# 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

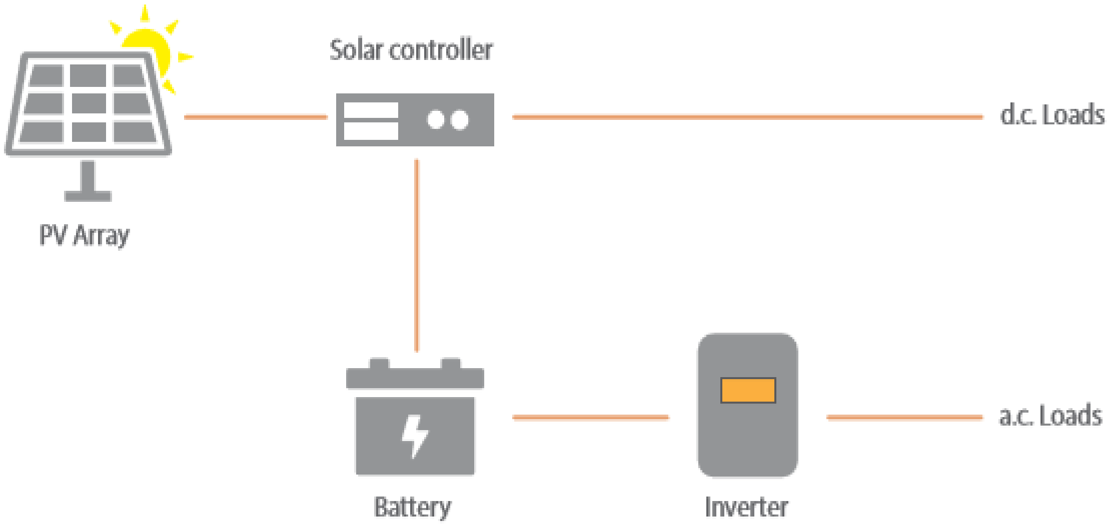



Figure 2: dc bus system

# 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

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

# AVERAGE DAILY ENERGY USAGE- HUMID SEASON

Say

$E_{dc}$ = 240 Wh

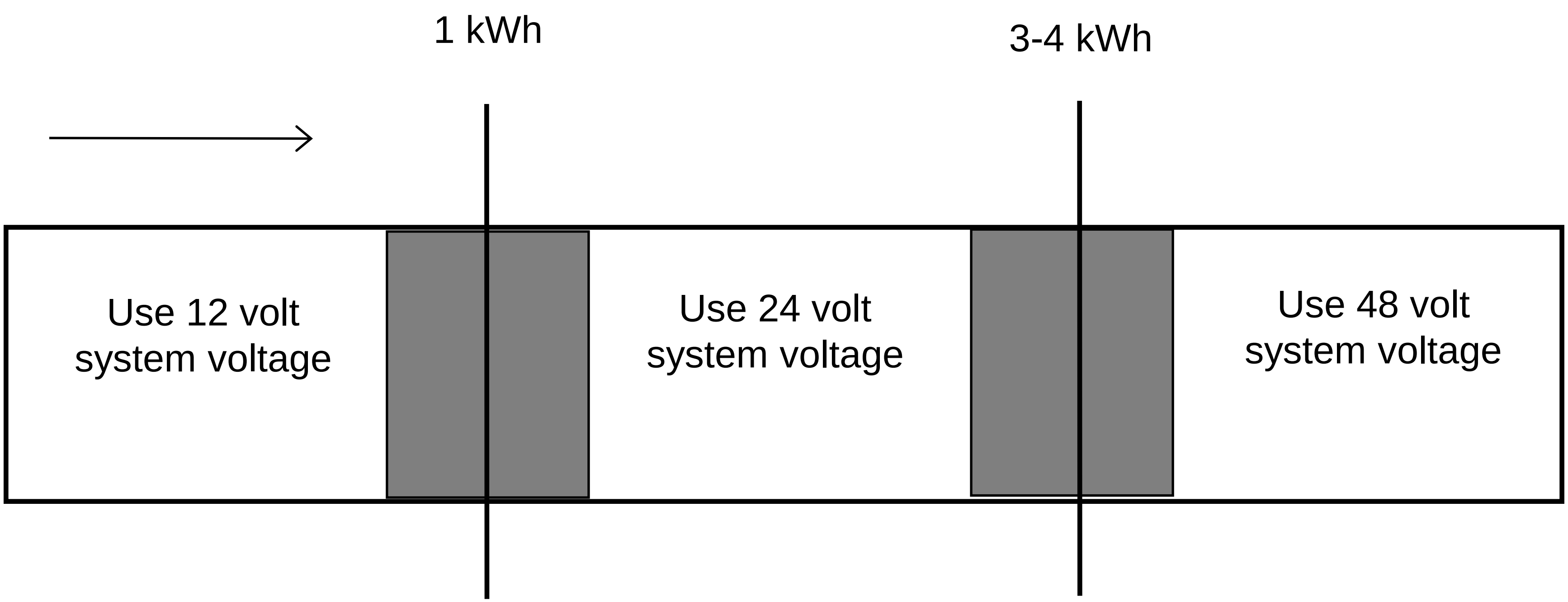
$E_{ac}$ = 1860 Wh

$\eta_{inv}$ = *90% (0.9)*

*Therefore*

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

# DETERMINATION OF SYSTEM VOLTAGE GUIDE ONLY



# DETERMINING BATTERY CAPACITY

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

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

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# 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 $C_{10}$

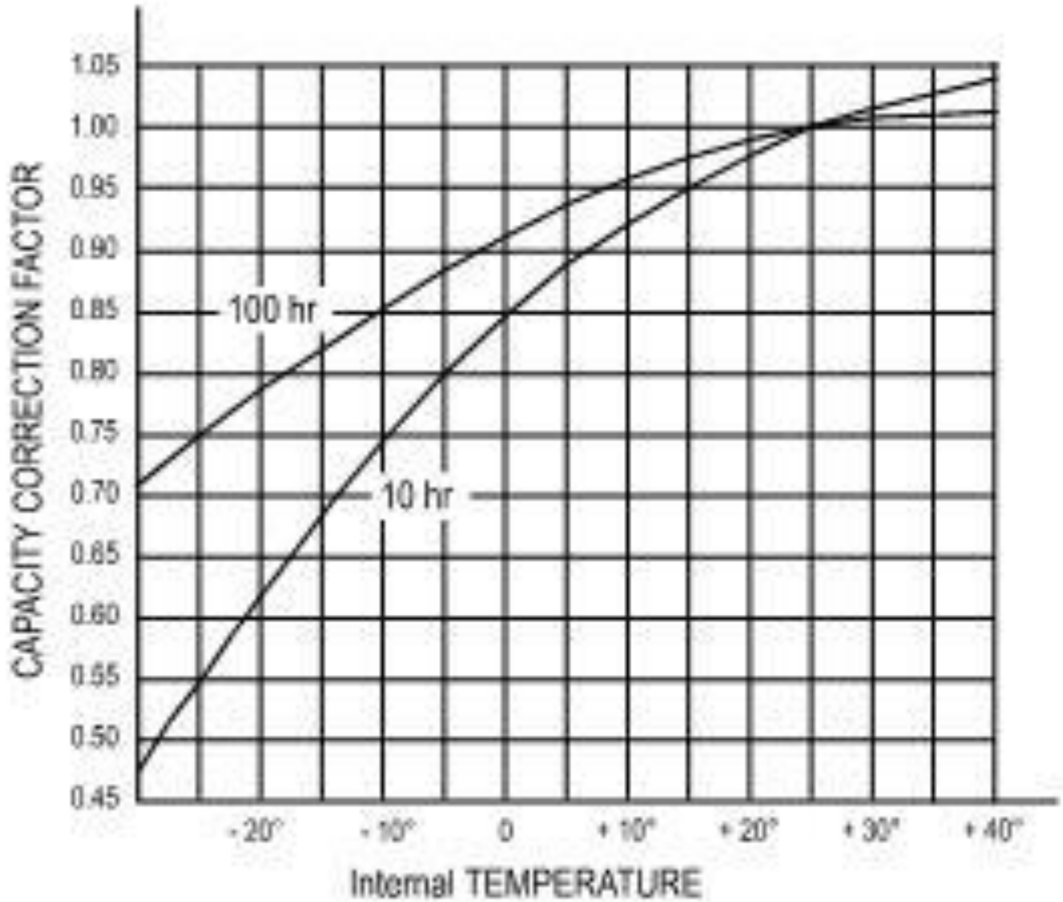
# SELECTING BATTERY

| 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 20$^oC$ (Europe Standards or 25$^oC$ )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

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# 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
- $C_5 = 5 \times 12.82 = 64.1Ah$

# 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

## Table 1 dc load (energy) Assessment

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| | | | **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 | |

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# EXAMPLE – AC LOADS

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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** | |
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| **Daily Load Energy A.C Loads (Wh)** | | | (AC10a) | **1500** | (AC10b) | **1860** | | | | | | |
| **Maximum ac demand (VA)** | | | | | | | **(AC11)** | **223** | | **598** | | |
| **Surge demand (VA)** | | | | | | | | | | **(AC12)** | **598** | |

# AVERAGE DAILY ENERGY USAGE

***Humid Season***

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

*Therefore*

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

***Rest of Year***

$E_{dc}$ = 180 Wh $E_{ac}$ = 1500 Wh $\eta_{inv}$ = *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

$$77 \div 0.9 = 85.6\text{Ah}$$

# 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 | $\Delta P_{max}$ | % | +/- 5 | | | | |
| Module efficiency | $\eta_m$ | % | 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$^{o}$C and 55 $^{o}$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

$$8.23 \times 0.95 = 7.82A$$

Then we derate the current for losses from dirt

$$7.82 \times 0.95 = 7.43A$$

# 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:

$$24 \div 12 = 2$$

# 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)

$$7.43 \times 4.42 = 32.8\text{Ah}$$

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

$$102.7 \div 32.8 = 3.13$$

**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

$\eta_{coul}$ = coulombic efficiency of the battery, dimensionless

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# 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

# AVERAGE DAILY ENERGY USAGE

***Humid Season***

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

*Therefore*

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

***Rest of Year***

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

*Therefore*

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

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# DETERMINATION OF WORST MONTH (USING LATITUDE TILT)

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# 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

- Cable loss- (transmission efficiency)
- MPPT efficiency of 95% and
- battery Wh efficiency of 80%.

Sub system effeciency

Energy required from array

Example

3% (0.97)
95%(0.95)
80% (0.80)

0.97 x 0.95x 0.80
=0.737

1847÷0.737 =2505Wh

# OVERSIZE FACTOR

Example

20%

Assume

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

$\gamma$ = 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 | 30ºC |
| Therefore the effective cell temperature is | 30ºC + 25ºC = 55ºC |
| Temperature above STC | 55ºC - 25ºC = 30ºC |
| Temperature CoeffIcient | –0.45%/ºC. |
| % Loss due to Temperature | 30 x -0.45% = -13.5% |
| Derating Factor of | 0.865 |

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# DERATING OF MODULE

| | |
|---|---|
| | Example |
| Information required | |
| 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

| | Example |
|---|---|
| Need to find out how modules to get the required Wh out of your PV array | |
| 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

$\eta_{pvss}$ = 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

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# 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<br>(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<br>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 | $\Delta P_{max}$ | % | +/- 5 | | | | |
| Module efficiency | $\eta_m$ | % | 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 $V_{oc}$ | $\beta_{Voc}$ | %/°C | -0.33 |
| Temperature coefficient of $I_{sc}$ | $\alpha_{Isc}$ | %/°C | 0.06 |

# DETERMINING MAX VOC OF MODULE

| Assume | Example |
| --- | --- |
| Minimum Temperature | $20^oC$ |
| STC | $25^oC$ |
| Temperature Coefficient | $-0.33\%/^oC$. |
| Voc | 22.46 |
| Temperature coefficient in V | $(-0.33/100)*22.46= -0.074V/^0C$ |
| Increase in Voc due to temperature | $(20^oC - 25^oC) \times -0.074V = 0.37$ |
| Voc at $20^oC$ | 22.46 + 0.37<br>= 22.83V |

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# MAX VOLTAGE OF MPPT

| | | Example |
|---|---|---|
| Assume | | |
| | Max Voltage | 150V |
| | Safety Margin | 5% |
| | Maximum Voltage of MPPT | 0.95 x 150<br>= 142.5 V |

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# MAX NUMBER OF MODULES IN STRING

| | Example |
|---|---|
| Assume | |
| 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

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