Clean Energy Council

TECH INFO

Energy Efficiency
and
Renewable Energy Bulletin

November, 2005

PV Sizing …

AS 4509.2 SPS design guidelines provides two methods - one for 'switched' regulators and a second where 'maximum power point tracking' (MPPT) regulators are used.
Refer to AS 4509.2 sections 3.4.3.7 to 3.4.3.10
The reason for the different approaches is straight forward …

- For 'switched' regulators - Plasmatronics PL, Trace and most smaller regulators.
  The PV string operating voltage is tied to the battery voltage regardless of irradiance. The PV output, in amps, is determined using an average module operating voltage.
- Where a MPPT regulator is used - integrated into stand-alone inverters or separate equipment such as AERL, RV Power, PSA, Outback brands.
  The PV string operating voltage depends on the power output of the string, which is mainly determined by the irradiance.

In both cases the PV cell temperature is a major factor in determining the module output. From AS 4509.2 …

$$T_{\text{cell,eff}} = T_{\text{a,day}} + 25°\text{C} \qquad \ldots 3.4.3.7$$

where
$T_{\text{cell,eff}}$ = average daily effective cell temperature, in degrees Celsius
$T_{\text{a,day}}$ = daytime average ambient temperature for the month of interest, in degrees Celsius

NOTE :

$T_{\text{a,day}}$ can be found in the Australian Solar Radiation Data Handbook for selected sites.
The 'daytime (or max.) average ambient temperature' is available from other data sources e.g. NASA data.

The following examples use performance data for an 85W mono-crystalline module
(facing true north at a tilt angle of 30°)
average irradiation – 6.1 kWh/m² [PSH]
and an average daily temperature of 26.7 °C
(from ASRDH for Canberra in March)
The average daily load is 3 kWh at the d.c. bus and a 24V battery bank has been selected.

… for 'switched' regulators

$$I_{\text{mod}} = I_{\text{T,V}} \times f_{\text{man}} \times f_{\text{dirt}} \qquad \ldots 3.4.3.8$$

where
I_{mod} = derated current output of the module (A)
$I_{\text{T,V}}$ = output current of the module at the average daily equivalent cell temperature, daily average module operating voltage, and irradiance specified under standard operating conditions (A)
f_{man} = derating factor for manufacturing tolerance, dimensionless
f_{dirt} = derating factor for dirt/soiling, dimensionless

To estimate $I_{\text{T,V}}$ IV curves of the module performance at different temperatures is required.
In this case with a cell temperature of 51.7°C (26.7 + 25) the curve for 50°C is used.
The module operating voltage is dependant on many factors such as battery voltage, wiring and regulator losses.
Given a battery that is above its nominal voltage and correctly sized wiring and regulator the operating voltage could be 14 to 16 Volts
(28 to 32V for a 24V nom. module)
From the IV curve for 50°C and using an operating voltage of 15V, the module output is around 4.8 A.

$$I_{\text{mod}} = 4.8 \times 0.95 \text{ (mfr. tol.)} \times 0.95 \text{ (dirt factor)}$$
$$= 4.33.\text{A}$$

The specifications for this module include …
Short circuit current (Isc) … 5.0 A
Current at Pmax (Imp) … 4.72 A
at Standard Test Conditions (STC)
1kW/m², Air Mass 1.5 and Cell temp 25°C

Clean Energy Council

TECH INFO

Energy Efficiency
and
Renewable Energy Bulletin

November, 2005

… for 'switched' regulators (continued …)

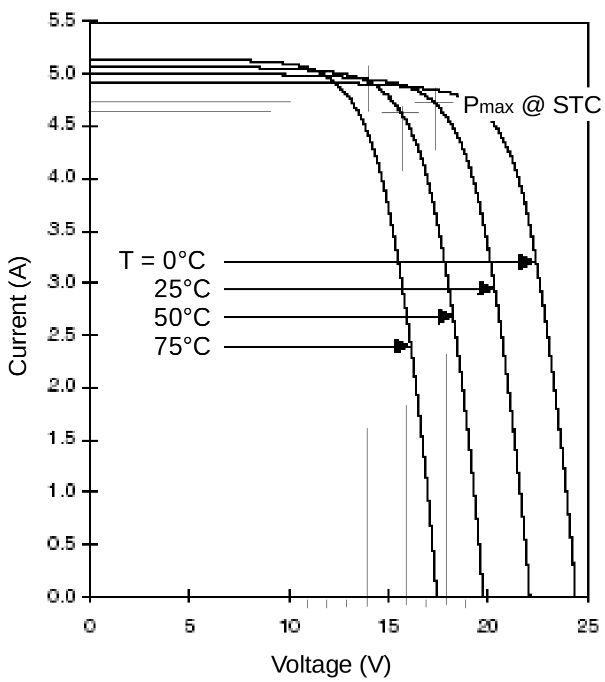
Get the IV temperature performance curves for the PV modules you are using
– check them out.

As can be seen, there are many factors determining the module operating voltage and hence output current.
This makes PV-battery charging operation very dynamic and difficult to determine an average module current.

At some point it is necessary to call time-out and select an average module current for use in sizing a PV array.

In the example above, with cell temperatures around 50°C and an operating voltage between 14V and 15V,
the module current output is between
Isc and Imp at STC, although at 16V the module current falls slightly lower (~ 4.6A)

BP 585 I-V Curves



For crystalline modules operating at a cell temperature around 50°C a module output current close to the Imp STC value could be
a reasonable estimate.
For different module technologies and/or operation at different cell temperatures the manufacturer's data must be consulted.

To calculate the number of strings required for a solar fraction of 1 …

$$N_p = (E_{tot} \times f_o) / (V_{dc} \times I_{mod} \times H_{tilt} \times \eta_{coul}) \qquad \text{. . . 3.4.3.11(1)}$$

where

- Np = number of parallel strings of modules in the array (rounded up to the next whole number)
- $Etot$ = total design daily energy demand from the d.c. bus, Wh
- fo = oversupply co-efficient, dimensionless
- Vdc = nominal d.c. voltage, V
- $Imod$ = de-rated output current of the module, A
- $Htilt$ = daily irradiation on the tilted plane, PSH
- $\eta coul$ = coulombic efficiency of the battery
  - 0.9 to 0.95 for lead-acid

N_p = (3000 x 1) / (24 x 4.33 x 6.1 x 0.9)
= 3000 / 570.5 = 5.25 ~ 6 strings

To determine the average output of the PV array …

$$Q_{array} = I_{mod} \times H_{tilt} \times N_p \qquad \text{. . . 3.4.3.10(1)}$$

where

- $Qarray$ = average daily charge output of the array, Ah
- $Imod$ = de-rated current output of a module, A
- $Htilt$ = daily irradiation on the tilted plane (i.e. on the plane of the array), PSH
- Np = number of parallel strings of modules in the array (an integer), dimensionless

Q_{array} = 4.33 x 6.1 x 6 = 158 Ah

The average energy from the PV array …
- including battery efficiency

$E_{batt} = Q_{array} \times V_{dc} \times \eta_{coul}$ = 158 x 24 x 0.9
= 3,413 Wh

Refer to AS 4509.2 Appendix B Table B8

Clean Energy Council

TECH INFO

Energy Efficiency
and
Renewable Energy Bulletin

November, 2005

… for MPPT regulators

A Maximum Power Point Tracking regulator is a DC-DC converter (usually step down).
MPPT has several advantages but
the main one for sizing PV, in battery charging systems, is that one major variable is removed
– the changing battery voltage.

First, a temperature de-rating factor is calculated

$f_{temp} = 1 - (\gamma \times (T_{cell,eff} - T_{stc}))$ . . . 3.4.3.9(1)

where
ftemp = temperature derating factor, dimensionless
γ = power temperature co-efficient, per degree C (typically 0.005 for crystalline silicon)
*T*cell, eff = average daily effective cell temperature, in degrees Celsius
*T*stc = cell temperature at standard test conditions, in degrees Celsius.

for the example …
f_{temp} = 1 - (0.005 x (51.7 - 25)) = 0.867

and then the module power …

$P_{mod} = P_{stc} \times f_{man} \times f_{temp} \times f_{dirt}$ . . . 3.4.3.9(2)

where
*P*mod = de-rated output power of the module, W
*P*stc = rated output power of the module under standard test conditions, in watts
*f*temp = temperature derating factor, dimensionless
*f*man = de-rating factor for manufacturing tolerance, dimensionless
*f*dirt = de-rating factor for dirt/soiling, dimensionless

again, for the example …
P_{mod} = 85 x 0.867 x 0.95 x 0.95 = 66.5 W

MPPT sizing MUST NOT be used for standard 'switched' regulators.

To calculate the number of strings required for a solar fraction of 1 …

$N_p = (E_{tot} \times f_o) / (P_{mod} \times H_{tilt} \times \eta_{pvss} \times N_s)$ . . . 3.4.3.11(2)

where
*N*p = number of parallel strings of modules in the array (rounded up to the next whole number)
*E*tot = total design daily energy demand from the d.c. bus, Wh
*f*o = oversupply co-efficient, dimensionless
*P*mod = de-rated power output of the module, W
*H*tilt = daily irradiation on the tilted plane, PSH
*N*s = number of series connected modules per string
*H*pvss = efficiency of PV sub system, dimensionless
$= \eta_{pv\text{-}batt} \times \eta_{reg} \times \eta_{batt}$ where
$\eta_{pv\text{-}batt}$ = energy transmission efficiency from the photovoltaic array to the battery (i.e. from the effect of cable losses)
η_{reg} = the energy efficiency of the regulator
η_{batt} = the energy efficiency of the battery i.e. watt-hour efficiency
- 0.8 to 0.85 for lead-acid

From the regulator manufacturer's data, a minimum of 3 modules per string is required.

N_p = (3000 x 1) /
(66.5 x 6.1 x (0.95 x 0.98 x 0.8) x 3)
= 3000 / 906 = 3.3 ~ 4 strings

The average energy from the PV array …
$E_{pv} = P_{mod} \times H_{tilt} \times N$ . . . 3.4.3.10(2)

where
*E*pv = design daily energy from the PV array, Wh
*P*mod = de-rated power output of a module, W
*H*tilt = daily irradiation on the tilted plane, PSH
N = number of modules in the array

- including wiring, MPPT and battery losses …
E_{batt} = 66.5 x 6.1 x 12 x (0.95 x 0.98 x 0.8)
= 3,625 Wh

NOTE : For grid-connect systems the η_{pvss} calculation, omit the battery efficiency and include both d.c and a.c. wiring losses in the transmission efficiency - as the voltages in this case are usually high, the transmission losses are normally less than 5%

The MPPT regulator power rating …

$P_{mppt} = P_{stc} \times N \times$ *oversize factor*

where
P_{stc} = rated output power of the module under standard test conditions, in watts
N = number of modules in the array
The oversize factor is usually 1
but may be reduced to ensure that the regulator is not operating at more than its rated power during periods of higher radiation and / or lower module temperatures.

Calculation of PV performance -

LIMITING FACTORS …
under normal conditions, in Australia
the hourly daytime average ambient temperature is normally not less than 0°C and not often more than 50°C, so
$T_{cell,eff}$ will be in the range : 25 to 75°C

Temperature Comparison

– using the example …

for a cell temperature of 75°C -
the PV energy delivered to the battery, by the MPPT gives a 10% improvement
and
for a cell temperature of 25°C -
the PV energy delivered to the battery, by the MPPT gives an increase approaching 8%.

Irradiation

For periods of reduced irradiation due to cloud cover, MPPT regulation can again produce an improvement.
This more difficult to quantify as the power input for ‘switched’ regulators in reduced irradiance conditions, is mainly determined by the battery voltage.

Conclusions …

The preceding calculations are based on the formulae provided in AS 4509.2 section 3.4.3

Using average daily temperatures for each month, the average performance gain using MPPT regulators is not greater than 10%.
- see comparison calculations above.

In areas of significantly lower (high altitudes) or higher (inland) ambient temperatures,
the day to day performance improvement may be slightly greater but is difficult to estimate without detailed site temperature data.

It is recommended that performance estimates for MPPT are based on AS 4509.2.

Refer to the alternate Table B8 for PV-MPPT Tech Info Nov, 2005