Sizing the Array/Battery and Inverter in an Off Grid System – (PWM and MPPT Controller)

INTRODUCTION

- This ½ day session looks at battery sizing, inverter sizing and array sizing in a dc bus system (PWM and MPPT controller) Off grid PV System
- The design of an off-grid PV power system should meet the required energy demand and maximum power demands of the end-user.

DC BUS SYSTEMS

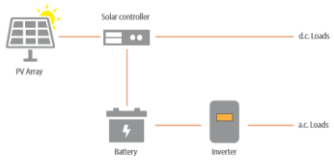


Figure 2: dc bus system

STEPS WHEN DESIGNING AN OFF GRID

The steps in designing a system include:

1. Carrying out a site visit and determining the limitations for installing a system and examining the location where the equipment will be installed
2. Determining the energy needs of the end-user
3. Determining the voltage and capacity of the battery bank.

STEPS WHEN DESIGNING AN OFF GRID

4. Determining the size of any inverter connected to systems supplying dc power.
5. Determining the size of the array.
6. Determining the size of the solar controller
7. Providing a quotation to the end-user.

SIZING THE INVERTER AND BATTERIES

- Comes from Load Assessment Form

SPECIFYING AN INVERTER

- Examine the loads which could be running at any one time
- The inverter needs to be able to run these loads simultaneously

EXAMPLE DC LOAD ASSESSMENT

Table 1 dc load (energy) Assessment

(1)	(2)	(3)	(4a)	(5a)	(4b)	(5b)	(6)	Comments
Appliance	Number	Power	Rest of year		Humid season		Contribution to maximum demand	
			Usage Time	Energy	Usage Time	Energy		
		W	H	Wh	h	Wh	W	
Light	6	5	6	180	8	240	30	
Daily Load energy-dc loads (Wh) (DC 7a)				180	(DC 7b)	240		
Maximum dc demand (W) (DC 8)							30	

EXAMPLE – AC LOADS

(1)	(2)	(3)	(4a)	(5a)	(4b)	(5b)	(6)	(7)	(8)	(9a)	(9b)	
Appliance	No.	Power	Rest of Year		Humid season		Power Factor	Contribution to max demand	Surge Factor	Contribution to surge demand		Comments
			Usage Time	Energy	Usage Time	Energy				Potential	Design	
		W	h	Wh	h	Wh		VA		VA	VA	
TV	1	25	4	100	4	100	0.8	31	1	31	31	
Fan	1	60	0	0	6	360	0.9	67	1	67	67	
Refrigerator	1	100	14	1400	14	1400	0.8	125	4	500	500	Duty cycle of 0.58 included
Daily Load Energy A.C Loads (Wh)			(AC10a)	1500	(AC10b)	1860						
Maximum ac demand (VA)								(AC11) 223		598		
Surge demand (VA)										(AC12)	598	

POSSIBLE INVERTER SIZE

- From the load (energy) assessment, the selected inverter must be capable of supplying 223VA continuously with a surge capability of 598VA for a short period of time.
- Allow 10% over-sizing.
- Consider future demand.

BATTERY SIZING

SUMMARY – BATTERY SIZING 1

- Carry out load assessment for dc and ac loads
- Find E_{tot} = dc loads + (ac loads/inverter efficiency)
- Select an appropriate system voltage
- Choose appropriate battery technology and Maximum DOD
- Select number of days of autonomy (3 – 5 days)

SUMMARY – BATTERY SIZING 2

- Use following equation to find battery capacity in Ah

$$C_x = \frac{E_{tot}}{V_{d.c.}} \times \frac{T_{aut}}{DOD_{max}}$$

- Derate battery capacity for operating temperature
- Consult the manufacturer's data sheets for maximum demand and surge capabilities (Compare C_5 and C_1 currents with maximum demand and surge currents for lead acid batteries)

SUMMARY – BATTERY SIZING 3

- Verify maximum continuous discharge current
- Ensure appropriate charge current
- Select the battery accounting for charge/discharge rates
- Find number in series and parallel BUT KEEP PARALLEL AT A MINIMUM NUMBER

AVERAGE DAILY ENERGY USAGE

$$E_{tot} = E_{dc} + \frac{E_{ac}}{\eta_{inv}}$$

E_{tot} = total designed daily energy demand from the d.c. bus in Watt-hrs

E_{dc} = design daily energy d.c. load in Watt-hrs

E_{ac} = design daily energy a.c.. load in Watt-hrs

η_{inv} = average energy efficiency of the inverter when supplying the design d.c. load

AVERAGE DAILY ENERGY USAGE- HUMID SEASON

Say

E_{dc} = 240 Wh

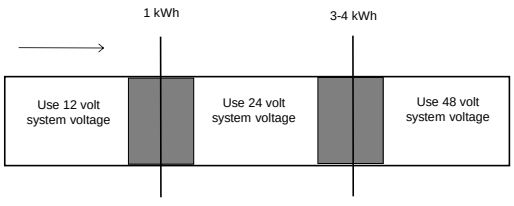
E_{ac} = 1860 Wh

η_{inv} = *90% (0.9)*

Therefore

E_{tot} = 240 + (1860/0.9)= 2307Wh or 2.3kWh

DETERMINATION OF SYSTEM VOLTAGE GUIDE ONLY



DETERMINING BATTERY CAPACITY

$$C_x = \frac{E_{tot} \times T_{aut}}{V_{dc} \times DOD_{max}}$$

$$C_x = \frac{\text{Daily Energy Requirement (Ah)} \times T_{aut}}{DOD_{max}}$$

USING 24V

- Daily Ah requirement = 2307/24 = 96Ah

DETERMINING BATTERY CAPACITY 1

Information required:

- Daily energy demand in Ah = 96Ah
- Number of days of autonomy = 5 days
- Maximum Depth of Discharge = 70%

DETERMINING BATTERY CAPACITY 2

To calculate the required battery capacity , multiply daily energy demand in Ah by the number of days of autonomy:

96Ah x 5 days = 480Ah for lead acid batteries

and divided by maximum depth of discharge

C_x= 480/0.7 = 686 Ah

DETERMINING BATTERY CAPACITY 3

- Battery Capacity = (5 x 2307 Wh)/0.7 = 16479 Wh for lithium ion batteries (assuming 70% usable with safety margin)

BATTERY DISCHARGE RATE

An easy approach is just say C_{10} or C_{20}

The actual rate should be based on the load profile of the actual system

Please refer to guideline for doing that.

Assume for the worked example we select C_{10}

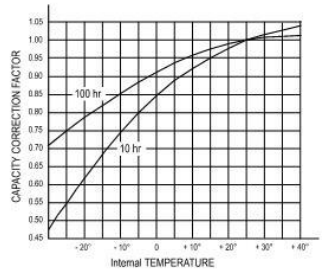
SELECTING BATTERY

Battery Model	Battery Capacities in AH					
	C_1	C_5	C_{10}	C_{20}	C_{50}	C_{100}
A	130	180	220	255	328	400
B	160	222	268	310	400	468
C	360	403	481	551	698	840
D	400	485	578	661	840	998
E	450	618	734	838	1056	1260

TEMPERATURE CORRECTION FACTOR

- Batteries have less capacity in temperatures colder then the test temperature (either 20ºC (Europe Standards or 25ºC)Australian Standards) .
- So battery capacity might need adjusting

TEMPERATURE CORRECTION FACTOR- LEAD ACID BATTERIES



- Assume lowest 24 hour average temperature is 20°C then the correction factor would be 0.99 at the 100 hr rate and 0.975 at the 20 hr rate.

EXAMPLE

- Assuming that at the 10 hour rate the correction factor is about 0.97;
- Actual Required Capacity is 686/0.97 = 707 Amp-hrs at C_{10}

So select Battery model 'E' with a C_{10} of 734 Amp-hrs

MAXIMUM OR SURGE DEMAND

- Typical maximum continuous discharge rate is given as the 5 hour rating (C_5)
- The surge rating as the 1 hour rating (C_1)
- Sometimes data is hard to get

CONSULT WITH MANUFACTURER

EXAMPLE

- Lets assume we have inverter with 250VA continuous rating (and customer does use that and 1000VA surge
- Typical maximum continuous discharge rate is given as the 5 hour rating (C_5)
- =30W/24V + (250VA/0.9)/24V= 12.82A
- C_5 = 5 x 12.82 = 64.1Ah

EXAMPLE Cont

- The surge rating as the 1 hour rating (C_1)
- =30W/24V + (1000VA/(0.9)/24V)= 48A
- C_1 = 1 x 48 = 48Ah

- Battery E easily meets both of the above requirements.

MAXIMUM CHARGE CURRENT

- Generally accepted that the maximum charge current for a battery is the C_{10} discharge current—sometimes stated as

  10% of the C_{10} rating

- To calculate the maximum charging current, multiply the C_{10} rating of battery by 0.1
- So for selected battery C_{10} =734 therefore maximum charge current = 73A

SERIES AND PARALLEL BATTERIES

- The number of batteries in series is determined by the system voltage divided by the voltage of the selected battery
- The number of batteries in parallel is determined by the overall capacity divided by the capacity of the selected battery (must be a whole number, in principle, always round up)

BATTERIES REQUIRED

Information Required

- Chosen battery capacity at required rate = 734Ah at C_{10}
- Chosen battery voltage = 2V
- Required battery capacity = 707Ah at C_{10}
- Required battery voltage = 24V

BATTERIES REQUIRED Cont

To work out the number of batteries in series, divide the required battery voltage by the voltage of the chosen battery

24/2 = 12

To work out the number of parallel strings, divide the required battery capacity by the capacity of the chosen battery

707/734 = 0.96 (round up to 1)

ALLOWING FOR FUTURE LOAD GROWTH

- If the loads are expected to change in the future (i.e. New TV, more lights), then this should be considered when choosing the battery capacity
- It is better to have a larger battery from the beginning, as you can't just add more battery capacity later on

SIZING ARRAY WITH STANDARD CONTROLLER

EXAMPLE DC LOAD ASSESSMENT

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Appliance	No.	Power	Rest of Year		Hot Season		Power Factor	Contribution to max demand	Surge Factor	Contribution to surge demand		Comments
			Usage Time	Energy	Usage Time	Energy				Potential	Design	
		W	h	Wh	h	Wh		VA		VA	VA	
TV	1	25	4	100	4	100	0.8	31	1	31	31	
Fan	1	60	0	0	6	360	0.9	67	1	67	67	
Refrigerator	1	100	14	1400	14	1400	0.8	125	4	500	500	Duty cycle of 0.58 included
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AVERAGE DAILY ENERGY USAGE

Humid Season

E_{dc} = 240 Wh E_{ac} = 1860 Wh η_{inv} = *90% (0.9)*

Therefore

E_{tot} = 240 + (1860/0.9) = 2307Wh

Rest of Year

E_{dc} = 180 Wh E_{ac} = 1500 Wh η_{inv} = *90% (0.9)*

Therefore

E_{tot} = *180* + (1500/0.9) = 1847Wh

DETERMINATION OF WORST MONTH (USING LATITUDE TILT)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Irradiation (kWh/ m^2)	6.69	5.9	5.78	5.33	4.76	4.42	4.66	5.22	5.82	6.26	6.46	7.01
Load (kWh)	2.3	2.3	2.3	1.8	1.8	1.8	1.8	1.8	1.8	2.3	2.3	2.3
Ratio	2.91	2.57	2.51	2.96	2.64	2.46	2.59	2.90	3.23	2.72	2.81	3.05

CALCULATING AH

	Example
Information Required:	
Daily energy required	1847Wh
System Voltage	24V
To determine the daily energy requirement divide the total daily energy in Wh by the system voltage	1847÷24=77Ah

AH REQUIRED FROM ARRAY

- Since the batteries are not 100% efficient, array needs to produce more than is required
- Battery 'round trip' efficiency depends upon coulombic efficiency of charging and discharging – typically 0.8-0.9

AMP-HOURS REQUIRED FROM ARRAY

Information provided:

Daily Load in Ah = 77 Ah

Battery 'round trip' efficiency = 90% (0.9)

To calculate the Amp-hours required from the array you need to divide the daily load in Ah by the battery 'round trip' efficiency

77 ÷ 0.9 = 85.6Ah

OVERSIZE FACTOR

- Without a back-up genset the PV array should be oversized to ensure that the battery can be recharged from maximum depth of discharge in an acceptable period while still meeting the daily load requirements.
- The PPA/SEIAPI guideline - 20%

OVERSIZE FACTOR

- Therefore the array output required is:

Array Output Required = 1.2 x 85.6 = 102.7 Ah

DERATING OF PV ARRAY

- Manufacturers Tolerance
  - Typically 5%
- Dirt
  - 0% to 10%
- Temperature
  - PV Cell's generally operate at about 25°C above the ambient temperature

  Effective cell temperature

  = Ambient temperature + 25°C

DETERMINING SIZE OF ARRAY REQUIRED

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)							
Module name			YGE 145	YGE 140	YGE 135	YGE 130	YGE 125
Module type			YLxxxP-17b (xxx=Pmax)				
Power output	P_{max}	W	145	140	135	130	125
Power output tolerances	ΔP_{max}	%	+/- 5				
Module efficiency	η_m	%	14.5	14.0	13.5	13.0	12.5
Voltage at P_{max}	V_{mpp}	V	18.15	18.01	17.77	17.51	17.34
Current at P_{max}	I_{mpp}	A	7.99	7.77	7.60	7.42	7.21
Open-circuit voltage	V_{oc}	V	22.46	22.28	22.00	21.67	21.46
Short-circuit current	I_{sc}	A	8.47	8.30	8.12	8.00	7.74

STC: 1000W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3.
Average relative efficiency reduction of 5% at 200W/m² according to EN 60904-1.

Electrical parameters at Nominal Operating Cell Temperature (NOCT)							
Power output	P_{max}	W	117.46	113.41	109.36	105.31	101.26
Voltage at P_{max}	V_{mpp}	V	16.73	16.59	16.38	16.14	15.98
Current at P_{max}	I_{mpp}	A	6.40	6.26	6.12	5.96	5.78
Open-circuit voltage	V_{oc}	V	20.44	20.28	20.02	19.72	19.53
Short-circuit current	I_{sc}	A	6.78	6.64	6.50	6.40	6.19

NOCT: open-circuit module operation temperature at 800W/m² irradiance, 20°C ambient temperature, 1m/s wind speed.

DETERMINING SIZE OF ARRAY REQUIRED

Information required

Manufacturer's tolerance = 5% (0.95)

Dirt derating factor = 5% (0.95)

If module current at 14V and 50°C and 55 °C cannot be supplied by the manufacturer- then use the halfway point between the Isc and Imp

i.e. (7.99 + 8.47)/2 = 8.23A

DETERMINING SIZE OF ARRAY REQUIRED

First we derate the module's current by the manufacturers tolerance

8.23 x 0.95 = 7.82A

Then we derate the current for losses from dirt

7.82 x 0.95 = 7.43A

DETERMINING SIZE OF ARRAY -SERIES

You then need to work out how many modules in each string

Information required:

System voltage = 24 V

Nominal module voltage = 12 V

To get the number of modules per string, you divide the system voltage by the nominal module voltage:

24÷12 =2

DETERMINING SIZE OF ARRAY – PARALLEL FIRST USING THE PSH AS PROVIDED

Lastly, you need to find out how many parallel strings to get the required Ah out of your PV array

Information required

- Module derated output current = 7.43 A
- Lowest monthly Peak Sun Hours at site = 4.42
- Daily load in Ah = 102.7 Ah

DETERMINING SIZE OF ARRAY – PARALLEL FIRST USING THE PSH AS PROVIDED

To get the daily output of each module, multiply the current (A) by the peak sun hours (h)

7.43 x 4.42 =32.8Ah

To get the number of parallel strings required, divide the daily load in Ah by the daily output of a module

102.7÷32.8 = 3.13

DO YOU ROUND UP OR DOWN = DISCUSS

DETERMINING SIZE OF ARRAY- 3 STRINGS

Month	PSH at latitude tilt	Daily energy from modules (Ah)	Excess energy from modules
January	6.69	149.1	53.0
February	5.9	131.5	35.4
March	5.78	128.8	32.7
April	5.33	118.8	36.6
May	4.76	106.1	23.9
June	4.42	98.5	16.3
July	4.66	103.9	21.7
August	5.22	116.4	34.2
September	5.82	129.7	47.5
October	6.26	139.5	43.4
November	6.46	144.0	47.9
December	7.01	156.3	60.2

DETERMINING SIZE OF ARRAY- 4 STRINGS

Month	Peak sun hours at 17° tilt	Average daily energy from modules (Ah)	Excess energy from Modules (Ah)
January	6.69	198.8	102.7
February	5.9	175.3	79.2
March	5.78	171.8	75.7
April	5.33	158.4	76.2
May	4.76	141.5	59.3
June	4.42	131.4	49.2
July	4.66	138.5	56.3
August	5.22	155.1	72.9
September	5.82	173.0	90.8
October	6.26	186.0	89.9
November	6.46	192.0	95.9
December	7.01	208.3	112.2

NUMBER OF STRINGS - FORMULA

The number of strings in parallel required is:

$$N_p = \frac{E_{tot} \times f_o}{V_{dc} \times I_{mod} \times H_{tilt} \times \eta_{coul}}$$

where

E_{tot} = total daily design energy demand from the dc busbar in watthrs

f_o = oversupply co-efficient, dimensionless

η_{coul} = coulombic efficiency of the battery, dimensionless

PWM CONTROLLER SIZING

- These should be sized so that they are capable of carrying 125% of the array short circuit current but if controllers are current limited this can be ignored.
- Most PWM are current limited
- However, even if controller is current limited if there is no 125% oversize then controller is working harder and it might shorten the lifetime of the controller

PWM CONTROLLER SIZING 2

- Based on short circuit current
- The controllers shall withstand the open circuit voltage of the array
- The oversize by 25% because currents greater than short circuit have been recorded.
- Remember to allow for future growth

CONTROLLER SIZING FOR EXAMPLE

- Isc = 8.47A
- 3 strings in Parallel = 3 x 8.47 = 25.41A
- 125% Oversize= 1.25 x 25.41A= 31.7A
- Voltage must be suitable for 24V nominal (about 22.46 x 2= 44.92VOC)

SIZING ARRAY WITH MPPT CONTROLLER

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AVERAGE DAILY ENERGY USAGE

Humid Season

E_{dc} = 240 Wh E_{ac} = 1860 Wh η_{inv} = *90% (0.9)*

Therefore

E_{tot} = 240 + (1860/0.9)= 2307Wh

Rest of Year

E_{dc} = 180 Wh E_{ac} = 1500 Wh η_{inv} = *90% (0.9)*

Therefore

E_{tot} =*180* + (1500/0.9)= 1847Wh

DETERMINATION OF WORST MONTH (USING LATITUDE TILT)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Irradiation (kWh/ m²)	6.69	5.9	5.78	5.33	4.76	4.42	4.66	5.22	5.82	6.26	6.46	7.01
Load (kWh)	2.3	2.3	2.3	1.8	1.8	1.8	1.8	1.8	1.8	2.3	2.3	2.3
Ratio	2.91	2.57	2.51	2.96	2.64	2.46	2.59	2.90	3.23	2.72	2.81	3.05

SYSTEM LOSSES (SUB-SYSTEM EFFICIENCY)

- When working with Wh, then the system losses include
  - the MPPT controller (regulator) efficiency (typically 90% to 95%.
  - the cable efficiency (cable losses)(less than 5%); and
  - the Wh efficiency of the battery (typically 70% to 80%).
- In all cases the actual design (cable losses) and manufacturers' (MPPT and Battery) data must be used.

DETERMINING ENERGY REQUIRED FROM ARRAY

Information required	Example
• Cable loss- (transmission efficiency)	3% (0.97)
• MPPT efficiency of 95% and	95%(0.95)
• battery Wh efficiency of 80%.	80% (0.80)
Sub system effeciency	0.97 x 0.95x 0.80 =0.737
Energy required from array	1847÷0.737 =2505Wh

OVERSIZE FACTOR

	Example
Assume	20%
Based on SEIAPI guideline	2505 x 1.2 = = 3006Wh

DERATING OF MODULE

As with the PWM controller the PV module will be de-rated due to:

- Manufacturer's Tolerance:
- Dirt:
- Temperature

DETERMINING SIZE OF ARRAY REQUIRED WHEN USING MAXIMUM POWER POINT TRACKER 1

$$P_{mod} = P_{stc} \times f_{man} \times f_{temp} \times f_{dirt}$$

where

P_{mod} = de-rated output power of the module, in Watts

P_{stc} = rated output power of the module under standard test conditions, in Watts

f_{temp} = temperature de-rating factor, dimensionless

f_{man} = de-rating factor for manufacturing tolerance, dimensionless

f_{dirt} = de-rating factor for dirt, dimensionless

DETERMINING SIZE OF ARRAY REQUIRED WHEN USING MAXIMUM POWER POINT TRACKER

$$f_{temp} = 1 - (\gamma \times (T_{cell.eff} - T_{stc}))$$

where

f_{temp} = temperature de-rating factor, dimensionless

γ = power temperature co-efficient per degree Celsius

$T_{cell.ef}$ = average daily effective cell temperature, in degrees Celsius

T_{stc} = cell temperature at standard test conditions, in degrees Celsius.

Effective cell temperature is

$T_{cell\text{-}eff} = T_{a.day} + 25^0$

EXAMPLE

	Example
Assume the ambient temperature	30°C
Therefore the effective cell temperature is	30°C + 25°C = 55°C
Temperature above STC	55°C - 25°C = 30°C
Temperature Coefflcient	–0.45%/°C.
% Loss due to Temperature	30 x -0.45% = -13.5%
Derating Factor of	0.865

DERATING OF MODULE

Information required	Example
Manufacturer's tolerance factor	95% (0.95)
Dirt derating factor	95% (0.95)
Temperature derating factor	86.5%(0.865)
First, we derate the module's power by the manufacturers tolerance	145 x0.95 =137.75W
Then we derate the power for losses from dirt	137.75x0.95 =130.86W
Last we derate because of temperature losses	130.86x0.865 =113.2W

DETERMINING SIZE OF ARRAY

Need to find out how modules to get the required Wh out of your PV array	Example
Information required	
Module derated output power	113.19W
Lowest monthly Peak Sun Hours at site	4.42
Daily load in Wh required from array	3006Wh
To get the daily output of each module, multiply the derated power (W) by the peak sun hours (h)	113.19 x 4.42= 500Wh
To get the number of modules required, divide the daily load in wh by the daily output of a module	3006÷500 = 6.01

DETERMINING SIZE OF ARRAY REQUIRED WHEN USING MAXIMUM POWER POINT TRACKER - FORMULA

Number of modules in the array

$$N = \frac{E_{tot} \times f_o}{P_{mod} \times H_{tilt} \times \eta_{pvss}}$$

Where

E_{tot} = total daily design energy demand from the dc busbar in Watt-hrs

f_o = oversupply co-efficient, dimensionless

η_{pvss} = efficiency of the PV sub-system, dimensionless

$= \eta_{ren\text{-}batt} \times \eta_{reg} \times \eta_{batt}$

HOW MANY IN SERIES AND HOW MANY IN PARALLEL?

Different MPPT allow different string voltages and therefore a different number of modules in the string.

Number of parallel strings is determined by:

Number in parallel = Total number of modules / Number of modules in string

SELECTING AN MPPT

	Example
Information required	
Number of modules in array	6
Rating of array	6 x 145=870Wp
Output Voltage is 24V dc,	24V
the output current from 6 solar modules would be no greater than	((870) /24) = 36.25A

However due to effect of temperature on the power and the fact that as the battery is charged voltage increases—so actaul output current will be a lot less than this value

MATCHING THE PV ARRAY TO THE MAXIMUM VOLTAGE SPECIFICATIONS OF THE MPPT

- For matching array to MPPT

Nominal Battery Voltage	Recommended min number of cells in the array string of modules
12V	60
24V	96
48V	168

SmartSolar Charge Controller	MPPT 75/10	MPPT 75/15	MPPT 100/15	MPPT 100/20
Battery voltage	12/24V Auto Select			
Rated charge current	10A	15A	15A	20A
Nominal PV power, 12V 1a,b)	145W	220W	220W	290W
Nominal PV power, 24V 1a,b)	290W	440W	440W	580W
Max. PV short circuit current 2)	13A	15A	15A	20A
Automatic load disconnect	Yes, maximum load 15A			20A
Maximum PV open circuit voltage	75V		100V	

BlueSolar Charge Controller	MPPT 150/35
Battery voltage	12 / 24 / 48V Auto Select (software tool needed to select 36V)
Rated charge current	35A
Nominal PV power 1a, b)	12V: 500W / 24V: 1000W / 36V: 1500W / 48V: 2000W
Max. PV short circuit current 2)	40A
Maximum PV open circuit voltage	150V absolute maximum coldest conditions 145V start-up and operating maximum
Maximum efficiency	98%
Self-consumption	12V: 20 mA 24V: 15 mA 48V: 10mA
Charge voltage 'absorption'	Default setting: 14,4 / 28,8 / 43,2 / 57,6V (adjustable)
Charge voltage 'float'	Default setting: 13,8 / 27,6 / 41,4 / 55,2V (adjustable)

MATCHING THE PV ARRAY TO THE MAXIMUM VOLTAGE SPECIFICATIONS OF THE MPPT

- It is important that the output voltage of the string is matched to the operating voltages of the MPPT and that the maximum voltage of the MPPT is never reached.
- The output voltage of a module is affected by cell temperature changes in a similar way to the output power.
- The manufacturers will provide a *voltage temperature coefficient*. It is generally specified in V/°C (or mV/°C) but it can also be expressed as a %.

MATCHING THE PV ARRAY TO THE MAXIMUM VOLTAGE SPECIFICATIONS OF THE MPPT

- To ensure that the Voc of the array does not reach the maximum allowable voltage of the MPPT the minimum day time temperatures for that specific site are required.

DETERMINING SIZE OF ARRAY REQUIRED

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)							
Module name			YGE 145	YGE 140	YGE 135	YGE 130	YGE 125
Module type			YLxxxP-17b (xxx=Pmax)				
Power output	P_{max}	W	145	140	135	130	125
Power output tolerances	ΔP_{max}	%	+/- 5				
Module efficiency	η_m	%	14.5	14.0	13.5	13.0	12.5
Voltage at P_{max}	V_{mpp}	V	18.15	18.01	17.77	17.51	17.34
Current at P_{max}	I_{mpp}	A	7.99	7.77	7.60	7.42	7.21
Open-circuit voltage	V_{oc}	V	22.46	22.28	22.00	21.67	21.46
Short-circuit current	I_{sc}	A	8.47	8.30	8.12	8.00	7.74

STC: 1000W/m² irradiance, 25°C cell temperature, AM1.5g spectrum according to EN 60904-3.
Average relative efficiency reduction of 5% at 200W/m² according to EN 60904-1.

Electrical parameters at Nominal Operating Cell Temperature (NOCT)							
Power output	P_{max}	W	117.46	113.41	109.36	105.31	101.26
Voltage at P_{max}	V_{mpp}	V	16.73	16.59	16.38	16.14	15.98
Current at P_{max}	I_{mpp}	A	6.40	6.26	6.12	5.96	5.78
Open-circuit voltage	V_{oc}	V	20.44	20.28	20.02	19.72	19.53
Short-circuit current	I_{sc}	A	6.78	6.64	6.50	6.40	6.19

NOCT: open-circuit module operation temperature at 800W/m² irradiance, 20°C ambient temperature, 1m/s wind speed.

THERMAL CHARACTERISTICS

Nominal operating cell temperature	NOCT	°C	46 +/- 2
Temperature coefficient of P_{max}	γ	%/°C	-0.45
Temperature coefficient of V_{oc}	β_{Voc}	%/°C	-0.33
Temperature coefficient of I_{sc}	α_{Isc}	%/°C	0.06

DETERMINING MAX VOC OF MODULE

Assume	Example
Minimum Temperature	20°C
STC	25°C
Temperature Coefficient	-0.33%/°C.
Voc	22.46
Temperature coefficient in V	(-0.33/100)*22.46= -0.074V/°C
Increase in Voc due to temperature	(20°C - 25°C) x -0.074V = 0.37
Voc at 20°C	22.46 + 0.37 = 22.83V

MAX VOLTAGE OF MPPT

Assume	Example
Max Voltage	150V
Safety Margin	5%
Maximum Voltage of MPPT	0.95 x 150 = 142.5 V

MAX NUMBER OF MODULES IN STRING

Assume	Example
Max Module Voltage	22.83V
Max Allowable MPPT Voltage	142.5
Maximum Number of modules in string	142.5÷22.83 =6.2
Round down to:	6
Minimum Number	3 (24V system)
Number required	6

HOW MANY?

- With the 6 modules we could therefore have one string of 6 BUT that would make the Voc of array being 6 x 22.83V = 137V
- That is Low Voltage and therefore battery would be treated as Low Voltage
- Recommend to have two strings of 3 modules. This will keep the array as Extra Low Voltage


The End
SEIAPI
WORLD BANK GROUP
SIDSDOCK