The Smart Solar Box XL:

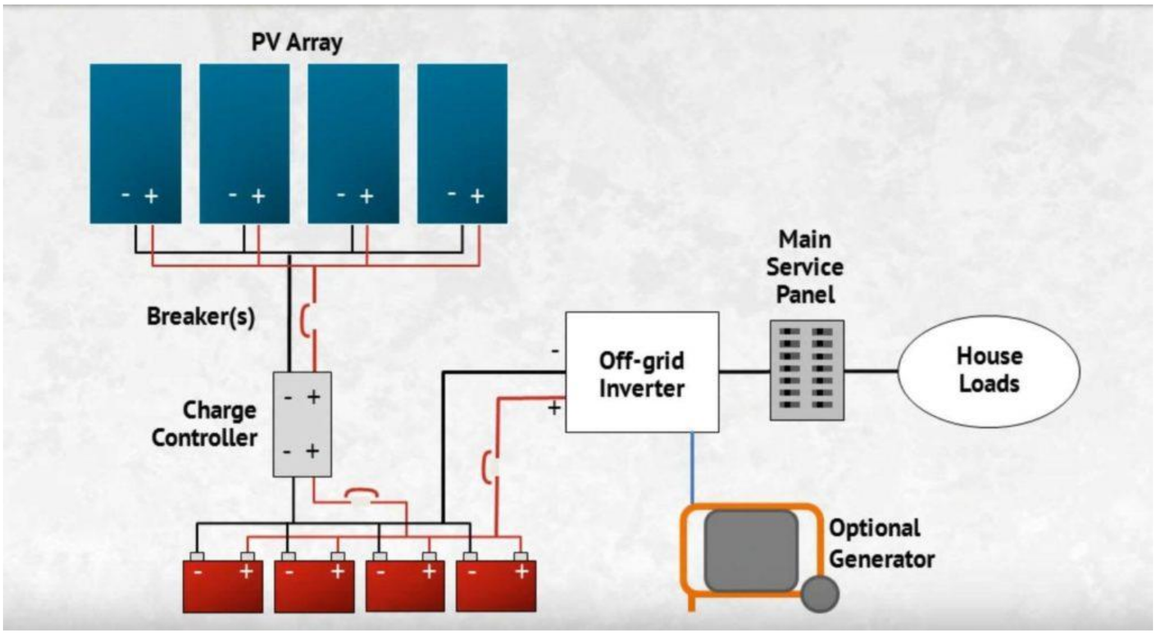
DIY Complete Guide step-by-step

The price of the solar panels is getting cheaper, day by day. The manufacturers are trying to make it more affordable, anyone can buy them and install a system for their home. The installation of a complete off grid solar system is still costly, because hiring laborers almost never go down in price. I write this complete guide to help you design & build off grid solar power system all by yourself.

If you decided to build a solar panels system for home to cover your electricity bill, this tutorial is for you.

Let’s start at the beginning

Here’s a basic schematic of a typical off-grid system.



You’ll notice there is a generator in the drawing. That is there for instances when there is not enough sun to provide the power needed, generally Winter, and if you have an occasional load that requires more power than your system can provide.

For instance, if you needed to use a welder for a project, it may not make sense to design the whole system to be able to accommodate a tool that is used once a year. Having a generator available for occasional use makes good sense. Keep this option in mind when designing your system.

Step 1: Analyze load and estimate daily usage (Figure out how much power you need)

Figuring out how much power you need is a critical step that many people try to skip. **Don't do this is a very important step, but keep in mind that with increasing demands on the amount of energy available for consumption, system portability can disappear and we talk about a fixed system adapted to the requirements of the house or caravan.**

Designing a solar system without knowing your loads is like being asked how much gas do I need to drive, without knowing what type of vehicle or how far you are driving.

1. Load Analysis

Unlike a grid tied system where you can just base the system on how much power you want to offset, an off grid solar system needs to provide all of your power. With an off-grid system, you need to take a good look at what you are powering, and how long you need to power it.

Going off-grid often takes changes to your lifestyle. It's not as simple as just saying, "I'm tired of paying the electric company, I'm taking my whole house off grid and stick it to the man".

You have to figure worst case scenarios: **winter time** – with little to no sun for days. Unless you are in a climate that has long sunny days all year round, most people who are doing a year round off-grid system will have a generator available to pitch in in the winter.

I read a quote from an off-gridder who said:

"if it's going to be a sunny day, I can cook waffles for breakfast. If it's cloudy, I have cereal."

When designing the system, you can't just say it's an "*average*" size system. No such thing. You also can't base it on the square footage of the house or cabin. One cabin may have air conditioning, an electric stove and water heater, electric washer and dryer, a fridge and freezer, and the other may have LED lights and a laptop.

Which one is “***average***“? Who’s to say? Do you think the same system will work for both cabins, even though they are the same physical size? You need to make a complete list of every electrical device you will be using, how much power it uses, and how long each day it will be on. Don’t forget anything.

2. Determining Loads

All UL listed equipment will have a power label on it. Since, you should be able to get all of the information you need off the labels. Here’s some examples from walking around my house. You can see some do list the watts, some list a voltage range, some and amps, and some list the DC voltage and amps used from a power block that is converting the AC voltage to DC.

LG Electronics Inc.
S/No.:
110KWEL42716
MODEL : WT5101HV
Product Code : T1309ADFH6.ASSEEUS
120 V 60 Hz 10 A
FULLY AUTOMATIC WASHING MACHINE/
LAVE LINGE AUTOMATIQUE
MADE IN KOREA/PRODUIT EN COREE

☎ (LG US) 1-800-243-0000
☎ (LG CANADA) 1-888-542-2623

C US

Certified by NSF/P172
Certifié par la NSF/P172

Energy Performance
Rendement
Énergétique
EP 3103134
101T0513

Volts x Amps = Watts

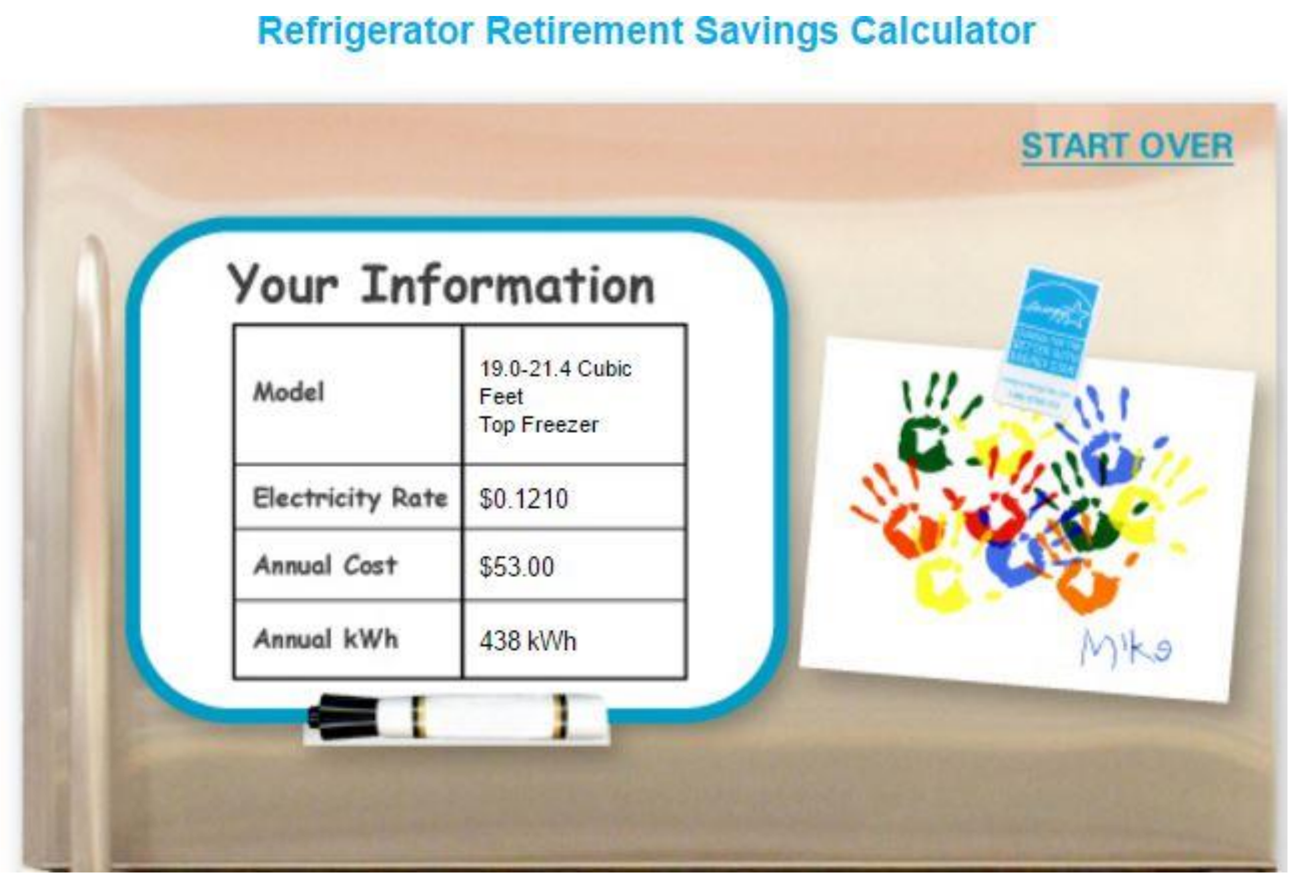
Watts x (hours a day) = daily W hours

- If the voltage listed is DC instead of AC, you would still multiply the DC volts by the Amps to get Watts.
- If the voltage listed is a range, like 100 to 240 volts, you would use the voltage that is used in your area, for instance, 120V for North American outlets.

3. Measuring Variable Loads

Some loads, like a refrigerator or a pump or furnace fan, are not on continuously and have a high surge when the compressor turns on, making it difficult to determine how much accumulated power, or watt hours, it uses throughout the day.

If it is **Energy Star** rated, you can find the Energy Star Label, either on the appliance or on the Energy Star web site. If it is not Energy Star rated, and you are looking to power it with solar, it may be worth it to replace it with an Energy Star fridge. The Energy Star label will tell you the average annual kwh used.



Refrigerator Retirement Savings Calculator

Your Information

Model	19.0-21.4 Cubic Feet Top Freezer
Electricity Rate	$0.1210
Annual Cost	$53.00
Annual kWh	438 kWh

From there, you can simply divide it by the number of days in the years

kWh a year / 365 days = kWh a day

A more accurate way of determining the power consumption is to measure it with a device like a **Kill-a-watt meter**.

You plug the meter into the outlet, and then plug your device into the meter. It will show you an instantaneous wattage, volts, amps, and accumulated watt hours. It also shows how long the unit was measuring, you can divide the Wh by hours to see how many watts it is drawing on average. Multiply that by 24 hours, and you have how much it actually used in a day.

Alright, now that we know what each device is using, what do we do with that info? Using a load calculator can help you create the loads list. This type of calculator are available on several websites of panel and solar components distributors, one such ex.

https://www.civicsolar.com/load-calculator

#Step 2: Calculate battery bank capacity

In this step, we'll discuss the different considerations that go into sizing your battery bank.

Now let's see what size battery bank we need to store the power would be generated from your DIY off grid solar system.

1. Voltage Selection

The first thing we need to decide is what voltage we will make the battery bank. Most off-grid battery banks are either 12, 24, or 48V.

What voltage are your loads?

Are you just powering a small video surveillance camera or light that runs off 12V DC? Or is it an AC system that will be using an inverter to convert from DC to AC? If it is using an inverter, what size does the power inverter need to be? Generally, the higher the output wattage, the higher the DC input.

For example, if it is a 2000W inverter, it may be available in 24VDC, but a 6000W inverter will certainly require 48V.

Another possible consideration is the distance between the solar panels and the battery bank. Depending on what type of charge controller you use, you may need to match the voltage of the solar array with the voltage of the battery bank. I'll get more into that in next steps.

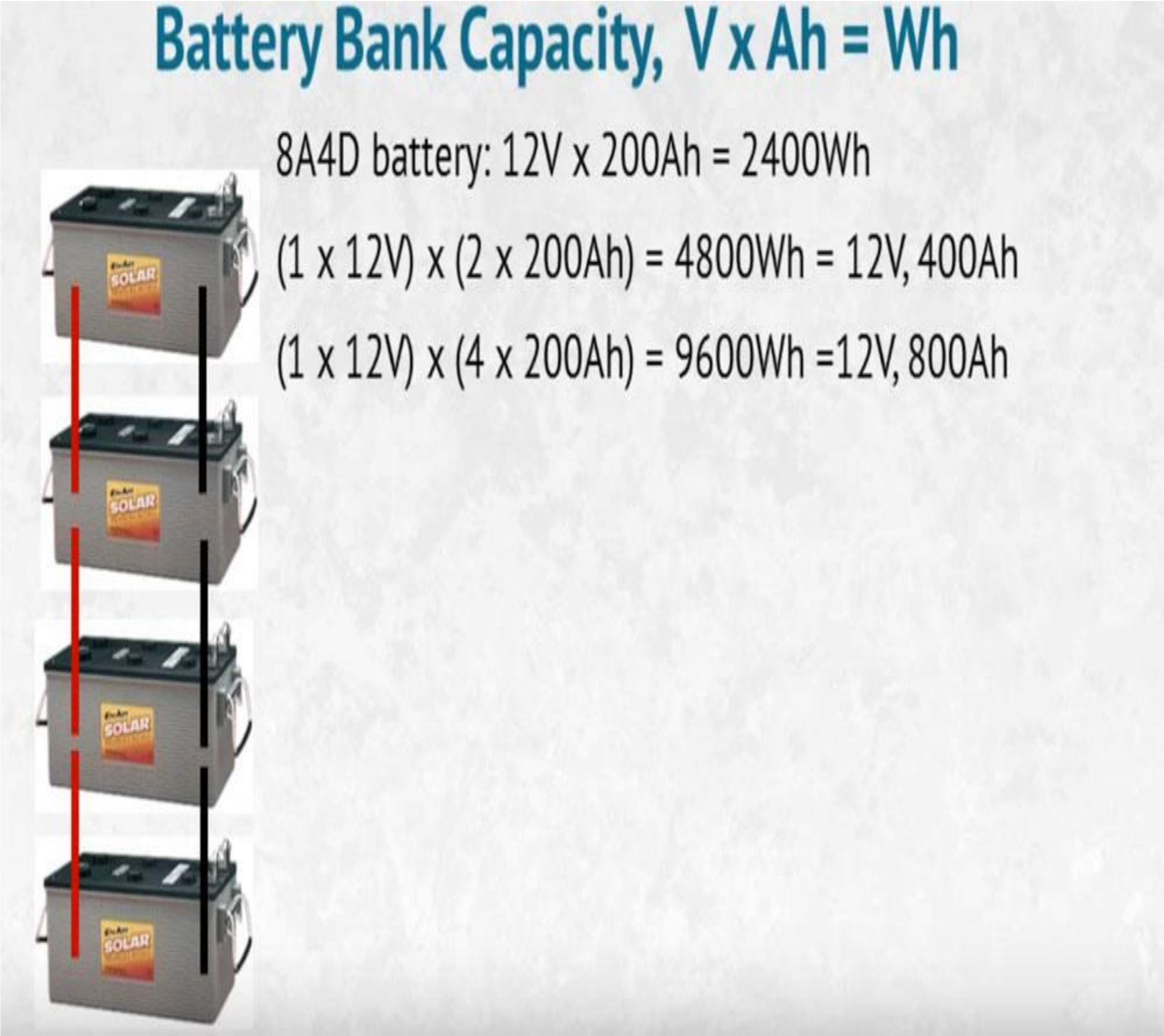
But if you do need to match voltages, keep in mind that if the panels are far away from the batteries, you can reduce the gauge of the expensive copper wire needed by using a higher voltage. Since using a higher voltage array results in lower current, you can potentially save money by running the system at 48V instead of 12V.

MK 8A4D AGM 200AH (20HR) LTP TERMINAL

Let’s get into this a little deeper. We’ll use an 8A4D battery as an example.

It is 12V and 200Ah. 12V x 200Ah = 2400Wh for 1 battery.

Remember that wiring in parallel increases the amphours, but keeps the voltage the same, and wiring in series increases the voltage, but keeps the amp hours the same. If I needed 4800Wh capacity, I can wire 2 of these batteries in parallel. However, if I needed 9600Wh, I would need 4 of these batteries, 4 x 12V x 200Ah.



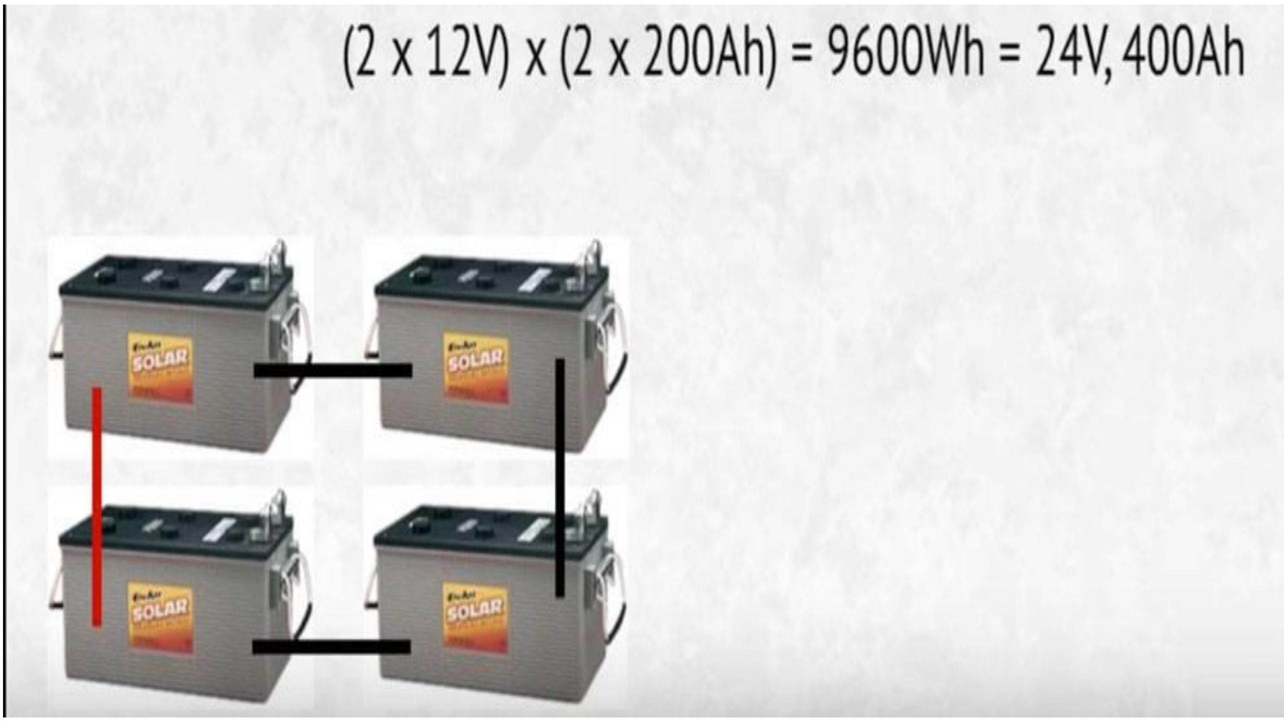
Battery Bank Capacity, V x Ah = Wh

8A4D battery: 12V x 200Ah = 2400Wh

(1 x 12V) x (2 x 200Ah) = 4800Wh = 12V, 400Ah

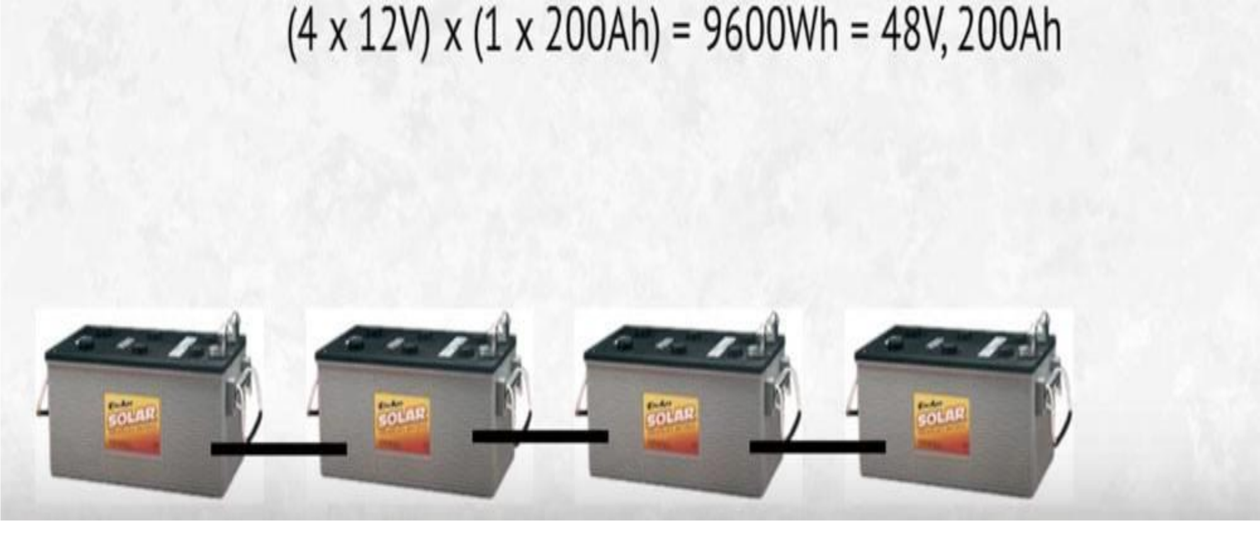
(1 x 12V) x (4 x 200Ah) = 9600Wh =12V, 800Ah

Since I want to limit the number of parallel strings I use, I can’t wire them all in parallel, but I could wire them in 2 parallel strings of 2 in series. In doing so, I made a 24V 400Ah battery bank, 24V x 400Ah = 9600Wh.



(2 x 12V) x (2 x 200Ah) = 9600Wh = 24V, 400Ah

Or, I can make a 48V system by wiring them into 1 string of 4 in series.



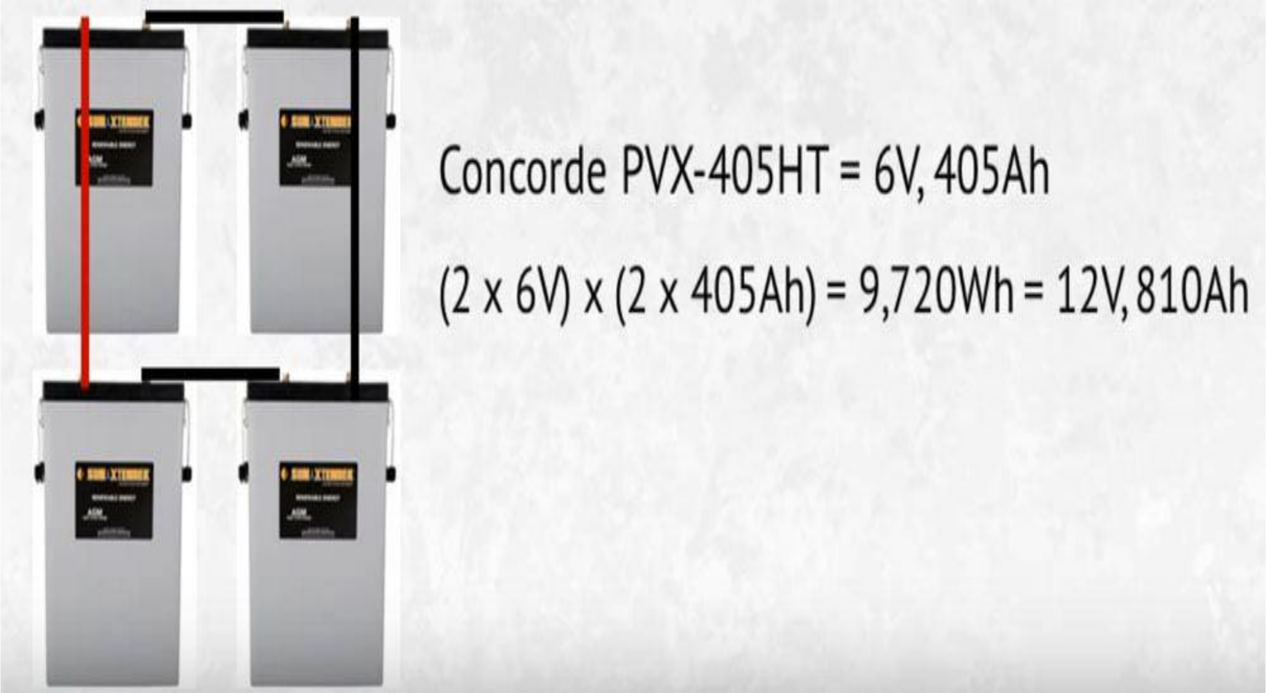
(4 x 12V) x (1 x 200Ah) = 9600Wh = 48V, 200Ah

To decide which voltage you use, you can then refer back to the other considerations of if you have any specific voltage DC loads, or if the inverter you picked requires a certain voltage.

If you did need to have a 9600Wh battery bank, as in the previous example, but you need a 12V bank for your loads, you can still accomplish this. You would want to pick a lower voltage but higher amps hour battery. 9600Wh / 12V = 800Ah.

How can we build that?

We can pick a lower voltage, higher amphour battery, like the Concorde PVX-405 at 6V and 405Ah, and wire them 2 parallel strings of 2 in series. The 2 6V batteries in series makes 12V, and the 2 405Ah batteries in parallel equals 810Ah, more than enough. When wired together, you get a 12V, 810Ah, 9720Wh battery bank.



2. Day of Autonomy

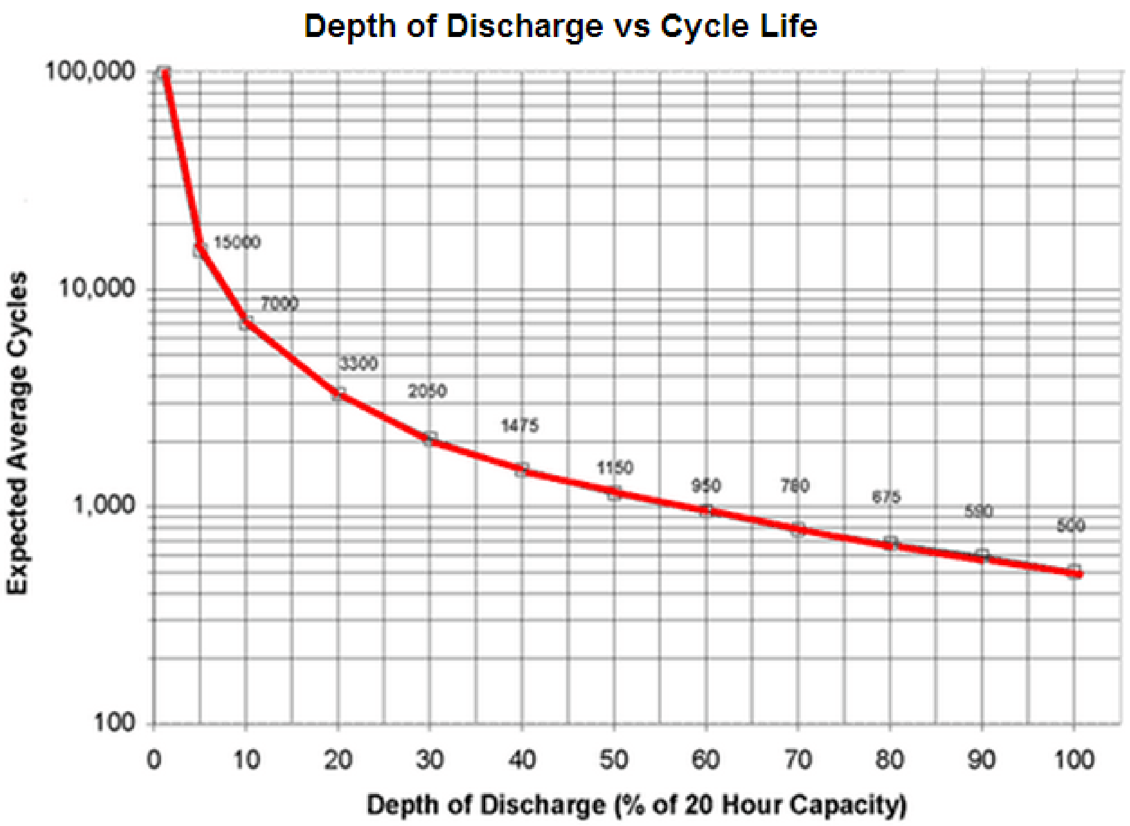
The amount of time (days) the system can operate on battery power alone with no input from other generation source (PV, wind, or generator).

Now that we’ve figured out how much power we use a day, we need to know how many days we plan on running our equipment off the battery bank if there is no sun to recharge it, or days of autonomy. This is a delicate balance, because the more days we select, the bigger, and more expensive the battery bank gets. But we don’t want to go too small either, because the less we drain the batteries, the longer the bank will live. This is where that generator I mentioned can come in handy.

For example, you could pick 3 days of autonomy, and plan on using the genny to charge up the battery bank if needed on day 4.

3. Depth of discharge

Depth of discharge, or ***DoD****, is how far down you can drain the battery.*



A lead acid deep cycle battery that is made for renewable energy systems can be drained down pretty low, but the less you drain it, the longer it will live. You'll often hear people say you can drain a deep cycle battery down to 50%. That's true, but if you do, it will last half as long as if you drained it to 20%. Each battery will have a depth of discharge chart.

You can see here that if you drain this battery down to 50%, using half it's power, you can get about 1150 cycles, or 1150 days if you do that every day. That's just over 3 years. But, if you only drain it 20%, you can get 3300 cycles, 9 years. That sounds great, except you have to remember that requires a bigger bank to use a smaller percentage. You have to balance the upfront cost of the system with how often you have to replace the batteries.

You may also hear the term State of Charge (or SoC). That is the percentage of how full the batteries are. It is the inverse of DoD. A battery that is at 30% depth of discharge is at 70% state of charge.

4. Battery Temperature

Batteries are rated at 77 degrees Fahrenheit, or 25 degrees Celsius. When the temperature gets colder than 77 degrees, the amp hour capacity decreases, but the lifespan increases. When a battery is hotter than 77, the capacity increases, but the lifespan decreases. To compensate for lower temperatures, we will need to increase capacity.

Lower Temperatures

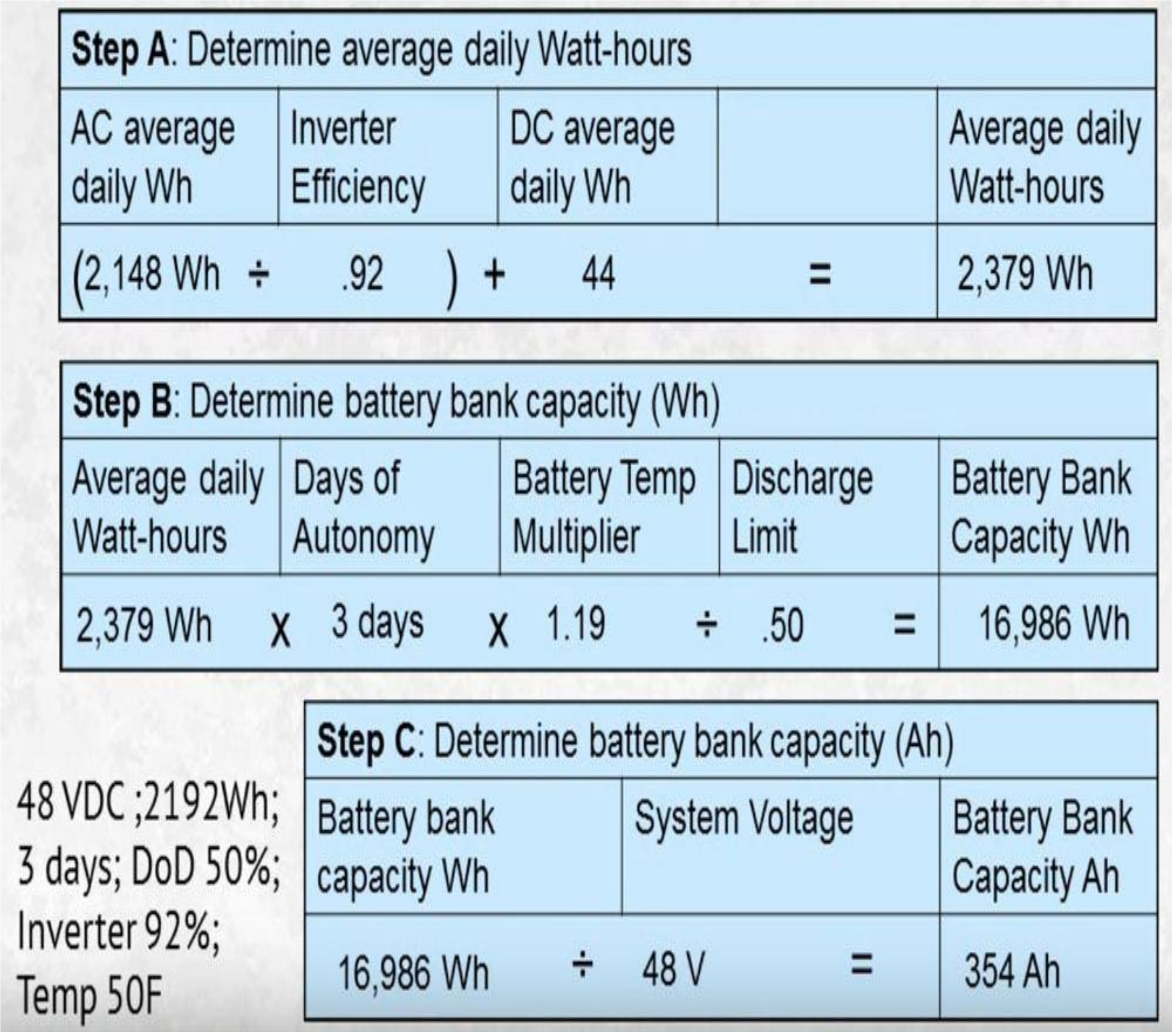
- Raise battery voltage
- Decrease capacity
- Increase lifespan

Higher Temperatures

- Lower battery voltage
- Increase capacity
- Shorten lifespan

OK, now that we know the variables, let’s do some math to figure out what size battery bank we need.

Assuming that we are using 2192Wh a day (but only 2148Wh was AC), 48V DC, 3 days of Autonomy, DoD 50%, 92% Inverter efficiency, temperature is 50F. We have:



Step A: Determine average daily Watt-hours

AC average daily Wh	Inverter Efficiency	DC average daily Wh		Average daily Watt-hours
(2,148 Wh ÷	.92) +	44	=	2,379 Wh

Step B: Determine battery bank capacity (Wh)

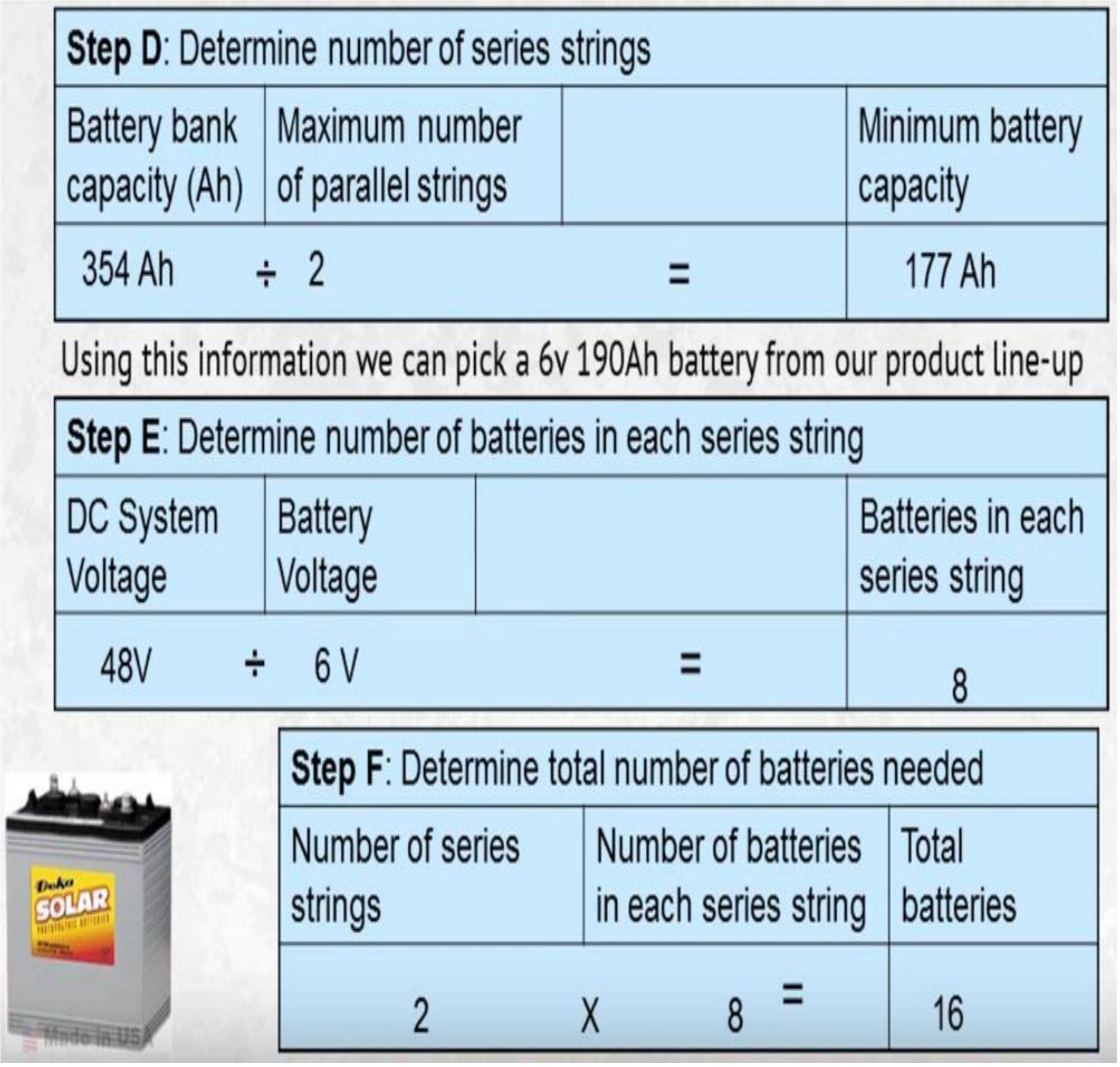
Average daily Watt-hours	Days of Autonomy	Battery Temp Multiplier	Discharge Limit	Battery Bank Capacity Wh
2,379 Wh x	3 days x	1.19 ÷	.50 =	16,986 Wh

48 VDC ;2192Wh;
3 days; DoD 50%;
Inverter 92%;
Temp 50F

Step C: Determine battery bank capacity (Ah)

Battery bank capacity Wh	System Voltage	Battery Bank Capacity Ah
16,986 Wh ÷	48 V =	354 Ah

We take our 354 Ah, and divide it by the maximum number of strings we want to use.



Step D: Determine number of series strings

Battery bank capacity (Ah)	Maximum number of parallel strings		Minimum battery capacity
354 Ah ÷	2	=	177 Ah

Using this information we can pick a 6v 190Ah battery from our product line-up

Step E: Determine number of batteries in each series string

DC System Voltage	Battery Voltage		Batteries in each series string
48V ÷	6 V	=	8

Step F: Determine total number of batteries needed

Number of series strings	Number of batteries in each series string	Total batteries
2 X	8 =	16

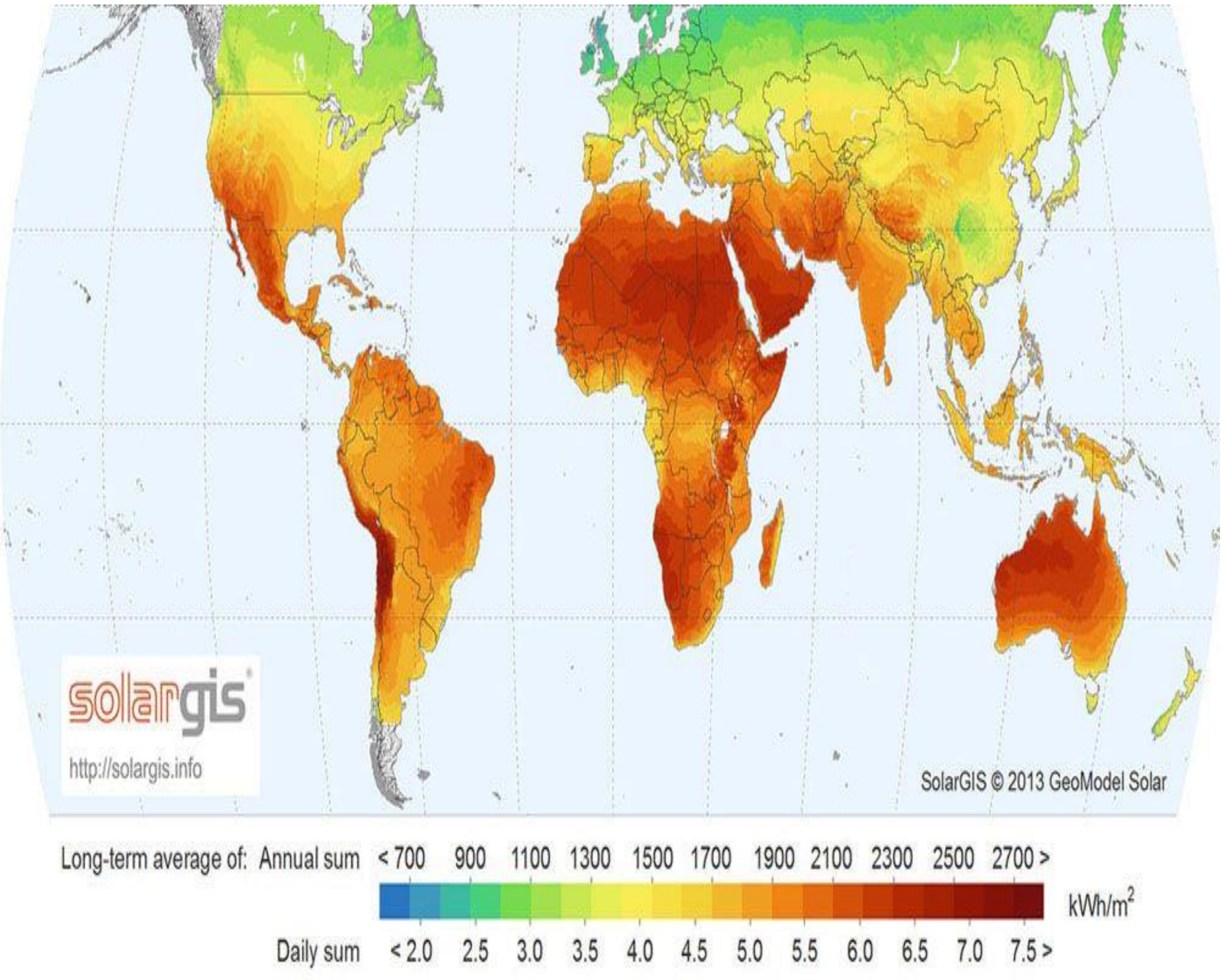
#Step3: Calculate solar array wattage

We’ll discuss the different considerations that go into determining how to size the Solar Array for an Off grid Solar System.

1. Insolation Maps: Annual Average

Insolation, also referred to as Peak Sun hours, is not the number of hours a day that the sun is shining. To deeply understand about it, read
https://en.wikipedia.org/wiki/Solar_irradiance

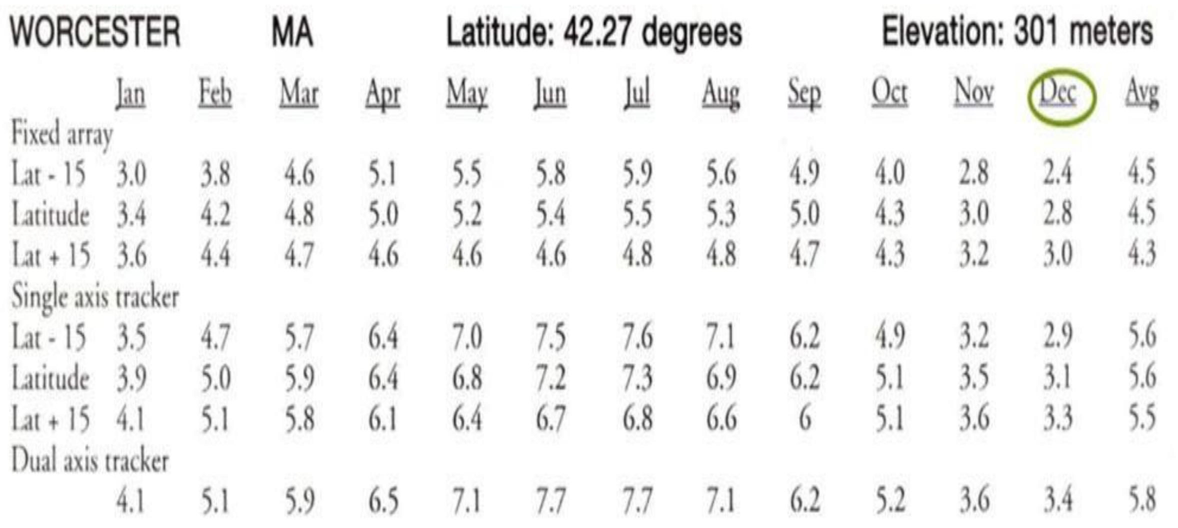
Here is Solar Insolation map of World:



You can easily find out peak sun hours of any location through the **insolation world map** that I compiled.

However, when you size an Off grid solar system, you must plan on worst case, which, unless it is a seasonal camp, would be winter. As you would imagine, the sun hours drops off dramatically in the north.

Designing my system, I’m going to look at the sun hours for December.



WORCESTER MA Latitude: 42.27 degrees Elevation: 301 meters

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Fixed array													
Lat - 15	3.0	3.8	4.6	5.1	5.5	5.8	5.9	5.6	4.9	4.0	2.8	2.4	4.5
Latitude	3.4	4.2	4.8	5.0	5.2	5.4	5.5	5.3	5.0	4.3	3.0	2.8	4.5
Lat + 15	3.6	4.4	4.7	4.6	4.6	4.6	4.8	4.8	4.7	4.3	3.2	3.0	4.3
Single axis tracker													
Lat - 15	3.5	4.7	5.7	6.4	7.0	7.5	7.6	7.1	6.2	4.9	3.2	2.9	5.6
Latitude	3.9	5.0	5.9	6.4	6.8	7.2	7.3	6.9	6.2	5.1	3.5	3.1	5.6
Lat + 15	4.1	5.1	5.8	6.1	6.4	6.7	6.8	6.6	6	5.1	3.6	3.3	5.5
Dual axis tracker													
	4.1	5.1	5.9	6.5	7.1	7.7	7.7	7.1	6.2	5.2	3.6	3.4	5.8

I’m designing my system to be tilted at 42 degrees off horizontal, I can look at the numbers for latitude, which is 42.27 degrees here. If I had it at a steeper angle, I would increase my winter production, but decrease my summer production.

Conversely, if I had it installed at a lower angle, I would increase my Summer, and decrease my winter.

Because winter in New England is pretty grim, with December going days without ever seeing the sunshine, I will be planning on using a generator when needed. But I’m still going to design this trying to optimize my solar contribution, and only use the generator when needed.

2. System inefficiencies

Let’s face it, there is no such thing as a perfect system with no losses. But in an off grid solar system, there’s a lot more than you would expect.

Due to things like soiling of the panels and voltage drop in the wire, losses in batteries and electronics, and several other factors, we’ll be losing about **1/3** of the rated power from the panels. A 100W rated panel may actually give us only 67W of usable power, or less, after all losses are factored in.

3. Minimum Watts needed

Here's the steps to calculate the minimum size array you need.

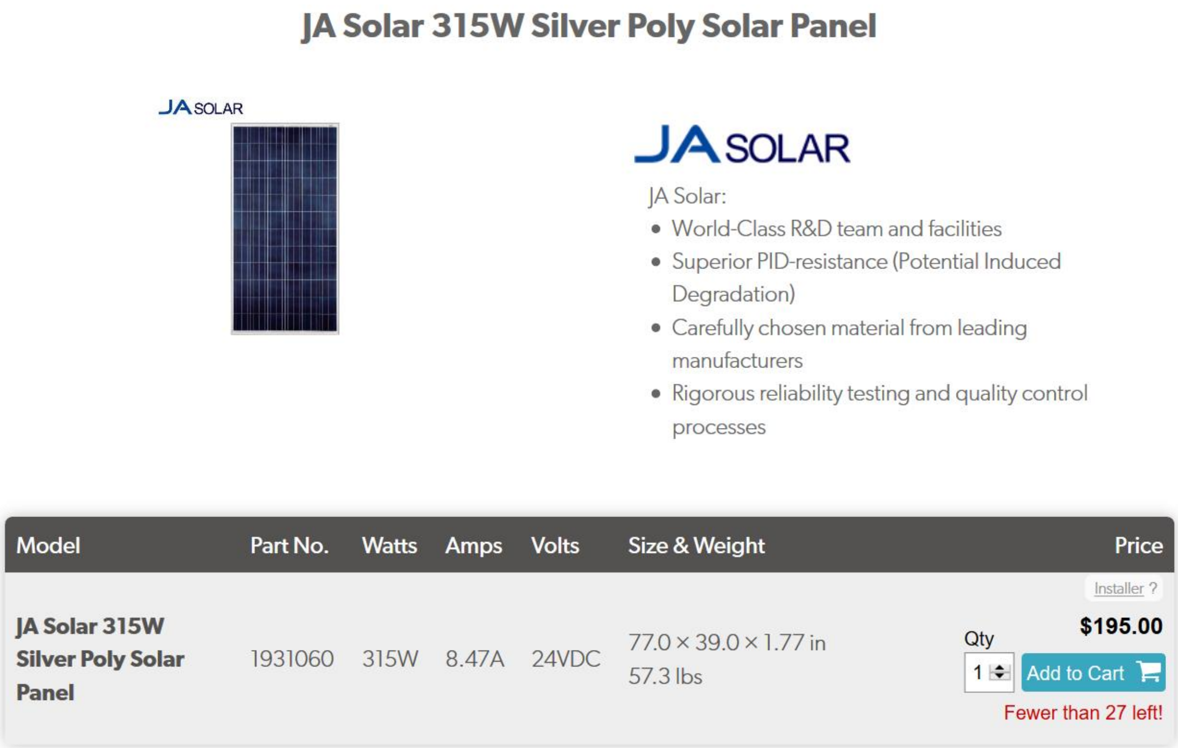
1. Start with daily Watt-hours
2. Divide by worse case Peak Sun Hours for location (typically Winter)
3. Divide by System Efficiency of 67%.

For instance, it was 2192Wh a day, peak sun hours = 2.8

2192Wh/2.8 sun hours/0.67 = 1168 W

4. Selecting solar panels

There are so many options that are available for solar panels, selecting which solar panel you use can seem daunting. For my system, I picked a nominal 24V, JA SOLAR 315W 72-cell polycrystalline module



JA Solar 315W Silver Poly Solar Panel

JA Solar:
- World-Class R&D team and facilities
- Superior PID-resistance (Potential Induced Degradation)
- Carefully chosen material from leading manufacturers
- Rigorous reliability testing and quality control processes

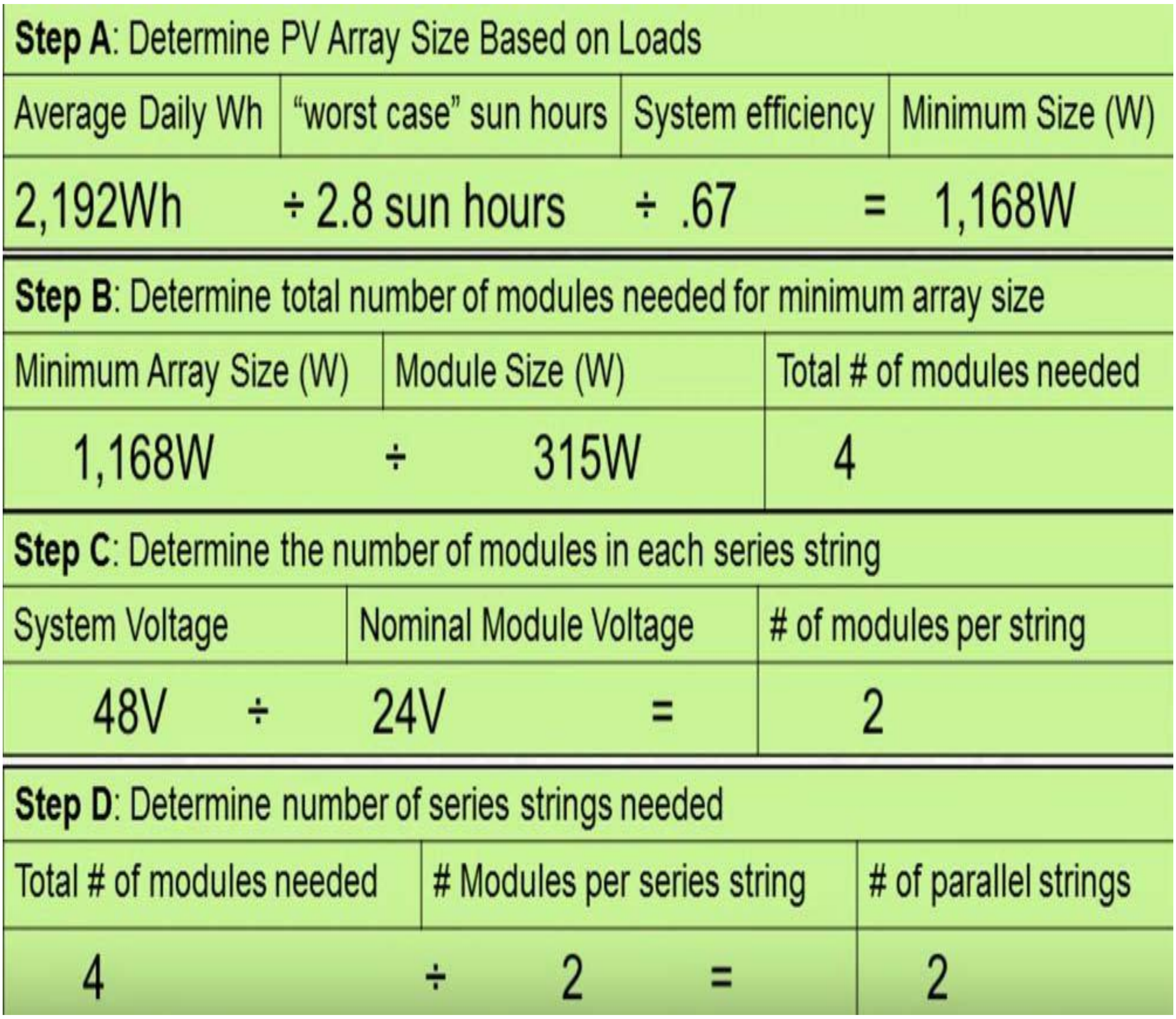
Model	Part No.	Watts	Amps	Volts	Size & Weight	Price
JA Solar 315W Silver Poly Solar Panel	1931060	315W	8.47A	24VDC	77.0 × 39.0 × 1.77 in 57.3 lbs	$195.00 Fewer than 27 left!

If the panel you select doesn't say what its nominal voltage is, you can look at the specs. A 24V panel has a Voc of about 46V, whereas a 20V nominal panel has a Voc of around 38V.

Now that we know how many watts of panels we need, and which ones we are using, the rest is pretty simple. You do need to make sure that the number of panels allows you to wire them, that the nominal voltage of the panels, either matches, or is higher than, the voltage of the battery bank.

In this example, I can wire them in 2 parallel strings of 2, which gives me a nominal 48V array charging a 48V battery bank. If I had determined that I needed 5 panels, I would have had to increase the array to 6, to allow for even strings of 2 in series.

5. Stand-alone Off-grid Solar System Example



Step A: Determine PV Array Size Based on Loads

Average Daily Wh	"worst case" sun hours	System efficiency	Minimum Size (W)
2,192Wh	÷ 2.8 sun hours	÷ .67	= 1,168W

Step B: Determine total number of modules needed for minimum array size

Minimum Array Size (W)	Module Size (W)	Total # of modules needed
1,168W ÷	315W	4

Step C: Determine the number of modules in each series string

System Voltage	Nominal Module Voltage	# of modules per string
48V ÷	24V =	2

Step D: Determine number of series strings needed

Total # of modules needed	# Modules per series string	# of parallel strings
4	÷ 2 =	2

#Step 4: Specify a charge controller

We'll discuss the 2 major types of charge controllers, and figure out how to select the right size for your Off Grid solar system, what charge controller is needed to manage that power.

1. Charge Controller Types

Charge controllers are available with 2 different technologies, PWM and MPPT. How they perform in a system are very different from each other. PWM vs. MPPT: Which type of solar charge controller is the best choice for your solar system?

An MPPT charge controller is more expensive than a PWM, and it is often worth it to pay the extra money.

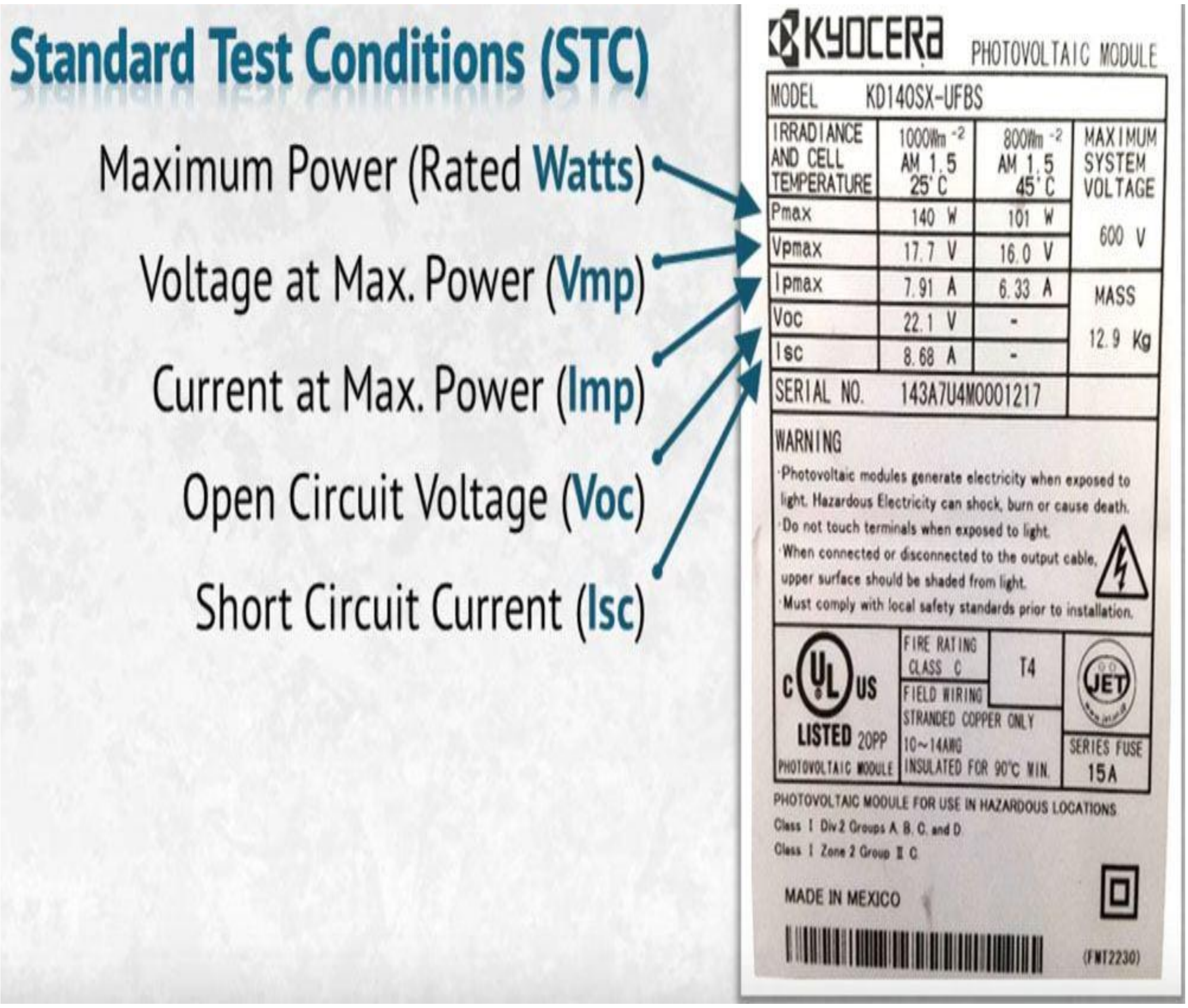
PWM charge controllers operate by making a connection directly from the solar array to the battery bank. During bulk charging, when there is a continuous connection from the array to the battery bank, the array output voltage is "pulled down" to the battery voltage. As the battery charges, the voltage of the battery rises, so the voltage output of the solar panel rises as well, using more of the solar power as it charges. As a result, you need to make sure you match the nominal voltage of the solar array with the voltage of the battery bank.

A 12V panel can charge a 12V battery. A 24V solar array is needed for a 24V battery bank, and 48V array is needed for 48V bank.

MPPT charge controllers measures the Vmp voltage of the panel, and down-converts the PV voltage to the battery voltage. Because power-in = power-out, when the voltage is dropped to match the battery bank, the current is raised, you are using more of the available power from the panel. You can use a higher voltage solar array than battery, like the nominal 20V grid-tied panels that are more readily available.

With a 20V panel, you can charge a 12V battery bank, or 2 in series can charge a 24V, and 3 in series can charge a 48V. This opens up a whole wide range of panels than now can be used for your Off grid solar system.

To determine what the specs are for a solar panel, you can look at its datasheet or the label on the back of the panel.



Standard Test Conditions (STC)

Maximum Power (Rated **Watts**)

Voltage at Max. Power (**Vmp**)

Current at Max. Power (**Imp**)

Open Circuit Voltage (**Voc**)

Short Circuit Current (**Isc**)

KYOCERA PHOTOVOLTAIC MODULE

MODEL	KD140SX-UFBS		
IRRADIANCE AND CELL TEMPERATURE	1000Wm^{-2} AM 1.5 25°C	800Wm^{-2} AM 1.5 45°C	MAXIMUM SYSTEM VOLTAGE
Pmax	140 W	101 W	600 V
Vpmax	17.7 V	16.0 V	
Ipmax	7.91 A	6.33 A	MASS
Voc	22.1 V	-	12.9 Kg
Isc	8.68 A	-	
SERIAL NO.	143A7U4M0001217		

WARNING
- Photovoltaic modules generate electricity when exposed to light. Hazardous Electricity can shock, burn or cause death.
- Do not touch terminals when exposed to light.
- When connected or disconnected to the output cable, upper surface should be shaded from light.
- Must comply with local safety standards prior to installation.

c UL us LISTED 20PP PHOTOVOLTAIC MODULE

FIRE RATING CLASS C	T4	JET
FIELD WIRING STRANDED COPPER ONLY 10~14AWG INSULATED FOR 90°C MIN.		SERIES FUSE 15A

PHOTOVOLTAIC MODULE FOR USE IN HAZARDOUS LOCATIONS
Class I Div.2 Groups A, B, C, and D
Class I Zone 2 Group II C

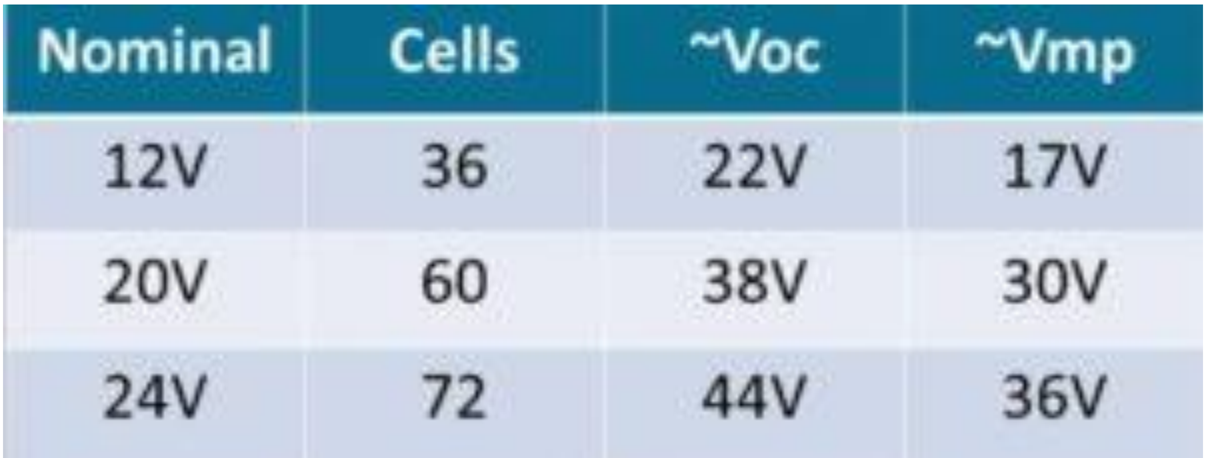
MADE IN MEXICO

(FMT2230)

When sizing a charge controller, the 2 numbers you are most interested in are **Open Circuit Voltage (Voc**), and **Short Circuit Current (Isc)**. These are the volts and amps the panel outputs when it is not connected to anything pulling it down.

2. Nominal Voltage vs. Rated Voltage

Nominal Voltage is a way to categorize battery based solar equipment. Because a higher voltage is required to charge a battery, nominal voltages are used to help see what equipment goes with what.



Nominal	Cells	~Voc	~Vmp
12V	36	22V	17V
20V	60	38V	30V
24V	72	44V	36V

3. PWM Charge Controller Sizing

Our first example is going to be one string of panels.

We check the label or datasheet and confirm with the Voc of 22.1V that it is a nominal 12V panel, and the Isc is 8.68A.

We then multiply the Isc by the number of parallel strings, 1, and multiply it by NEC’s safety factor of 1.25, to get 10.85A minimum charge controller amperage requirement.

I’ll round up to a nice 15A Morningstar ProStar 15M with a meter.

Example: **Now let’s try it with 4 parallel strings of the same 140W panel.**

Notice I’m not talking about how many panels are in each string, because I’m using a PWM charge controller, I know that I’m using the right number to match the voltage of my battery bank, I’ve got 1 for a 12V, 2 in series for a 24V, and 4 in series for a 48V battery bank.

4 strings x short circuit current x 1.25 NEC = 43.4A

I’ll round up to a nice **Morningstar TriStar 45** charge controller.

4. MPPT charge controller

If you are using the same nominal voltage panels as battery bank, the math is the exact same as with the PWM charge controller.

An MPPT charge controller can manage the same or higher nominal voltage panels as batteries. There are some “Boost” charge controllers that can take a lower voltage panel, and Boost it up to the correct voltage to charge a higher voltage battery bank.

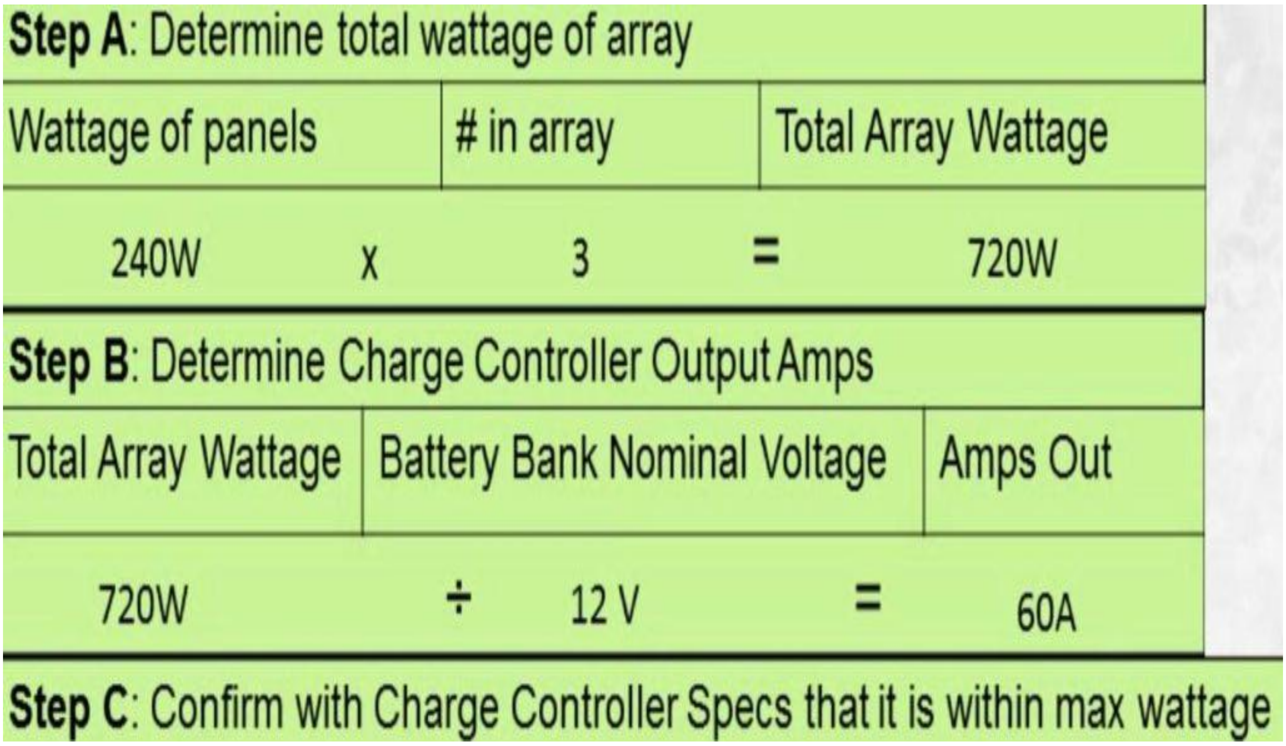
These are generally designed to take a single panel to charge a 36V or 48V golf cart. However, most MPPT charge controllers need the nominal voltage to be equal to or higher than the battery bank.

Because **W = V x A**, and the watts are constant, if the voltage drops, the current goes up.

For example, if you have a 200W panel with a voltage of 40V and a current of 5A, if the voltage drops in half to 20V, the current doubles to 10A. 200W remains the same. When the voltage of the array is higher than the battery, the charge controller will reduce the output voltage to charge the batteries, and increase the current output.

A lot of MPPT charge controllers can handle a higher input voltage that nominal 48V. This allows you to use several solar panels in series to increase the voltage in the line going from the panels outside to the charge controller and batteries inside. When you see the max voltage rating of a charge controller, that is the highest Voc voltage of the string of panels.

Let’s look at what happens when we put a string of 3 240W panels in series and send it into a 12V battery bank through our MPPT charge controller.



Step A: Determine total wattage of array

Wattage of panels	# in array	Total Array Wattage
240W x	3	= 720W

Step B: Determine Charge Controller Output Amps

Total Array Wattage	Battery Bank Nominal Voltage	Amps Out
720W	÷ 12 V =	60A

Step C: Confirm with Charge Controller Specs that it is within max wattage

Outback makes a fabulous FlexMax 60.

5. Put it all together

Looking back through our list of steps, we have everything we need to calculate the charge controller needed.

1. Load list (2192W)
2. Select system Voltage (48VDC)
3. Calculate battery bank capacity (354Ah)
4. Calculate approximate array size (1168W)
5. Specify charge controller size (V,A)
6. Specify inverter size (48V, 2000W, 6800W surge)

First: <u>PWM charge controller</u>

We need at least 1168W of solar. We also know we need to have the nominal voltage of the array equal the 48V battery bank. We will use 2 24V panels in series to equal 48V. If we use the JA SOLAR 315W panels, 1168W/315W = 3.7, which means we need 4 of the panels à 2 parallel strings of 2 in series.

Sizing a PWM Charge Controller

Total # of Series Strings	Module Short Circuit Current (Isc)	Safety Factor	Minimum Current Capacity
2 x	9.16 A x	1.25 =	22.9 A

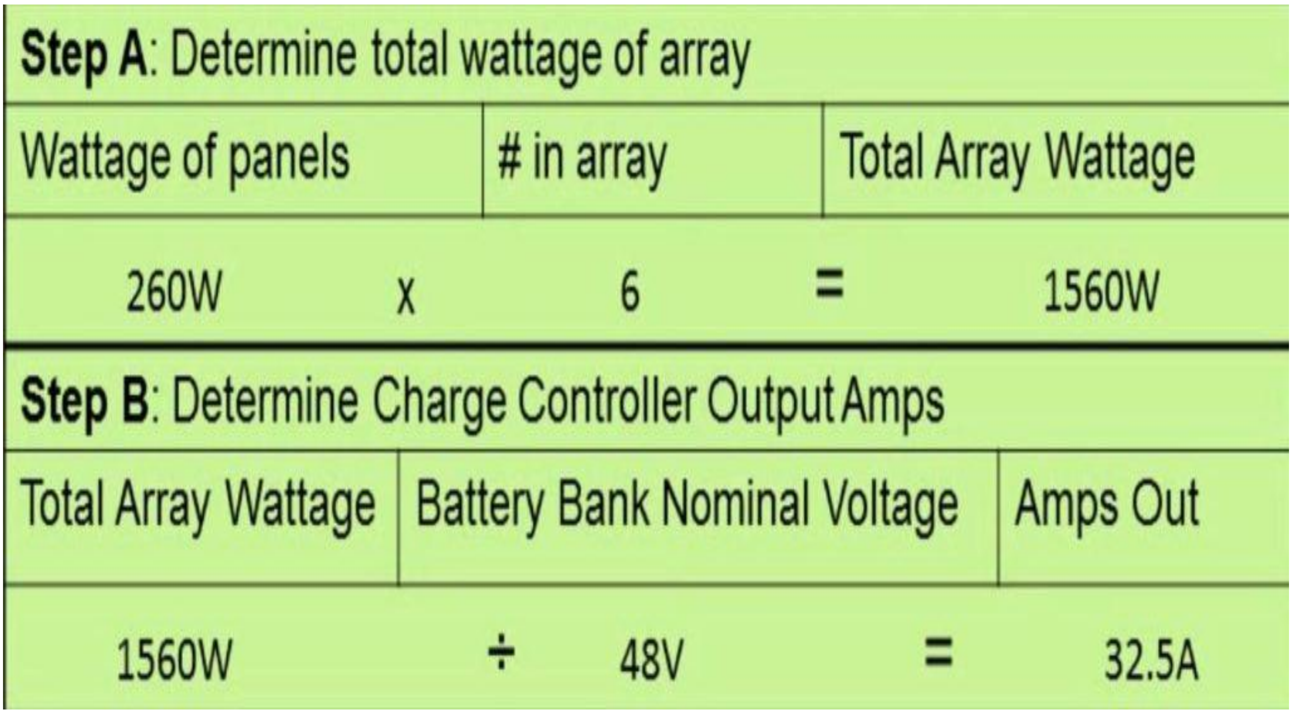
We can use a 25A or 30A charge controller.

<u>Second: MPPT charge controller</u>

If we wanted to use nominal 20V panels, traditionally used in grid-tied system, we would have to use 3 in series to get at least 48V nominal.

If we use the Kyocera 260W panels, 1168/260W = 4.5, but we know we have to do strings of 3, we have to use a number divisible by 3, round up to 6 panels. We'll have 2 parallel strings of 3 in series.

Let's look at what happens when we take our 2 parallel strings of 3 Kyocera 260W panels in series and send it into a 48V battery bank through our MPPT charge controller.



Step A: Determine total wattage of array

Wattage of panels	# in array	Total Array Wattage
260W x	6 =	1560W

Step B: Determine Charge Controller Output Amps

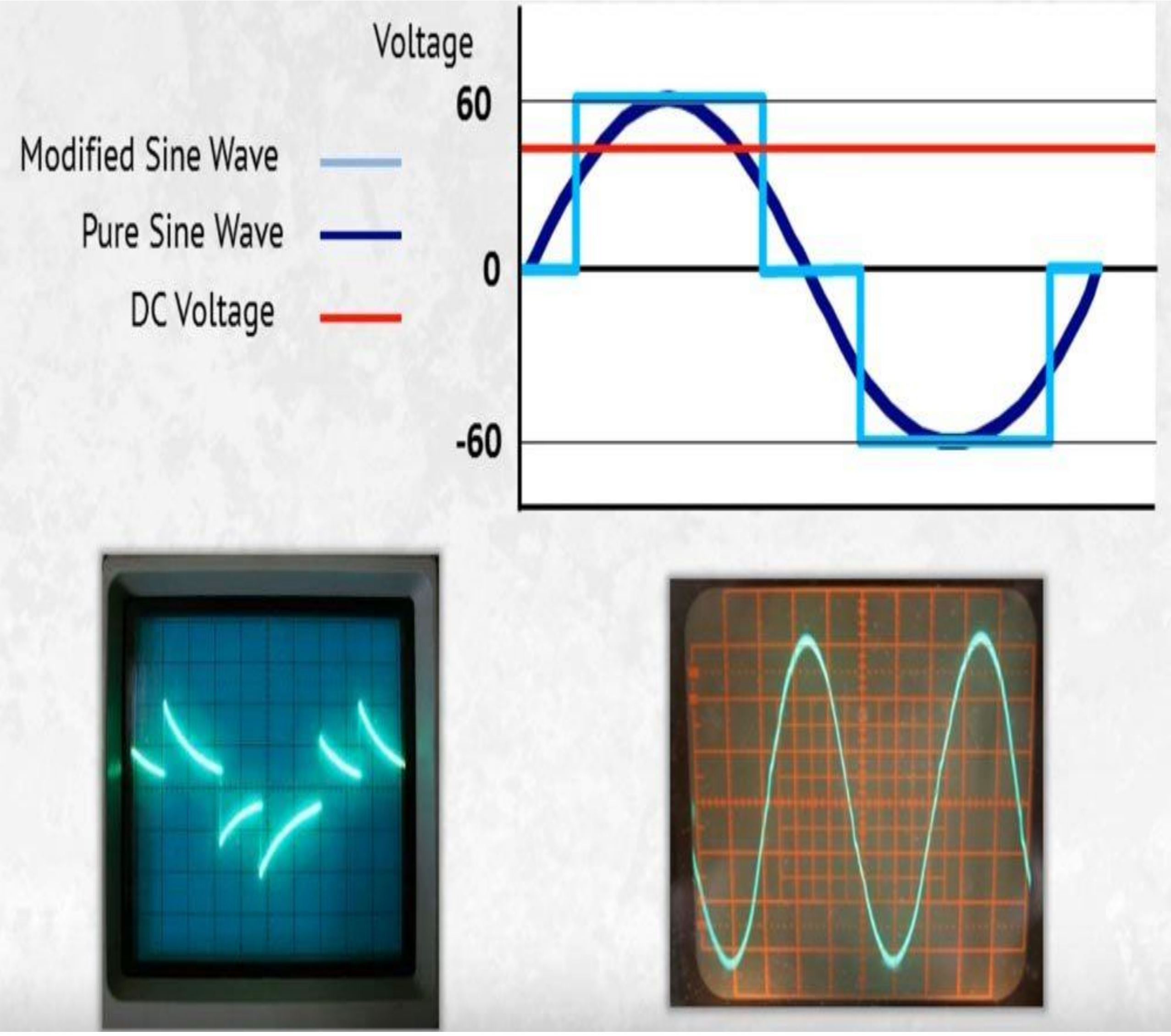
Total Array Wattage	Battery Bank Nominal Voltage	Amps Out
1560W ÷	48V =	32.5A

I can probably use MorningStar's Trisar 45.

#Step 5: Size and specify an off-grid inverter

For this final step of designing, we'll select the inverter for our off grid solar system. We're getting closer to completing the Smart Solar system. We've figured out the house loads, done the batteries and panels, the charge controller, the final component is the inverter.

1. Converting from DC to AC



The primary job of an inverter is to convert the DC (or Direct Current) power from the battery bank, as seen in the red line, to AC (or Alternating Current) power needed for most appliances.

To do that, it must take the constant DC voltage and change it to a sine wave curve that goes above and below 0 volts. When inverters first came out, the most common way to do this was to make the voltage go straight up and down, creating a blocky signal. This is called **Modified Sine Wave**, seen in light blue. More advanced Modified Sine waves make multiple steps, trying to come close to a pure sinewave. You can see an output of a modified sinewave on an oscilloscope at the bottom left. It is an approximation of a **Pure Sine Wave** shown on the right. Other than how the signal looks, what's the difference between the 2 outputs?

A Modified Sinewave Inverter

- For simple systems
- Typically inexpensive
- Fine for older TVs, incandescent light, motors with brushes
- Generally not good with: electronics, audio, induction motors, rechargeable batteries, digital clocks

Pure Sine Wave Inverter

- Mandatory for grid-tied
- Preferred for off grid homes or large systems
- More expensive than Modified Sine Wave inverter
- Necessary for electronics, florescent lights and dimmers, inductive loads to operate at their best.

2. Inverter: Off-grid (stand-alone)

Once the Charge controller has charged up the battery bank, the off grid solar inverter converts the 12, 24, or 48VDC battery bank to AC voltage. The AC output depends on your requirements, in North America you can use 120V single phase, 240V split phase, 208 or 480V 3-phase, etc.

Depending on how you wire the output of the inverter, and which inverter you get, you could have both 120V and 240V as an output. You need to determine what your loads require, and select and configure the inverter accordingly. An off-grid inverter can't sell extra power back to the grid. However, an inverter/charger can connect to the grid (if available) to act as a battery charger.

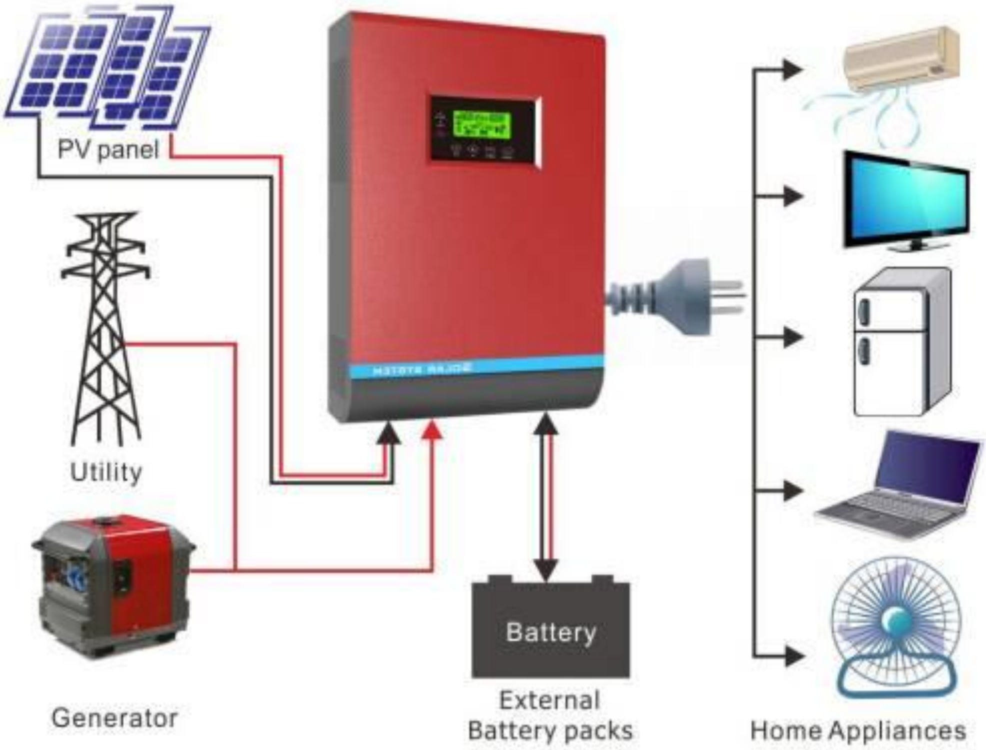
For instance, if you have a boat or RV with an inverter/charger, when you connect to shore power, you can use the grid to charge your battery bank when the solar doesn't provide enough power. But that AC connection is one-directional, it will only take from the grid, not send back. Likewise, you can often connect a generator to the AC input of an inverter charger to top off the batteries when needed. This is a common configuration for off-grid homes that need more power in the winter than the sun can provide.

3. Inverter: Feature; Off-grid and GTBB

Battery based inverters have a lot of options to choice from. Not all of the inverters have all of the features, you need to decide which features are required, and select the inverter based on which has them.

Some of the features are:

- Integrated AC charging
- Automatic generator start
- Invert transfer switch
- Remote controls
- Display
- Stackability



The ability to charge the battery bank from an AC source like the grid or a generator, even automatically starting the generator when the batteries are low, and turning it off when they are charged.

Some can automatically use the generator to assist with high loads. Since the inverter is often installed in an out of the way location near the batteries, a remote control or display in the living area is useful to keep an eye on the system.

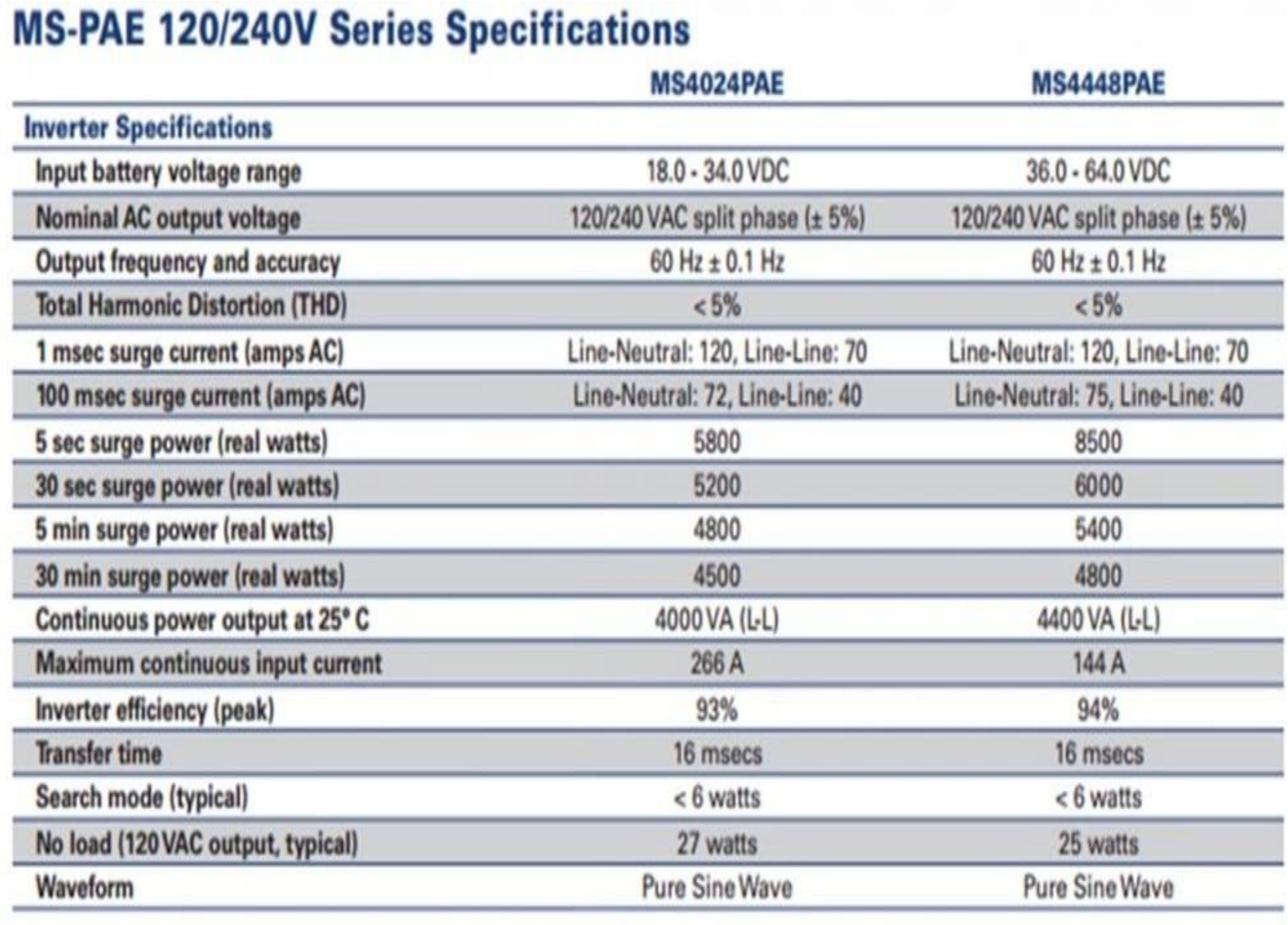
Some inverters even have the ability to monitor the system remotely via the web. This is very useful for part time locations that you are not always there to keep an eye on.

Many inverters can be stacked to increase either the voltage or the current, or both. This allows you to use multiple inverters in a master/slave configuration, automatically turning on only the inverters as needed, conserving battery power.

4. Solar Charge Inverter Selection

When selecting an inverter, there are several key factors to look for.

Looking at the datasheet of a Magnum Energy PAE series inverter, we can compare the MS4024PAE and the MS4448PAE.



MS-PAE 120/240V Series Specifications

	MS4024PAE	MS4448PAE
Inverter Specifications		
Input battery voltage range	18.0 - 34.0 VDC	36.0 - 64.0 VDC
Nominal AC output voltage	120/240 VAC split phase (± 5%)	120/240 VAC split phase (± 5%)
Output frequency and accuracy	60 Hz ± 0.1 Hz	60 Hz ± 0.1 Hz
Total Harmonic Distortion (THD)	< 5%	< 5%
1 msec surge current (amps AC)	Line-Neutral: 120, Line-Line: 70	Line-Neutral: 120, Line-Line: 70
100 msec surge current (amps AC)	Line-Neutral: 72, Line-Line: 40	Line-Neutral: 75, Line-Line: 40
5 sec surge power (real watts)	5800	8500
30 sec surge power (real watts)	5200	6000
5 min surge power (real watts)	4800	5400
30 min surge power (real watts)	4500	4800
Continuous power output at 25° C	4000 VA (L-L)	4400 VA (L-L)
Maximum continuous input current	266 A	144 A
Inverter efficiency (peak)	93%	94%
Transfer time	16 msecs	16 msecs
Search mode (typical)	< 6 watts	< 6 watts
No load (120VAC output, typical)	27 watts	25 watts
Waveform	Pure Sine Wave	Pure Sine Wave

The first thing to look for is input DC voltage. The 4024 connects to a 24V battery bank, you can see the input voltage range is 18V x 34V. Whereas the 4448 is a 48V battery bank, its voltage range is 36V x 64V. Both of these models are able to output split phase 120V and 240V, 60Hz. These can be used in North America with regular household appliances, and with larger appliances

that use 240V, like a well pump.

You can see that the 4024 can handle a continuous load of 4000W, and the 4448 can do 4400W, both of them are able to handle our continuous loads of 1938W. But now let look at the surge rating we were talking about. We calculated we need to be able to handle a surge of up to 6843W. The 4024 can handle 5800W for up to 5 seconds, but the 4448 can handle up to 8500W. That will allow us to handle our 6843W surge.

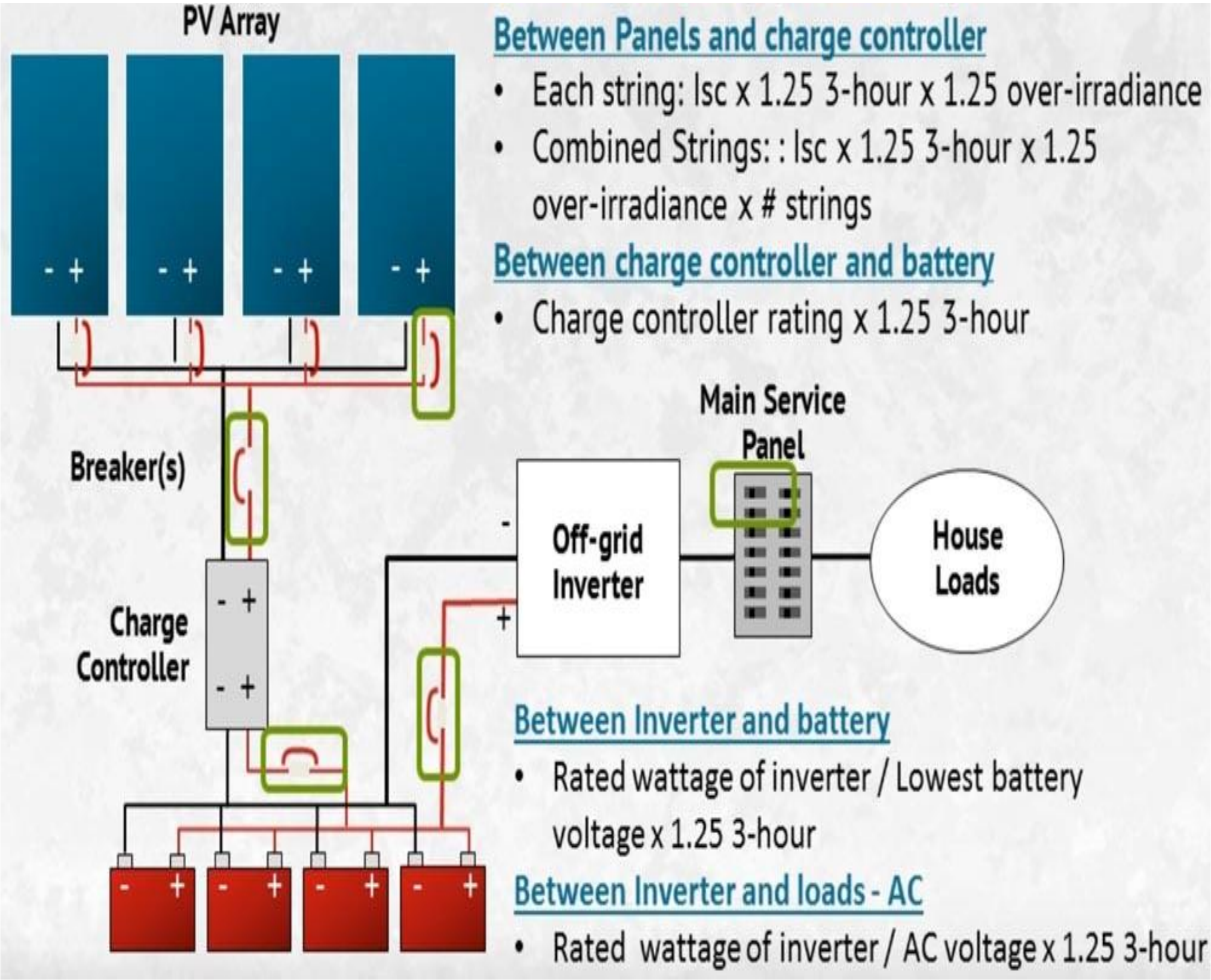
I'm picking the 48V MS4448PAE for my inverter.

5. Breaker

We've now done all of the major components of an Off grid solar system except one: "***The over current protection, or breakers***"

I'm just going to do a quick sizing of them. There are 4 main segments that will require breakers, between the panels and the charge controller, both in the combiner box and in the DC Load center, between the charge controller and the battery, between the battery and the inverter, and between the inverter and the AC loads.

You can see this image to set it up



Between Panels and charge controller

- Each string: Isc x 1.25 3-hour x 1.25 over-irradiance
- Combined Strings: : Isc x 1.25 3-hour x 1.25 over-irradiance x # strings

Between charge controller and battery

- Charge controller rating x 1.25 3-hour

Between Inverter and battery

- Rated wattage of inverter / Lowest battery voltage x 1.25 3-hour

Between Inverter and loads - AC

- Rated wattage of inverter / AC voltage x 1.25 3-hour

Conclusion

Now you can easily build and design an Off Grid Ready SMART SOLAR BOX XL, perhaps not as portable but adapted to your needs.

Thank you for reading!!!