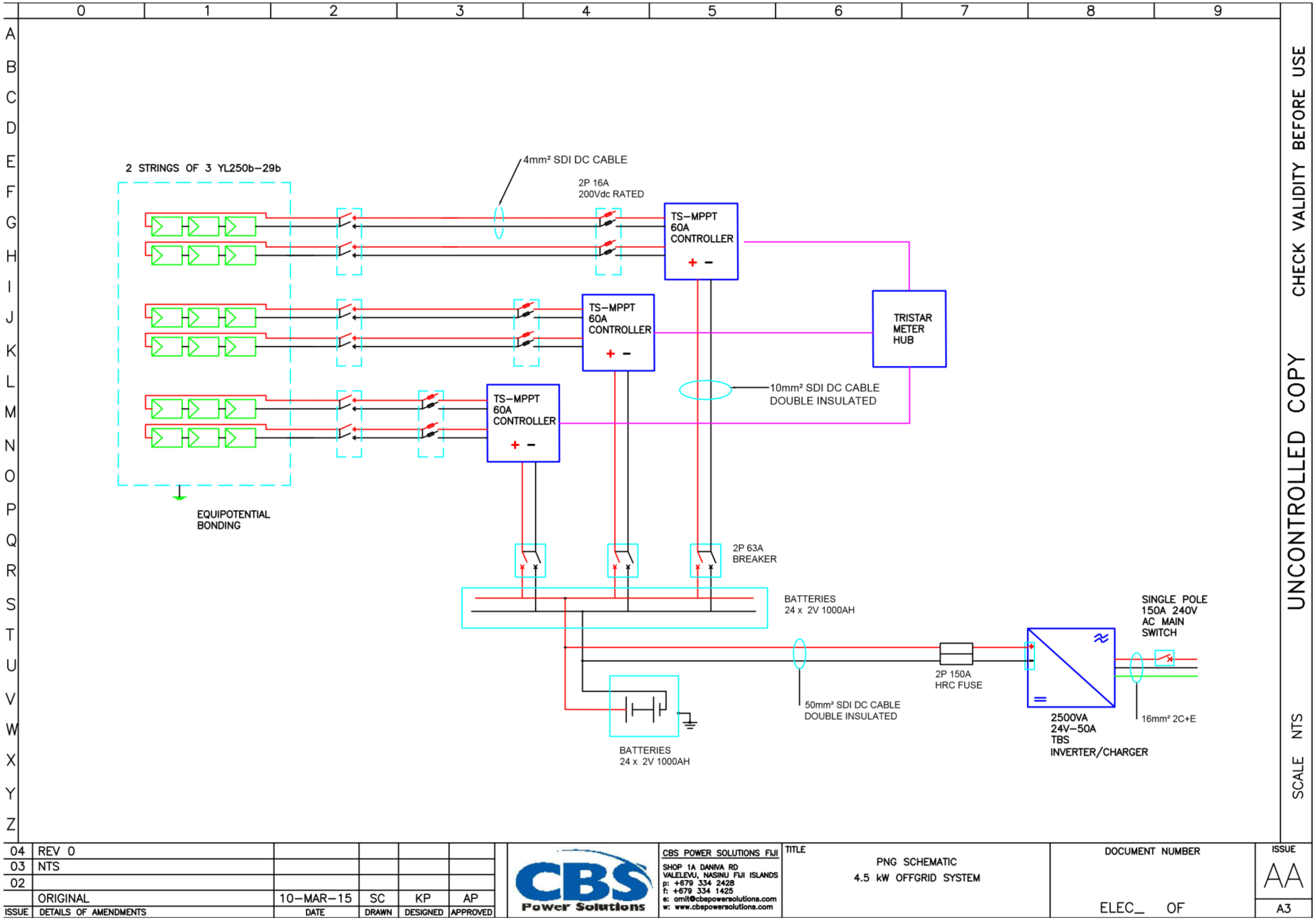
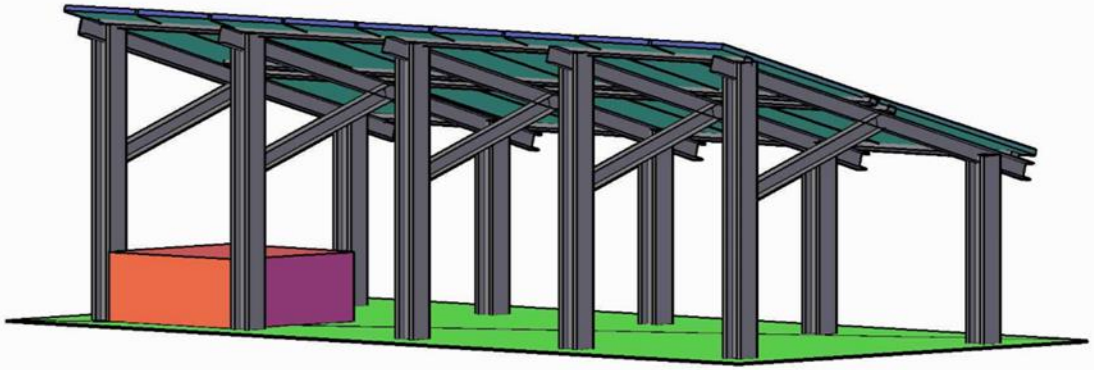
Online Supplementary Document

Duke et al. Solar powered oxygen systems in remote health centers in Papua New Guinea: a large scale implementation effectivenss trial.

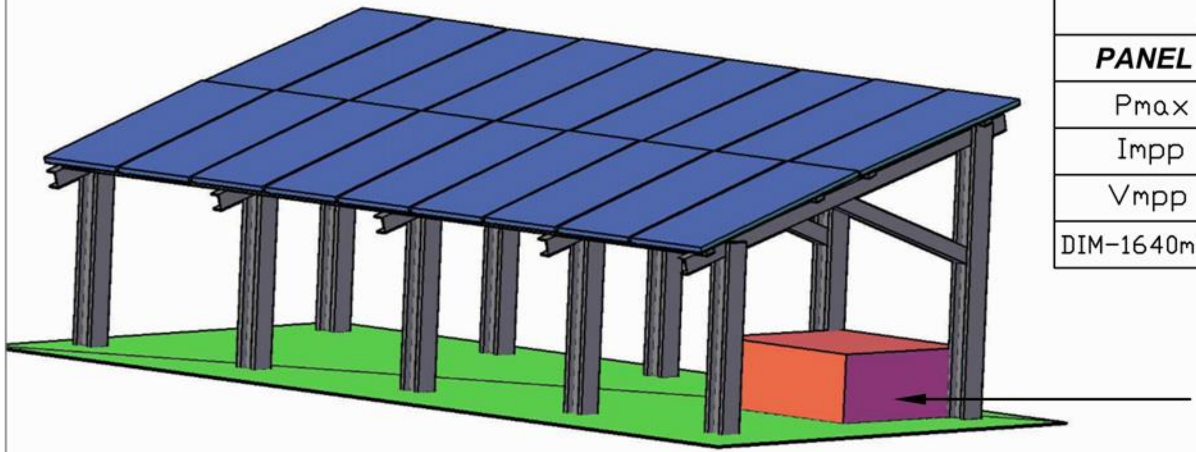
J Glob Health 2017;7:010411

Solar power and engineering calculations





2 STRINGS OF 13 YL250P-29b PANELS



PAPUA NEW GUINEA - OFFGRID SYSTEM		
PANEL SPECS.	**BATTERY BOX**	**BATTERY**
Pmax 250W	LENGTH 1400mm	1000AH
Impp 8.39A	DEPTH 850mm	48V
Vmpp 29.8V	WIDTH 950mm	
DIM-1640mm X 990mm		

ISSUE	DETAILS OF AMENDMENTS	DATE	DRAWN	DESIGNED
01	ALL MEASUREMENTS IN MM			
02	NTS			
03				
04				
05	ORIGINAL	02-03-14	SC	KP

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TITLE

PNG PROJECT
PANEL STRUCTURE

4.5 kW OFFGRID SYSTEM

DOCUMENT NUMBER

PVSTRCTRE_01 OF 01

SYSTEM DESIGN & ENGINEERING CALCULATIONS

CIRCUIT 1

Description	Value	Unit
Load in Watts	1339	Watts
Days of Autonomy	3	Days
System Voltage	24	Vdc
SOLAR MODULE SPECS		
Maximum Power	250	Watts
Maximum Voltage	29.8	Volts
Maximum Current	8.39	Amps
Open Circuit Voltage	37.6	Volts
Short Circuit Current	8.92	Amps
Temperature Coefficient of P_{max}	-0.42	%/°C
Temperature Coefficient of V_{oc}	-0.32	%/°C
Temperature Coefficient of I_{sc}	0.05	%/°C
Power Tolerance f_{man}	-0/+5	W
ENVIRONMENT CONDITIONS & LOSSES		
De-rating factor for direct f_{dirt}	2	%
Peak Sun Hours	4.53	Hrs/day
Design Maximum Ambient Temperature	30	°C
Design Minimum Ambient temperature	17	°C
Site Maximum Ambient Temperature	30	°C

The Temperature derating factor is determined as follows:

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

Cell temperature at standard test conditions 25°C

Average daily cell temperature in °C

Power temperature coefficient per degree Celsius

Temperature de-rating factor (dimensionless)

$T_{cell.eff}$ = Ta + 25°C = 28°C + 25°C =53°C f_{temp} = 1 –

[0.42/100 x (53– 25)] = **0.882**

The Temperature derated Output of module is determined as follows:

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

De-rating factor for dirt (dimensionless)

De-rating factor for temperature (dimensionless)

Manufacturing Tolerance (as per manufacturers datasheet)

Rated Module output under Standard Test Conditions (STC)

De-rated Power output of the module in Watts

P_{mod} = 250 x 1.02 x 0.882 x 0.98 = **220.41Watts**

To determine the number of modules in the array to meet the daily design energy demand is calculated as follows:

$$N = (E_{tot} \times f_o) / (P_{mod} \times H_{tilt} \times \cap_{pvss})$$

Efficiency of the PV Sub-system (dimensionless)

Peak Sun Hours for the specified tilt angle

De-rated power output of the module in Watts

Oversupply co-efficient (dimensionless) _ we have designed the system with 25% oversupply

Total Daily design Energy Demand

Number of Modules required in the array

Etot = (290W x2x24Hrs x3dys/7dys)+(200Wx8Hrs)+(9Wx16x5Hrs)+(15Wx24Hrsx3dys/7dys)+(3000Wh) Etot = 11440 Wh/day

N = (11440Wh x 1.25) / (220.41 x 4.50 x 0.80) = **18.02**....round off to **18 panels**

Since our design is based on MPPT analysis, we will look at an MPPT controller which can handle 18x250Wp=4500Wp

Controller chosen:	**controller 1 -**	**1 x 60A Tri-Star MPPT**
	Controller 2 -	**1 x 60A Tri-Star MPPT**
	Controller 3 -	**1 x 60A Tri-Star MPPT**

Array Configuration:

6 panels per controller

2 strings of 3 panels in series per controller (See schematic attached)

The controllers will have synchronized charging to the battery with a meter Hub.

Battery Calculations

To determine the size of Battery Bank to meet the daily design energy demand is calculated as follows:

$$C_x = (E_{tot} / AV_{dc}) \times (T_{aut} / D.O.D)$$

Total number of days of autonomy required in days

System Average Voltage in 24 Volts

Total energy requirement in Watt hours

Battery Bank Capacity at a certain discharge rate, x

Battery Bank at 80% depth of discharge and 3 days back up:

C_{10} = (11440 / 24) x (3 /0.8) = **1787.5 AH Bank**

System Configuration:

18 x 250W Panels

1800Ah@24V Battery bank

Cable sizing and Voltage drop calculations

-Length of DC cable $L_{DC\ cable} = 10m$
-Maximum power point current of panel $I_{MP} = 8.39A$
-Maximum power point voltage of array $V_{Array\ max}$.....Refer to calculation below

$$V_{Array\ max} = No. of\ panels\ \{V_{mp} - [\gamma_{Vmp}\ (T_{min} - T_{STC})]\}$$

$V_{Array\ max}$ $= 3\ \{29.8 - [0.125(50℃ - 25℃)]\}$ (At lower temperature since voltage would be higher)

$$V_{Array\ max} = 80.025\ V$$

Determining cross sectional area of the array cable

$$A_{DC\ cable} = {2\ x\ L_{DC\ cable}\ x\ I_{MP}\ x\ \rho} / {\%V_{drop}\ x\ V_{Arraymax}}$$

$A_{DC\ cable} = 2\ x\ 10\text{m}\ x\ 8.39\ x\ 0.0183 / 0.01\ x\ 80.025$ ....(1% voltage drop assumed)

$A_{DC\ cable} = 3.83mm^2 \ldots\ldots\ldots..$ $\boldsymbol{4mm^2\ SDI\ cable\ would\ be\ suitable}$

Determining cross sectional area of Battery charging cable

$$A_{DC\ cable} = {2\ x\ L_{DC\ cable}\ x\ I_{dcbat}\ x\ \rho} / {\%V_{drop}\ x\ V_{Batsys}}$$

$A_{DC\ cable} = 2\ x\ 5\text{m}\ x\ 60\ x\ 0.0183 / 0.01\ x\ 24$ ....(1% voltage drop assumed)

$A_{DC\ cable} = 45.75 \ldots\ldots\ldots..$ $\boldsymbol{50mm^2\ PVC\ cable\ would\ be\ suitable}$

Determining cross sectional area Inverter DC cable

$$A_{DC\ cable} = {2\ x\ L_{DC\ cable}\ x\ I_{dcinv}\ x\ \rho} / {\%V_{drop}\ x\ V_{inverterdc}}$$

$A_{DC\ cable} = 2\ x\ 5\text{m}\ x\ 105\ x\ 0.0183 / 0.01\ x\ 24$ ....(1% voltage drop assumed)

$A_{DC\ cable} = 80.08mm^2 \ldots\ldots\ldots..$ $\boldsymbol{80mm^2 PVC\ Battery\ cable\ \ chosen}$

Inverter Selection calculations

AC Load

(16 x 9W LED lights)+(2x290W Oxy Concentrator)+(200W desktop)+(1x15W Oximeter)+(650kWh/yr) =**1339 W**

The oxygen concentrator will have a surge for very short period of time, so we need to make sure that the inverter chosen can supply that surge for a short period, usually 1 second.

In this case the inverter size chosen is a **2500VA 24V TBS Inverter**. Refer to attached datasheet for specs.

Protection Equipment Sizing

DC breakers:

PV breaker sizing

Rated PV breaker Voltage

$$V_{OC\ arraymax} = No.\ of\ panels\{V_{OC} - [\gamma_{Voc}(T_{min} - T_{STC})]\}$$

$$V_{OC\ arraymax} = 3\left\{37.6 - \left[\frac{0.32}{100} x\ 37.6(50-25)\right]\right\} = 104.96V$$

$$V_{OC\ arraymax} = V_{PV\ Breaker}$$

$V_{PV\ Breaker} = \mathbf{103.78}V$ ...**Approx 125Vdc rated PV Breaker**

Rated PV Breaker Current

$$I_{Pv\ Breaker} = 1.25\ x\ I_{sc\ array}$$

$$I_{Isolator} = 1.25\ x\ 8.92A$$

$I_{Isolator} = 11.15$ … …**Approx 16A rated PV breaker required**

Battery Charging Breaker

Rated voltage to be 24Vdc as per battery bank voltage

Rated current= 1.25% x Rated controller current= 1.25% x 60A= **75A** Breaker

Inverter DC Side Breaker

For a 2500VA 24V TBS Inverter:

Inverter surge power/system voltage=5500W/24V=229.17A….**250A HRC Fuse**

Inverter AC Side Breaker

Inverter AC surge power/AC system voltage=5500W/240=22.9…..**32A Main Switch**

Yearly Average Energy Yeild

Overall system efficiency

$$f_{system} = f_{inv} \; x \; f_{voltdropACDC} \; x \; f_{dirt} \; x \; f_{temp} \; x \; f_{man\ tol}$$

$$= 0.93 \; x \; 0.98 \; x \; 0.98 \; x \; 0.91 \; x \; 1$$

$$= \mathbf{0.812......81.2\%}$$

Expected yearly output of the system

$$E_{avg} = No.\, of\ panels\ x\ P_{mod\ derated}\ x\ peak\ sun\ hours\ x\ 366\ days\ x\ f_{system}$$

$$= 18\ x\ 220.41W\ x\ 4.53\ x\ 365\ x\ 0.812$$

$$= \mathbf{5.33}\ \boldsymbol{MWh/year}$$

Solar panel configuration at Keripia Health Centre, Western Highlands Province, PNG