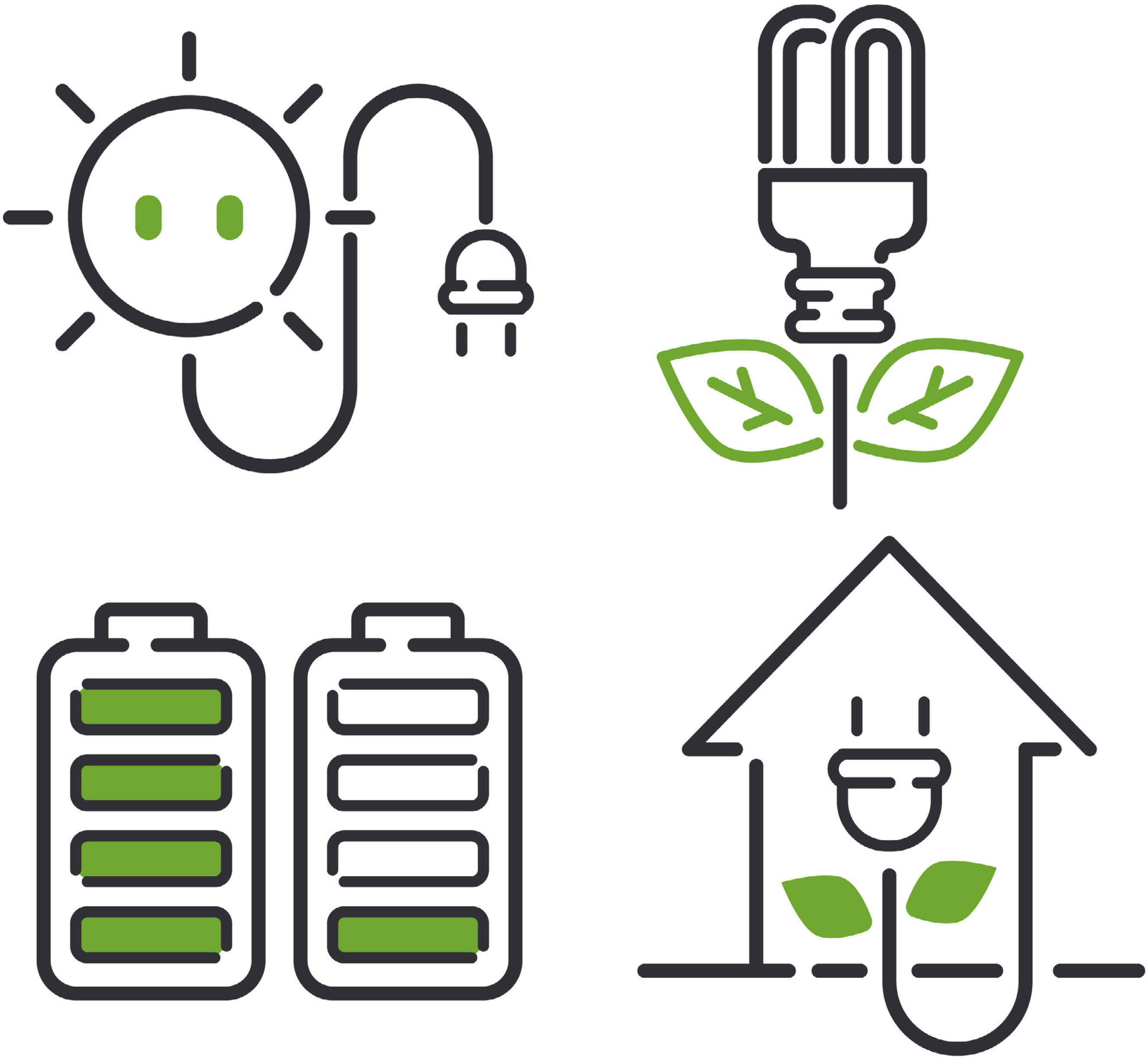
SegenSolar
(Pty) Ltd



SegenSolar Off-Grid PV Guide

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Registered in South Africa No. 2012/208988/07
VAT No. 4780271773

SegenSolar
Off-Grid PV Guide

Introduction

This document gives an overview of the design principles of small-medium scale off-grid solar PV systems in areas of high and consistent irradiance throughout the year, e.g. Southern Africa, and describes the products offered by SegenSolar to meet these requirements.

SegenSolar is a long-established major PV distributor in Europe and our team have 20 years of experience designing off-grid systems for Africa including Malawi, Sierra Leone, Tanzania, Burundi, Egypt, Ghana and Kenya. These systems have ranged in size from 5kWp – 200kWp using a combination of solar PV, battery storage, and diesel generators to provide affordable 24/7 reliable power to organisations including hospitals, schools, monasteries, governments, guest houses and training facilities. We have used this extensive experience combined with the latest products from major manufacturers and software design technology to bring a comprehensive portfolio and expertise to the Southern African market.

Whilst many of the components and some of the design principles are also applicable to on-grid self-consumption systems and grid-backup systems this document has been specifically written to focus on full daily cycle off-grid solar PV solutions and the guidance is only fully applicable for these applications. This guide does not cover 'pico' systems, typically 50W – 250W nor central storage solutions, typically 250kW+ as the components for these solutions are not supplied by SegenSolar. Three-phase solutions will also not be covered in the guide as SegenSolar do not currently supply a three-phase product range.

Typical applications for solar off-grid systems include:

- Very small single-phase residential, 250W – 4kW single-phase, direct DC charging of batteries and inverter.
- Medium size single/three-phase residential 3kW – 15kW, AC charging via charger/inverter. Typically, with a small backup generator for peak requirements and low irradiance days.
- Remote telecoms facility, 2kW – 25kW, AC charging, high capacity, high reliability.
- Rural farm, business, Government, health, 15kW – 250kW, multiple clusters of AC charger/inverters three-phase with large battery bank. Typically, with a generator for daily use to supplement the PV during the day and evening peak usage.
- Existing diesel generator facility. 15kW – 250kW 'Fuel Save' PV system and battery storage to reduce diesel usage by meeting some demand from PV and significantly reducing the generator hours of usage.
- SegenSolar sells a portfolio of off-grid products in South Africa and 'Near Africa', e.g. Namibia, from quality manufacturers for small – medium off-grid applications.

The primary manufacturers supplied are:

- **Hoppecke** – Batteries: Blocs and cells; circulation pumps
- **SMA** – Battery Inverters
- **Victron** – Chargers, inverters, batteries, monitors, fuses

The use of top quality components is initially more expensive but over a 10 – 15 year life of a system will be much cheaper than using less capable batteries and inverters with a shorter life span requiring possibly multiple replacements during the system life.

System configurations that SegenSolar will support with the product portfolio and on-line designer include:

- Charger, battery, inverter – DC coupled
- PV Inverter, battery, inverter/charger – AC coupled
- Diesel Hybrid systems with generators
- Three phase clusters with large battery packs

We have a product portfolio that supports 12V, 24V and 48V battery configurations with the choice of battery voltage mainly dependent on the system size.

SegenSolar provides its on-line designer tool to enable simple single-phase off-grid systems to be easily configured with facilities including:

- Panel to charge controller matching
- Battery cable sizing and voltage drop calculations
- Battery sizing calculator using solar irradiance data and a selection of load profiles
- Battery fuse size calculation
- Inverter / battery type compatibility matching
- Full bill of materials generation and costing

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Design considerations

There are many factors that need to be taken into account when designing an off-grid PV system.

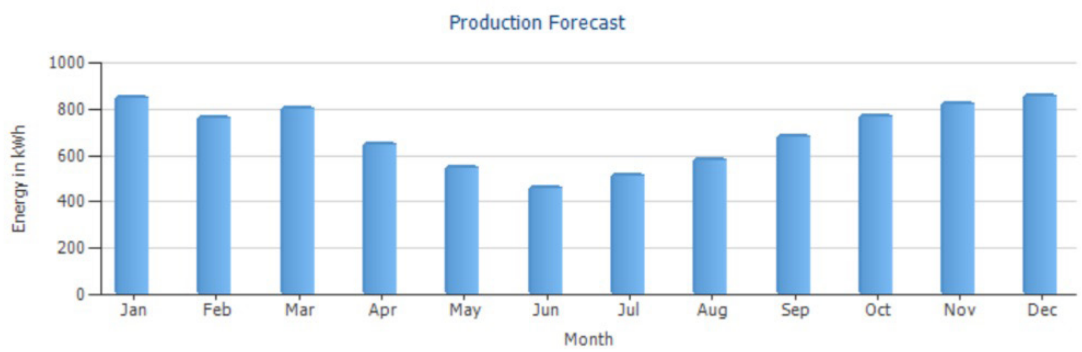
1. The expected hourly usage of the power, the load profile, which can vary significantly between the days of the week and the time of the year. The more accurately this can be predicted the more likely the designed system will be to meet the user's expectations and investing significant time and effort into this stage of the project will bring big rewards.

2. Irrespective of the technology and design used for the PV system it is always most effective to optimise the efficiency of the loads as much as possible. Use of low voltage LED lights, DC fans, fridges, TVs and other low power devices will enable a smaller more efficient PV storage system to be designed and overall will be much more cost effective. The Steca 160l 24V chest fridge will typically use 150W per day compared to about 500W for a similar 230V AC fridge. The extra cost of the Steca fridge will be less than the extra cost of the solar panels, batteries and inverters needed to power the standard fridge. The same will apply to LED lighting, efficient DC fans, DC LED TVs and most other high efficiency DC devices.

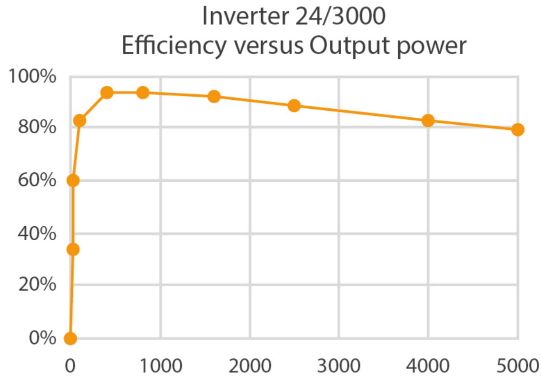
3. An off-grid system needs to be sized to be effective in the winter months when the solar irradiance levels are at their lowest and the energy demand typically highest. Battery storage will tend to work hard in winter near their maximum rated power and occasional high DOD whereas in summer power usage will be less and low DOD quite common. The PV array needs to be sized to generate sufficient energy to fully recharge the battery pack in the darkest months, which typically involves oversizing the array relative to the rest of the system, and the battery pack needs to have sufficient capacity to power the required loads from dusk until dawn in winter, unless an additional generator is available to top up the battery charge. The chart below (1) shows an example of the monthly generation variance for Cape Town for a 5kWp PV system. As can be seen the energy available in April – September is significantly less than October – March. This variance is less than other parts of Southern Africa including Johannesburg, where the monthly generation is almost even all year round.

1

5kWp PV System - Cape Town



4. All the elements of an off-grid system have an efficiency that needs to be taken into account and typically the full battery charge/discharge cycle is about 70% efficient for most 48V lead-acid battery systems including all the components. This can fall to 60% or even lower when high charge/discharge rates are experienced and with lower battery voltage systems. Shown below is the efficiency of a Victron 3kW/24V inverter at different power outputs:



This is typical of other similar devices as the energy loss in all electrical items is highly dependent on the current and all devices have a minimum power usage irrespective of output power. This needs to be factored into the battery sizing calculation requiring the PV generator and battery bank to be 30% - 40% larger than might initially appear to be the case. More detailed information can be found on-line from SMA;

http://files.sma.de/dl/7910/Efficiency-FSS-TI-en-10.pdf

and Victron; https://www.victronenergy.com./upload/documents/Output-rating-operating-temperature-and-efficiency.pdf

5. MPPT charge controllers for direct DC charging of batteries have a limited input voltage range, much lower than is typical for PV inverters, and so for larger PV arrays or where there is a significant distance between the PV array and the battery bank, an AC coupled system is likely to be the most appropriate due to the issues with voltage drop between the PV modules and the charger/inverter. This limitation alone will typically limit the practical size of DC charged systems to about 4kWp as it is rarely practical to site a large PV array a few meters from the storage system. Shown in the chart (2) opposite are some example Victron DC coupled systems with PV modules, charge controller, battery and inverter.

2 Example Victron DC coupled systems

	Volts	PV Modules	Charge Controller	Battery	Inverter
540Wp	12V	2 X 270W	MPPT-150-35	BLOC-12V-150AH	VEDIR-12-375-IEC
1.6kWp	24V	6 X 270W	MPPT-150-70	BLOC-24V-150AH	C 24-1200
4.0kWp	48V	15 X 270W	MPPT-250-85	BLOC-48V-200AH	48-3000-VE.Bus

6. For very small systems it may be appropriate to use a lower cost PWM charge controller where the optimised functions of the MPPT charge controller do not make the extra cost worthwhile. SegenSolar supply small PWM charge controllers for one or two panel 24V systems that can be used with the Canadian Solar 320W/325W (72 cell) module for minimum cost low power systems. These PWM charge controllers have a separate load output that shuts down when the battery power runs low so there is no need for a separate battery protect, further reducing the system cost. The PWM charge controllers may not be appropriate where the cell temperature is likely to exceed 70°C as the voltage from the PV modules may drop below the minimum charging voltage for prolonged periods. They are also only advisable where the solar modules can be located within a few meters of the charge controller and battery system otherwise there may be excessive voltage drop between the modules and the charge controller. They are not recommended for larger than 2 panel systems where an MPPT charge controller will prove more beneficial and cost effective.

7. Lead-acid systems will have a maximum number of cycles that is related to the depth of discharge and typically systems should be designed with no more than an average DOD of 50%. The Solar and OPzV Blocs supplied by SegenSolar have a specified cycle life of 2,500 at a 50% DOD in at an ambient temperature of 20°C and the OPzS and OPzV 2V cells, 3,000. With a system designed for all year-round use, which will be less heavily used in the summer months, this will allow a service life of 10 – 15 years. Shown in the chart (3) on the following page is the relationship between DOD and cycle life for the Hoppecke OPzV batteries at 20°C. This curve is similar for all the lead-acid batteries sold by SegenSolar but the actual values depend on the specific battery model.

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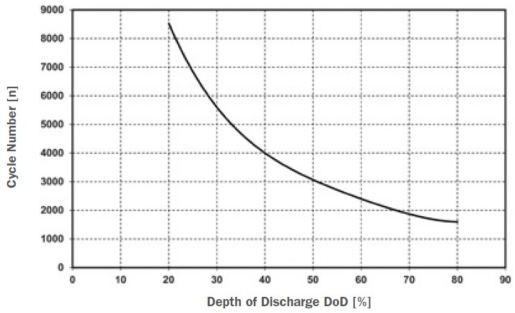
3 **Hoppecke OPzV Cycle Life & DOD**



8. The life of the batteries is also significantly influenced by the ambient temperature. With the cycle life reducing by about 15% for every 5°C of increase in ambient temperature above 20°C c. e.g. the number of cycles of the OPzV 2V cells will reduce from 3,000 at 20°C down to 2,400 at 30°C. The chart (5) on the following page shows the relationship between temperature, DOD and cycle life for a Hoppecke OPzV battery. This clearly shows that the combined effect of higher DOD and higher ambient temperature can have a very significant impact on cycle life of lead-acid batteries and this normally results in designing systems with a lower average daily DOD if the ambient temperature is higher. E.g. to achieve a 3,000 cycle life at 30°C would require an average DOD of 40%, not 50% as at 20°C.

9. The system should be designed at the highest practical battery voltage, typically 24V or 48V for residential scale systems and larger and only 12V for very small systems. The table (4) below shows the recommended kWh of system that should be designed with each battery Solar Bloc size sold by SegenSolar. It is recommended to put 2 or 4 smaller batteries in series than use 1 or 2 larger ones. E.g. 4 X 105Ah @ 48V will be a more efficient system than 2 X 200Ah @ 24V and only slightly more expensive due to lower cable costs of the 48V design offsetting the higher battery cost.

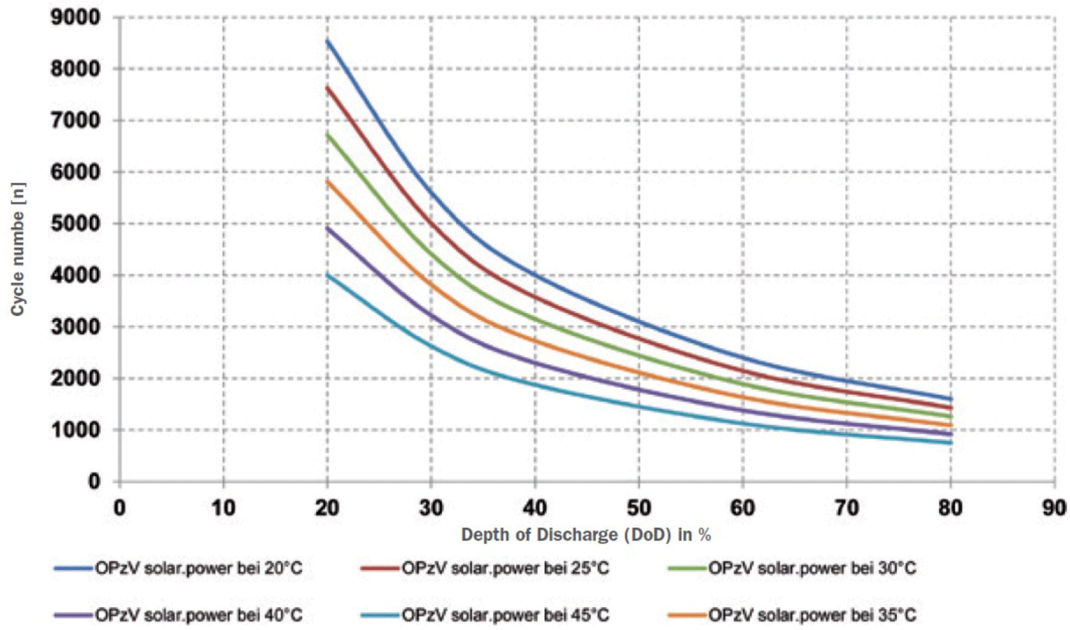
4 **Hoppecke Solar Bloc kWh System Design**

Voltage	105AH	150AH	200AH	250AH
12	1260	1800		
24	2520	3600	4800	
48	5040	7200	9600	12000

If there are DC loads like LED lights, fridges, fans etc. then a 24V system may be more appropriate than a 48V one as availability of 24V devices is better and cheaper than 48V ones with their efficiency increasing all the time. Where the DC loads are not close to the PV storage system then a 48V battery system with a DC-DC converter located near to 12V or 24V DC loads may be the optimal configuration.

With the larger OPzV 2V high current battery cells the sizing and length of the battery cable is critical to ensure efficient and safe design.

5 **Relationship between temperature, DOD and cycle life for a Hoppecke OPzV battery**



10. Where the power supply needs to be assured then an automatically controlled generator is essential to cope with days of low irradiance or higher than normal demand. There are excellent guides from Victron: https://www.victronenergy.com/upload/documents/White_paper_Using_the_Phoenix_MultiPlus_to_reduce_operating_cost_of_a_generator_EN.pdf and SMA: http://files.sma.de/dl/7910/SIGEN-13FE0914.pdf which explain how to design systems using Solar PV and generators. With both SMA and Victron products the power from the PV array and storage system can be used to supplement the power from the generator at times of peak load which enables a smaller generator to be used giving significant capital and running cost savings. The generator can be smaller, the same size or larger than the PV inverter system giving maximum design flexibility to optimize return on investment period or average cost of energy.

11. A 'Fuel Save' system is in many ways similar to a full off-grid PV system but typically the design aim is to reduce existing diesel fuel usage and generator maintenance costs and not replace the generator completely with the PV/storage solution. Usually the PV, storage and inverter solution is sized to minimize the economic payback period of the additional investment and not to maximize the payback over a longer period of time. This often results in a PV, storage and inverter sub-system with less than half the rated power and daily usage of the existing generator but typically resulting in 80% or more reduction in generator operating hours, 60% or more reduction in fuel usage and economic payback periods significantly less than 5 years. The generator will still be used most days for short periods of time to satisfy peak demand but the majority of hours each day the loads will be supplied from the PV and storage system.

12. The battery needs to be sized taking into account the expected discharge rate. If the energy is expected to be drawn down gradually overnight, then the battery pack can be sized at its C20 rating but if it is expected there will be significant short term power requirements then its C5 or lower rating would be appropriate. The efficiency of the battery at C5 will be significantly less than at C20, typically a 10% reduction, and this needs to be taken into account during the sizing calculations.

13. Batteries should ideally be connected in series and not in parallel and not usually more than 2 banks in parallel. Each parallel bank must be individually fused.

14. Battery cables should be kept as short as possible and sized to not only minimize voltage drop but also minimize ripple effects.

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15. Always ensure a system has a battery monitoring capability. Both SMA and Victron provide monitoring devices and for more extensive monitoring a SolarLog system with multiple sensors and AC device control can provide greater control and monitoring of AC loads.

16. For AC Coupled systems one or more load shedding connections are highly recommended to switch off non-essential loads when the battery capacity is reduced. Typically, there will be two relays, one will switch off non-essential loads when the battery capacity is low, e.g. 30%, and the other will switch off all loads when the battery capacity is very low, e.g. 20%, to prevent the Inverter/Charger from switching off and not allowing charging then next day without manual intervention. It would be beneficial to have at least a small DC coupled charge controller and PV array on each battery bank to ensure that the batteries can be re-charged without the need for AC charging in the event of a total shutdown due to very low battery capacity.

17. Always install a fuse between the inverter/charger and the battery bank. The fuse should be rated at 10% higher than the maximum current in peak operation. It is also important to note that fuses should be rated for DC and that they can handle fault currents associated with batteries.

18. The choice of AC or DC coupled is mainly determined by the proportion of energy that will be used during solar generating hours compared to from the battery outside of generation hours. The more daylight energy that is expected to be used the more appropriate an AC coupled system may be due to their significantly higher efficiency when driving AC loads directly from a PV inverter. Larger systems with PV arrays greater than 5kWp will almost always be better designed as AC coupled systems due to the voltage drop issues between the array and the battery bank. The increasing efficiency and availability of 24V devices like LEDs, fridges, TV, fans along with higher voltage MPPT chargers has made it more practical to design larger DC coupled systems with a great proportion of DC rather than AC loads. A system which 2 years ago would have been AC coupled needing 6kWp of PV modules could now be implemented as a DC coupled system with mainly DC loads using just 4kWp of PV modules and this trend is continuing.

19. Always use software to determine compatibility between solar modules and the MPPT and cable size calculations, don't guess.

20. The PV array should be sized so that sufficient energy is available to fully charge the batteries at least once every two weeks. Bear in mind the time taken to fully charge a battery might be more than 12 hours, which in most locations will be more than a whole day of irradiance. It could be worth considering having a genset generator on site for an occasional boost charge.

SegenSolar design tool

There are many factors that need to be taken into account when designing an off-grid PV system that require a lot of detailed engineering knowledge and calculation.

SegenSolar have built all the specifications of the products supplied into a database along with solar irradiance data and developed automatic calculation software to enable complete off-grid systems to be designed using SegenSolar supplied components in a few minutes.

The SegenSolar on-line designer will allow selection of:

- Solar PV array module type, layout and roof mounting structure
- Site location, elevation and distance to inverter
- Single-phase grid requirements
- System type self-consumption, grid backup or off-grid
- DC or AC coupled
- PV inverter or charge controller model based on selected PV array size and phases
- Battery inverter model
- Battery bank type, voltage and capacity
- Distance from battery inverter to battery bank
- Size of diesel generator and cost per hour at different power outputs

It will automatically calculate results based on the input parameters, stored component specifications and solar irradiance data:

- Hourly generation from the PV array for each month of the year at the specified location
- The expected full charge/discharge cycle efficiency of the system at C10 and C5 usage
- Maximum recommended sustained and peak charge and discharge rates
- All the required mounting system components
- Required DC PV cable size to limit voltage drop to less than 2%
- Required DC battery cable size to limit voltage drop to less than 2%
- Required battery fuses
- All required cables, isolators and applicable accessory options

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BYD batteries

http://www.byd.com/energy/technology.html

BYD are the world's largest manufacturer of Lithium Ion Batteries, with over 20 years' experience supplying and developing their products and brand.

SegenSolar will be stocking a 2.5kWh wall mounted package, a 2.5kWh rack mounted unit, a 12.8kWh rack mounted package for commercial systems, and the 2.5kWh unit rack which holds 4 batteries.

BYD –B-BOX-12.8

The BYD B-BOX 12.8 is a lithium (LiFePO4) battery unit with a battery management system and can be used with an external inverter or charger. This is an expandable unit that can have up to 409kWh added, using parallel interconnection.

Key features:

-Parallel interconnection of several systems

-Flexible combination of capacity

-Support for RS485-/CAN-communication

-Lithium iron phosphate (LiFePO4) battery: Maximum security, cycle-stability

BYD B-BOX 2.5 Rack Mounted

This 2.5kWh rack mounted battery box fits in the 2.5 unit rack; this can hold up to 4 of the 2.5 lithium iron batteries.

Battery Features:

-Stable discharge platform

-Excellent safety performance

-Long life cycle

-High temperature performance

BYD-B-BOX-2.5 Wall Mounted

The wall mounted 2.5kWh wall mounted battery box has been designed for the residential system as it is small lightweight unit that fits in a small area.

Compatible with: GoodWe BP2500, GoodWe ES, Victron and the Solis hybrid.

BYD-2.5 Unit Rack

The BYD unit rack offers a storage solution for up to 4 B-BOX 2.5kWh lithium iron battery units with an integrated battery management system.

Key Features

-Flexible combination of capacity

-Parallel interconnection of several systems

-Emergency stop switch

Hoppecke batteries

http://sun.hoppecke.com/

Hoppecke is a long standing German battery manufacturer with an excellent reputation for off-grid batteries across Africa.

SegenSolar stocks a number of standard sizes of batteries in each range, which will allow most small – medium scale systems to be supplied from stock.

Larger systems with bespoke sizes can be supplied to special order on a 12 – 14 week lead time from the German factory. It is expected however that most system requirements can be supplied using the standard size packs and multiple inverters to provide the rated power required.

Solar blocs

https://www.hoppecke.com/en/product/sun-power-vr-m/

These are standard solar grade deep cycle batteries suitable for residential scale grid backup and off-grid solutions and SegenSolar stocks 4 sizes to enable a range of battery banks from 1.2kWh to 12kWh, 12V – 48V to be supplied.

SegenSolar offer 105AH and 150AH 12V and 200AH and 250AH 6V, normally intended to be connected in series into 24V and 48V packs to minimize voltage drop and maximize efficiency.

In daily usage they have a cycle life of 2,000 – 2,500 cycles giving a 10 year lifespan in typical operating conditions.

Power bloc OPzV

https://www.hoppecke.com/en/product/sun-power-vr-l-bloc/

These are long life VRLA sealed gel batteries with a high cycle life and are optimized for medium scale off-grid applications and the products SegenSolar are stocking are ideally suited to 48V off-grid packs from 8.8kWh – 17kWh.

SegenSolar offer 180AH 12V, 250AH and 370AH 6V, normally intended to be connected in series into 48V packs to minimize voltage drop and maximize efficiency.

They are fully compatible with the full range of Victron 12V, 24V and 48V products and with a full 48V pack, the SMA Sunny Island battery inverters.

These provide an excellent solution for small – medium scale off-grid applications with a long service life and simple installation with zero maintenance.

Hoppecke 12V Solar Bloc

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2V OPzV sealed gel cells

https://www.hoppecke.com/en/product/sun-power-vr-l/

Intended for larger off-grid applications the products SegenSolar stocks are ideally suited to 48V off-grid packs of 22kWh, 44kWh and 65kWh.

They are sealed units, making them maintenance free and suitable for environments where there is nobody available to maintain the battery bank at regular intervals.

Installation can be vertical on the floor, on racks or on horizontal shelves.

Their flexibility of installation and low maintenance makes them an attractive option for most remote applications. Care needs to be taken to ensure that access is practical as each cell can be a significant weight as they are pre-filled with gel at the factory. They are also relatively more expensive than the vented lead-acid cells which will tend to be more suitable for larger installations where cost per kWh is crucial.

2V OPzS vented lead-acid cells

https://www.hoppecke.com/en/product/sun-power-v-l/

Intended for larger off-grid applications the products SegenSolar stock are ideally suited to 48V off-grid packs of 19kWh, 38kWh and 55kWh.

They are supplied dry with no acid in them and are much lighter than the pre-filled gel batteries. With regular maintenance, these batteries will have a very long service life.

They need to be installed by an experienced person taking relevant safety precautions and in a well ventilated room.

Larger 48V packs up to 225kWh can be supplied by special order.

For larger systems of 1000Ah+ it is recommended to use a circulation pump which injects air into the bottom of the cells to ensure regular circulation of the acid. This will reduce the charging time needed and improve the charging efficiency by up to 10%. The table below (6) is from a Hoppecke research paper which gives a comparison of systems with and without a circulation pump.

6 **Hoppecke charging efficiency comparisons - with / without circulation pump**

	Standard IUIa-Charge Without Mechanical Electrolyte Mixing	Standard IU-Charge With Mechanical Electrolyte Mixing
Charge Factor CF (%)	120	106
AH - Efficiency (%)	83.3	94.3
WH - Efficiency (%)	71.7	80.0
Water Consumption / SERVICE COSTS (%)	333	100
Capacity loss due to electrolyte Stratification (sulfation and operation at reduced states of charge)	YES	NO
MAX. Charging Voltage	Up to 2.70 V/Cell (112%)	2.40 V/Cell (100%)
System Costs (%)	100	110

Typical applications for OPzS and OPzV batteries

These will normally be installed to make up 48V packs and utilized by schools, hospitals, remote Government buildings, rural agricultural businesses with little or no grid connection.

In a properly designed system with typical daily DOD cycles of 30% - 50% they can be expected to have a service life in excess of 10 – 15 years.

The choice of sealed gel or vented lead-acid most often depends on the availability of local maintenance capability and the environment into which they are to be installed.

SMA battery inverters

http://www.sma-south-africa.com/

SMA have been selling their Sunny Island range into off-grid applications for many years and now offer versions rated from 3.3kW – 8kW.

They operate with 48V battery packs and have a range of options including remote control and string configurations and are optimum for AC coupled systems using PV inverters for direct AC power generation and usage.

A simple small system using a single-phase PV inverter and Sunny Island can be easily configured and installed.

Sunny island accessories

Remote Control

Multi-Cluster Box and Controller

RS 485 Interface

Home Manager or Cluster Controller

SMA have an excellent Planning Guidelines document on designing off-grid systems using the SMA Sunny Island products:

http://files.sma.de/dl/1353/Designing-Off-GridSystem-PL-en-22.pdf

SMA Single Cluster and Multi Cluster Comparison

			Single Cluster				Multi Cluster			
	1 Phase	kVA	3 Phase	kVA	MC Box	SRC	3 Phase	kVA	MC Box	SRC
SI3.0M	1	3.0	3	9.0	N/A	1				
SI4.4M	1	4.4	3	13.2	N/A	1				
SI6.0M	3	18.0	3	18.0	N/A	1	18	108	1	6
SI8.0M	3	24.0	3	24.0	N/A	1	18	144	1	6

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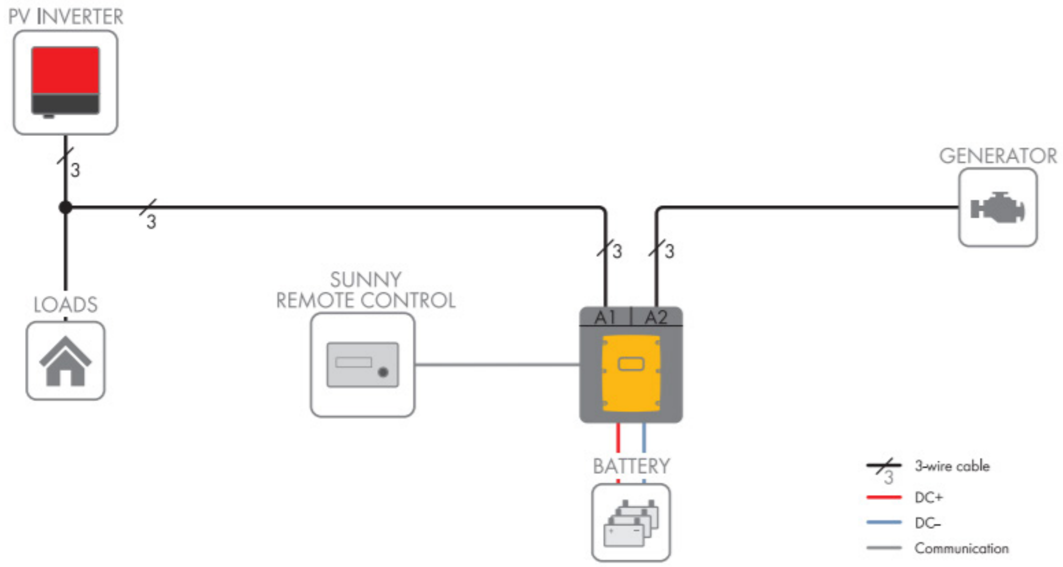
Example simple off-grid Sunny Island system



Example large, multi-cluster off-grid Sunny Island system

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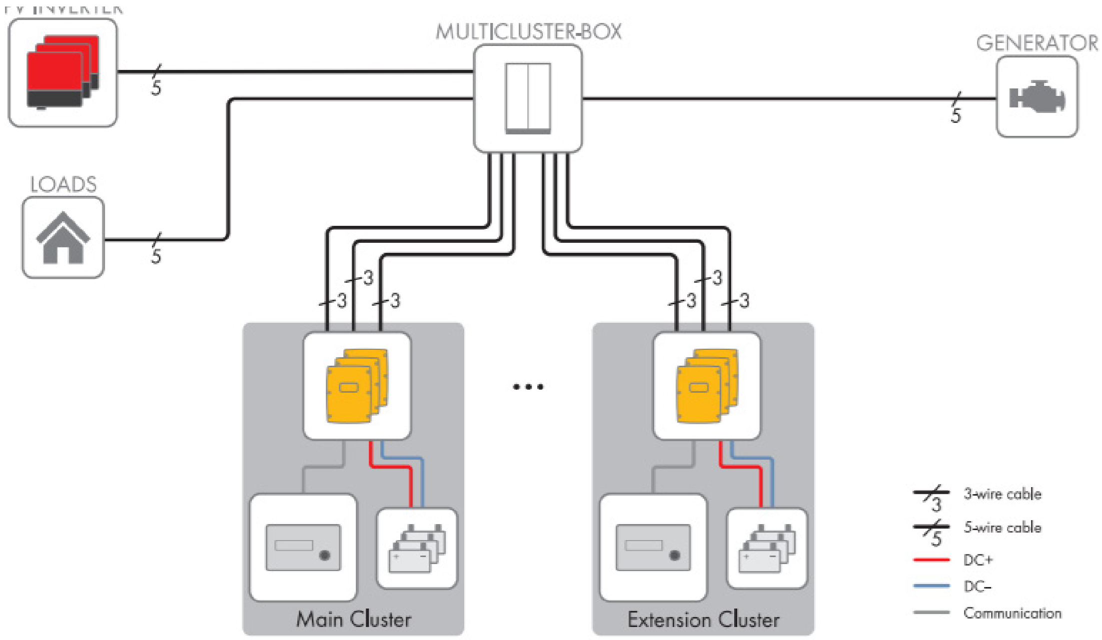

Victron energy

https://www.victronenergy.com/

Victron is a long-established brand in South Africa and offers a wide range of solutions from very small 12V systems through to 15kW battery inverters which can be clustered in parallel.

The product ranges stocked by SegenSolar include all the components needed to implement complete off-grid systems.

Full details of the Victron off-grid product portfolio can be found on their website:

https://www.victronenergy.com/upload/documents/Brochure-Off-Grid,-back-up-and-island-systems-EN_web.pdf

MPPT charge controllers

https://www.victronenergy.com/solar-charge-controllers

The Victron range of 'Blue Solar' MPPT charge controllers allow direct charging of batteries from the standard 60 and 72 cell solar panels supplied by SegenSolar with rated power from 130W up to 6kW.

Most products will auto select the battery voltage based on the connected battery pack at 12V, 24V or 48V with the option to manually set 36V if required.

The number of solar modules that can be connected in series and parallel to a Charge Controller depends on the module type, the charge controller voltage and current range and the battery voltage and needs a software tool to calculate accurately. You can use the SegenSolar on-line design tool or a modified version of the Victron MPPT Calculator Excel sheet pre-loaded with all the SegenSolar solar modules:

http://portal.segensolar.co.za/reseller/docs/VE-MPPT-Calc-2_2-Segen.xlsx

Typically string lengths of 3 – 5 are the maximum with multiple strings in parallel for higher power systems and where there are more strings than DC inputs string cables need to be combined with MC4 combiners or a string combiner box. With the 60 cell 270W Canadian Solar modules supplied by SegenSolar the configurations supported in normal operating conditions are as detailed below.

Some models are supplied with MC4 connectors and some with terminal connectors. It is not recommended to combine more than 2 PV strings into a single MC4 connected input and for larger power systems a DC combiner box located near to the PV array and a large area DC cable, e.g. 10mm2, run to the charge controller may be advisable.

A new range of 'Smart MPPT' Charge Controllers has an optional plug-in display and built-in Bluetooth connectivity.

*Not recommend as charger is oversized, there are better lower cost alternatives.
+Not recommended as MPP voltage is low, there are better higher voltage alternatives.
~Not recommended using MC4, use DC combiner box near modules and TR model.

9

PV V	Bat V	Max Charging A/PV Connector											
	A	15	30	35	45	50	60	70	70	85	85	100	100
	Conn	TR	TR	TR	MC4	TR	MC4	MC4	TR	MC4	TR	MC4	TR
75 (1)	24	1											
100 (2)	12		2			3+							
	24	1+	4			6							
150 (3)	12			3	3*		4	4*		4*		6	
	24			4	6		8	9	9	10	10	12	14~
	48			6	12		12*	12*	18	18	21~	18	21~
250 (5)	12									5	5	6*	
	24									10	10	12	14~
	48									24	24	24	28~

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Larger charge controllers are recommended to operate at higher battery voltages and SegenSolar recommends the maximum rated power of 12V systems should be 1.6kWp and 24V systems 3.2kWp.

Where there are options for the same number of modules with different string lengths then the longer string lengths will normally perform better with lower voltage drop.

Oversizing the array may be appropriate in off-grid applications to maximize the generation on low irradiance days.

The new Victron 250V MPPT Smart Chargers have increased the possible string lengths up to 5 modules in series. When used at 48V battery voltage these can be effective for system sizes up to 6kWp which were previously impractical for DC coupled designs using Victron Charge Controllers.

PWM charge controller

https://www.victronenergy.com/solar-charge-controllers/bluesolar-pwm

For very small systems, one or two 320/325W panels on a 24V battery system, a low cost PWM charge controller may be appropriate. These include an automatic cut off mechanism on a separate load output and so don't require a Battery Protect. These are especially suited to small automated applications like powering fridges/freezers and lighting overnight.

SegenSolar does not supply the 36 cell panels that would be required to support a 12V PWM system, but these could be sourced elsewhere and used with Victron products supplied.

Battery protect

https://www.victronenergy.com/battery_protect/battery-protect

Where there are directly connected DC loads, e.g. LEDs, fans, fridges etc. it is essential to use a battery protect device to disconnect the loads when the battery capacity falls below a pre-defined minimum level to prevent the loads from draining the battery completely and damaging it. The exception being some devices like the Steca fridge/freezers which have built-in battery protection shutdown.

The use of small 12V/24V DC loads near the PV storage system is the most efficient use of the energy and when combined with an MPPT Charge Controller then a very efficient and cost effective off-grid system can be configured.

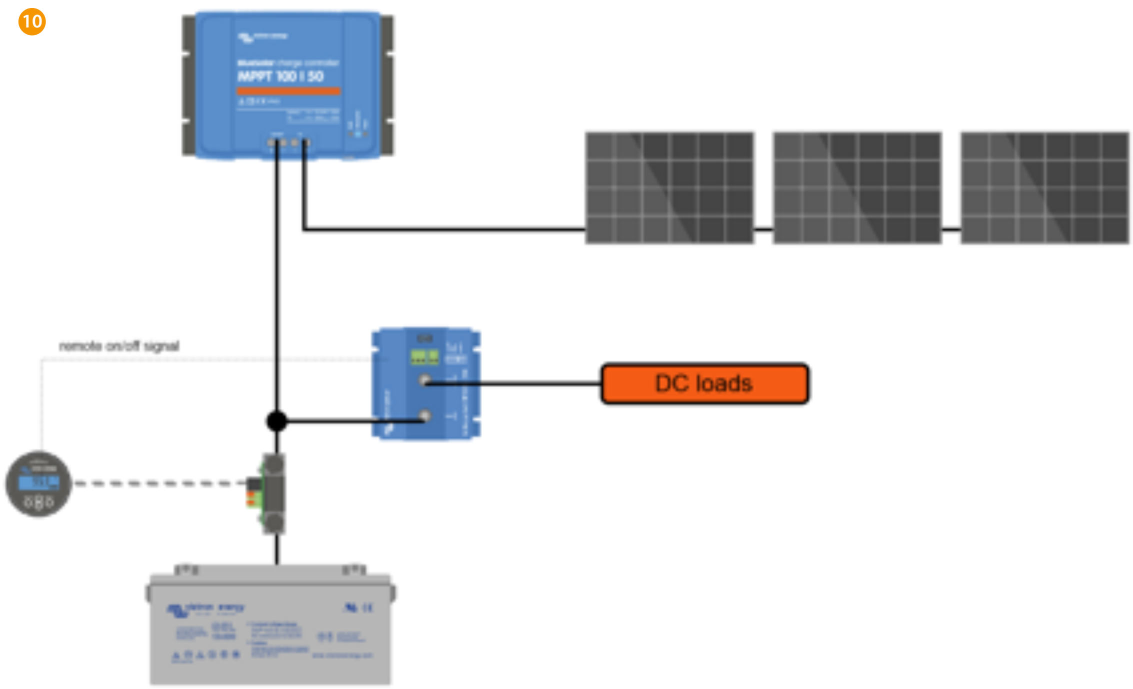
All the battery protectors also allow remote control from a Battery Monitor.

A Battery Protect can be added to any system, 12V, 24 or 48V but the availability of 48V DC devices is very limited and so more typically DC loads are connected at 12V or 24V.

The battery protector should be installed as close as possible to the battery to avoid voltage drop between the battery and the battery protector giving a false reading.

This device is built-in to the MPPT 75/15, 100/15 and the PWM range, but with other MPPT charger controllers or AC inverter/charger systems an additional battery protect device is required in the illustration (10) below.

10



DC-DC converters

https://www.victronenergy.com/dc-dc-converters

With 48V battery systems it is often impractical to utilize DC devices like LEDs at 48V as these are mainly available at 12V and 24V however the use of a 48V – 12V or 48V – 24V converter located as near as possible to the loads can be effective in making efficient use of energy from the PV storage system.

These convert the 48V DC from the battery into 12V or 24V for use by the load with reasonable efficiency and the 48V cable from the battery to the DC-DC converter will help to minimize the voltage drop compared to long 12V or 24V cables.

SegenSolar are offering 24V and 48V to 12V and 24V DC from 110W up to 250W DC-DC converters for use with 48V off-grid systems 12V or 24V loads.

Always use in combination with a battery protector to prevent the battery from being fully discharged.

Battery inverters

https://www.victronenergy.com/inverters

The Victron range of 'Phoenix' inverters generate pure sine wave AC from 12V, 24V or 48V battery packs and SegenSolar stocks inverters with rated powers from 250W up to 5KW including the new range of VE.Direct products which provide excellent configuration and monitoring capabilities.

A simple off-grid system can be configured with an MPPT charge controller, a battery and a battery inverter.

The battery voltage can be designed at 12V, 24V or 48V using lead-acid or lithium-ion depending on the size of the PV array and the power requirements. Typically, systems daily loads of up to 1.5kWh are 12V, between 1kWh and 4kWh are 24V and 3kWh+ are 48V. The higher the battery voltage typically the more efficient the system will be, but more batteries will be required to achieve the required voltage.

Inverter / chargers

https://www.victronenergy.com/inverters-chargers

The Victron range of 'Multiplus' and 'Quattro', combined chargers and inverters rated from 500W up to 15KW with dual AC outputs and one or two AC inputs, can be used in a wide variety of applications including DC and AC coupled off-grid, grid-backup and self-consumption systems and are compatible with lead-acid and Li-Ion battery packs at 12V, 24V and 48V.

The Multiplus can be configured to auto start/stop a generator with a remote start functionality to provide almost unlimited generation capacity and along with a Charge Controller and battery bank an efficient and cost effective off-grid solution can be configured. Additional relays can be programmed to make use of summertime excess generation.

The Quattro range provides two AC inputs and is suitable where there is a grid connection available and a generator input is also required.

All models can be used in parallel on the same phase to enable higher power rating with up to 6 devices in parallel.

The table (11) below details the maximum system configurations for a selection of Victron Multiplus and Quattro charger/inverters. There is no advantage to using multiple smaller devices so always design with the smallest number of devices to meet the required power rating.

Victron Maximum System Configurations

11

	Single Phase	kVA	Three Phase	kVA
Multiplus 5kW	6	30	6 X 3 (18 X Multiplus)	90
Quattro 10kW	6	60	5 X 3 (15 X Quattro)	150
Quattro 15kW	6	75	4 X 3 (12 X Quattro)	180

All devices in a parallel connected, single phase system must share the same battery pack using exactly the same length of battery cables to ensure even distribution of energy. Use of short DC cables and a low resistance bus bar is highly recommended to minimize voltage drop and ensure equal resistance to each device.

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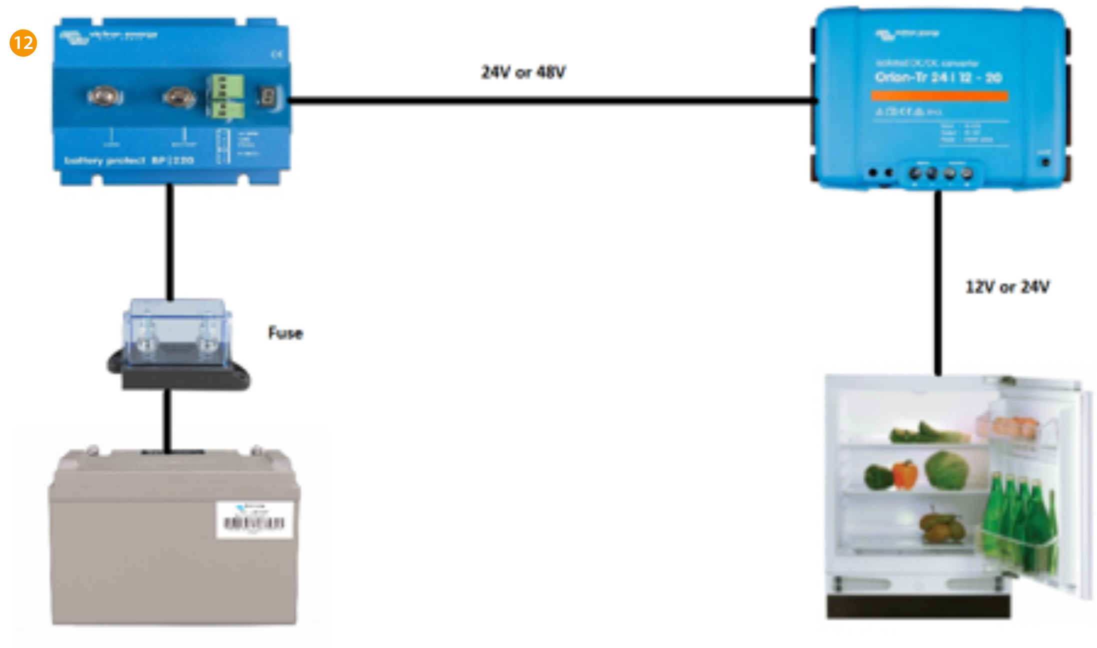
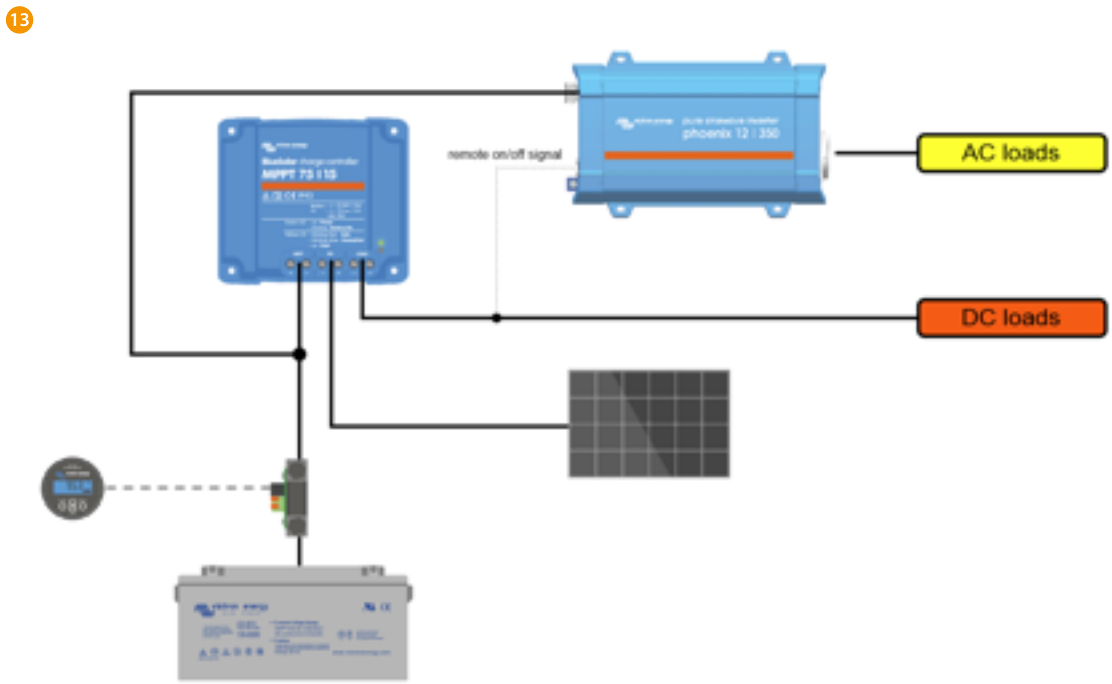

12
24V or 48V
Fuse
12V or 24V


13
remote on/off signal
AC loads
DC loads

The new 'Multi' 500W range is ideal for small off-grid applications providing a very cost-effective entry level solution.

MPPT / inverter / chargers

https://www.victronenergy.com/inverter-charger-mppt/easysolar

Victron offer a range of 'Easy Solar' combined MPPT chargers and inverters rated from 1.6kW up to 5kW with Solar MPPT charger and grid-connected/off-grid inverter, some with built-in control panel for maximum single device integration and rapid install time.

These are ideal for PV off-grid systems where simplicity of system design, minimum components and rapid installation time are important. Depending on their rated power they support battery packs at 12V, 24V and 48V with a rated power up to 5kW with a 48V battery voltage.

The Easy Solar can be configured to automatically stop/start a generator and therefore can provide all the functions of a fully autonomous off-grid system in a single device.

With a battery charge current up to 100A @ 48V and supporting up to 5kWp of solar PV panels the Easy Solar is an ideal device for rural residential properties with no grid connection or needing grid backup or re-enforcement when combined with the Hoppecke solar or OPzV blocs.

Battery fuses

The primary role of a battery fuse is to protect equipment and the location from battery fault current. Generally the natural currents seen in a battery system are quite high, which in turn means that most fuses suited to doing this job are big.

The importance of what they do should never be underestimated. Battery fault currents, should they occur, can be huge and it's vital that such protective parts are fitted to ensure a system works safely.

SegenSolar provide a wide selection of battery storage scale DC fuses and holders that should be fitted between the battery and the equipment it's connected to. The correct rating is always dependant on the battery max current and is generally 10% higher than the total rated current of the devices attached to the battery, e.g. the battery inverter(s).

Battery monitors

Battery monitors provide an easy-to-read visual status of the battery. These products allow the system owner to make an informed choice on when to use power or when to manually charge the battery from another power source. Battery monitors are frequently required as part of an off-grid system in order to control battery health.

Communication and control devices.

All battery systems require communication and control devices to be included in their design in order for the system to work correctly and efficiently. Such devices allow the following:

- sending of signals from AC meters back to charge controllers
- automatic control of generators
- remote switching
- remote monitoring, including viewing of load and discharge profiles.

Installers are advised to contact the SegenSolar Technical support team to discuss site-specific requirements, in order that the most appropriate product can be recommended for a project.

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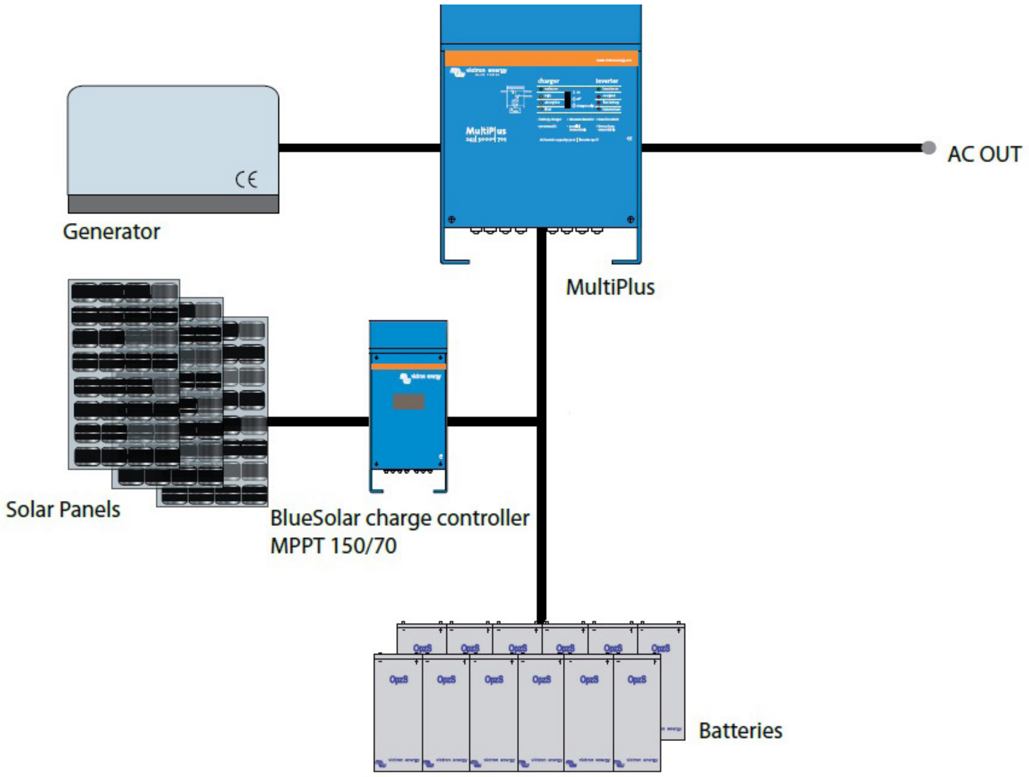
14


Generator
MultiPlus
AC OUT
Solar Panels
BlueSolar charge controller
MPPT 150/70
Batteries

Battery cables

Typically, batteries are connected at relatively low voltage and high currents and it is essential to minimize voltage drop and ripple currents to use an appropriate size of battery cable and to have short cable lengths. Excessive voltage drop will result in loss of system efficiency and in extreme cases heating of the cable possibly causing a fire risk. Excessive ripple will reduce the lifetime of the inverter.

SegenSolar supply battery cables in red and black with sizes ranging from 16mm² up to 95mm² with any length required being cut to order in the SegenSolar warehouse.

SegenSolar also supply a range of cable lugs suitable for the battery and inverter products we supply which can be soldered or crimped onto the battery cables.

The calculation of the required cable size is done by the SegenSolar, SMA or Victron designer software, aiming to ensure the voltage drop is less than 3% across the required length of the cable and requires the current to the battery which is related to the power rating and voltage and the length of the cable.

For example, a 1.2kW system at 12V, which is the largest practical size for a 12V system, would require a 95mm² battery cable @ 4m, which will add about 10% to the electrical items price, and is one of the reasons it is recommended to use higher battery voltages for larger rated systems.

Example system – 2.4kWP - Low power AC, 24/7 DC power

Where only low power AC loads are required and no generator capability this example system uses a 150V/85A MPPT and a low power 500W inverter along with a Battery Protect for LED lighting and low power AC loads including a LTE router and LED TV. The overnight usage is estimated at 1kWh under normal conditions but the system design allows for up to 1.5kWh at a 40% DOD and 90% discharge efficiency.

The 24V fridge is directly connected to the battery, not via the battery protect, as it has a built-in battery protect mechanism which will shut down the compressor when the battery is near exhaustion but maintain the fridge control mechanism. The cut off voltage of the battery protect should be set slightly higher than the fridge so that the lights and other DC loads are turned off before the fridge shuts down.

The use of a DC coupled system is appropriate because the AC loads are very low and the primary requirement is to drive the low voltage fridge 24hr and LED lights at night. Use of 24V DC loads and DC charging is much more efficient than similar AC loads and AC charging.

As the DC cable to the loads is at 24V a substantial cable size may be required dependant on the length and maximum load.

The rating of the PV array compared to the battery capacity is relatively large as there is no generator to provide additional energy so the PV array needs to be large enough for all year round usage. In this example diagram (13) on the following page, the 9 X 270W panels could be expected to provide the whole energy requirement of this lower load system all year round in areas of high irradiance.

The battery cable needs to be large as the currents are high at 24V.

The design can be easily scaled up with a larger charge controller, more solar panels, a larger inverter and a larger battery bank.

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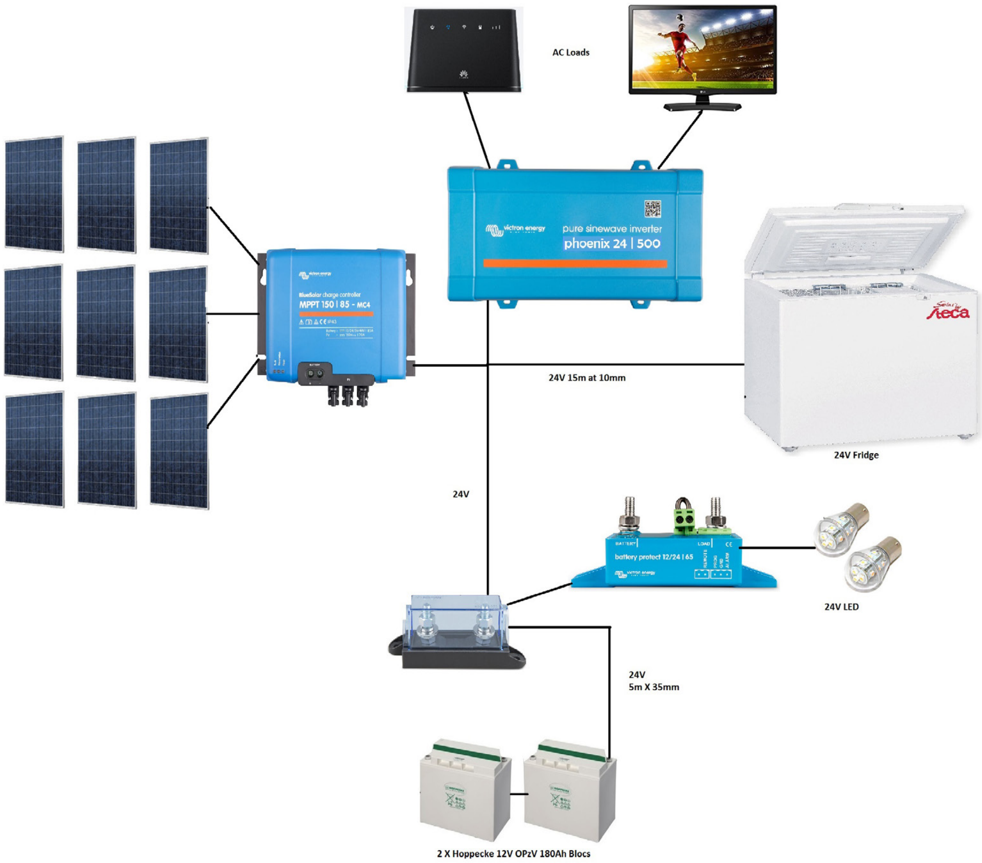
15 Example system – 2.4kWP - Low power AC, 24/7 DC power



Example system – 3.2kWP - Low AC usage, 24/7 DC power

This example system uses the EasySolar 48-3000 with a combined MPPT charger and AC charger/ inverter along with a Battery Protect and 48V – 24V DC-DC Converter to optimally power a 24V fridge and freezer, LED lighting along with low power AC loads including a LTE router and LED TV. The overnight usage is estimated at 2.0kWh under normal conditions but the system design allows for up to 3.0kWh at a 40% DOD and 90% discharge efficiency.

The use of a DC coupled system is appropriate because the AC loads are modest and the primary requirement is to drive the low voltage fridge/freezer 24hr and LED lights, network and TV at night. Use of 24V DC loads and DC charging is much more efficient than similar AC loads and AC charging.

Installing the 48V – 24V DC-DC converter near the loads enables a relatively long and modest sized DC cable from the system to the DC-DC converter with low losses.

The rating of the EasySolar at 3kW allows short term use of larger AC loads including a microwave, electric kettle, iron etc.

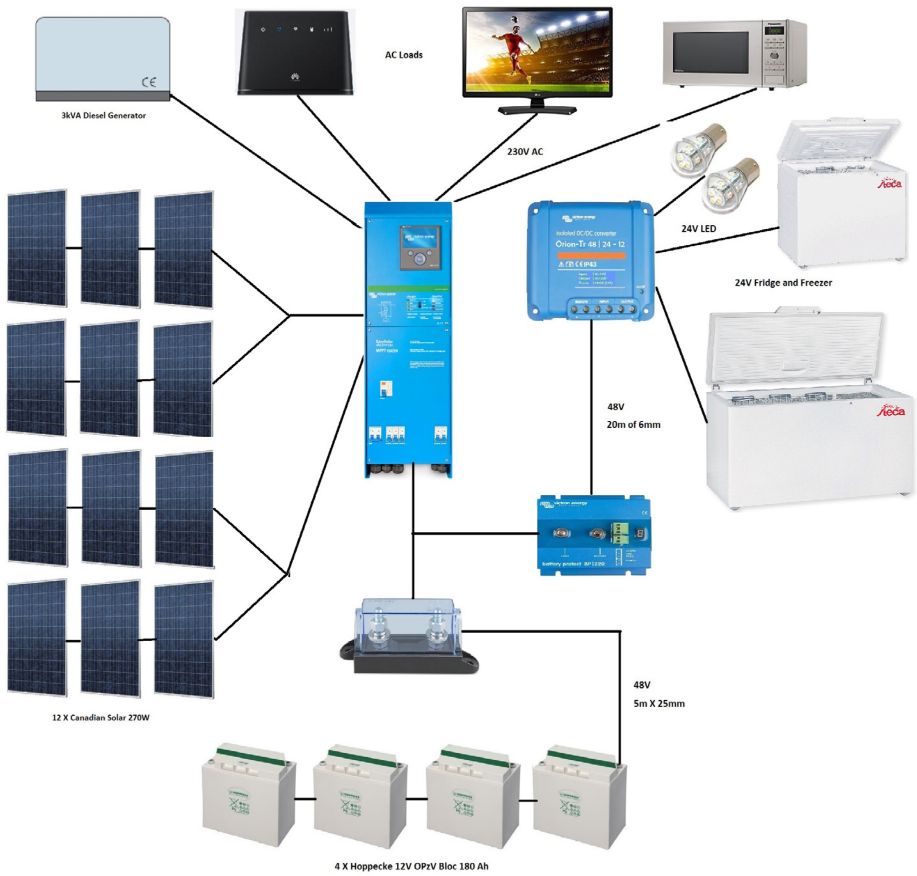
The rating of the PV array is relatively small compared to the battery capacity as the majority of the power is expected to be used during daylight hours with only a high efficiency fridge, freezer and LED lighting needing to be powered overnight. In the example diagram (16) below 12 X 270W panels could be expected to provide most of the energy requirement all year round in area of high irradiance and minimising battery discharge during the day for optimum battery life.

The small diesel generator provides additional power and top up for the batteries during periods of high usage or low irradiance and this could enable a lower number of solar panels to be installed, depending on the load profile and irradiance expected at the site.

The design can be easily scaled up with the EasySolar 48-5000 and a larger battery bank.

Example system – 3.2kWP - Low AC usage, 24/7 DC power

16



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Example system – 7.5kWP high power AC loads – AC/DC charging

This example has high power AC loads mainly used during daylight hours and therefore the use of an AC coupled system is appropriate, also allowing the PV array to be sited some distance from the system due to the high string voltage. Most of the AC load will be provided efficiently direct from the PV inverter during daylight, topped up from the battery via the Sunny Island during periods of peak usage or low irradiance.

An additional DC coupled small array and Charge Controller is included to provide additional high efficiency charging of the battery for overnight use and to ensure the battery can be recharged after a system shutdown or failure on the AC side. Both of the DC loads are provided efficiently direct from the MPPT Charge Controller or from the battery bank overnight with additional battery charging coming from the AC coupled array when the AC loads are not in use.

The AC Charger/Inverter sub-system is based on SMA using the SB5000TL-21, Sunny Island 6.0 and Sunny Island Remote Control. The DC charger and load sub-systems are based on Victron using a 150V/45A Charge Controller, 48V 100A Battery Protect and 48V-24V 12A DC-DC Converter.

These sub-systems operate independently but are all connected via a high current bus bar to a common 48V 520Ah battery pack.

The diesel generator provides additional power and top up for the batteries during periods of high usage or low irradiance and is only expected to run for short periods of the day, especially in the summer months with significant usage only in the darkest three months of the year.

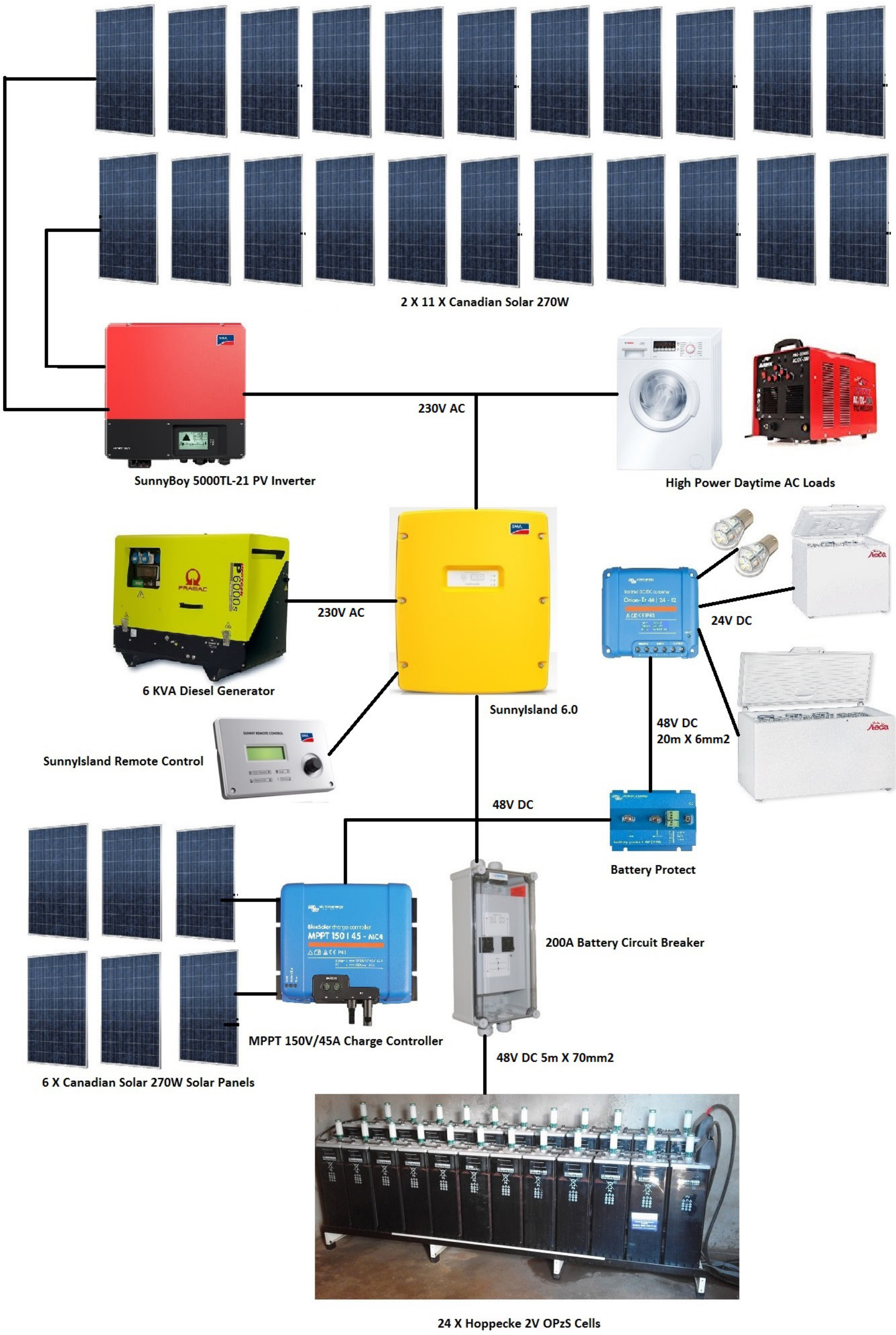
The use of AC PV Inverters directly driving the high power AC loads minimizes high current flows on the low voltage DC bus, with most energy being generated and directly consumed at 230 AC. This optimises system efficiency and reduces power losses and heat dissipation. Highly efficient DC loads driven directly from the charge controller during the day and battery bank at night enables the AC battery inverter to automatically go into standby mode at night, significantly reducing power consumption.

This design is easy to scale up with multiple PV inverters and arrays, larger or multiple Sunny Island battery inverters, larger or multiple MPPT charge controllers and PV arrays and a larger or multiple battery banks whilst maintaining essentially the same architecture.

The example (17) on the following page shows the 7.5 kWP high power system.

17

7.5kWP High Power System



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