OFF GRID PV POWER SYSTEMS

SYSTEM INSTALL GUIDELINES

These guidelines have been developed by the Sustainable Energy Industry Association of the Pacific Islands in Collaboration with the Pacific Power Association
They represent latest industry BEST PRACTICE for the design and installation of PV Grid Connect Systems.

Issue 1 September 2012

GENERAL

The performance of a reliable installation, that fulfils a customers needs, requires both careful design and correct installation practice and conformance to relevant standards.

STANDARDS for INSTALLATION

Installation should follow any standards that are typically applied in the country or region where the solar installation will occur. The following lists the relevant standards in Australia, New Zealand and USA. They are listed because some Pacific island countries and territories do follow those standards.. These standards are often updated and amended so the latest version should always be applied.

In Australia and New Zealand the main standards required are …

_	AS/NZS 3000	Wiring Rules
_	AS/NZS 4509	Stand-alone power systems
_	AS 4086.2	Secondary batteries for stand-alone power supplies
_	AS/NZS5033	PV Array
_	AS 3010.1	Electrical Installations Supply Generating set
_	AS 3595	Energy management programs
_	AS 1359.51	Noise level limits
_	AS 1768	Lightning Protection

In USA PV systems must be in accordance with following codes and standards:

- Electrical Codes-National Electrical Code Article 690:Solar Photovoltaic Systems and NFPA 70
- Uniform Solar Energy Code
- Building Codes- ICC, ASCE 7
- UL Standard 1701; Flat Plat Photovoltaic Modules and Panels
- UL Standard 1741 , Standard for Inverter, converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources

DOCUMENTATION

All complex systems require a user manual for the customer. Off-grid power systems are no different. The documentation for system installation that should be provided include …

- List of equipment supplied.
- Shutdown and isolation procedure for emergency and maintenance.
- Maintenance procedure and timetable.
- Commissioning records and installation checklist.
- Warranty information.
- System connection diagram.
- Equipment manufacturers documentation and
- handbooks for all equipment supplied.
- Battery record logbook.
- Generating set service logbook

ORIENTATION AND INCLINATION

For best year round performance a fixed array should be mounted facing true north (± 10°) in South Pacific or True South (± 10°) in North Pacific at an inclination equal to the latitude angle in the tropics and latitude angle plus 5° to 15° outside of the tropics.

Between latitudes 10° South and 10° North the array should be tilted at a minimum of 10 degrees.

However the correct tilt angle should be determined based on energy usage and also the local weather conditions at different times of the year. For example if an island typically has very cloudy conditions in one period of the year (e.g. wet season) then the array should be tilted to suit the sun's altitude in the sunny period of the year.

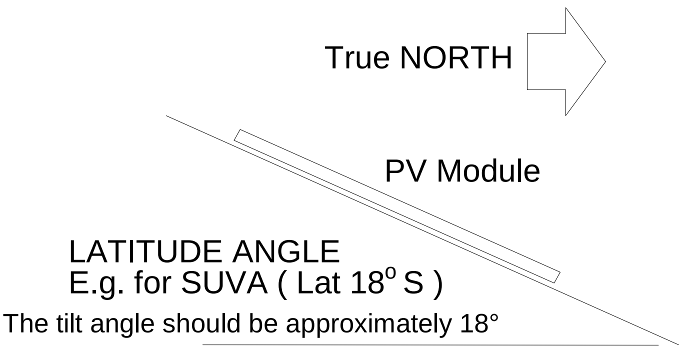

Figure 1 a

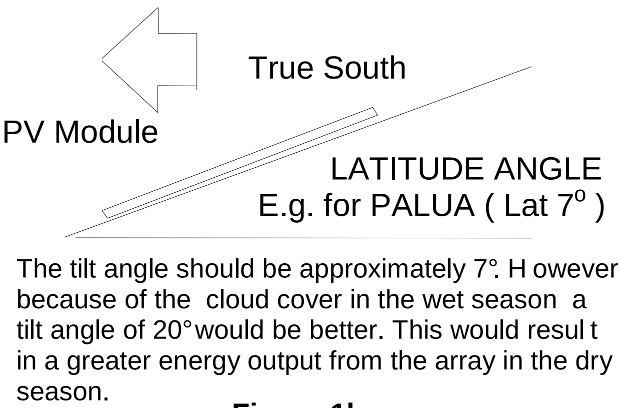

Figure 1b

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An alternative mounting arrangement can allow seasonal adjustment of array tilt to increase the energy input.

ROOF MOUNTING

- If the modules use crystalline cells then it is preferable to allow sufficient space below the array (> 50mm or 2 inches) for ventilation cooling. This will be subject to the constraints of the customer or architect.
- It is important to allow sufficient clearance to facilitate self cleaning of the roof to prevent the build up of leaves and other debris.
- If fauna are a problem in the vicinity of the installation then consideration should be given to how to prevent them gaining access under the array.(see cable protection)
- All supports, brackets, screws and other metal parts should be of similar material or stainless steel to minimise corrosion. If dissimilar metals (based on their galvanic rating) are used then the two surfaces of the metals should be separated by using rubber washes or similar.
- Where timber is used it must be suitable for long-term external use and fixed so that trapped moisture cannot cause corrosion of the roof and/or rotting of the timber. The expected replacement time should be stated in the system documentation.
- Any roof penetrations must be suitably sealed and waterproof for the expected life of the system. If this is not possible then this must be detailed in Maintenance Timetable
- All fixings must ensure structural security when subject to the highest wind speeds for the region and local terrain - This may require specific tests of the fixing/substrate combination on that roof.
- The installer shall ensure that the array frame that they install has applicable engineering certificates verifying that the frame meets wind loadings for that particular location.
- The installer must follow the array frame suppliers/manufacturers recommendations when mounting the array to the roof support structure to ensure that the array structure still meets wind loading certification.
- All external wiring must be protected from UV and mechanical damage in such a manner that it will last the life of the system..

FREE STANDING PV ARRAYS

These must be wind rated to meet the wind loading for the region.

BATTERY INSTALLATION

LAYOUT OF BATTERY ENCLOSURE

The main considerations for the battery enclosure are …

- it must be safe, with restricted access (ie. Prevent children easily accessing the batteries)
- all equipment must be readily accessible for maintenance
- it must have adequate ventilation
- it should be vermin proof

The main safety considerations are …

- explosion due to a spark in the presence of hydrogen build up
- excessive currents caused by battery shorts
- leakage of battery acid from battery cells
- personal safety in the presence of acid

To negate the risk of explosion there must be no opportunity for hydrogen to build up. This requires adequate ventilation with no possibility of spark ignition.

VENTILATION (Metric Calculations)

Ventilation must be provided. The minimum area required for natural ventilation for both inlet and outlet apertures (for wet lead acid batteries) are given by …

$$A = 100q_v \text{ cm}^2$$

Where q_v is the minimum exhaust ventilation rate

in litres per second = $0.006 \times n \times I$

and n = the number of battery cells

I = the charging rate in amperes

NOTE : The charging rate in amperes is the maximum output rating of the largest charging source or the rating of its output fuse or circuit breaker. Where two parallel battery banks are used, the charging rate is halved.

Best practice is to provide input ventilation vents below the level of battery and the output vents on the opposite side of the batteries, as high as possible in the enclosure to prevent hydrogen build up.

VENTILATION (Imperial Calculations)

Ventilation must be provided. . The minimum area required for natural ventilation for both inlet and outlet apertures (for wet lead acid batteries) are given by …

$$A = 15.5q_v \text{ in}^2$$

Where q_v is the minimum exhaust ventilation rate

in litres per second = $0.006 \times n \times I$

and n = the number of battery cells

I = the charging rate in amperes

NOTE : The charging rate in amperes is the maximum output rating of the largest charging source or the rating of its output fuse or circuit breaker. Where two parallel battery banks are used, the charging rate is halved.

Best practice is to provide input ventilation vents below the level of battery and the output vents on the opposite side of the batteries, as high as possible in the enclosure to prevent hydrogen build up.

VENTILATION- VALVE REGULATED (SEALED) BATTERIES

The charging rate I in the ventilation formula is 0.5A per 100Ah at the 3h rate (C_3)of discharge of battery capacity for lead acid batteries.

e.g. battery has C_3 rating of 500Ah therefore the charge current used in ventilation formula is :
(500Ah/100Ah) x 0.5A = 2.5A

Note; This is based on the charger (either solar controller or separate grid power battery charger) has an automatic overvoltage cut-off. If not maximum change current must be used.

SPARK IGNITION SOURCES
Electrical equipment or storage for other equipment should not be mounted above the battery bank.

Connection or disconnection of any equipment at the battery terminals must not occur where there is any possibility of the presence of any hydrogen build up.

- battery charging equipment should be hard wired, do not use temporary connection.
- battery terminals should be shrouded to prevent inadvertent short circuits.
- ensure sufficient clearance between battery terminals and metal walls
  (or insulate using non-metallic sheet)
- maximise separation between battery terminals
- use insulated tools during any battery work

Battery fusing preferably should not be in the same enclosure as the battery bank but if they are then they should be either a minimum of 500mm away from the batteries or 100mm below the top of the batteries. Another method to keep the fuse separate from the battery bank is to place a vertical partition between the batteries and the fuse, thereby keeping the fuse as close to the batteries as possible but isolated from any hydrogen build up. In any case the main battery fusing should be located below the battery vents. (Normally below the top of the batteries).

PREVENTING EXCESSIVE CURRENT FROM BATTERIES
Battery shorts are prevented by shrouding terminals and ensuring safe separation between live terminals.
Battery shorts are controlled by using appropriate circuit protection.

Overcurrent protection is to be provided in each battery output conductor except where one side of the battery bank is earthed (ground), in which case only the unearthed (ungrounded) conductor requires overcurrent protection.

Normal practice is to either fuse the positive and earth (ground) the negative or fuse all conductors.

ACID LEAKAGE
Provision must be made to contain any spilled electrolyte. Battery trays should be able to hold at least the electrolyte content of one cell of the battery bank.

ACID SPLASHES
A ready supply of water should be available and any person working on the batteries should wear rubber gloves, safety glasses and long sleeved protective clothing. Eye wash equipment should be available, in case of accident.
Walls near the batteries should be protected by acid resistant paint or non-metallic sheet.

SAFETY AND WARNING SIGNS
A “battery explosion warning" sign must be mounted so that it is clearly visible on approach to the battery bank. An "electrolyte safety" sign should be mounted adjacent to the battery bank.

MAIN BATTERY PROTECTION
Overcurrent protection and the ability to readily isolate a battery bank must be provided.

To select the appropriate main battery protection …

- 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]

- Obtain inverter manufacturers data
  - Continuous power rating (Watts)
  - 3 to 10 second surge rating (Watts)
  - Average inverter efficiency

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

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

NOTE : Allowance for any significant DC demand must be included when sizing the main protection

- Consult the Time-Current characteristic to determine the appropriate rating.

CABLE SELECTION-Metric Cables

- All cables should be sized to meet the maximum current
- Cable losses between the PV array and the battery bank should never exceed 5%
- Cable losses between the battery bank and any DC load should never exceed 5%

The following sizing methods (based on voltage drops) can be used for all types of currently available copper cable.

NOTE : the rated voltage or current carrying capacity (CCC) of any cable must never be exceeded eg. some automotive types are rated at 32V

1. The voltage drop (V_d in volts) is given by …

$$V_d = (2 \times L \times I \times \rho) \div A$$

where L = route length of cable in metres
I = current (A)
ρ = resistivity of Cu wire (Ω/m/mm²)
= 0.0183 Ω
A = Cross Sectional Area (CSA) of cable (mm²)

2. Voltage drop in volts per 10 metres of route length of twin cable (using the above formula)

Wire size mm²		**2**	**3.2**	**5**	**7.5**	**15**
Amps	CCC	15	20	25	45	70
0.5		0.09	0.06	0.04	0.02	0.01
1.0		0.18	0.11	0.07	0.05	0.02
1.5		0.27	0.17	0.11	0.07	0.04
2.0		0.37	0.23	0.15	0.10	0.05
2.5		0.46	0.29	0.18	0.12	0.06
3.0		0.55	0.34	0.22	0.15	0.07
4.0		0.73	0.46	0.29	0.20	0.10
5.0		0.92	0.57	0.37	0.24	0.12
7.5		1.37	0.86	0.55	0.37	0.18
10		1.83	1.14	0.73	0.49	0.24
15		2.75	1.72	1.10	0.73	0.37
20			2.29	1.46	0.98	0.49
25				1.83	1.22	0.61
30					1.46	0.73
40					1.95	0.98
50						1.22

Notes : Cable size and CCC from Pirelli automotive data
Shaded areas indicate that the CCC is exceeded
Refer also, to PV module and Inverter manufacturers' recommendations.

3. Route lengths to produce 5% voltage drop (12V systems) for twin cable (using the above formula)

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

CABLE SELECTION-Imperial Cables

- All cables should be sized to meet the maximum current
- Cable losses between the PV array and the battery bank should never exceed 5%
- Cable losses between the battery bank and any DC load should never exceed 5%

The following sizing methods (based on voltage drops) can be used for all types of currently available copper cable.

1. The voltage drop (V_d in volts) is given by …

   $V_d = (2 \times L \times I \times \rho) \div 1000$

   where L = route length of cable in metres
   I = current (A)
   ρ = resistivity of Cu wire (Ω/1000 ft.)

   Note: Resistivity values for copper wire at 75℃ ar e listed in Chapter 9, Tables 8 and 9 of the US National Electric Code. The resistivity value varies for cables with different cross sectional areas.

2. Voltage drop in volts per 50 ft. (15.2 m) of route length of twin cable (using the above formula)

Wire Size- AWG	14	12	10	8	6	4	2	1
(mm²)	*(2.08)*	*(3.31)*	*(5.26)*	*(8.36)*	*(13.29)*	*(21.14)*	*(33.61)*	*(42.39)*
Amps								
0.5	0.16	0.10	0.06	0.04	0.02	0.02	0.01	0.01
1.0	0.31	0.20	0.12	0.08	0.05	0.03	0.02	0.02
1.5	0.47	0.30	0.19	0.12	0.07	0.05	0.03	0.02
2.0	0.63	0.40	0.25	0.16	0.10	0.06	0.04	0.03
2.5	0.79	0.50	0.31	0.19	0.12	0.08	0.05	0.04
3.0	0.94	0.59	0.37	0.23	0.15	0.09	0.06	0.05
4.0	1.26	0.79	0.50	0.31	0.20	0.12	0.08	0.06
5.0	1.57	0.99	0.62	0.39	0.25	0.15	0.10	0.08
7.5	2.36	1.49	0.93	0.58	0.37	0.23	0.15	0.12
10	3.14	1.98	1.24	0.78	0.49	0.31	0.19	0.15
15	4.71	2.97	1.86	1.17	0.74	0.46	0.29	0.23
20			2.48	1.56	0.98	0.62	0.39	0.31
25				1.95	1.23	0.77	0.49	0.39
30					1.47	0.92	0.58	0.46
40					1.96	1.23	0.78	0.62
50							0.97	0.77

Notes : CCC data from 2011 NEC Table 310.15(B)(16) and resistivity values from 2011 NEC Ch. 9, Table 8
Shaded areas indicate that the cable ampacity might be exceeded at high temperatures
Refer also, to PV module and Inverter manufacturers' recommendations.

3. Route lengths to produce 5% voltage drop (12V systems) for twin cable (using the above formula)

Maximum Distance in feet to produce 5% voltage drop (12V system)

Wire Size- AWG	14	12	10	8	6	4	2	1
(mm²)	*(2.08)*	*(3.31)*	*(5.26)*	*(8.36)*	*(13.29)*	*(21.14)*	*(33.61)*	*(42.39)*
Current (A)								
1	95.5	151.5	241.9	385.6	611.0	974.0	1546.4	1948.1
2	47.8	75.8	121.0	192.8	305.5	487.0	773.2	974.0
3	31.8	50.5	80.6	128.5	203.7	324.7	515.5	649.4
4	23.9	37.9	60.5	96.4	152.7	243.5	386.6	487.0
5	19.1	30.3	48.4	77.1	122.2	194.8	309.3	389.6
6	15.9	25.3	40.3	64.3	101.8	162.3	257.7	324.7
7	13.6	21.6	34.6	55.1	87.3	139.1	220.9	278.3
8	11.9	18.9	30.2	48.2	76.4	121.8	193.3	243.5
9	10.6	16.8	26.9	42.8	67.9	108.2	171.8	216.5
10	9.6	15.2	24.2	38.6	61.1	97.4	154.6	194.8
11	8.7	13.8	22.0	35.1	55.5	88.5	140.6	177.1
12	8.0	12.6	20.2	32.1	50.9	81.2	128.9	162.3
13	7.3	11.7	18.6	29.7	47.0	74.9	119.0	149.9
14	6.8	10.8	17.3	27.5	43.6	69.6	110.5	139.1
15	6.4	10.1	16.1	25.7	40.7	64.9	103.1	129.9
16	6.0	9.5	15.1	24.1	38.2	60.9	96.6	121.8
17	5.6	8.9	14.2	22.7	35.9	57.3	91.0	114.6
18	5.3	8.4	13.4	21.4	33.9	54.1	85.9	108.2
19	5.0	8.0	12.7	20.3	32.2	51.3	81.4	102.5
20	4.8	7.6	12.1	19.3	30.5	48.7	77.3	97.4

CABLE PROTECTION

All sub-circuits, including PV array and auxiliary charging circuits should be protected by HRC fuses or circuit breakers. In addition these circuits being capable of being isolated without the use of tools. Any circuit breaker used in DC circuits must be rated for the appropriate DC voltage and be non-polarised.

All cables used in the installation should be securely fixed in place to minimise any movement of the cable. Any exposed cabling will be protected from UV and mechanical damage eg. run in conduit.

Crimp style termination of wiring should use the appropriate crimping tool.

LICENCING

EXTRA LOW VOLTAGE (ELV)

All extra low voltage wiring should be performed by a 'competent' person, which is defined as …
" a person who has acquired through training, qualifications, experience or a combination of these, knowledge and skill enabling that person to correctly perform the task required."

LOW VOLTAGE (LV)

All Low Voltage work (> 50V AC > 60V or 120V DC) should be undertaken in accordance with the regulatory requirements of the country..

INSTALLATION CHECKLIST

PV ARRAY

PV Array orientation ………………….. °

- [ ] Solar array is securely mounted and supported
- [ ] Timber used is suitable for external use or is properly sealed
- [ ] No dissimilar metals are in contact with the array frames or supports
- [ ] Roof penetrations are suitably sealed and weatherproof
- [ ] PV wiring losses are less than 5% at the maximum current output of the array
- [ ] PV wiring is protected by appropriate circuit breakers or fuses
- [ ] Wiring is protected from UV and mechanical damage

BATTERY INSTALLATION

- [ ] Wiring is protected from mechanical damage
- [ ] The batteries are installed in a dedicated battery room, enclosure or restricted access area
- [ ] Ventilation is in accordance with guidelines
- [ ] Acid leakage containment
- [ ] Batteries are **not** in contact with the floor of the enclosure / room
- [ ] All battery interconnects and terminals are protected against accidental short circuit
- [ ] All crimp lugs have been fitted using an appropriate tool
- [ ] Battery bank is protected by C/B or fuses
- [ ] All electrical equipment is mounted outside the battery enclosure / room
- [ ] There are no exposed live parts on any installed equipment

EXTRA LOW VOLTAGE CABLING

- [ ] Cabling is sized to minimise losses in accordance with these guidelines
- [ ] All sub-circuits are protected by appropriate fuses or circuit breakers

SAFETY

- [ ] Battery warning sign " DANGER - Risk of Battery Explosion " is permanently fixed outside the battery room / enclosure in a prominent position
- [ ] " Electrolyte Burns " sign is permanently fixed in a prominent position adjacent to the battery bank
- [ ] A fresh water supply is available for eyewash and rinsing any acid spills

110/230 VOLT (LV) INSTALLATION

- [ ] All Low Voltage wiring has been installed in accordance with local regulations

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This checklist is based on the Sustainable Energy Industries Association of the Pacific islands Installation Guidelines. The guidelines demonstrate the latest industry "best practice".

AUTHORISATION :

I, ……………………………………………………

verify that the following system has been installed to the standard indicated by these guidelines .

Name of the person for whom the system was installed

……………………………………………………………………

Location of system ………………………………………….

……………………………………………………………………

Signed ……………………………………………………….

Date : / / .

Attach a separate sheet detailing any departures

Appendix 1 – Table of Abbreviations and Acronyms

d.c.	Direct current
a.c.	Alternating current
AS/NZS	Australia Standard/New Zealand Standard
UL	Underwriters Laboratory
ICC	International Code Council
NFPA	National fire Protection Association
ASCE	American Society of Civil Engineers
IEEE	Institute of Electrical and Electronics Engineers
Wh	Watt hours
kWh	Kilowatt hours
W	Watts
W_P	Watts peak
H	hours
V	Volts
A	Amps
VA	Volt amps
Ah	Amp hours
PV	Photovoltaic
PSH	Peak sun hours (kWh/m^2)
kWh/m^2	Kilowatt hours/metres squared
V_{oc}	Open circuit voltage (volts)
V_{mp}	Maximum power point voltage (volts)
I_{sc}	Short circuit current (amps)
I_{mp}	Maximum power point current (amps)
LV	Low Voltage (>=120V DC in Australian Standards)
ELV	Extra Low Voltage (<120V DC in Australian Standards)
UV	Ultraviolet light
HRC	High Rupturing Capacity
CCC	Current Carrying Capacity
V_d	Voltage drop
CSA	Cross Sectional Area of cable (mm^2)
Cu	Copper
C/B	Circuit breaker