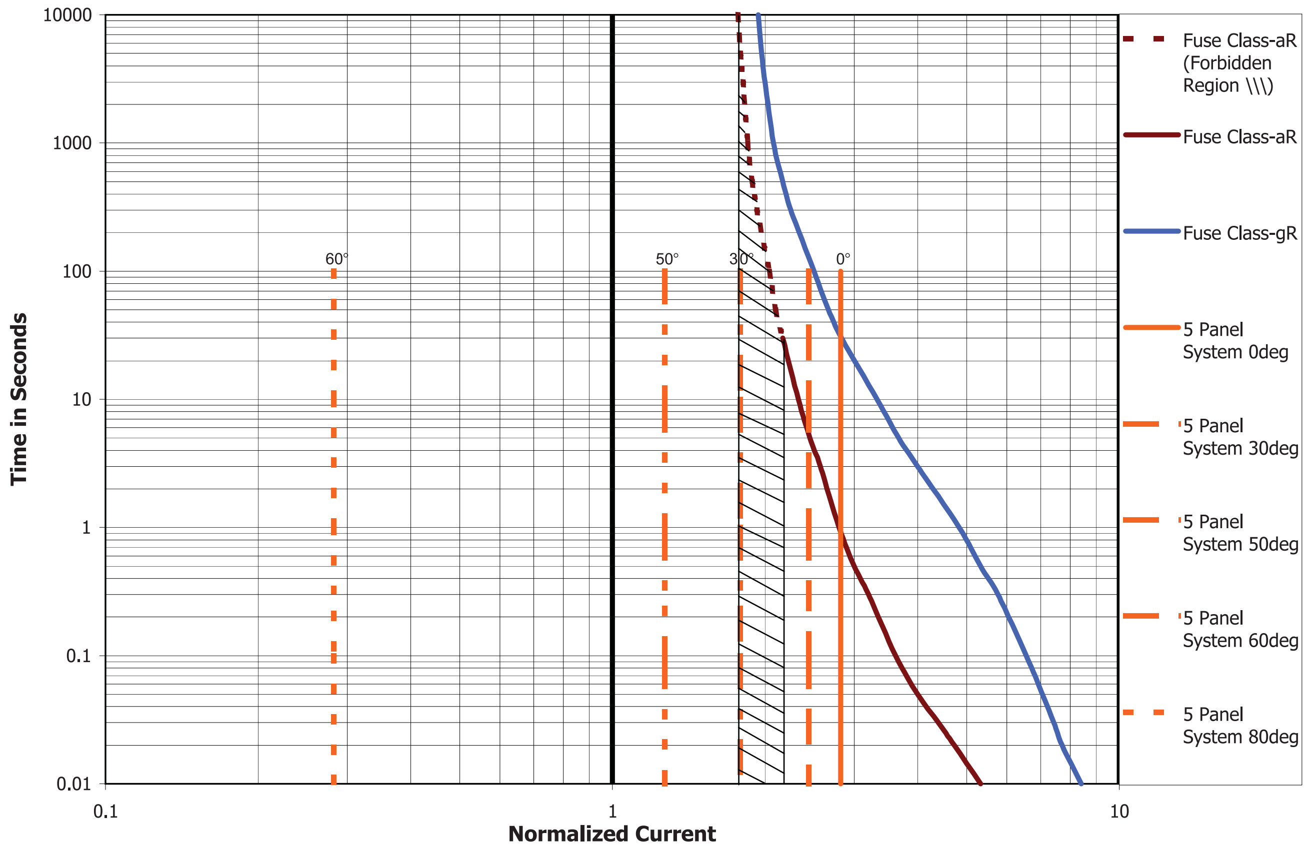
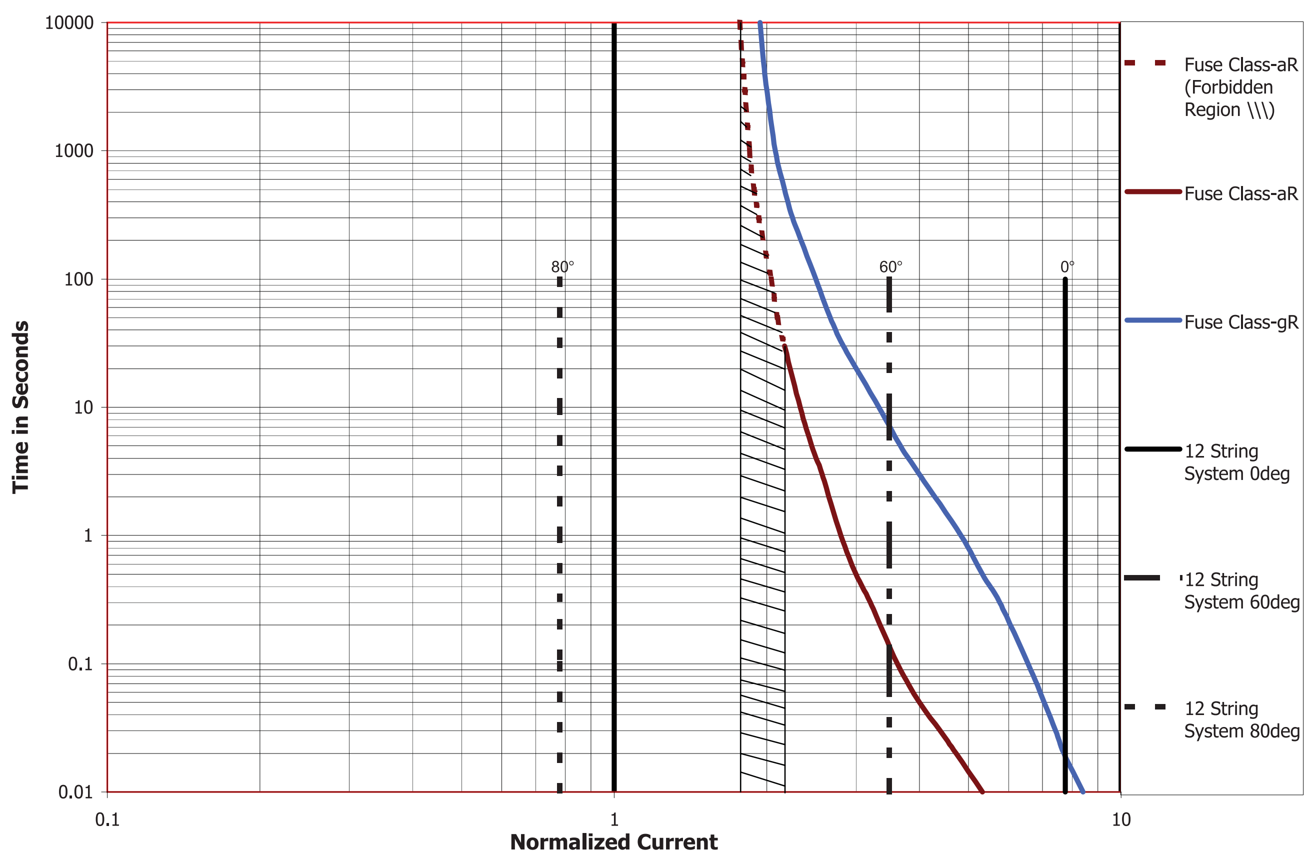


Figure 3b

12 Panel Array Short Circuit Current Normalized to Fuse Rating vs incidence angle - Kelley Cosine



The available fault current at a particular incidence will be the PV string rated short circuit current x (0.64)x(n-1)x(Kelley cosine value). This equation indicates that the short circuit current can be maintained above fuses minimum clearing current over a larger angle by increasing n, the number of PV strings paralleled.

This also reduces the time that the fuse is in "overload" condition. As can be seen in figures 3a and 3b.

This will provide longer times of available short circuit current that is capable of clearing the fuse during the daylight hours. There then comes twice a day in the am and the pm where the angle of incidence is such that there is not enough current to clear the fuse, again this depends upon n- number of PV strings paralleled. The example is for the partial range fuse with minimum string configuration of n=5. The minimum clearing current is 2.2 this would give the Kelley cosine value of 2.2/(0.64x(5-1)) =0.55, about 56°. The angle that provides a current equal to the fuse rating is about 70° (Kelley Cosine 0.391). This is about 1/2hour (based on 12 hour sunlight day) that the fuse is operating in the forbidden region.

THIS IS THE IMPORTANCE OF USING PV FUSES.
FOR PARTIAL RANGE CLASS aR FUSES THE SHORT CIRCUIT CURRENT MIGHT BE OF SUCH A TIME DURATION THAT THE FUSE COULD FAIL!

Available SIBA fuses for PV applications

Fuse/size	Rating/Test		Fuse Base/Module/Mounting
10mmx38mm			
5021506.0.5A-20A UL-Rec	900Vdc/1000Vdc		5106304.DC 6101701 Mounting Clips 5806306 Mounting Clips for PC Board
5021606.0.5A-20A UL-Rec	900Vdc/1000Vdc	PCB mount	
5021706.0.5A-20A UL-Rec	900Vdc/1000Vdc	50.6mm	
14mmx51mm			
5020406.4A-25A	900Vdc/1100Vdc		6100101.2 Mounting Clips 5805806 Mounting Clips for PC Board
5020506.4A-25A	900Vdc/1100Vdc	63.5mm	
NH1			
2002820.35A-200A UL Rec	900Vdc/1100Vdc		2102801UL Rec
NH3			
2003120.50A-400A	900Vdc/1100Vdc		2103101

2800202 – Micro-Switch for size NH1 and NH3

For the inverter SIBA URS square-body fuses 700V or 1300V series fuses.
For transformer's high side and filtering use SIBA HH series fuses.

New size fuses for PV application are being developed in 6.3mmx32mm, 10mmx51mm, 10mmx85mm and 20mmx127mm.

By; Mark Rudy
Abe Faraj

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