AE SOLAR
alternative energy

Smart Hot-Spot Free Modules

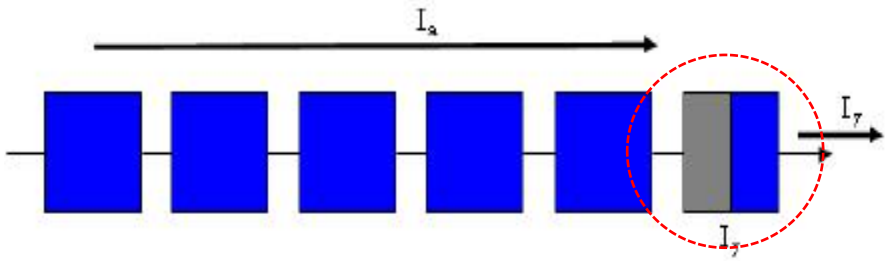
Generating More Power with Better Safety & Reliability

Content

Hot Spots on Solar Modules

***Hot spots** are a common occurrence on solar modules and they are usually hard to predict or pre-detected. As a result, junction boxes with bypass diodes have been installed on all modules to protect them from hot spot damages.*

- **What is a hot spot?** **A heated area caused by a drop in output current in one or more cells in a string.**
- **What causes a hot spot?** **A number of factors could cause hot spots, including cell efficiency mismatch, micro-cracks in cells, blockages or shadows, and a variation in cell degradation speed. This results in heat accumulation. Some hot spots can be traced back to problems during manufacturing, others occur during operation, more likely as time passes. Usually hot spots can not be predicted or pre-detected, except in cases when there is a permanent blockage/shadow in a part of a solar system.**

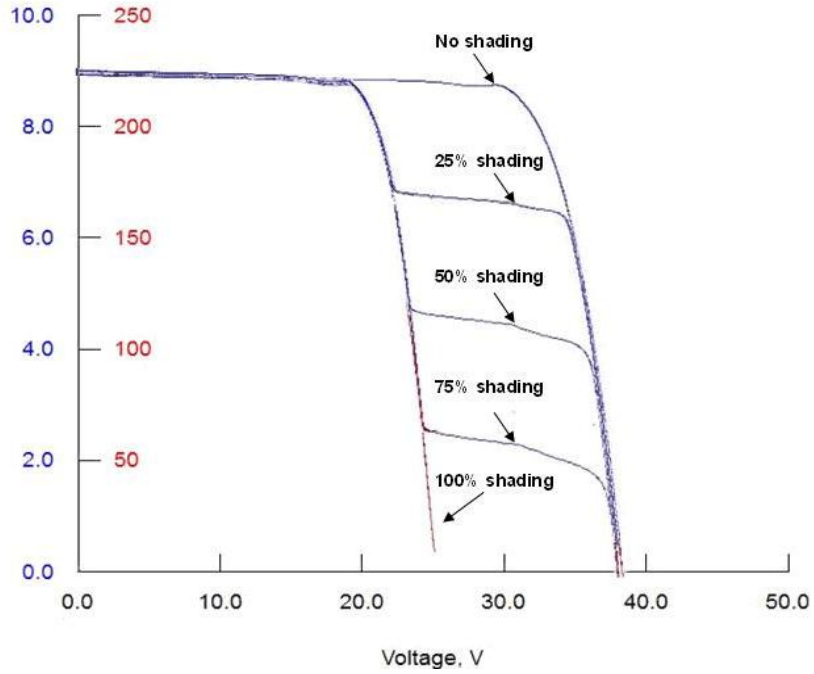


Hot Spot Damages

Hot spots can cause serious damages to solar modules. Any power generated by good cells can be consumed by problem cells in a string. Hot spots not only reduce output efficiency, but also cause heat accumulation and potential fire.

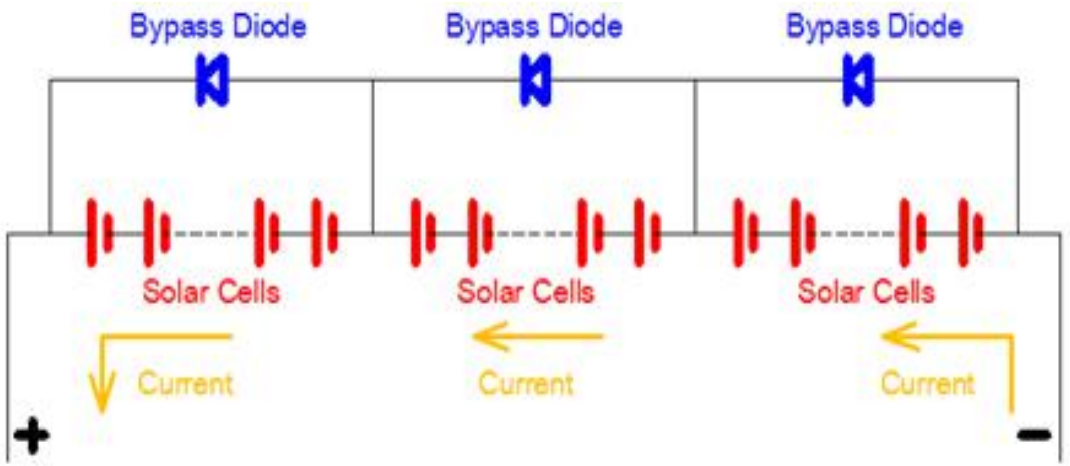
- **Heat damages : Cell temperatures can go up to 150℃ when a hot spot occurs. The destructive effects are permanent and irreversible, such as cell or glass cracking, melting of solder, encapsulation material fatigue, and cell degradation. Hot spots are a potential threat to operation safety and module reliability.**

- **Reduction in output power: Efficiency will fall as the area of shadow grows. When bypass diode is being activated, the whole string of cells will be bypassed, causing up a 30% loss in module output.**



Problem string is being bypassed, and module voltage falls by 1/3

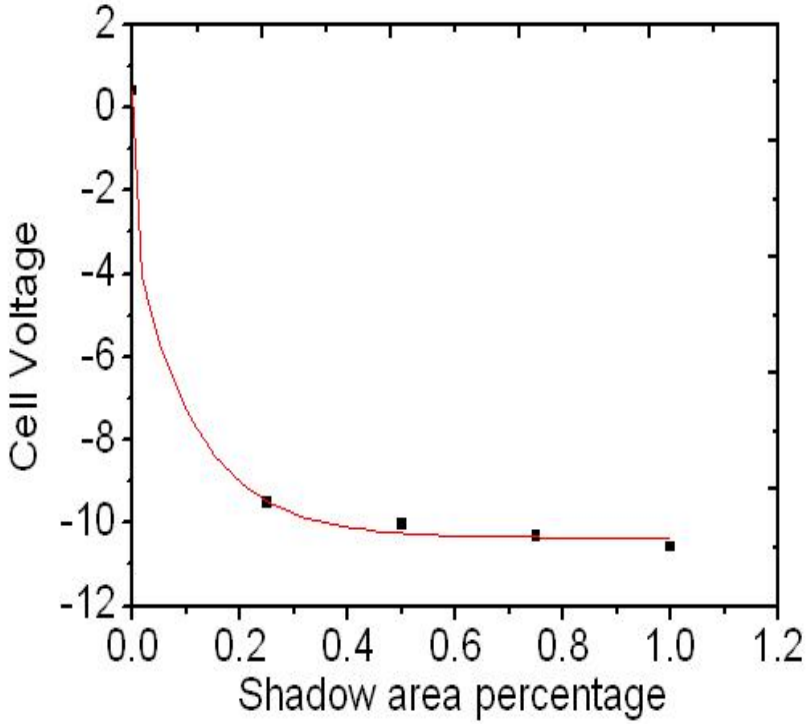
Hot Spot Protection for Traditional Modules



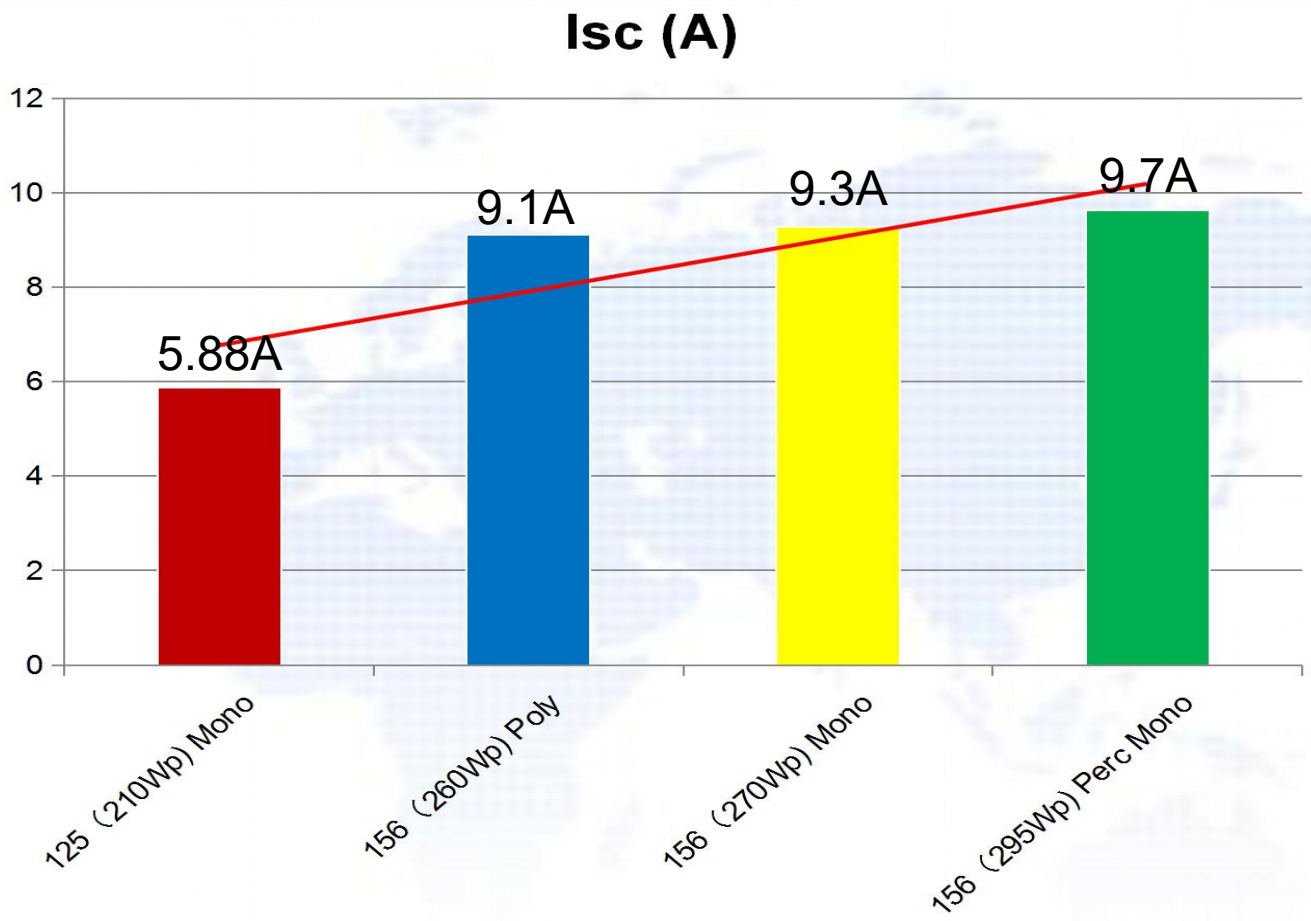
Currently the majority of modules use three bypass diodes to protect 60 or 72 cells, or one diode for every 20 or 24 cells.

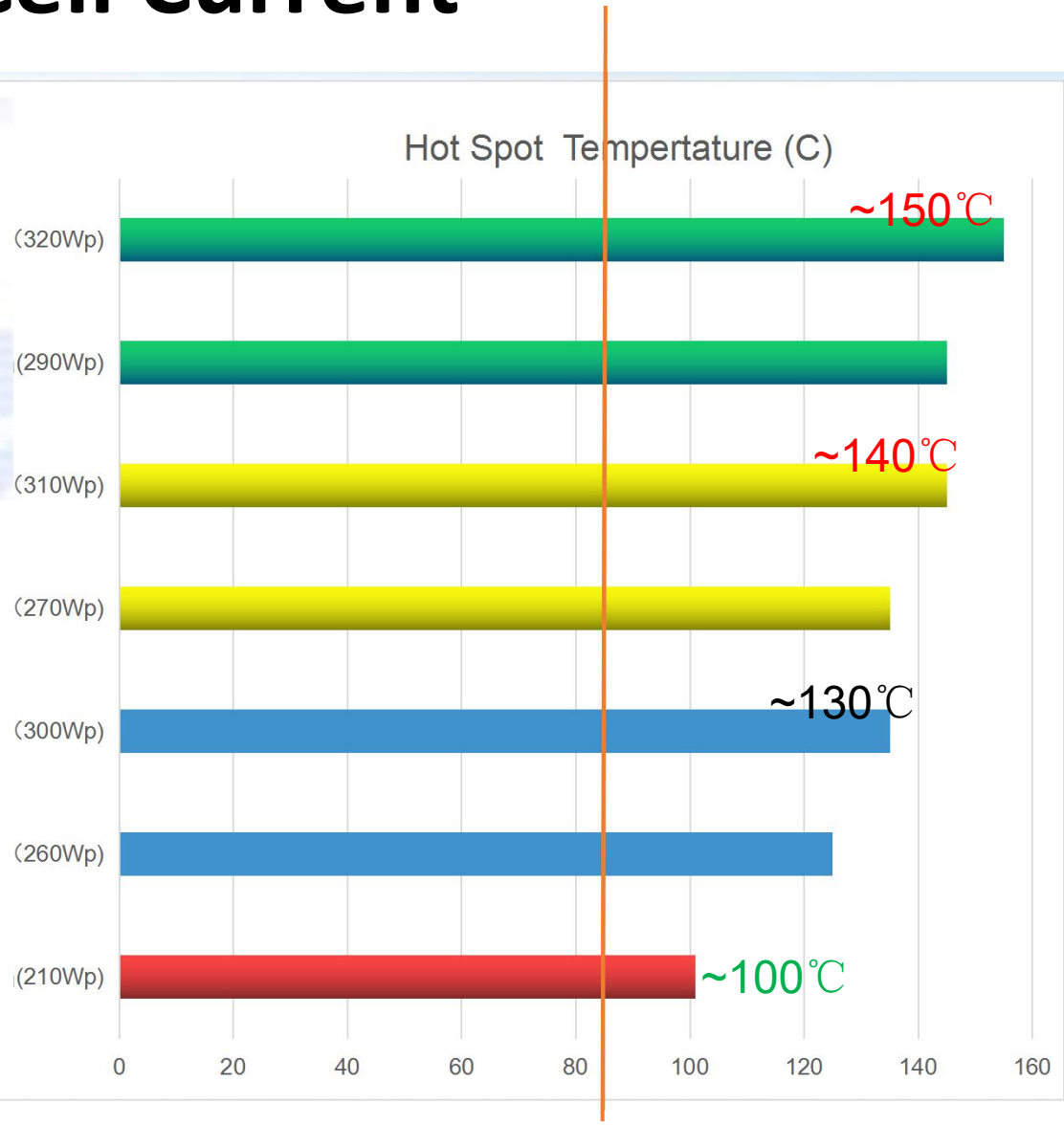
- **Bypass diodes are installed on parallel cell strings on a traditional module to reduce or prevent hot spots, caused by a reverse bias across a shaded cell. When the reverse voltage reaches 0.6V, the bypass diode will be activated. The entire string (including cells not affected) will be bypassed.**

- **The reverse voltage will go up as the number of cells increases in a string. The problem cell will cause more power dissipation and reach a higher temperature. For the same output, a 72-cell module will have a higher hot spot temperature when compared with a 60-cell module.**



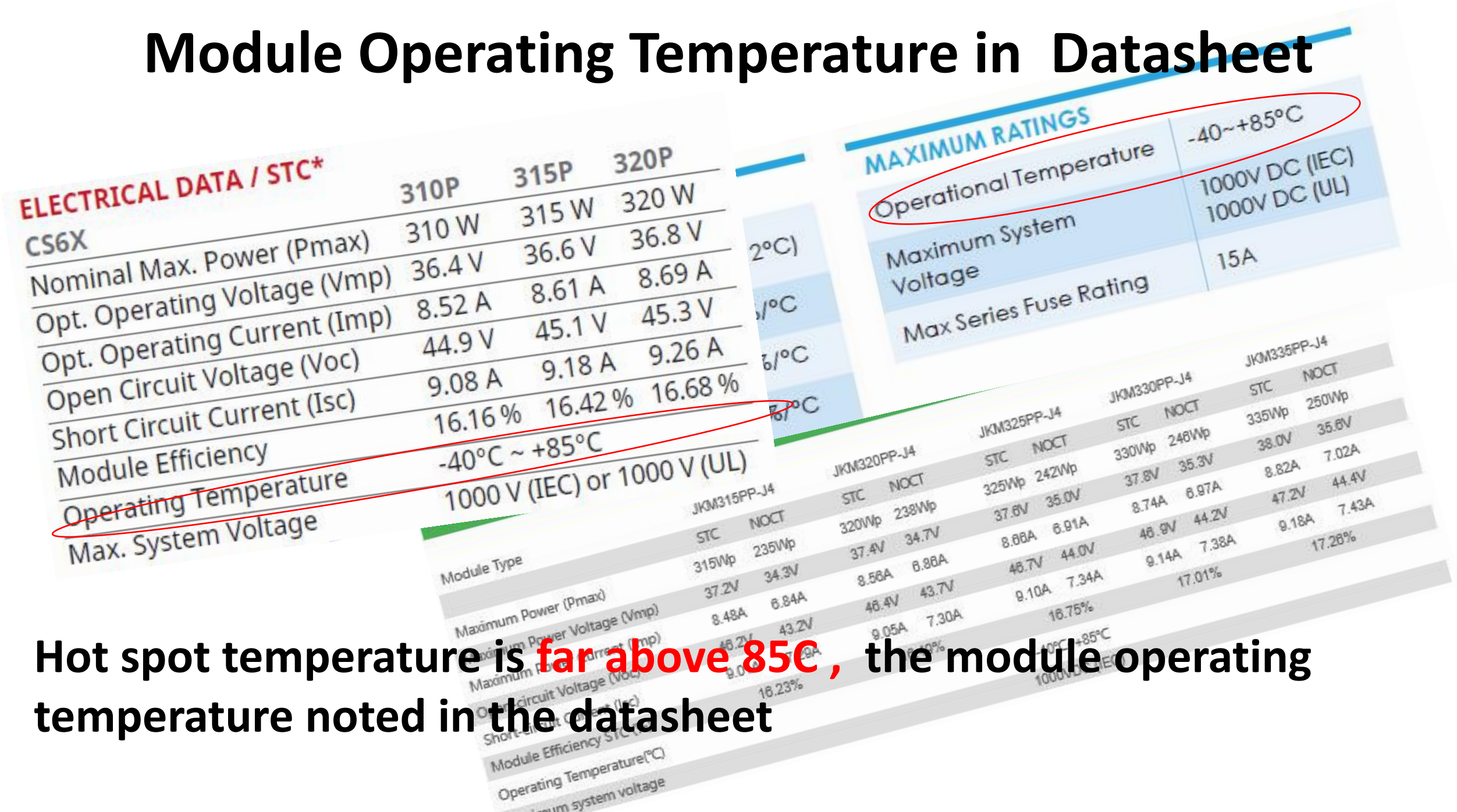
Hot Spot Temperature & Cell Current





This graph shows a dominant positive correlation between hot spot temperature & cell current

Module Operating Temperature in Datasheet



ELECTRICAL DATA / STC*			
CS6X	310P	315P	320P
Nominal Max. Power (Pmax)	310 W	315 W	320 W
Opt. Operating Voltage (Vmp)	36.4 V	36.6 V	36.8 V
Opt. Operating Current (Imp)	8.52 A	8.61 A	8.69 A
Open Circuit Voltage (Voc)	44.9 V	45.1 V	45.3 V
Short Circuit Current (Isc)	9.08 A	9.18 A	9.26 A
Module Efficiency	16.16 %	16.42 %	16.68 %
Operating Temperature	-40°C ~ +85°C		
Max. System Voltage	1000 V (IEC) or 1000 V (UL)		

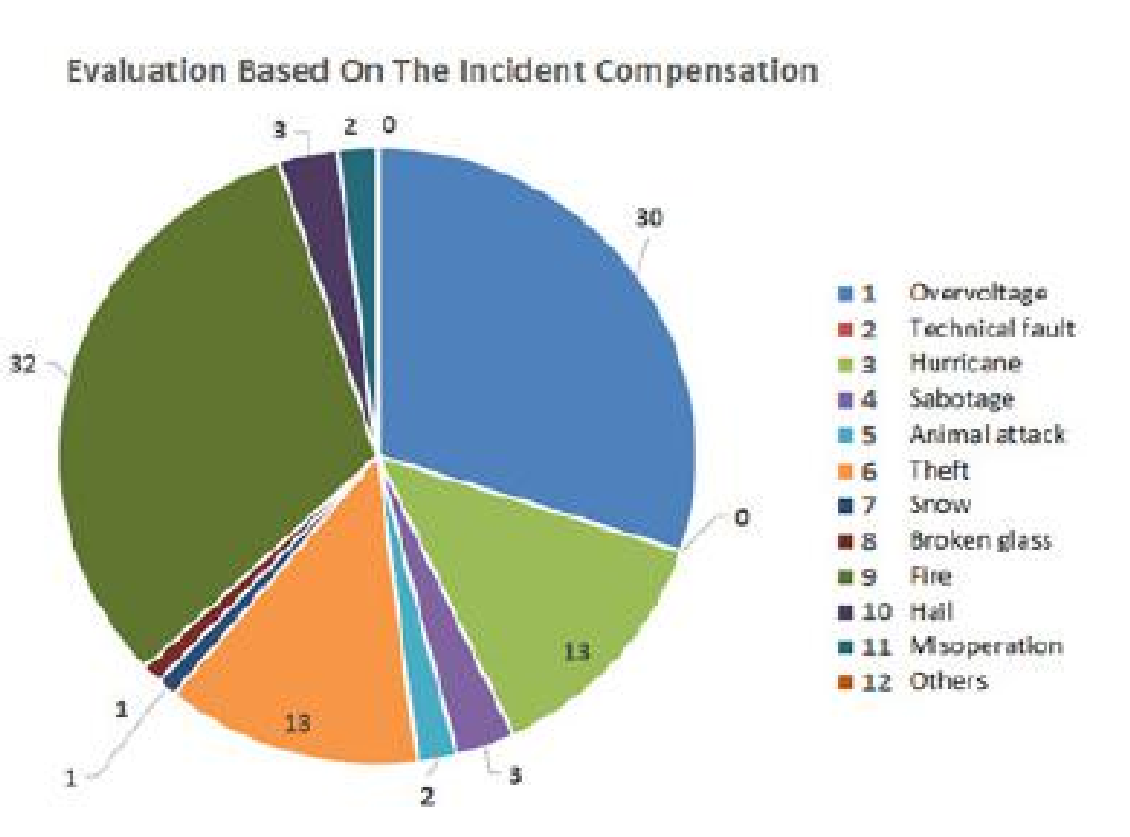
MAXIMUM RATINGS	
Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC (IEC) 1000V DC (UL)
Max Series Fuse Rating	15A

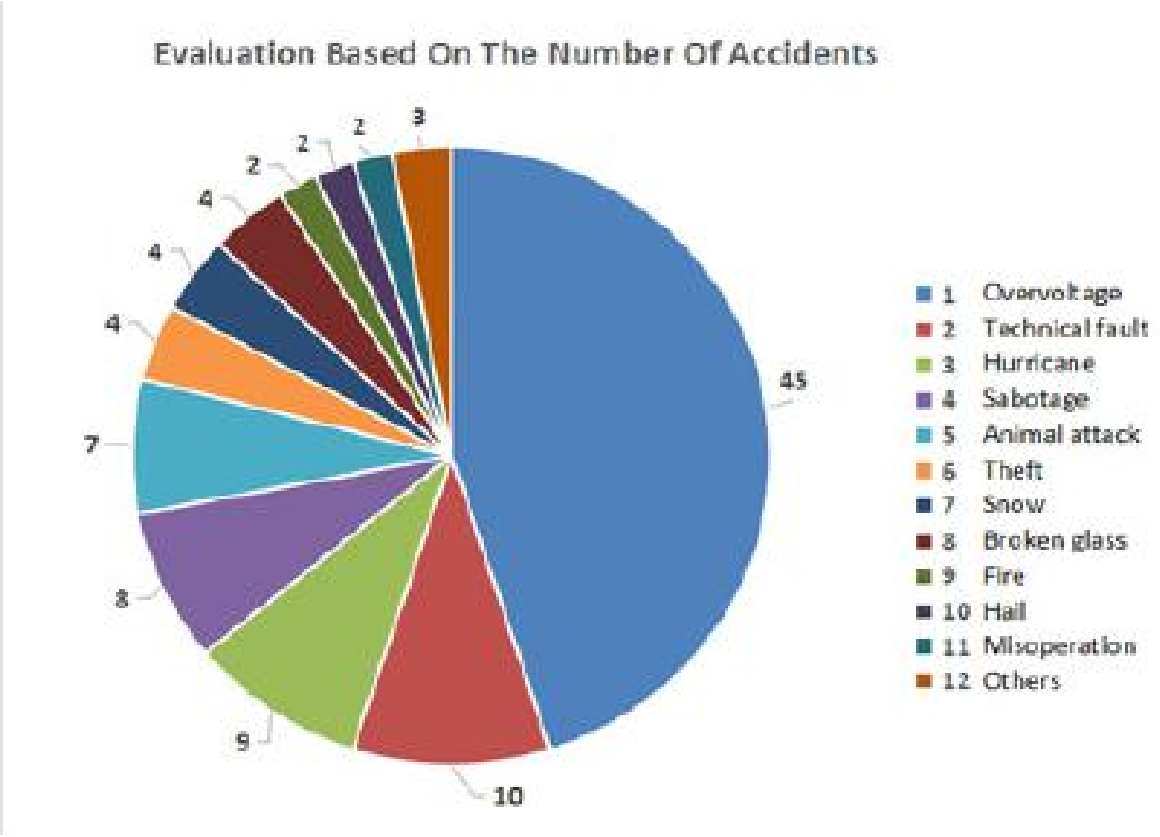
Module Type	JKM315PP-J4		JKM320PP-J4		JKM325PP-J4		JKM330PP-J4		JKM335PP-J4	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	315Wp	235Wp	320Wp	238Wp	325Wp	242Wp	330Wp	246Wp	335Wp	250Wp
Maximum Power Voltage (Vmp)	37.2V	34.3V	37.4V	34.7V	37.6V	35.0V	37.8V	35.3V	38.0V	35.6V
Maximum Power Current (Imp)	8.48A	6.84A	8.56A	6.86A	8.66A	6.91A	8.74A	6.97A	8.82A	7.02A
Open-circuit Voltage (Voc)	46.2V	43.2V	46.4V	43.7V	46.7V	44.0V	46.9V	44.2V	47.2V	44.4V
Short-circuit Current (Isc)	9.0	7.9A	9.05A	7.30A	9.10A	7.34A	9.14A	7.38A	9.18A	7.43A
Module Efficiency STC (%)	16.23%				16.75%		17.01%		17.26%	
Operating Temperature(℃)									-40℃ ~+85℃	
Maximum system voltage									1000VDC (IEC)	

Hot spot temperature is far above 85C , the module operating temperature noted in the datasheet

Fire Damages at Solar Farms

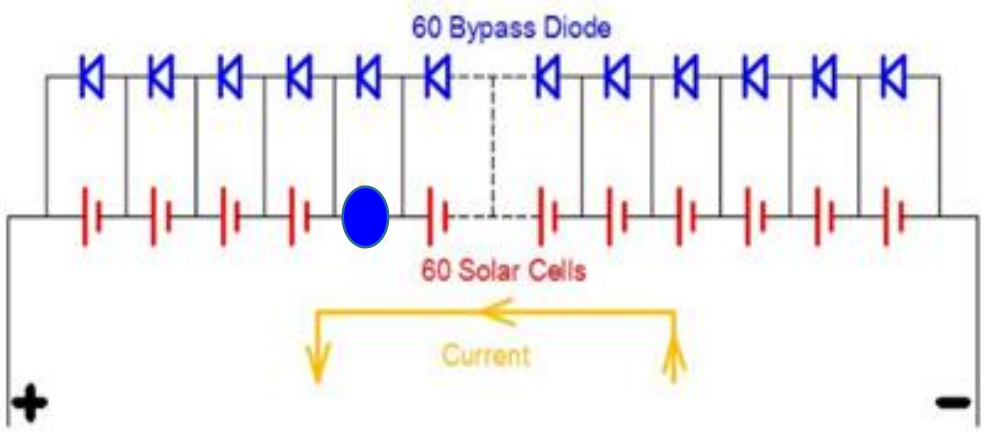
According to German insurance company Mannheimer Versicherung, fire accounts for **2%** of all accidents at solar farms, which is the lowest. However, the amount of compensation accounts for **32%**, the highest among all accidents.

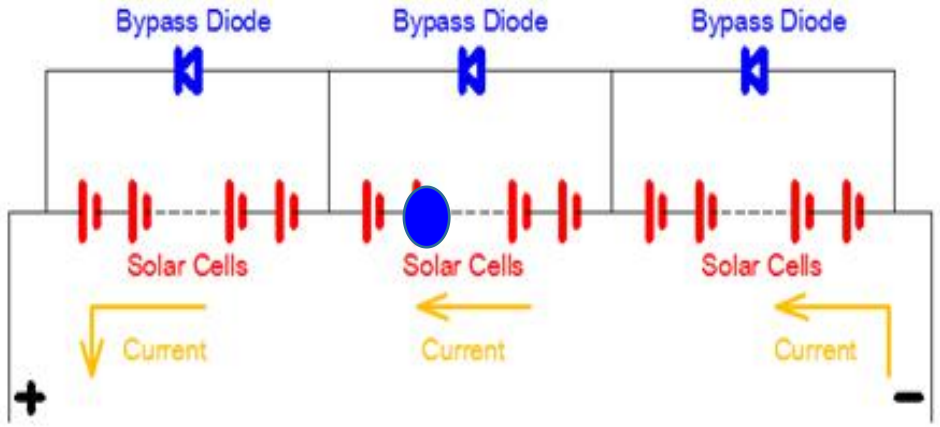




* PV Plant Safeguarding: Evolve from Passive to Proactive

Hot-Spot Free Technology





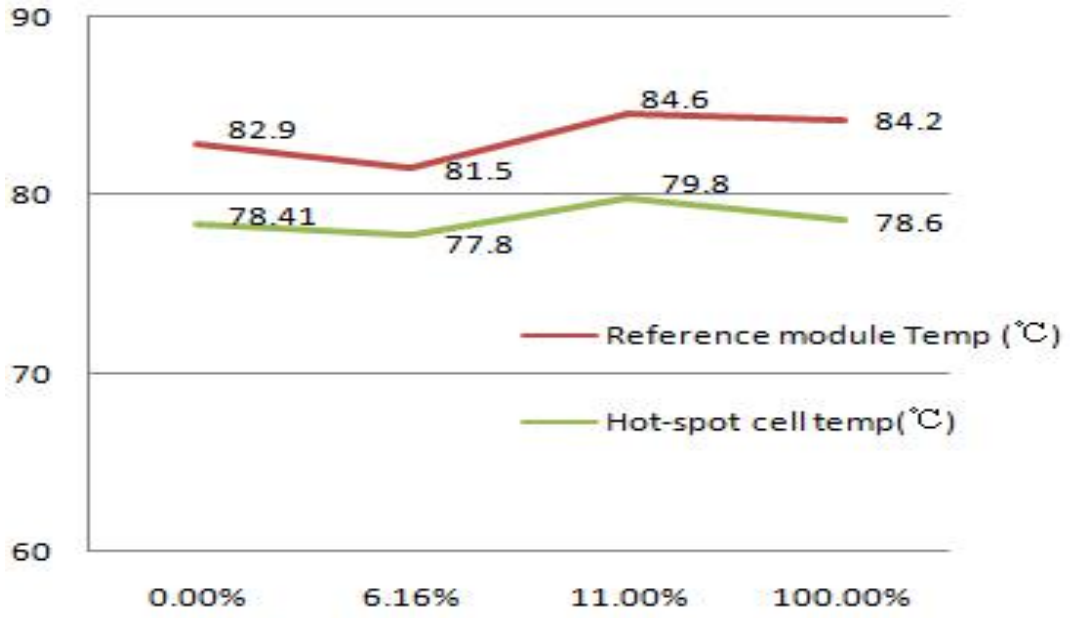
Core technology - each cell is being protected by a bypass diode

When the current of a single cell does not match the current of the whole string, that cell has a reverse voltage which, when measured larger than 0.6V, will activate the bypass diode. As a result, the rest of the good cells will not be affected by the disruption. The problem cell will consume less energy generated by the good cells, and produce less heat. Meanwhile, only the problem cell will be bypassed, and the rest of good cells will continue to generate power.

Reducing Safety Hazards Caused by High Temperature

- ✓ Eliminating overheating
- ✓ Meeting requirement of module operation temperature at 85C

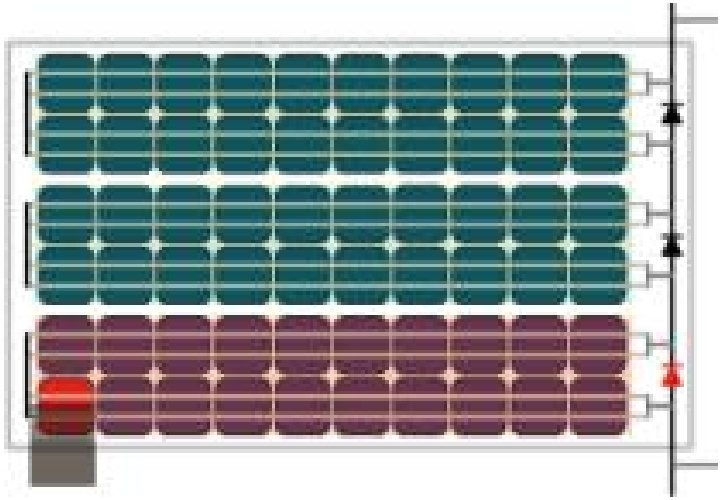
Tests conducted under the IEC61215 have shown that with a zero, a small percentage and a 100% of shading, respectively, hot spot temperature stayed below the target at the test center, meeting the 85C requirement for module operation, drastically reducing safety hazards by eliminating the cause of high temperature.



More Power Generation (I) – Maximum Output when One Cell in Zero to 100% in Shade

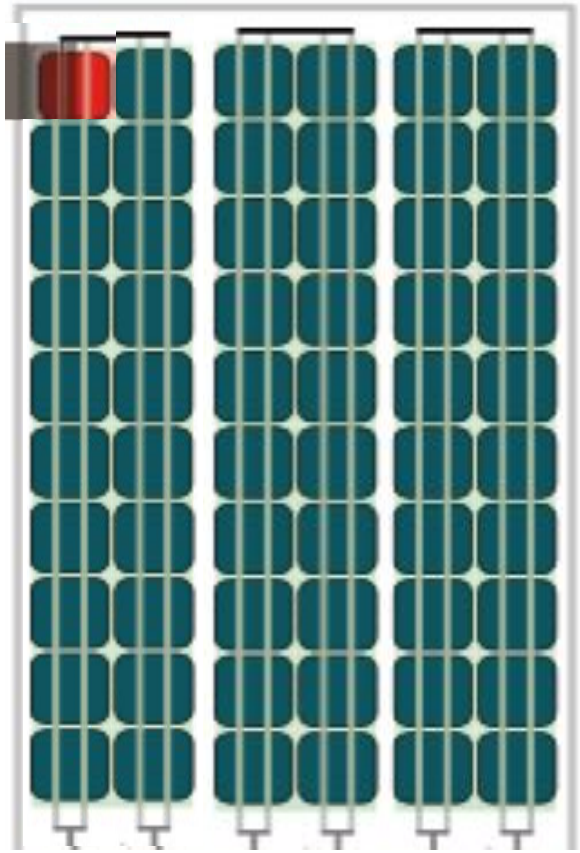
Output comparison when one cell is in shade (60-cell module)

Shade area	0%	10%	20%	30%	40%	50%	100%
Output of hot-spot free module	100%	98%	96%	96%	96%	96%	96%
Output of traditional module	100%	98%	91%	83%	73%	65%	65%
Output Gain	**0**	**0**	**5%**	**13%**	**23%**	**31%**	**31%**



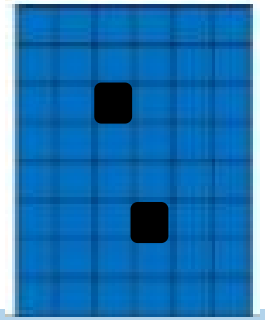
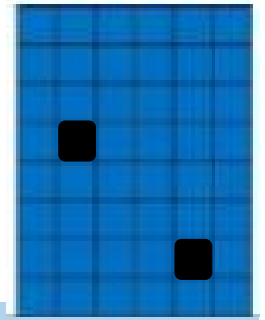
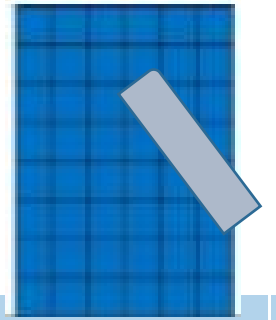
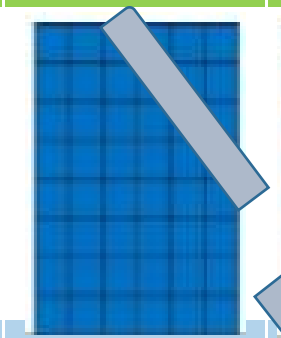
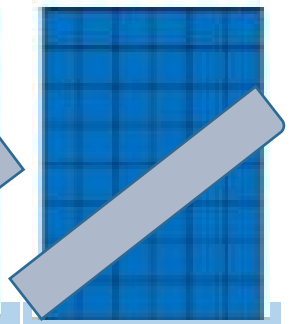
A hot-spot free module will only lose the output of one single cell in shade, while a traditional module will lose output of more cells than the one in shade.

A hot-spot free module can generate 30% more power when compared with a traditional module



More Power Generation (II) – Maximum Output when Multi Cells in Shade

Output comparison when more than one cells are in shade (72-cell module)

shades	2 cells in a string	1 cell each from 2 strings	1 row of cells	1 vertical row of cells	Across 3 rows	Across 4 rows	Across 6 rows
							
Output of hot-spot free module	95%	95%	83%	67%	84%	73%	63%
Output of traditional module	64%	38%	1%	65%	30%	30%	1%
Output Gain	**31%**	**57%**	**82%**	**2%**	**54%**	**43%**	**62%**

When multiple cells are in shade, a hot-spot free module can generate 80% more power , when compared with a traditional module

Smart Optimizer Feature – Reduces Output Mismatch between Modules in Strings

Comparison of output current & voltage (60-cell module)

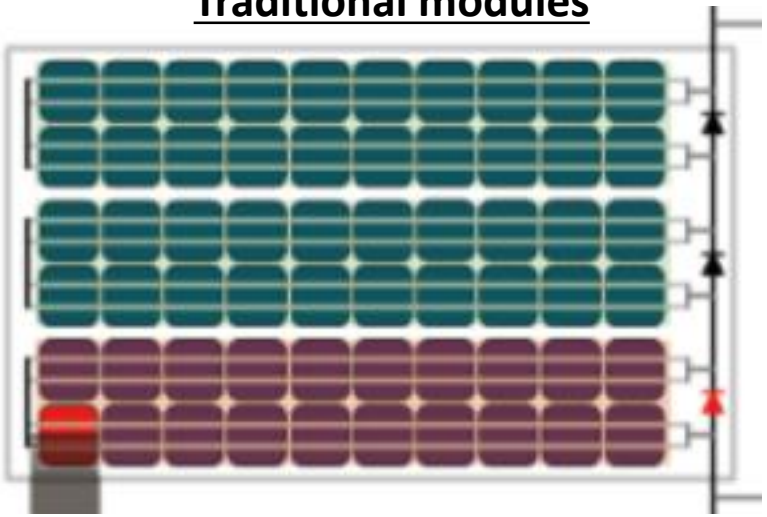
	Shade area	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
Imp	Hot-spot free module	0	-0.77%	-2.17%	-1.76%	-0.78%	0.66%	0.66%					
	Traditional module	0	-0.28%	-3.1%	-7.99%	-12.5%	-17.2%	-22.2%	-27.9%	-33.5%	-38.6%	-0.4%	-0.3%
	Hot-spot free module: current drops by <5%; traditional module: ~ 35%												
Vmp	Hot-spot free module	0	0.56%	0.69%	-1.1%	-2.78%	-4.21%	-4.22%					
	Traditional module	0	0.09%	1.85%	3.73%	5.02%	6.13%	7.13%	8.09%	9.14%	9.69%	-34.87%	-34.88%
	Hot-spot free module: voltage drops <5%: traditional module: ~ 35%												

- ✓ From the moment when mismatch happens to the moment before diode activates, a hot-spot free module will see its current drops by less than 5%; for a tradtional module, current drops by about 35%
- ✓ As mismatch worsens, diode will be activated. A hot-spot free module will see its voltage drop by less than 5%; for a tradtional mpdule, voltage drops by about 35% (output losses for an entire string)

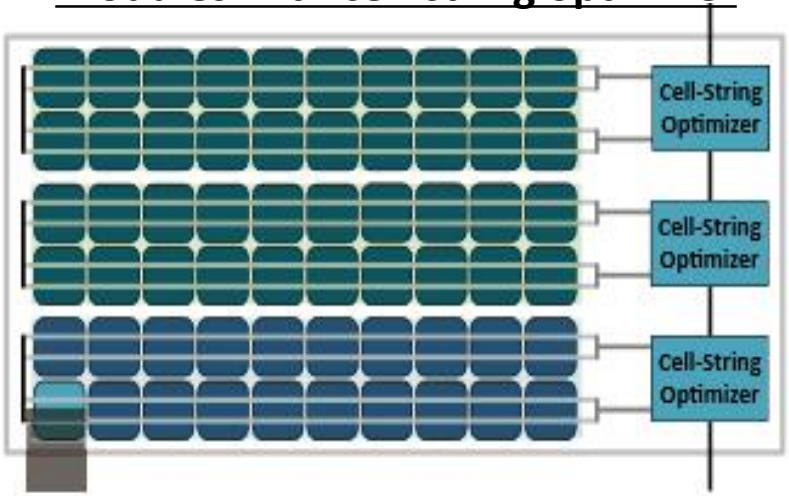
Both before and after diode avtivation, a hot-spot free module will see a less than 5% drop in current and voltage, which will reduce output mismatch and maintain output level by all working cells. This smart optimizer feature helps increase system power generation by over 10%.

Output Comparison of 3 Modules in Shade

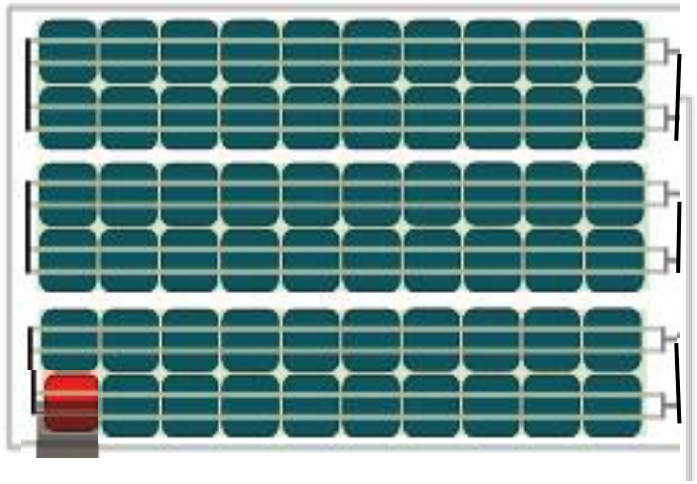
Traditional modules



Modules with cell-string optimizer



Hot-spot free modules

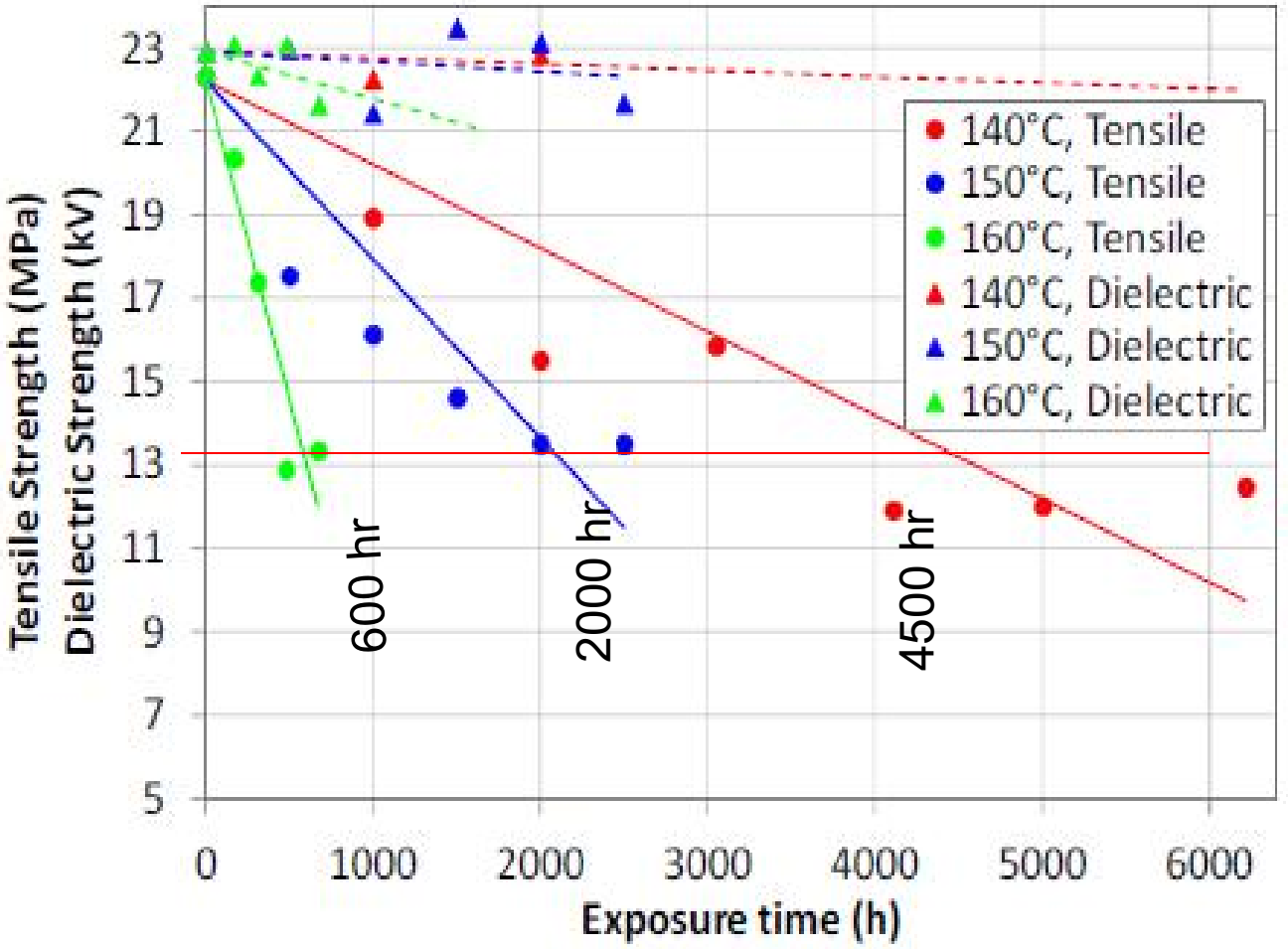


	Traditional modules	Modules with cell-string optimizer	Hot-spot free modules
Bypass diode not activated	As shadow area increases, current drops, module output falls; hot spot reaches high temperature	Output current will not change with shadow area. Meanwhile, there is no current mismatch between modules, which helps eliminate high temperature caused by hot spots. However, as shadow area grows to 100% of a cell, module will lose up to 30% of its output.	As shadow area increases, output will not be lost except for the single mismatched cell. There is no high temperature caused by hot spot. Current drops by less than 5%.
Bypass diode activated	A whole string bypassed; module output and voltage drop by 1/3, then output current restored		Only shaded cell will be bypassed; module output loss will be limited to that of an individual cell; voltage loss for that cell will be less than 5%

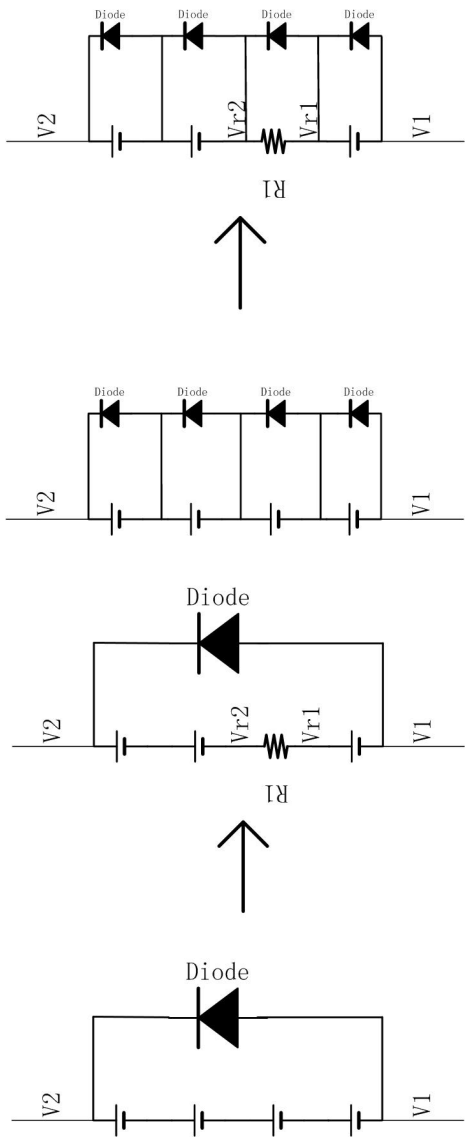
Reducing Heat Damage & Ensuring Long Module Life

The low temperature feature of a hot-spot free module ensures long-term product reliability.

- High temperature speeds up degradation process in polymer materials over time. For example, at 150C the service life of a 120℃ RTI back sheet will be reduced to 2,000 hours from 100,000 hours.
- A hot-spot free module has a lower temperature which not only eliminates a potential cause for back sheet degradation, but also prevents damage to silicon-based cells. The result is enhanced module life of up to 25 years.



Diode Power Consumption Comparison



	Traditional Module 60 Cells	Traditional Module 72 Cells	Hot-Spot Free Module 72 Cells
Quantity of diodes	3	3	72
Diode power consumption in module	$P_{Diode\text{-}consumption} = \{(V_{oc\text{-}cell} * Q_{cell}) * I_R\} * Q_{diode}$		
Voltage on each diode（V）	V_{20}=0.60*20=12	V_{24}=0.60*24=14.4	V_1=0.60*1=0.60
Total diode reverse power consumption（25/50℃）	P=0.60*20*3*I_{R20} = 36I_{R20}	P=0.60*24*3*I_{R24} =43.2I_{R24}	P=0.60*72*1*I_{R1} =43.2I_{R1}

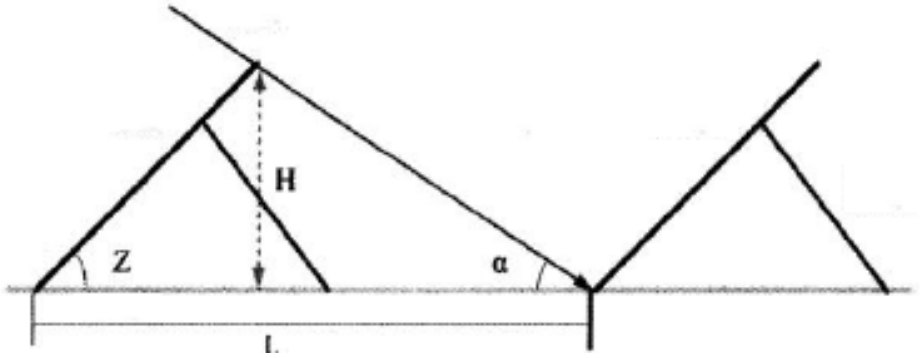
As voltage on diode rises, it will cause a bigger leakage in reverse current, resulting in a higher power consumption:

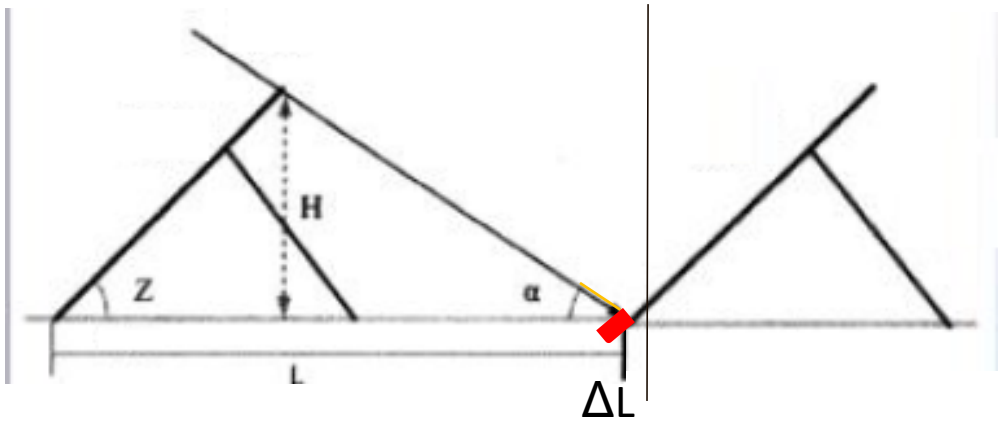
$$I_{R24} > I_{R20} > I_{R1}$$

For a hot-spot free module, total diode power consumption is lower than the combined power consumption by three diodes in a traditional module

	0.6V	12V	14.4V
25℃	3.1uA	9.5uA	10.3uA
50℃	25uA	52uA	53.3uA

Generating More Power – Higher PR, Less Land & Better Return





The higher the latitude, the more improvement in PR and GCR

For hot-spot free modules, only shaded cells will be bypassed. Before 9AM and after 3PM, when the front or back rows of cells are in shadow, the remaining cells will continue to generate electricity, improving efficiency (PR) and land utilization rate (GCR).

(A) ***Case Study*** – Orvieto, Italy (42.7 degree north latitude) On same amount of land, PR raised by 0.9%; for same amount of output, installation row gaps reduced to 4.37m from 5.8m, using 35% less land

	pitch	kWh/yr	kWh/kWp/y	PR	GCR	Ground
6P-260P	5.8	8215	1580	88.1	0.27	117.037
cpm	5.8	8296	1595	89	0.27	117.037
cpm	4.37	8215	1580	88.1	0.36	87.77778

(B) ***Case Study*** – Pissaud, France (46.04 degree north latitude) On same amount of land, PR raised by 0.7%; for same amount of output, installation row gaps reduced to 3.21m from 3.8m, using 14.3% less land

	pitch	kWh/yr	kWh/kWp/y	PR	GCR	Ground	ratio
6P-260P	3.8	6755	1299	86	0.42	75.2381	
cpm	3.8	6815	1310	86.7	0.42	75.2381	
cpm	3.21	6755	1299	86	0.49	64.4898	1.166667

Hot-Spot Free Modules: Better Safety, Reliability & Return

- Drastically reducing temperature on hot-spot cells, to below **85C** from the current 160C, hence eliminating potential safety hazards such as fire and material degradation, and ensuring better safety, longer module life and higher returns
- Preventing sharp falls in module output caused by hot spots or module shading and, with smart optimizer, reducing current and voltage mismatch to significantly increase overall return for both roof and ground installations

Hot-spot free modules – generating more power with better safety & reliability

No more hot spots on modules; no more mismatch in systems