Determining Cable Sizes and Protection in an Off grid PV System

CABLE SIZING

CURRENT CARRYING CAPACITY - CCC

- Current carrying capacity is defined as the amperage or the current a conductor can carry before deteriorating or before its insulation is affected.
- Generally, these values could be obtained from cable manufacturers for a particular cable
- They are subject to derating factors based on the method of installation, grouping, temperature and other external factors.

TYPICAL CCC –OLEX CABLE AC

Cond. size	Unenclosed space		Spaced from surface		Touching		Enclosed conduit in air		Partially surrounded by thermal insulation		Completely surrounded by thermal insulation		Buried direct		Underground ducts				Single phase voltage drop mV/A.m	
mm²																				
	Cu	Al	Cu	Al	Cu	Al	Cu	Al	Cu	Al	Cu	Al	Cu	Al	Cu	Al	Cu	Al	Cu	Al
1	16		16		13		13		11		6		18		18		21		51.6	
1.5	21		21		16		18		14		8		23		23		26		33.0	
2.5	30		29		23		24		20		12		32		32		36		18.0	
4	40		39		31		32		25		16		41		41		47		11.2	
6	51		49		40		41		33		20		52		52		58		7.50	
10	69		67		54		54		44		27		69		69		77		4.46	
16	92	72	89	69	72	56	70	54	56	43	36	28	122	95	89	69	99	77	2.81	4.68
25	124	96	119	92	97	75	94	73	75	58	48	38	158	123	116	90	129	100	1.78	2.95
35	153	119	145	113	119	92	112	87	90	70	59	46	190	147	139	108	155	120	1.29	2.14
50	187	145	177	137	146	113	138	107	110	86	–	–	225	174	168	130	186	145	0.96	1.58
70	238	184	223	173	184	143	170	132	136	105	–	–	277	215	206	160	228	177	0.680	1.10
95	295	229	276	214	230	178	212	164	169	131	–	–	332	257	252	195	278	215	0.507	0.804
120	344	267	321	249	267	208	242	188	193	150	–	–	378	294	287	223	316	245	0.415	0.644
150	395	307	367	285	308	239	282	219	225	175	–	–	424	329	329	255	354	274	0.352	0.535
185	459	357	424	331	358	279	320	249	256	199	–	–	480	374	373	291	408	317	0.301	0.439
240	549	427	505	394	428	334	381	298	305	238	–	–	556	434	438	342	472	368	0.255	0.352
300	636	495	582	456	495	388	–	–	–	–	–	–	628	491	496	388	546	425	0.229	0.300
400	744	583	676	535	577	456	–	–	–	–	–	–	713	564	575	454	621	487	0.209	0.256
500	867	685	780	624	668	535	–	–	–	–	–	–	805	644	649	520	721	570	0.194	0.226
630	1014	808	897	730	770	627	–	–	–	–	–	–	904	737	750	611	816	652	0.181	0.202

PV CABLE SIZING

TYPICAL PV CABLE - CCC

Electrical Characteristics

Conductor Size mm^2	Voltage drop factor mV / A.m	Current Rating (exposed) Amps	Insulation Resistance MΩ.km	Conductor Resistance Ω/km @ 20°C
2.5	20.4	21	690	7.98
4	12.6	27	570	4.95
6	8.42	34	490	3.30
10	4.87	48	370	1.91
16	3.09	63	340	1.21

SELECTION OF CURRENT CARRYING CAPACITY OF PV STRING CABLES

- If a fault current protection device is located in the string cable, the string cable must have a rating equal to or greater than the current rating of the fault current protection device. For example, if the fault current protection device is rated at 8A, the string will need to be rated with a current carrying capacity (CCC) of a minimum of 8A.

SELECTION OF CURRENT CARRYING CAPACITY OF PV STRING CABLES

- If no fault current protection is provided, the current carrying capacity (CCC) of the string cable will be rated according to:

$$\mathbf{CCC \geq 1.25 \times I_{SC\ MOD} \times (Number\ of\ parallel\ connected\ Strings - 1) + I_n}$$

where

- I_n is the current rating of the nearest downstream overcurrent protection device.

SELECTION OF CURRENT CARRYING CAPACITY OF PV ARRAY CABLES

- If a fault current protection device is located in the array cable, the array cable must have a current rating equal to or greater than the current rating of the fault current protection device.

- If no fault current protection device has been included, the current carrying capacity of the PV array cable will be rated according to:

$$\mathbf{CCC \geq 1.25 \times I_{SC\ ARRAY}}$$

PV CABLE PROTECTION

SOLAR ARRAY DC CABLE PROTECTION

- Each solar module has a maximum reverse current rating provided by the manufacturer.
- If the array consists of parallel strings such that the reverse current flow into a string with a fault can be greater than the maximum reverse current for the modules in that string, then protection shall be provided in each string.
- The protection to be used shall be dc rated fuses that meet the specification shown in 18.2 of the guideline.

WORKED EXAMPLE

The reverse current rating for a module is 15A while the short circuit current is 8.9A.

If the array consists of two (2) parallel strings and a fault occurs in one (1) string then the potential fault current will come from the other one (1) string which is only 8.9A and is less than the reverse current rating so no protection is required.

NO PROTECTION REQUIRED

WORKED EXAMPLE

However, if the array consists of three (3) parallel strings and a fault occurs in one (1) string then the fault current could come from the other two (2) strings.

This current is 17.8A (2 x 8.9A) and is now greater than the reverse current rating of the module. Protection is now required.

WORKED EXAMPLE

- A formula for determining the maximum number of strings allowed before fuses are required is:

Maximum Number of Strings without string protection

= reverse current rating of a module/I_{sc} of the module

- So in the example; Max Number of strings = 15/8.9 = 1.69 rounded up to 2.

PV FUSES

Fuses used in PV arrays shall —

(a) be rated for dc use;

(b) have a voltage rating equal to or greater than the PV array maximum voltage determined in section 5 of the guidelines;

(c) be rated to interrupt fault currents from the PV array; and

(d) be of an overcurrent and short circuit current protective type suitable for PV complying with IEC 60269-6 (i.e. Type gPV) or the equivalent through the NEC.

STRING PROTECTION

The fuses shall have the following current rating:

$$1.5 \times I_{sc\ of\ module} < I_{TRIP} < 2.4 \times I_{sc\ of\ module}$$

and

$$\text{Fuse Rating} < I_{RC\ of\ module}$$

- Where
- $I_{sc\ of\ module}$= Module short circuit current
- I_{TRIP} = rated trip current of the fault current protection device.
- $I_{RC\ of\ module}$= Module reverse current rating

Note : For countries following NEC the requirements are:

- Minimum fuse rating 1.56 x I_{sc} of module(string)
- Maximum fuse rating less than reverse current rating of the module(string)

ARRAY CABLE PROTECTION

- Array overcurrent protection is designed to protect the entire PV array from external fault currents.
- For off grid systems this can only occur in dc bus systems when the solar controller (switching type solar controller or MPPT) allows fault current from the battery bank to back-feed through the controller.

ARRAY CABLE PROTECTION

- If array overcurrent protection is required for a system, the nominal rated current for the overcurrent protection device will be as follows:

$$1.25 \times I_{\mathrm{SC\ -ARRAY}} \leq I_{\mathrm{TRIP}} \leq 2.4 \times I_{\mathrm{SC\ \ ARRAY}}$$

Where:

- $I_{\mathrm{SC\_ARRAY}}$ = short-circuit current of the array.
- I_{TRIP} = rated trip current of the fault current protection device.

Note : For countries following NEC the requirements are:

– Minimum fuse rating 1.56 x I_{sc} of array)

EXAMPLE 1

An array consists of 3 parallel strings. These connect to a controller and then to a battery bank. For this exercise, assume the main battery protection is not sized to protect the array cable. Each string has 2 modules in series, with the following characteristics:

- V_{nom} = 24V (V_{oc} =44.2 and V_{mp} = 38.8)
- I_{sc} = 5.4A
- $I_{mod\ reverse}$=15A

What size array cable and array fuse are required?

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EXAMPLE 1

A table showing current carrying capacities of different cable sizes has been provided to assist you.

Table 1: Current carry capacities of cables

Conductor Size (mm^2)	**Current Rating (A)**	**Voltage Rating (VDC)**
2.5	21	1000
4	27	1000
6	34	1000
10	48	1000
16	63	1000

SOLUTION

<u>Array Protection</u>

- Must be between 1.25 and 2.4 times the array short circuit current (from
- Hence: Minimum fuse size = 1.25 x 3 x 5.4 = 20.25A

  Maximum fuse size = 2.4 x 3 x 5.4 = 38.88A
- The fuse chosen is 30A.

<u>Array cable</u>

- The circuit protection can be smaller than the current carrying capacity of the cable but never larger.
- Thus, the cable chosen from Table 1 is 6mm^2 with a CCC of 34A.

VOLTAGE DROP

DETERMINING THE SIZE OF THE DC AND AC CABLES

The cables in an installation must be sized correctly so that:

1. there are not excessive voltage drops (also corresponding power loss) in the cables;
2. there is not excessive current through the cables compared with the safe current handling capability of the cables; and
3. maximum voltage rating of any cable is **never** exceeded

VOLTAGE DROP

Why do we care?

- Power losses in cables
- Voltage rise

Voltage Drop in a wire is a function of three parameters :

- conductor cross sectional area (mm^2),
- length of wire; and
- current flow in the wire.

RESISTIVITY

- The resistivity, ρ , varies dependent of the type of material.
- For copper the resistivity is 0.0183, while for aluminium it is 0.0294.
- Note: it can be slightly different for some cables depending on number of strands etc.

VOLTAGE DROP

- The voltage drop between the PV array and the battery bank should never exceed 5%
- The voltage drop between the battery bank and any DC load should never exceed 5%
- The voltage drop between the PV array and Solar Controller should never exceed 3% (dc bus)
- The voltage drop between the PV array and PV inverter should never exceed 3% (ac bus)

CALCULATING VOLTAGE DROP (METRIC) FOR SYSTEMS THAT INCLUDE PWM SOLAR CONTROLLERS

- The voltage drop along a cable is given by:

$$\mathbf{V_d} = \frac{\mathbf{2 \times L_{CABLE} \times I \times \rho}}{\mathbf{A_{CABLE}}}$$

- Voltage drop (in percentage) = $\frac{V_d}{V_{batt}} \times 100$

Where:

- $\mathbf{L_{CABLE}}$ = route length of cable in metres (multiplying it by two adjusts for total circuit wire length since a complete circuit requires a wire out and another wire back along the route).
- **I** = current in amperes.
- $\boldsymbol{\rho}$ = resistivity of the wire in Ω/m/mm^2
- $\mathbf{A_{CABLE}}$ = cross sectional area (CSA) of cable in mm^2.
- $\mathbf{V_{batt}}$ = the nominal voltage of the battery which is the dc system voltage.

WORKED EXAMPLE

A solar array has been installed and the distance between the output of the array and the solar controller is 10 metres. The short circuit current of the array is 9.6A.

- The cable has a cross sectional area of 10 mm^2
- The cable is copper with a resistivity of 0.0183 ohms/metres/mm^2
- The battery voltage of the system is 12V .

WORKED EXAMPLE SOLUTION

$$\mathbf{V_d} = \frac{\mathbf{2 \times L_{CABLE} \times I \times \rho}}{\mathbf{A_{CABLE}}}$$

= (2 x 10 x 9.6 x 0.0183)/10 V

= 0.35

Voltage Drop in percentage = $\frac{V_d}{V_{Batt}} \times 100$

= 0.351/12 × 100

= 2.9%

CALCULATING VOLTAGE DROP (METRIC) FOR SYSTEMS THAT INCLUDE A MPPT

The voltage drop along a cable is given by:

$$\mathbf{V_d} = \frac{\mathbf{2 \times L_{CABLE} \times I \times \rho}}{\mathbf{A_{CABLE}}}$$

$$\text{Voltage drop (in percentage)} = \frac{V_d}{V_{MAX}} \times 100$$

Where:

- **L_{CABLE}** = route length of cable in metres (multiplying it by two adjusts for total circuit wire length since a complete circuit requires a wire out and another wire back along the route).
- **I** = current in amperes.
- ***ρ*** = resistivity of the wire in Ω/m/mm^2
- **A_{CABLE}** = cross sectional area (CSA) of cable in mm^2.
- **V_{MAX}** = maximum line voltage in volts

WORKED EXAMPLE

A solar array has been installed and the distance between the output of the array and the solar controller is 10 metres. The short circuit current of the array is 9.6A.

- The cables has a cross sectional area of 4 mm^2
- The cable is copper with a resistivity of 0.0183 ohms/metres/mm^2
- The array has maximum power point voltage of 154.4V.

WORKED EXAMPLE SOLUTION

$$\mathbf{V_d} = \frac{\mathbf{2 \times L_{CABLE} \times I \times \rho}}{\mathbf{A_{CABLE}}}$$

$= 2 \times 10 \times 9.6 \times 0.0183/4$ V

$=0.88$V

Voltage Drop in percentage = $\frac{V_d}{V_{MAX}} \times 100$

$= 0.88/154.4 \times 100$

$= 0.57\%$

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MAXIMUM DISTANCE IN METRES TO PRODUCE 5% VOLTAGE DROP (12V SYSTEM)

Current (A)	$1mm^2$	$1.5mm^2$	$2.5mm^2$	$4mm^2$	$6mm^2$	$10mm^2$	$16mm^2$
1	16.4	24.6	41	65.6	98.4	163.9	262.3
2	8.2	12.3	20.5	32.8	49.2	82	131.1
3	5.5	8.2	13.7	21.9	32.8	54.6	87.4
4	4.1	6.1	10.2	16.4	24.6	41.0	65.6
5	3.3	4.9	8.2	13.1	19.7	32.8	52.5
6	2.7	4.1	6.8	10.9	16.4	27.3	43.7
7	2.3	3.5	5.9	9.4	14.1	23.4	37.5
8	2.0	3.1	5.1	8.2	12.3	20.5	32.8
9	1.8	2.7	4.6	7.3	10.9	18.2	29.1
10	1.6	2.5	4.1	6.6	9.8	16.4	26.2
11	1.5	2.2	3.7	6.0	8.9	14.9	23.8
12	1.4	2.0	3.4	5.5	8.2	13.7	21.9
13		1.9	3.2	5.0	7.6	12.6	20.2
14		1.8	2.9	4.7	7.0	11.7	18.7
15		1.6	2.7	4.4	6.6	10.9	17.5
16		1.5	2.6	4.1	6.1	10.2	16.4
17			2.4	3.9	5.8	9.6	15.4
18			2.3	3.6	5.5	9.1	14.6
19			2.2	3.5	5.2	8.6	13.8
20			2.0	3.3	4.9	8.2	13.1

MAXIMUM CABLE LENGTHS IN METRES FOR 12V SYSTEM 3% VOLTAGE DROP

Current (A)	$1mm^2$	$1.5mm^2$	$2.5mm^2$	$4mm^2$	$6mm^2$	$10mm^2$	$16mm^2$
1	9.8	14.8	24.6	39.3	59.0	98.4	157.4
2	4.9	7.4	12.3	19.7	29.5	49.2	78.7
3	3.3	4.9	8.2	13.1	19.7	32.8	52.5
4	2.5	3.7	6.1	9.8	14.8	24.6	39.3
5	2.0	3.0	4.9	7.9	11.8	19.7	31.5
6	1.6	2.5	4.1	6.6	9.8	16.4	26.2
7	1.4	2.1	3.5	5.6	8.4	14.1	22.5
8	1.2	1.8	3.1	4.9	7.4	12.3	19.7
9	1.1	1.6	2.7	4.4	6.6	10.9	17.5
10	1.0	1.5	2.5	3.9	5.9	9.8	15.7
11	0.9	1.3	2.2	3.6	5.4	8.9	14.3
12	0.8	1.2	2.0	3.3	4.9	8.2	13.1
13		1.1	1.9	3.0	4.5	7.6	12.1
14		1.1	1.8	2.8	4.2	7.0	11.2
15		1.0	1.6	2.6	3.9	6.6	10.5
16		0.9	1.5	2.5	3.7	6.1	9.8
17			1.4	2.3	3.5	5.8	9.3
18			1.4	2.2	3.3	5.5	8.7
19			1.3	2.1	3.1	5.2	8.3
20			1.2	2.0	3.0	4.9	7.9

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CALCULATING VOLTAGE DROP (IMPERIAL) FOR SYSTEMS THAT INCLUDE A PWM SOLAR CONTROLLER

- This section is for systems that are using switching type (e.g. PWM) solar controllers.
- To determine the voltage drop the following formula is used. The equation is derived from Ohm's Law i.e. V=IR:

$$V_d = \frac{I \times 2 \times d}{1000\, ft / kft} \times \left(\frac{\Omega}{kft} \right)$$

Where:

V_d	= voltage drop
d	= route length of dc cable in feet (2 x adjusts for total circuit wire length)
I	= dc current in amperes (commonly I_{mp})
Ω/kft	= ohms/thousand feet (resistance)

$$\text{Voltage drop (in percentage)} = \frac{V_d}{V_{batt}} \times 100$$

CABLE RESISTANCE FOR UNCOATED COPPER CABLE AT 75°C (167°F) - NEC

Wire Size (AWG)	dc Resistance (Ohms per 1000 feet)	ac Resistance (Ohms to neutral per 1000 feet)
14	3.14	3.1
12	1.98	2.0
10	1.24	1.2
8	0.778	0.78
6	0.491	0.49
4	0.308	0.31
2	0.194	0.20
1	0.154	0.16
1/0	0.122	0.13
2/0	0.0967	0.10
4/0	0.0608	0.067

WORKED EXAMPLE

A solar array has been installed and the distance between the output of the array and the inverter is 33 feet. The short circuit current of the array is 9.6A.

- The cable is AWG 6
- The battery voltage of the system is 12V .
- From Table 4 (previous slide), the dc Resistance in Ohms per 1000 feet =0.491

WORKED EXAMPLE SOLUTION

Therefore:

$$V_d = \frac{I \times 2 \times d}{1000\, ft / kft} \times \left(\frac{\Omega}{kft} \right)$$

= 9.6 x 2 x 33 x 0.491/1000 V

= 0.311 V

Voltage Drop (in percentage) = $\frac{V_d}{V_{Batt}} \times 100$

= 0.311/12 x 100

= 2.6%

CALCULATING VOLTAGE DROP (IMPERIAL) FOR SYSTEMS THAT INCLUDE A MPPT

- This section is for systems that are using Maximum Power Point Trackers (MPPT) as the solar controller (dc bus) or a PV inverter that includes an MPPT controller (ac bus).
- To determine the voltage drop the following formula is used. The equation is derived from Ohm's Law i.e. V=IR:

$$V_d = \frac{I \times 2 \times d}{1000\, ft / kft} \times \left(\frac{\Omega}{kft} \right)$$

Where:

V_d	= voltage drop
d	= route length of dc cable in feet (2 x adjusts for total circuit wire length)
I	= dc current in amperes (commonly I_{mp})
Ω//kft	= ohms/thousand feet (resistance)

$$\text{Voltage drop (in percentage)} = \frac{V_d}{V_{MAX}} \times 100$$

WORKED EXAMPLE

A solar array has been installed and the distance between the output of the array and the inverter is 33 feet. The short circuit current of the array is 9.6A.

- The cable is AWG 10
- The array has maximum power point voltage of 154.4V.
- From Table 4, the dc Resistance in Ohms per 1000 feet =1.24

WORKED EXAMPLE SOLUTION

Therefore:

$$V_d = \frac{I \times 2 \times d}{1000\, ft / kft} \times \left(\frac{\Omega}{kft} \right)$$

= 9.6 x 2 x 33 x 1.24/1000 V

= 0.786V

Voltage Drop (in percentage) = $\frac{V_d}{V_{MAX}} \times 100$

= 0.786/154.4 x 100

= 0.51%

MAXIMUM DISTANCE IN FEET TO PRODUCE 5% VOLTAGE DROP (12V SYSTEM)

Wire Size-AWG (mm²)	14 (2.08)	12 (3.31)	10 (5.26)	8 (8.36)	6 (13.29)	4 (21.14)	2 (33.61)	1 (42.39)
Current (A)								
1	34.10	54.26	86.23	137.05	217.87	346.56	550.98	694.92
2	17.05	27.13	43.11	68.52	108.93	173.28	275.49	347.46
3	11.37	18.09	28.74	45.68	72.62	115.52	183.66	231.64
4	8.52	13.57	21.56	34.26	54.47	86.64	137.75	173.73
5	6.82	10.85	17.25	27.41	43.57	69.31	110.20	138.98
6	5.68	9.04	14.37	22.84	36.31	57.76	91.83	115.82
7	4.87	7.75	12.32	19.58	31.12	49.51	78.71	99.27
8	4.26	6.78	10.78	17.13	27.23	43.32	68.87	86.86
9	3.79	6.03	9.58	15.23	24.21	38.51	61.22	77.21
10	3.41	5.43	8.62	13.70	21.79	34.66	55.10	69.49
11	3.10	4.93	7.84	12.46	19.81	31.51	50.09	63.17
12	2.84	4.52	7.19	11.42	18.16	28.88	45.92	57.91
13	2.62	4.17	6.63	10.54	16.76	26.66	42.38	53.46
14	2.44	3.88	6.16	9.79	15.56	24.75	39.36	49.64
15	2.27	3.62	5.75	9.14	14.52	23.10	36.73	46.33
16	2.13	3.39	5.39	8.57	13.62	21.66	34.44	43.43
17	2.01	3.19	5.07	8.06	12.82	20.39	32.41	40.88
18	1.89	3.01	4.79	7.61	12.10	19.25	30.61	38.61
19	1.79	2.86	4.54	7.21	11.47	18.24	29.00	36.57
20	1.70	2.71	4.31	6.85	10.89	17.33	27.55	34.75

MAXIMUM DISTANCE IN FEET TO PRODUCE 3% VOLTAGE DROP (12V SYSTEM)

Wire Size-AWG (mm^2)	14 (2.08)	12 (3.31)	10 (5.26)	8 (8.36)	6 (13.29)	4 (21.14)	2 (33.61)	1 (42.39)
Current (A)								
1	20.46	32.56	51.74	82.23	130.72	207.93	330.59	416.95
2	10.23	16.28	25.87	41.11	65.36	103.97	165.30	208.48
3	6.82	10.85	17.25	27.41	43.57	69.31	110.20	138.98
4	5.11	8.14	12.93	20.56	32.68	51.98	82.65	104.24
5	4.09	6.51	10.35	16.45	26.14	41.59	66.12	83.39
6	3.41	5.43	8.62	13.70	21.79	34.66	55.10	69.49
7	2.92	4.65	7.39	11.75	18.67	29.70	47.23	59.56
8	2.56	4.07	6.47	10.28	16.34	25.99	41.32	52.12
9	2.27	3.62	5.75	9.14	14.52	23.10	36.73	46.33
10	2.05	3.26	5.17	8.22	13.07	20.79	33.06	41.70
11	1.86	2.96	4.70	7.48	11.88	18.90	30.05	37.90
12	1.70	2.71	4.31	6.85	10.89	17.33	27.55	34.75
13	1.57	2.50	3.98	6.33	10.06	15.99	25.43	32.07
14	1.46	2.33	3.70	5.87	9.34	14.85	23.61	29.78
15	1.36	2.17	3.45	5.48	8.71	13.86	22.04	27.80
16	1.28	2.03	3.23	5.14	8.17	13.00	20.66	26.06
17	1.20	1.92	3.04	4.84	7.69	12.23	19.45	24.53
18	1.14	1.81	2.87	4.57	7.26	11.55	18.37	23.16
19	1.08	1.71	2.72	4.33	6.88	10.94	17.40	21.94
20	1.02	1.63	2.59	4.11	6.54	10.40	16.53	20.85

EXAMPLE – VOLTAGE DROP METHOD WHEN SELECTING CABLE (PWM Controller)

Cable length = 12m between solar array and standard controller

Array current = 30A

System voltage = 24V

Using copper wire – resistivity = 0.0183

Maximum allowable voltage loss = 3% (0.03)

EXAMPLE – VOLTAGE DROP METHOD WHEN SELECTING CABLE (PWM Controller) SOLUTION

Minimum cross-sectional area =

$$\frac{2 \times 12 \times 30 \times 0.0183}{0.03 \times 24}$$

$$= 18.3 \text{ mm}^2$$

Choose the next size of cable ABOVE this – 25mm squared.

Next, we have to check that the 25mm sq. cable can carry 30A.

Upon checking CCC tables, it can carry more than 30A, therefore 25 sq. should be ok.

EXAMPLE - VOLTAGE DROP METHOD WITH MPPT (MPPT Controller)

Cable length = 10m between solar array and MPPT controller

Array current = 27.3A

Vmpp of array= 92.1V

Using copper wire – resistivity = 0.0183

Maximum allowable voltage loss = 3% (0.03)

EXAMPLE - VOLTAGE DROP METHOD WITH MPPT (MPPT Controller)

Minimum cross-sectional area =

$$\frac{2 \times 10 \times 27.3 \times 0.0183}{0.03 \times 92.1}$$

$$= 3.61 \text{ mm}^2$$

Choose the next size of cable ABOVE this – 4mm squared.

Check CCC. Upon checking CCC of 4mm sq. cable, it was found that 4mm sq cable can carry around 32A, therefore ok.

CABLE SIZING BETWEEN STANDARD SOLAR CONTROLLER AND BATTERY

- The cables between the standard solar controller and the battery shall have a voltage rating greater than the maximum voltage rating of the battery when being charged.
.
- The ***current carrying capacity of the cable between the controller and battery shall be capable of carrying the maximum charge current from the array.***

- The dc current rating of the associated over-current protection shall not be greater than that of the cable.

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EXAMPLE

- The distance between standard controller and battery is 2m. The maximum charge current is 30A. What size cable is appropriate?

EXAMPLE SOLUTION

- Cable must meet both CCC and voltage drop .
- A cable that can carry the maximum charge current of 30A, from CCC tables, a 4mm sq. cable is appropriate, Alternatively, we can also use the voltage drop method here.
- We then determine the voltage drop present in the cable, if it exceeds say 3%, we can increase the cable size to reduce the voltage drop.

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CABLE SIZING BETWEEN MPPT CONTROLLER AND BATTERY

- ***The current carrying capacity of the cable between the controller and battery shall be capable of carrying the maximum charge current from the MPPT.***
- The dc current rating of the associated over-current protection shall not be greater than that of the cable.
- If it is an non-seperated MPPT (all are at moment) the cable needs voltage rating greater than the Voc of the array.

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CABLE SIZING BETWEEN BATTERY AND BATERY INVERTER (IF APPLICABLE)

- ***The current carrying capacity of the cable between the battery bank and the battery inverter shall be capable of carrying the maximum current based on either the 30 minute power rating of the inverter (if provided) or the continuous power rating of the inverter.***
- The dc current rating of the associated over-current protection shall not be greater than that of the cable

EXAMPLE

- The continuous rating of inverter of an inverter is 2000W. The surge rating is 4000W. The system voltage is 24V and the inverter efficiency is 90%. What size cable is required between battery and inverter if the distance is 3m?
- I cont = (2000/(24 x 0.9)) = 92.59 A
- I surge = (4000/(24 x 0.9)) = 185.19A

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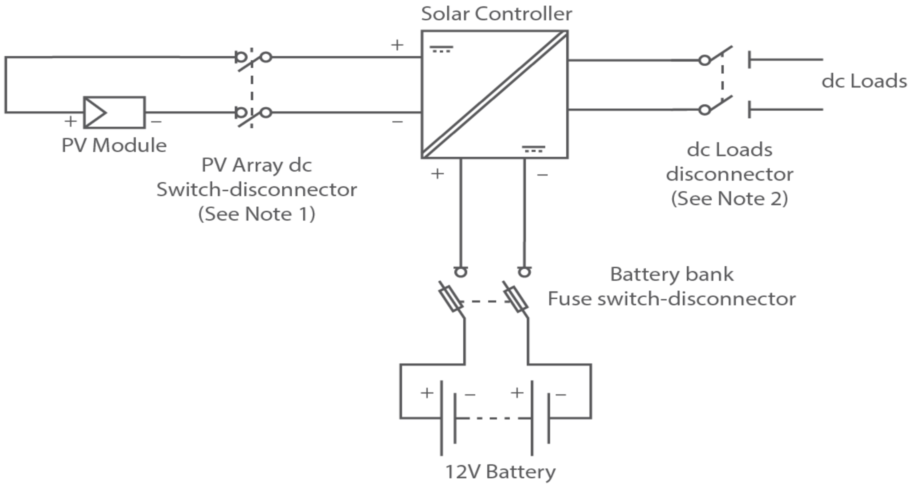
EXAMPLE SOLUTION

- If we size using surge current, it will lead to a bigger cable size. Assuming that cables have the capacity to take surge currents for few seconds, we can just use the continuous rating.
- We can thus use a 25mm sq. cable that meets this current requirement.
- We need to check for the percentage voltage drop as a matter of check.

SYSTEM CABLE PROTECTION and ISOLATION

PROTECTION REQUIREMENTS IN SYSTEM

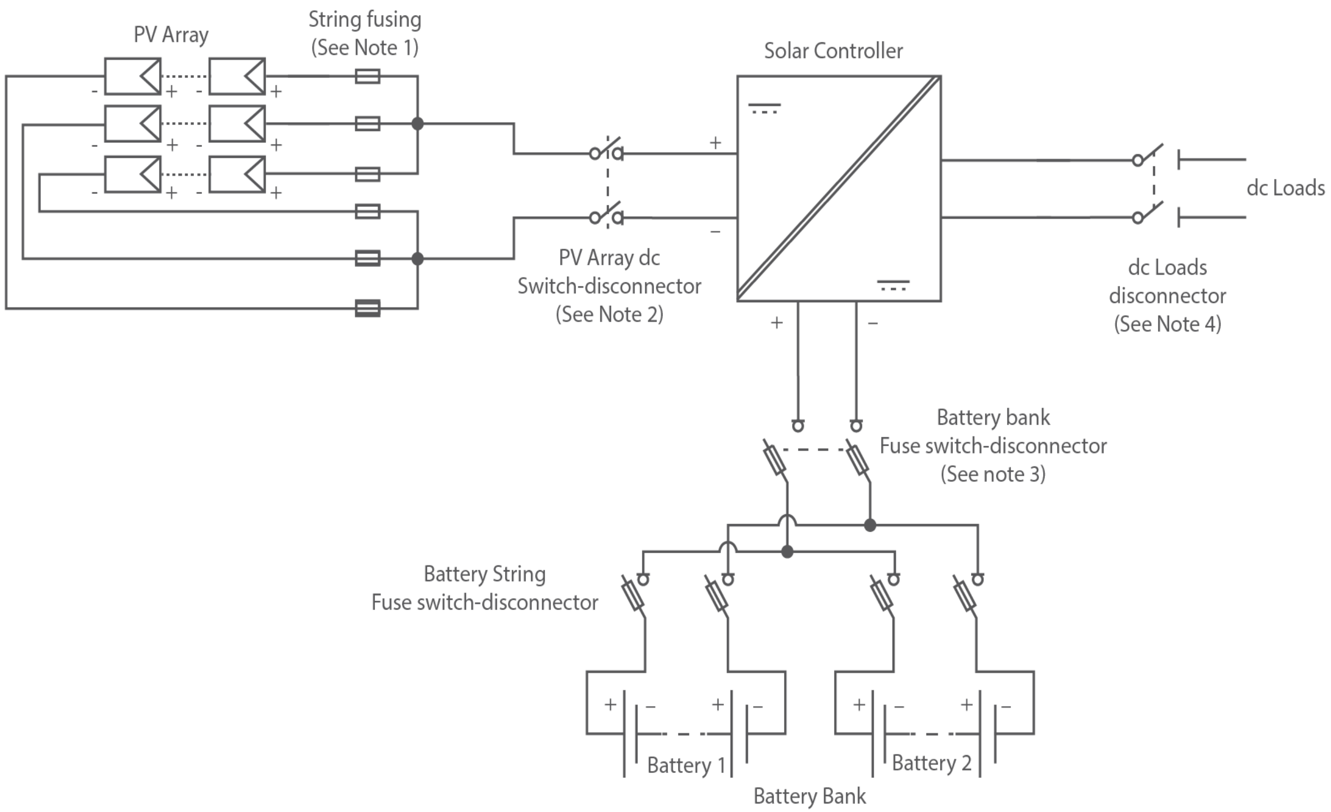
- All cables shall be electrically protected from fault currents that could occur.
- **dc bus-Simple dc only system**



Notes:

1. A PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting. However many standards allow the battery bank switch fuse to meet the isolation requirement. A switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the PV array cables and the solar controller allows back feed from the battery bank.

dc BUS - LARGER dc ONLY SYSTEM



dc BUS-LARGER dc ONLY SYSTEM

Notes

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module.
2. The PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch fuse to meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the PV array cables and the solar controller allows back feed from the battery bank.

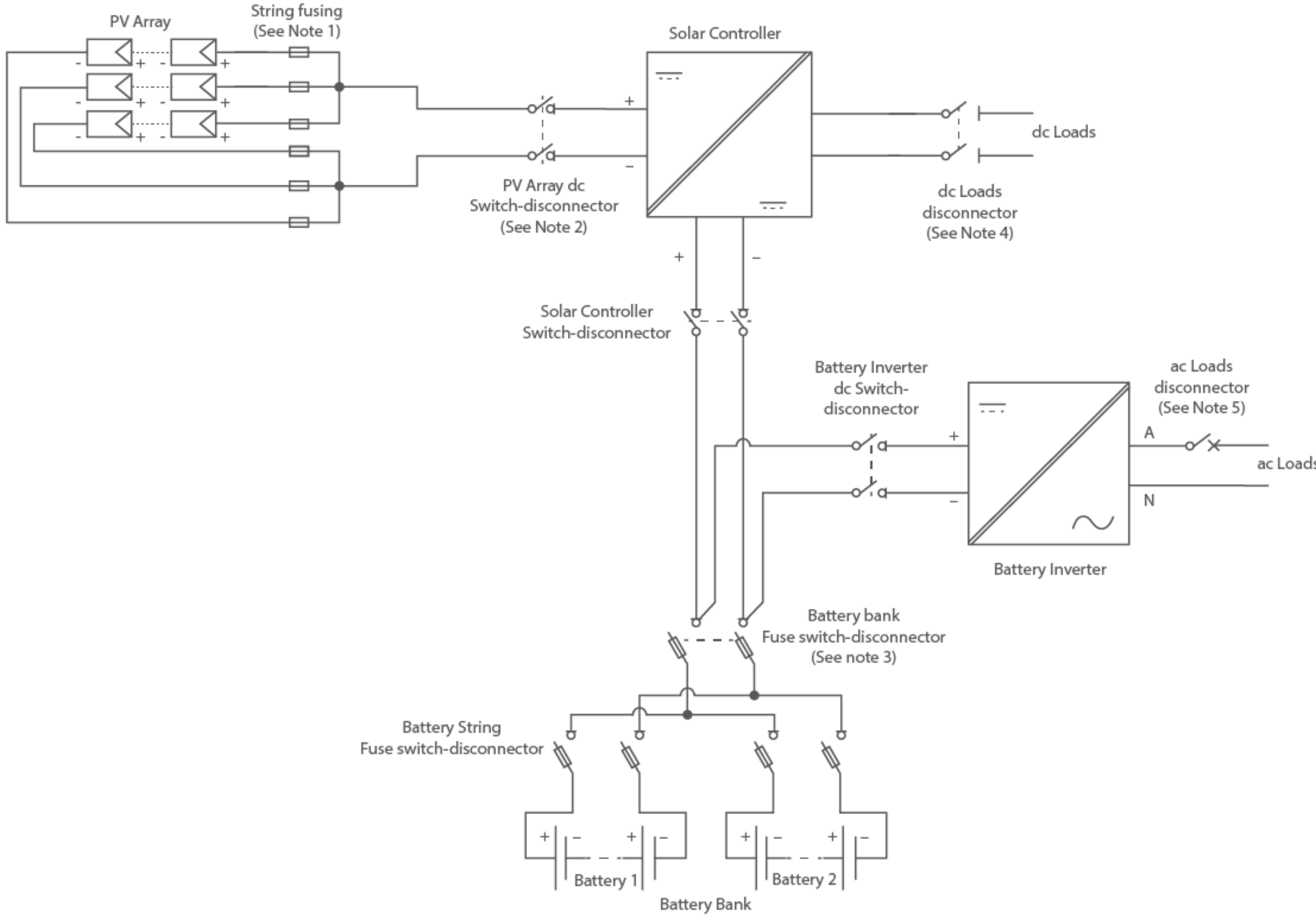
dc BUS-LARGER dc ONLY SYSTEM

Notes

3. Batteries in parallel each require their own isolation and protection devices. Over-current protection is required for the battery bank cable when the current-carrying capacity of the battery bank cable is less than the sum of all individual battery over-current protection devices. A battery bank switch disconnecting device is recommended because it allows the disconnection of the complete battery bank via the one switch disconnector.

4. The loads dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch-fuse to meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the load cables.

dc BUS WITH dc AND ac LOADS



dc BUS WITH dc AND ac LOADS

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module.

2. The PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch fuse to meet the isolation requirement. The switch disconnector will be required as a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the PV array cables and the solar controller allows backfeed from the battery bank.

dc BUS WITH dc AND ac LOADS

- **Notes:**

3. Batteries in parallel each require their own isolation and protection devices. Over-current protection is required for the battery bank cable when the current-carrying capacity of the battery bank cable is less than the sum of all individual battery over-current protection devices. A battery bank switch disconnecting device is recommended because it allows the disconnection of the complete battery bank via the one switch disconnector. Sometimes this might be a four (4) pole device to allow different size fuses to protect the inverter cable and the solar controller cable which will be generally be different cross sectional areas (or gauges)

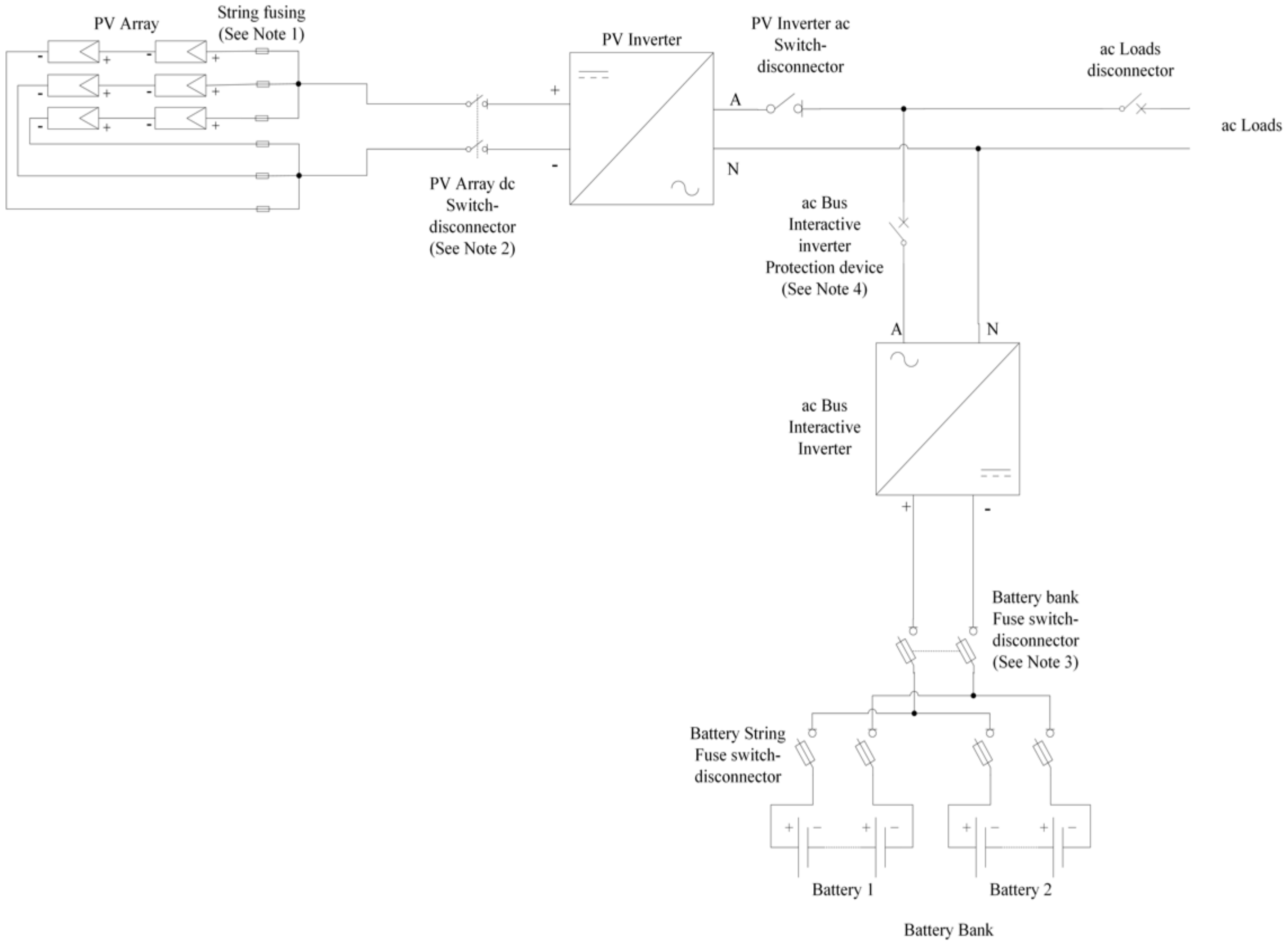
dc BUS WITH dc AND ac LOADS

Notes:

4. The loads dc switch disconnector is recommended because it helps with maintenance and trouble shooting although many standards allow the battery bank switch-fuse to meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the load cables.

5. A separate ac load disconnector is required if the battery inverter does not have a switch disconnector on the ac output. This will be required as a protection device (e.g. an ac circuit breaker) for protecting the ac load cable.

ac BUS WITH ac LOADS



ac BUS WITH ac LOADS

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module.
2. A PV array dc switch disconnector is required but it can be part of the inverter
3. Batteries in parallel each require their own isolation and protection devices. Over-current protection is required for the battery bank cable when the current-carrying capacity of the battery bank cable is less than the sum of all individual battery over-current protection devices. A battery bank switch disconnecting device is recommended because it allows the disconnection of the complete battery bank using only one switch disconnector.

ac BUS WITH ac LOADS

Notes:

4. A separate ac bus interactive inverter disconnector device is required if the battery inverter does not have a switch disconnector on the ac output. This will be required to be a protection device (e.g. ac circuit breaker) for protecting the ac load cable.

BATTERY CABLE PROTECTION- dc BUS – dc LOADS ONLY

- For dc bus systems with dc loads only, as shown in previous Figures , the only battery cables are those between the battery bank and the controller. The protection devices will be rated to allow the **maximum charge current provided by the solar controller and the maximum dc load current** that is to be provided by the solar controller.

BATTERY CABLE PROTECTION- dc BUS – ac AND dc LOADS

- dc bus systems with ac and dc loads as shown in previous Figure can potentially have two different sized battery cables:
- the battery cable between the battery bank and the solar controller.
- The battery cable between the battery bank and the battery inverter.

BATTERY CABLE PROTECTION- dc BUS – ac AND dc LOADS

- The protection devices for the cable connected to the solar controller from the battery will be rated to allow **the maximum charge current** provided by the solar controller to the battery and the maximum dc load current that is to be provided at the output of the solar controller, whichever is larger. This protection device will need to be suited for motors of there are any dc motors connected to the system. These fuses are a specific type to allow for the motor surge capability.
- The protection device for the battery cable to an inverter will be determined via the process defined in section 18.13

BATTERY CABLE PROTECTION - ac BUS

- Systems with an ac bus as shown in previous Figure only have one set of cables from the battery bank and that is to the battery inverter.

- The protection device for the battery inverter will be determined via the process defined in section 18.13

BATTERY CABLE PROTECTION- BATTERY INVERTER

To select the appropriate battery protection for the cable to the battery inverter:

- Obtain the battery inverter manufacturer's data of:
    - Continuous power rating (Watts)
    - 3 to 10 second surge rating (Watts)
    - Average inverter efficiency (%)

- Obtain Time-Current characteristics for the overload protection to be used.

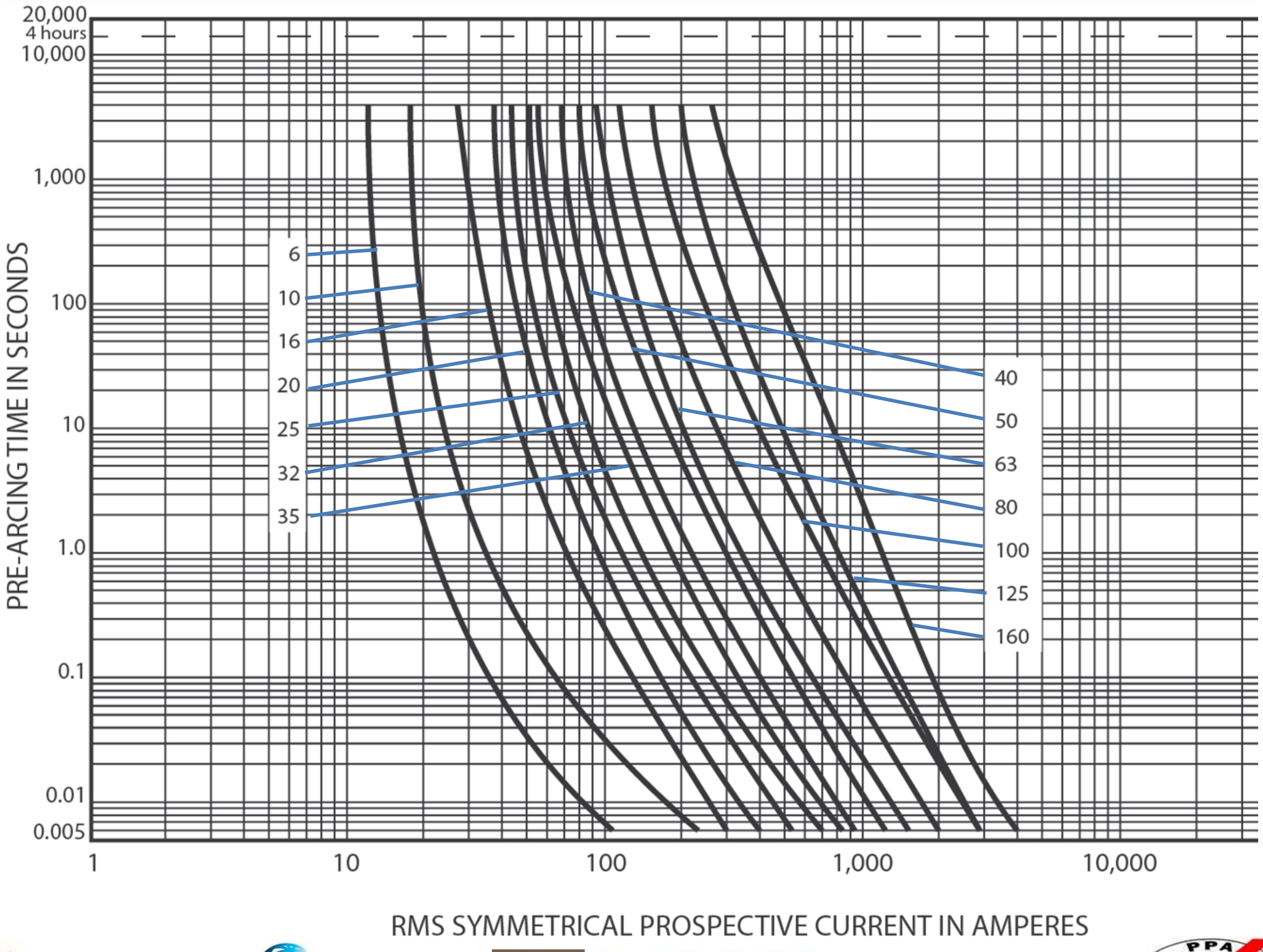
[All manufacturers publish time-current information for their circuit breaker and HRC fuse ranges]

BATTERY CABLE PROTECTION- BATTERY INVERTER

- For each inverter power rating determine the current drawn from the battery bank using:

$$I = \frac{\text{Inverter Power Rating (W)}}{(\text{inverter efficiency} \times \text{nominal battery voltage})}$$

- Consult the Time-Current characteristic of available overload protection devices to determine the device with an appropriate rating that matches the maximum load and maximum load surge characteristics.


20,000
4 hours
10,000
1,000
100
10
1.0
0.1
0.01
0.005
PRE-ARCING TIME IN SECONDS
6
10
16
20
25
32
35
40
50
63
80
100
125
160
1
10
100
1,000
10,000
RMS SYMMETRICAL PROSPECTIVE CURRENT IN AMPERES

EXAMPLE

- The inverter has continuous rating of 800W and surge rating of 1600W. Assume system voltage is 24V and inverter efficiency is 93%.

EXAMPLE SOLUTION

- The continuous current will be 800/(24 x 0.93) = 35.84 A and surge current will be 1600/(24 x 0.93) = 71.68A.
- We need a fuse that is able to carry these currents and rupture beyond this current.
- Some inverter manufacturers also provide the 12s surge rating. The fuse firstly should be able to carry continuous current and also should be able to carry the 12s surge current for 12 seconds.

EXAMPLE SOLUTION

- Referring to NHG General purpose fuse time-current graph, a **40A** fuse is chosen.
- This rating should also be checked against the cable current carrying capacity as it should be less.
- Generally, a 35mm^2 cable can carry around 110A, therefore 80A fuse will ensure protection of the cable.

The End

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