Fusing of PV arrays

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Overview

– AS5033 requirements
– Module and Array Faults
– Protection Schemes
– Fuse characteristics and test results
– PV Module Characteristics
– Fuse selection and module characteristics

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AS5033 Installation of photovoltaic arrays

General installation requirements for PV Arrays
- 600V between positive and negative conductors
- +/- 600V wrt earth

Provides requirements for protection of arrays in addition to AS/NZS3000 protection requirements

International draft IEC 62548 is based on AS5033

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Faults in arrays

Failures in PV Modules due to
- Overloading
- Overheating
- Mechanical

Typical Causes
- Reverse current
- Shading
- Earth faults
- Short circuits:- modules, junction boxes or module wiring
- Backfeeding
- Incorrect installation (reversed string or module)
- Storms & projectiles

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Consequences of not protecting modules

Degradation of module performance

Degradation of parts

- Cells
- Interconnects
- Junction boxes

Failure of parts

Arcing

Fire

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AS5033 Protection requirements

Bypass diodes

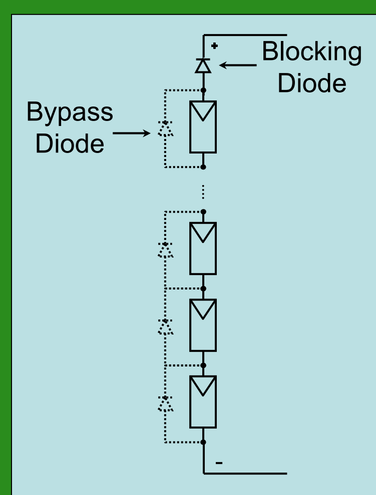
- normally fitted by manufacturer

Blocking diodes

- are not a substitute for fault current protection.
- Refer to AS5033 section 2.3 for ratings of diodes

Fault Current Protection

- (Next slide)



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Fault Current Protection

AS5033 Section 2.4 covers the requirements.

Discrimination – lower levels trip first

String protection is related to Module Reverse current rating (refer AS5033 Table 2.1)

Defines when and how large the sub array and array protection is required

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PV Protection Current Rating

For strings where no manufacturer rating (AS5033 2.4.3)

or

PV array (AS5033 2.4.4)

or

PV sub array (AS 5033 2.4.5)

Use I_{trip}

More than 1.25 x Isc
Less than 2 x Isc

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Fuses

Fuse ratings

- Breaking Capacity
- Voltage Rating (V_{n})
- Rated current (I_n)
  - Note temperature current derating
- Conventional Non-Fusing Current (I_{nf})
- Conventional Fusing Current (I_f)
- Pre-arcing time (Joule Integral I^2t)

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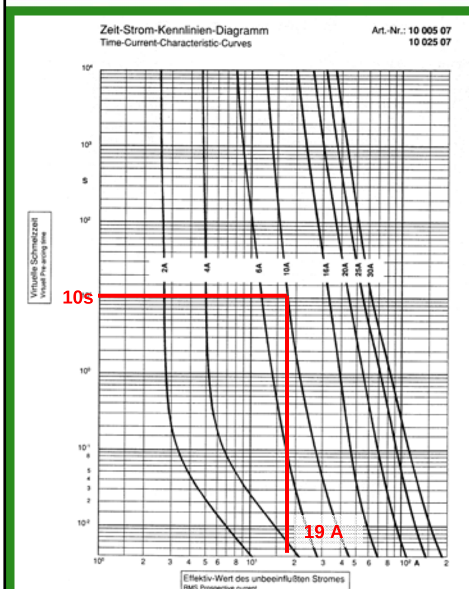
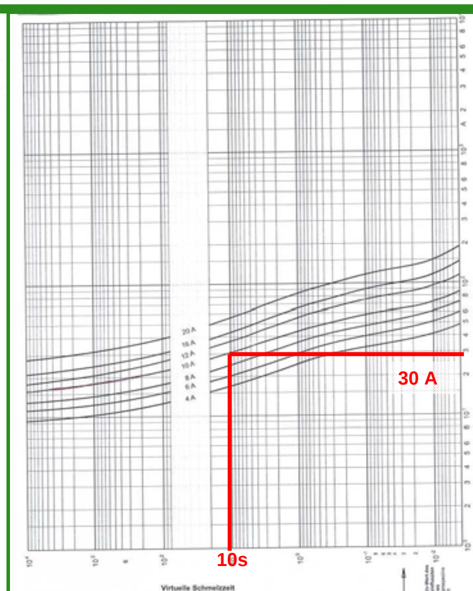
Fuse time characteristic curve





Fuse Standard

IEC 60269 Low-voltage fuses

- Part 1: General requirements
- Part 2: Supplementary requirements for fuses for use by authorized persons ….
- Part 3: Supplementary requirements for fuses for use by unskilled persons …..
- Part 4: Supplementary requirements for fuse-links for the protection of semiconductor devices

These are also adopted as AS/IEC

Other similar standards UL & BS

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Key factors for consideration

Fuses typically have

- $I_{nf} = 1.1 * I_n$
- $I_f = 1.9 * I_n$ or $1.6 * I_n$ subject to fuse type
- Conventional time 1 hour for smaller fuse ratings

Type of fuse / intended application

- "g" = general purpose fuse typically meets IEC std
- "gG" = General application
- "gM" = Motor circuits (don't use these)
- "gR" = semiconductor devices (these are better)

Note many different types – different manufacturers check time characteristic curves

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Conventional use of fuses

Protection and safety

Typically

- Used with sources having high fault (kA) capability
- Protection of cabling and traditional circuit components
- Used to avoid fires in installation
- Equipment designs attached are “fail safe” (ie meets AS 3100 or similar standard)

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Example of String Protection

Following slides depict PV Application of fuses

Protection against string faults

Ignores any other sources (grid or batteries)

- i.e. low fault current situation

Example uses a BP Solar Module, however, other module manufacturers recommend a similar fuse rating for their modules.

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PV Strings – Rated Trip Current

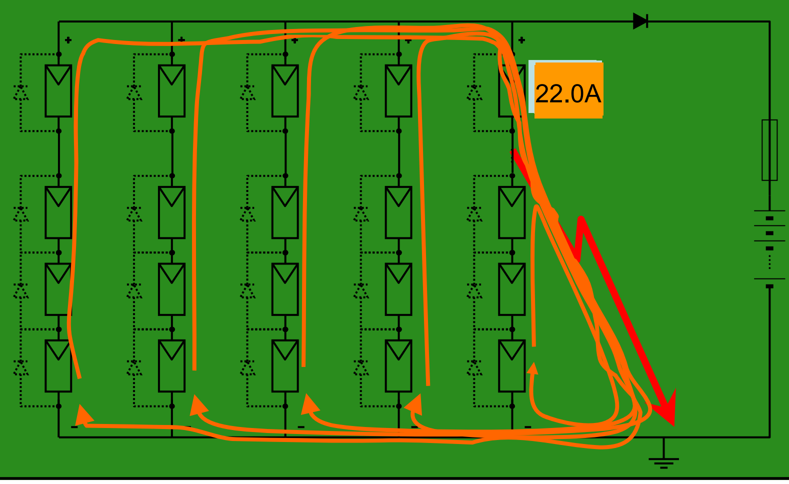
As per manufacturer

bp solar

Typical Electrical Characteristics	BP 4175	BP 4165[3]
Rated Power (P_{max})[1]	175W	165W
Warranted minimum power	170W	160W
Voltage at P_{max} (V_{mp})	35.4V	34.3V
Current at P_{max} (I_{mp})	4.9A	4.8A
Short circuit current (I_{sc})	5.5A	5.4A
Open circuit voltage (V_{oc})	44.5V	43.7V
Temperature coefficient of I_{sc}	(0.065±0.015)%/°C	
Temperature coefficient of V_{oc}	-(160±20)mV/°C	
Temperature coefficient of P_{max}	-(0.5±0.05)%/°C	
NOCT[2]	47±2°C	
Maximum series fuse rating	15A (BP 4175S) / 20A (BP 4175J)	
Maximum system voltage	600V (IEC 61215 rating) 1000V (TÜV Rheinland rating)	

Explanatory Example

For BP 4175: I_{sc} = 5.5A, $I_{mod\ reverse}$ = 16.5A,
($I_{modreverse}$ / I_{sc}) = 3 therefore np = 4 (table 2.1)



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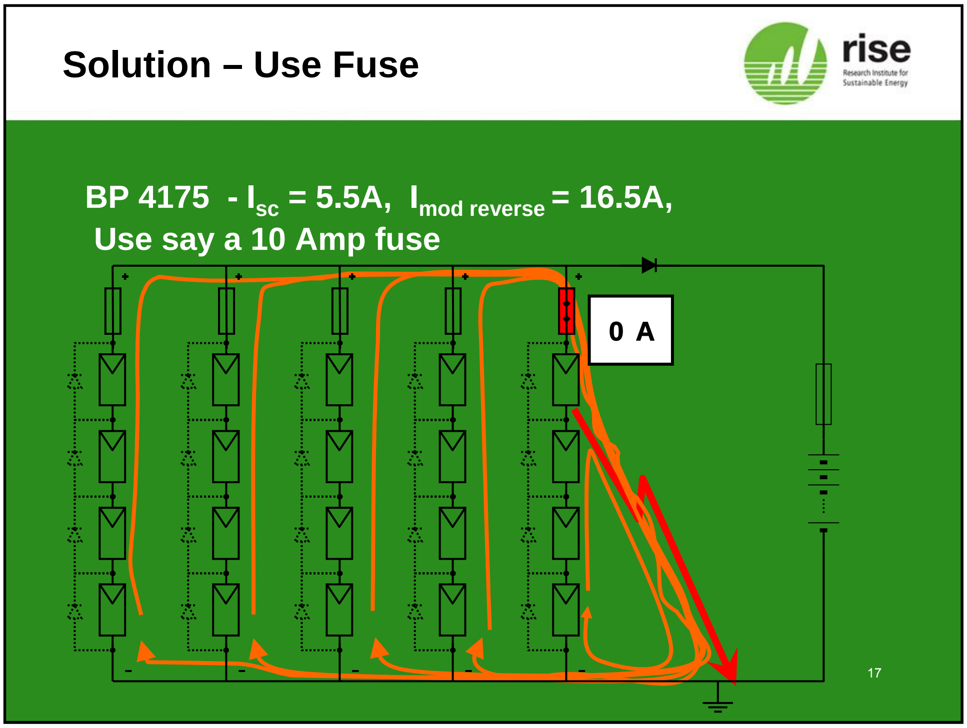
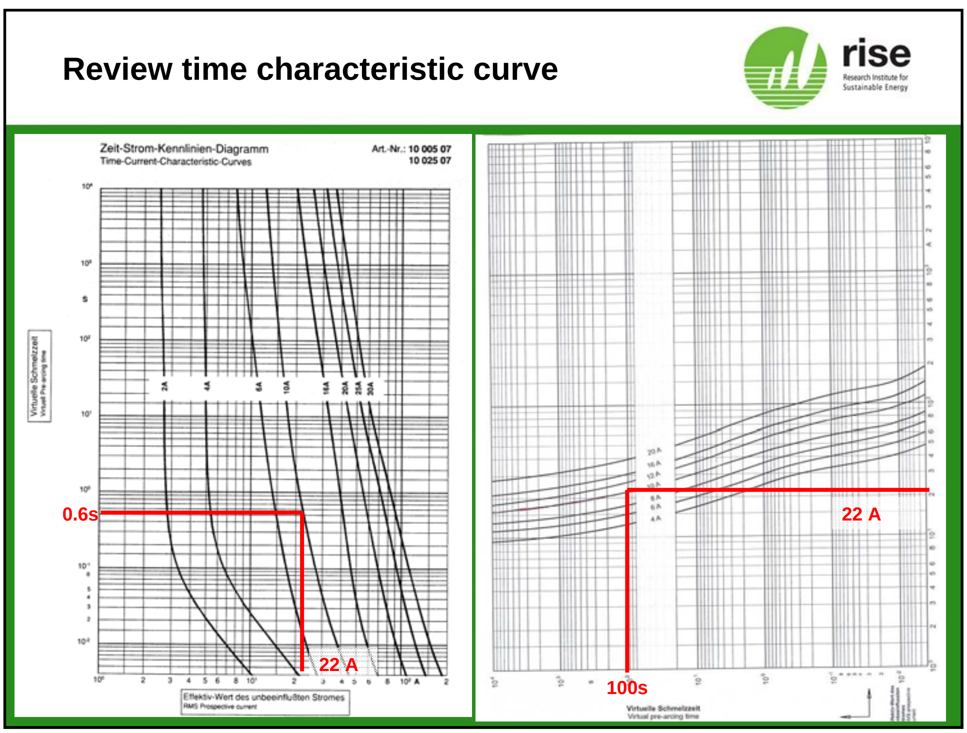

Solution – Use Fuse
rise
Research Institute for Sustainable Energy
BP 4175 - Isc = 5.5A, Imod reverse = 16.5A,
Use say a 10 Amp fuse
0 A
17


Review time characteristic curve
rise
Research Institute for Sustainable Energy
Zeit-Strom-Kennlinien-Diagramm
Time-Current-Characteristic-Curves
Art.-Nr.: 10 005 07
10 025 07
0.6s
22 A
Effektiv-Wert des unbeeinflußten Stromes
RMS Prospective current
100s
22 A
Virtuelle Schmelzzeit
Virtual pre-arcing time

What can a PV Module handle

Swiss and German research shows:

- Reverse currents (I_R) up 3 time I_{sc} no change IV curve
- Thermal losses of 800 to 900 W/m^2
- With 1000 W/m^2 radiation typical cell temperature increase 50C
- Max cell operating temperatures of 90 -100 C
- Crystalline silicon cells

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What can't a PV Module handle

Swiss and German research shows:

- Reverse currents (I_R) up 7 time I_{sc} results in permanent damage after short time
- Cell temperatures reached over 150C
- Damage to EVA encapsulation
- Damage to internal connections

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Module rating requirements

IEC61730.1 require modules to be marked with
- Manufacturer's mark,
- Type or Model number and serial number
- Terminal polarity
- Maximum system voltage and safety class

Additional markings or in installation information
- Voltage open circuit, Current short circuit
- Maximum over-current protection rating
- Recommended maximum series/parallel module configurations
- Application class of product

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Module Reverse Current Overload Test

IEC61730.2 applies
- A reverse test current
- 135 % of the module's overcurrent protection rating
- For 2 hours duration
- Pass condition is no evidence of "heating" on indicators

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Fuse tests

No flames or smoke!

Three fuses

- 1000V 11A DMM fuse
- gR “ultra rapid” 10A 440V
- gR PV-FUSE 10A 900V

Which one works best?

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Three Fuses

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Specifications

Fuse	I_n	V_n DC	Breaking Capacity
Bussmann DMM-B-11A	11 A	1000 V	20 000 A
SIBA Ultra Rapid gR	10 A	440 V	100 000 A
SIBA PV-Fuse gR	10 A	900 V	30 000 A

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Current source Results

The setup

- 60V 100 A Power supply
- Current control mode
- Applied voltage limit 50 V
- Short circuit across fuse

What is a suitable response time?

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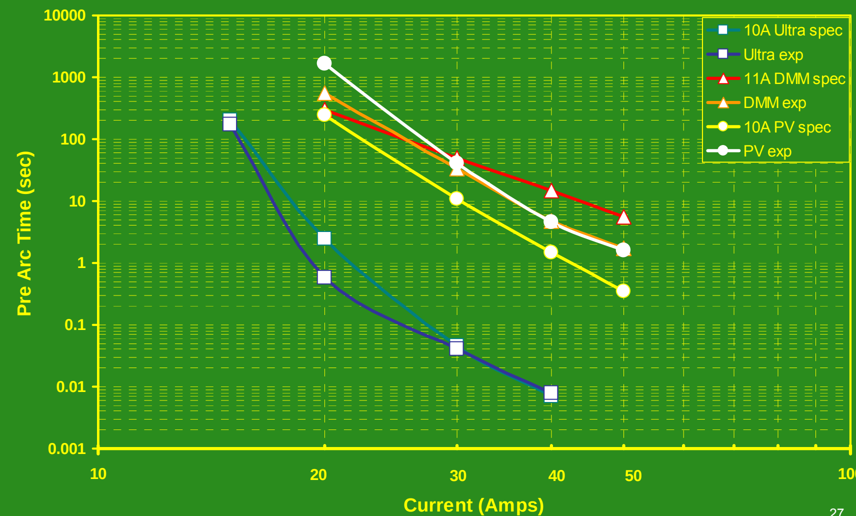
Time results (current source)



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Real Array Results

The setup

- 4 strings of BP275’s
- 15 module in series
- 300 V open circuit
- Short circuit across fuse
- Real sunshine conditions

What is a suitable response time?

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Real Array Results

PV Fuse

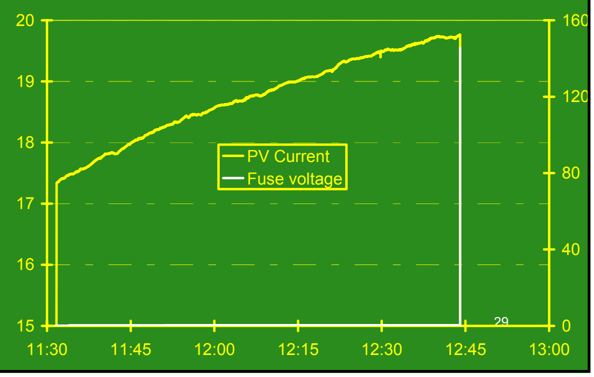
- –2:30pm 18.9 A current falling – no break!
- –11:30am 17.4 A current rising
  12:40pm 19.8 A break (graph)

DMM Fuse

- –514 s, 20 A, break

Ultra Rapid

- –15 s, 15 A, break
- –0.7 s, 20 A, break



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Summary

Fuse selection

- Recommendation for string fuses
  - Manufacturer's
  - AS 5033
- Review time characteristics
- Know what you are attempting to protect
- Fuse type (gR or PVFUSE)
- Correct Fuse holder and installation
- DC Voltage Rating
- Power dissipation
- Reliability

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Summary

Standards Development

– Recommendation for string fuses?

– $1.25 \times I_{SC\ MOD} \leq I_{TRIP} \leq 2 \times I_{SC\ MOD}$

  - IEC draft $1.4 \times I_{SC\ MOD} \leq I_{TRIP} \leq 2.4 \times I_{SC\ MOD}$

– What is the definition of I_{TRIP}

  - Fuse rated current (as it is now)
  - Conventional Non fusing current
  - Conventional fusing current

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