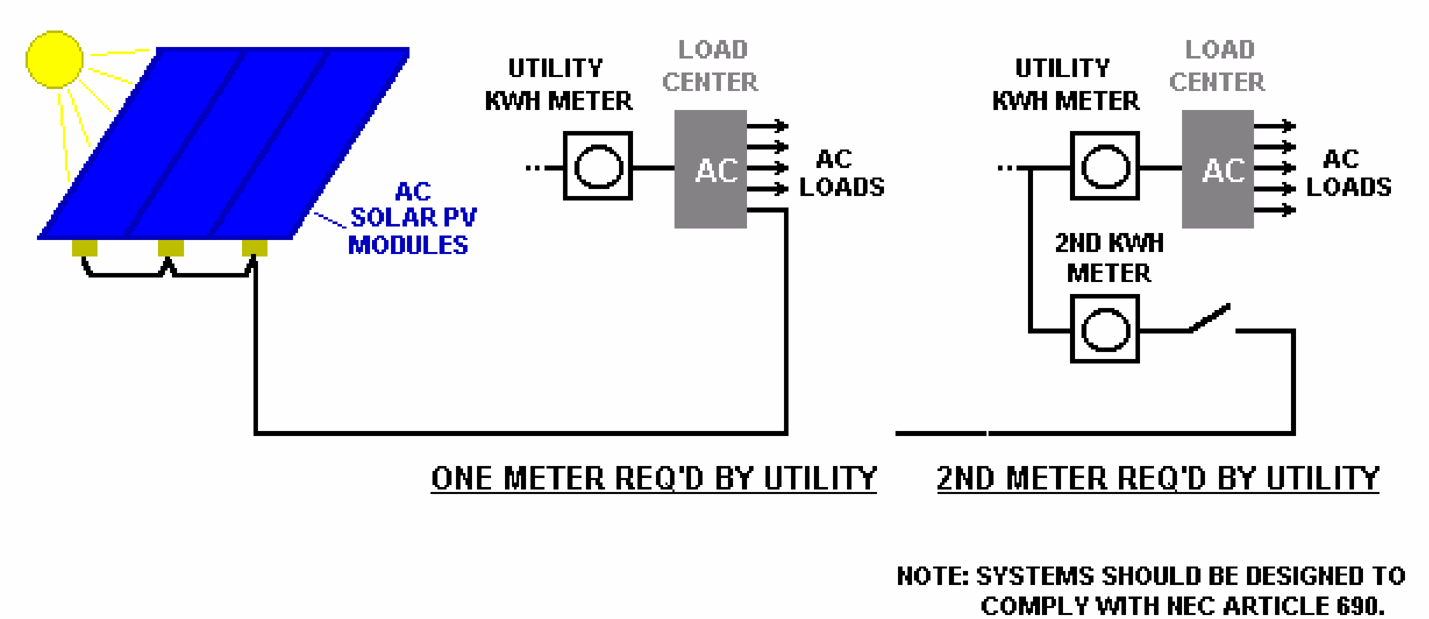
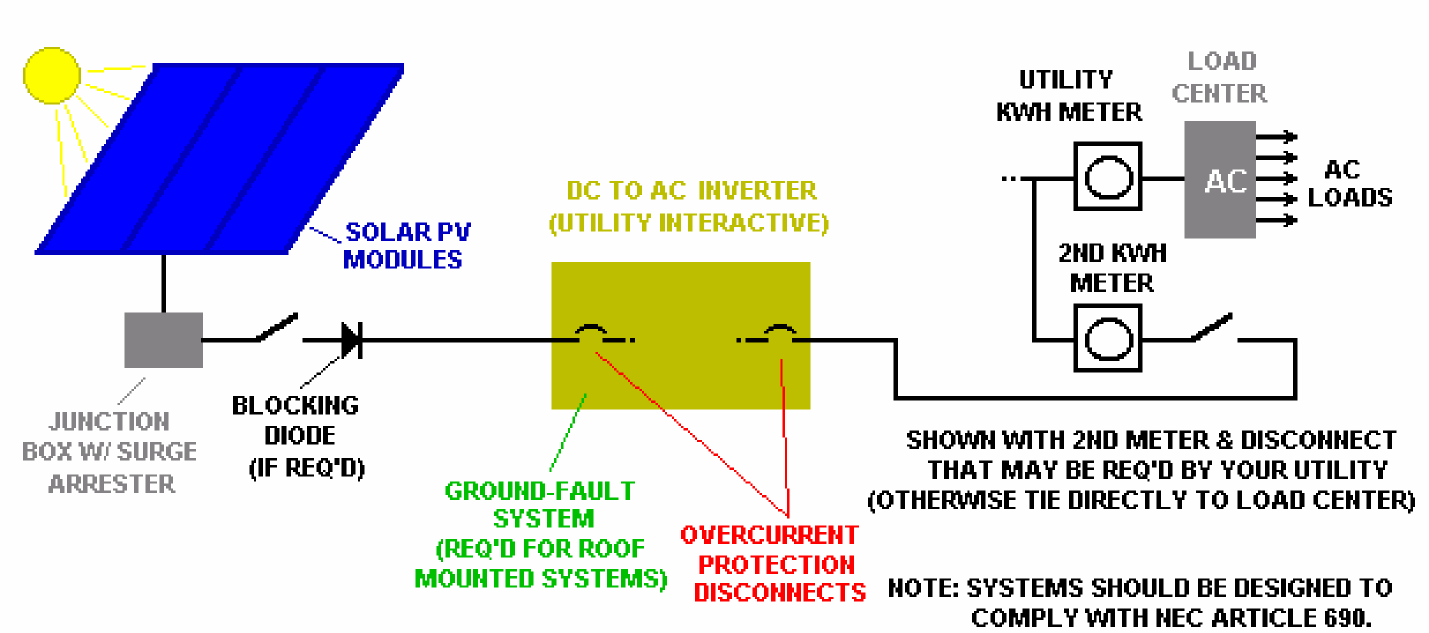
PV (photovoltaic) Basics

There are generally two types of PV systems. The first and easiest (though the least flexible) is a grid tie system where the power generated by the solar panel (panels) runs an inverter which is tied directly to the power grid on the home (or customer) side of the power meter. These types of systems are generally less expensive (per watt of installed power) than a stand-alone type of system. A big minus is that the inverter is controlled by the utility company and during a power outage; you probably won't be able to utilize the energy. A less known but equally distracting thing about these types of systems is that the utility generally "buys" your excess during off-peak periods and then "sells" you back the power during peak times (can cost 2 to 10 times more than off-peak). On the other hand, a big plus is that the required expenditure can be considerably less than a comparable stand-alone system (with batteries). The maintenance is also less, as batteries don't need to be replaced. Two configurations are illustrated below. The first one simply uses grid-tie panels with the inverters mounted directly to the panels. The second one is a little more flexible in that you can use standard panels and add additional panels when you need or want to.



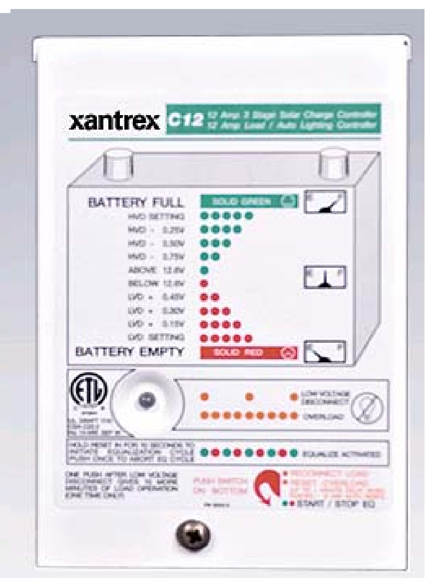


For stand-alone types of systems, you will need several basic components, which are outlined below.

1. PV panel (varying wattages available from a few watts to several hundred watts per panel).

2. A DC load center for hooking up your batteries, charge controller, and PV panels. Note that AC is not handled by your DC load center. Expect to pay between $100 and $500 for this component. The Trace DC load center pictured below is about $260 with a 250-amp DC breaker installed.

3. A charge controller is used to regulate the output of your PV array and also keep the batteries from being over-charged. Depending upon the model, it can also divert the load to another application (such as pumping water) when the batteries are fully charged and there is excess capacity. The model pictured below costs about $130 and can safely handle 60 amps (@12VDC and 24VDC) on a continuous basis.



4. An inverter is the component used to convert the DC from the PV array and batteries into usable AC power to run your household appliances. There are generally two types. The least expensive is what is called a modified sine wave. This type of inverter is OK for running lights, some types of motors and resistive type loads (electric frying pan, toaster). Other appliances such as microwave ovens and anything that uses a transformer may not operate correctly or may even be damaged by this type of "dirty" power.

The second type of inverter is true sine wave inverter. These are generally much more expensive than the corresponding modified sine wave inverter of equal power ratings. The above 2500 watt modified sine wave inverter will run anywhere from $180 (internet) to about $400 locally (Fry's). The same $400 will only get you about 1000 watts of pure sine wave power but the pure sine wave inverter will run any load that runs from your local utility. Motors will also operate more efficiently (less noise and less heat) from a sine wave inverter. A 1000-watt model is shown below and lists for about $360. A good general-purpose off-grid system can and should have both types of inverters.

5. An optional but useful component is a bus transfer switch. The one shown below has three inputs (utility, generator, inverter) and will automatically switch to between the three, depending upon which are available. The model shown below costs about $230.

6. Last but not least is the battery (or batteries). Generally, flooded lead-acid deep-cycle type batteries are the cheapest ones and offer the most amp-hours per dollar. Remember that these generally have a limited number of charge-discharge cycles and will need to be replaced regularly. Don’t, for instance, just put in enough capacity to handle one day’s worth of usage, as the batteries will most likely last less than a year under these circumstances. Instead, plan for a few days to a week’s worth of capacity. Not only will you be prepared for extended cloudy weather but you will only need to change out the batteries every four to six years. Of course a down side of these types of batteries is that they produce explosive hydrogen gas during charging and the space where the batteries reside must be vented with a non-explosive type of ventilator. For larger installations, a hydrogen monitor is also probably a good idea (be prepared to spend about $500 and up for a hydrogen monitor). More expensive (amps/dollar) types of batteries include SLA (sealed lead acid) and glass mat types of batteries. The sealed lead acid batteries normally don’t vent the hydrogen gas during charging but can under extreme conditions and this must be accounted for when choosing a mounting location. The glass mat types are generally the most expensive but can be classified as a dry-cell type of battery. Even when the case is cracked or damaged, the electrolyte will not spill. They can also have an extended number of charge-discharge cycles when compared to the flooded lead acid battery.

   I will add a note here about battery capacities. Generally, you may see some of the following battery ratings and each is a little different.

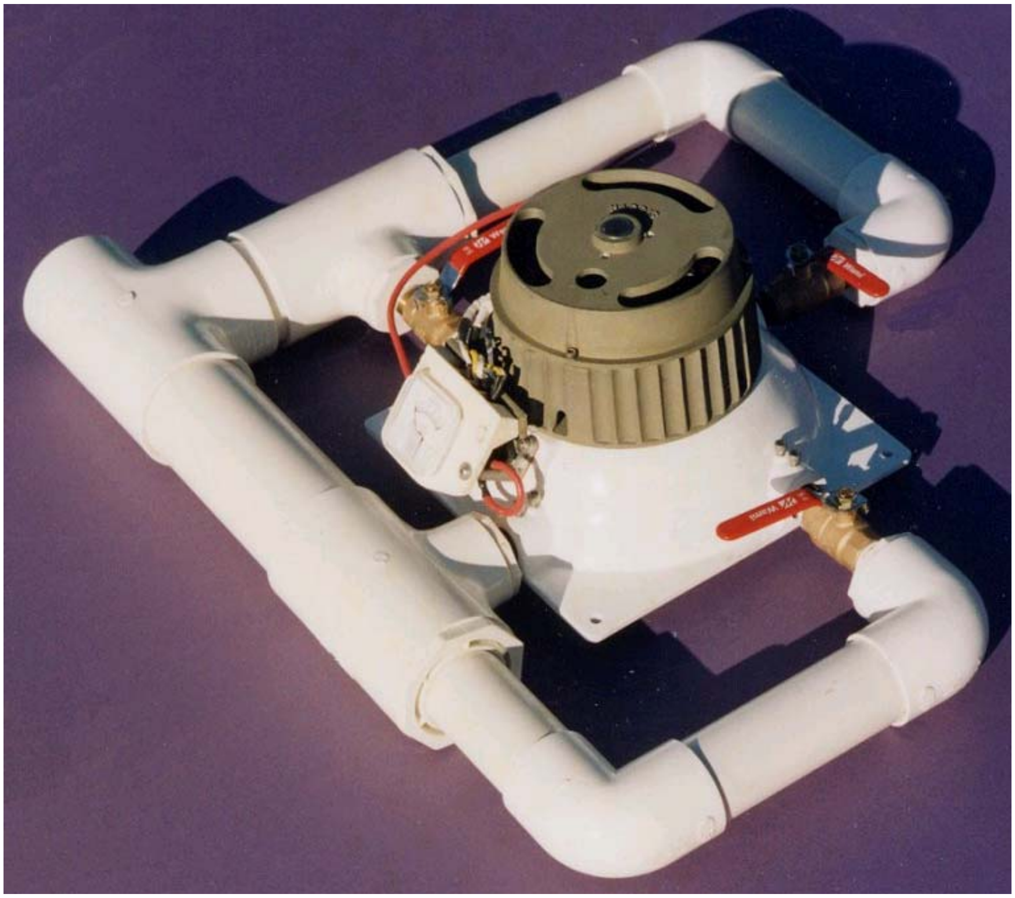
   - 20 hour rate: This is the amp hour capacity of the battery if it is discharged to 80% of the full charge terminal voltage over a 20 hour period. For a 100 amp-hour battery, the most you can discharge per hour is 5 amp-hours or about 60 watts. If you discharge at a higher rate, the actual capacity of the battery is diminished. If you discharged at 100 amp-hours, for instance, the battery will only last about 30 minutes.
   - 25 amp-hour reserve: This is the battery capacity in minutes that the battery can sustain a 25 amp-hour load until the battery reaches 80% of the full charge terminal voltage (battery considered dead at 80% terminal voltage or 9.6 VDC for a 12 volt battery).
   - Cold-cranking amps: This is the maximum amperage the battery can sustain over a 25 second period with an ending terminal voltage of 7 volts.

Interestingly enough, when you consider the total battery capacity, the 20 hour rating for a 100 amp-hour battery is about 1200 watts. The same battery capacity in cold cranking amps is only about 34 watts!

Other Components That Should Be Considered

With a relatively large PV array installed, you can also "sell" excess power back to the utility that they must buy from you. The trick is to sell it back to them when you want to sell it and not when they want to buy it. For instance, with a grid-tied array, you sell excess power to the utility during off-peak hours. The utility uses this excess capacity to do only one thing: pump water! That's right, they pump water to either a reservoir or water tower when the electricity is cheap and then use the potential energy of the water to run a turbine to offset the more expensive peak times. You can actually do the same thing, especially if you already have the property with an elevation change, a pond, or both. If you also have a fast moving stream, there are other options as well to supplement your off-grid power system.

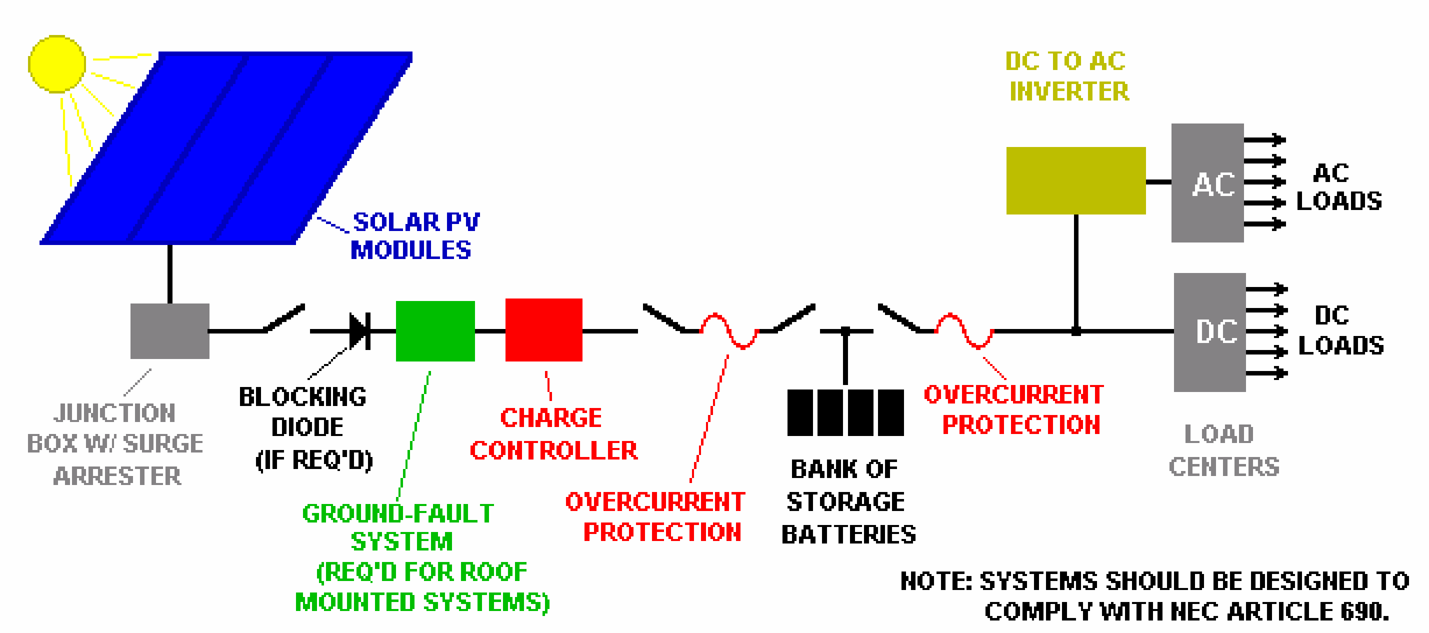
Below is a simple hydroelectric generator that is available for between $850 to about $2K, depending upon options.



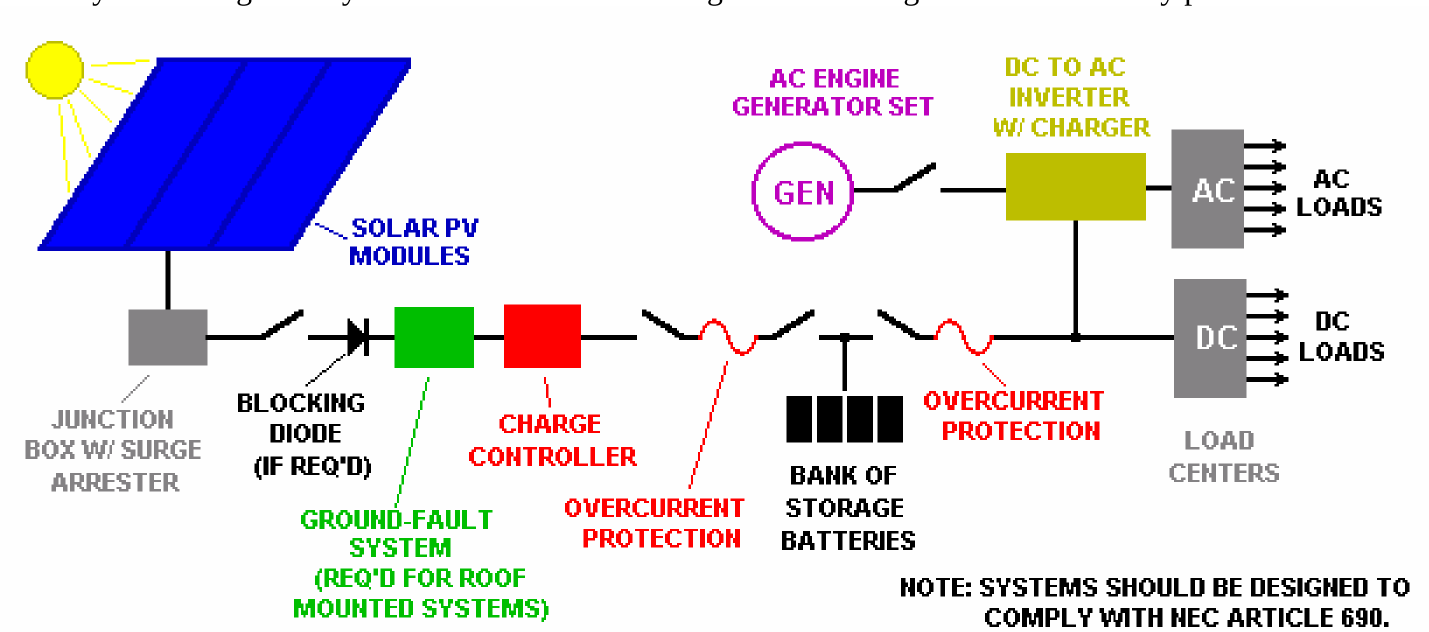
This one can generate about 2500 watt-hours. Bigger models are available if your needs are larger. A fast moving stream can be used with the following type of generator if this resource is available at your location.

You can also supplement with wind (not a viable option for this location). Lastly, consider the following type of human-powered generator for use when all else fails. This generator, coupled with highly efficient lighting and refrigeration, can keep you going with nothing else is available.

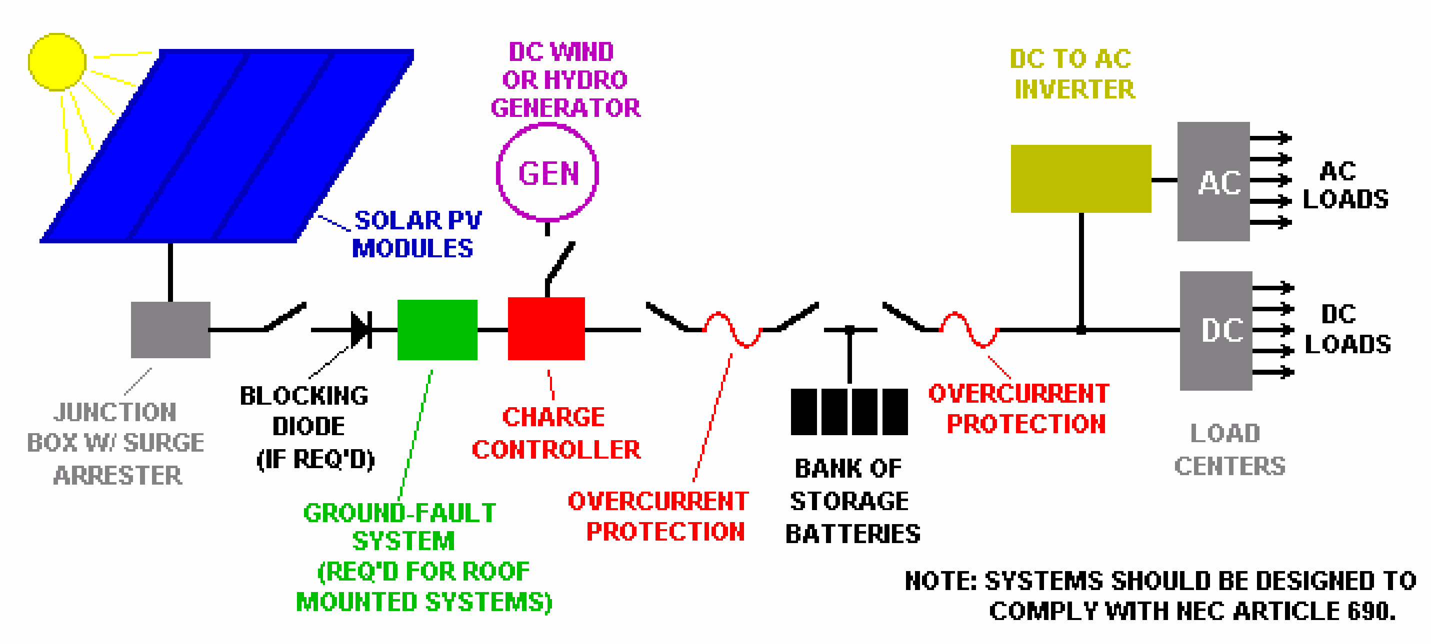
Here are some ways of hooking up a PV system. The first one is the simplest but illustrates all the key components.



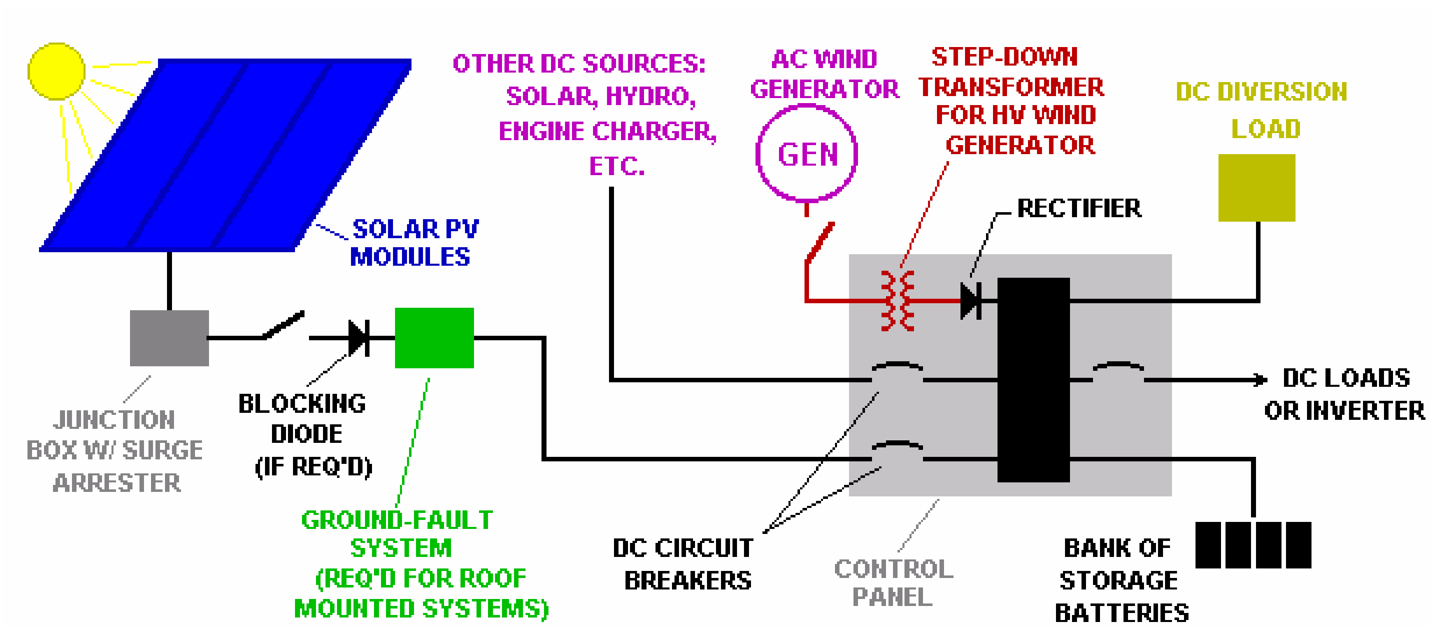
Note that this system doesn't allow for selling your excess capacity back to your local utility. The next setup allows you to charge / run your electrical needs from a generator during an extended cloudy period.



Here, the generator is simply hooked to an inverter with charging capability. These types of inverters generally have AC pass-thru as well so that the generator is hooked to the AC load center via the inverter. This hookup scheme has limited flexibility. The next diagram illustrates a more flexible hookup for your generator. It can also be used for hooking up other alternative energy sources, such as wind or hydroelectric. Note that here, the AC or DC alternative sources are run thru the charge controller, which allows for more alternatives in the choice of your inverter.

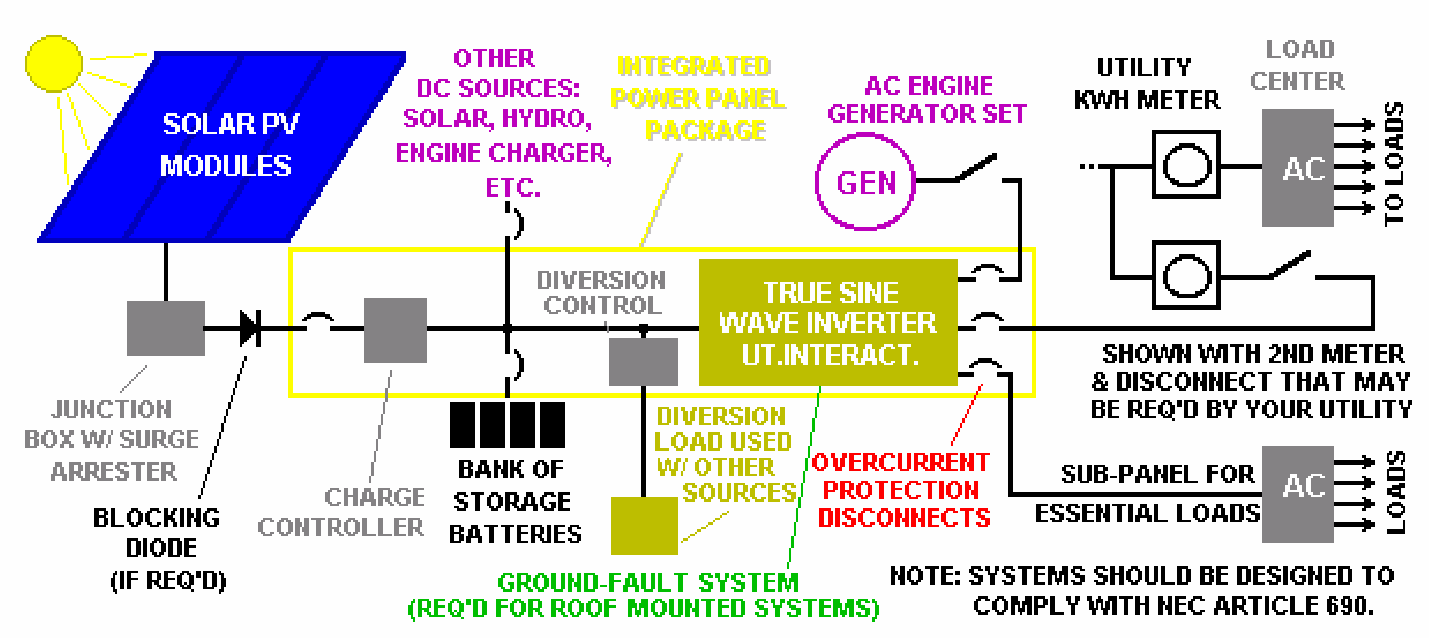


You can also buy prepackaged control centers, which have the inverter, charge controller, and load centers assembled into one box. A hookup for a typical control box is shown below.



Here, a DC diversion load is used. Diversion loads are important, especially when using a hydroelectric or wind generator. The diversion load protects these types of generators from over-spinning when the load is too small. These loads are generally resistive and can be used to heat water or run incandescent type lights.

The last hookup pretty much covers all bases, including selling of excess capacity back to the utility.



Safety

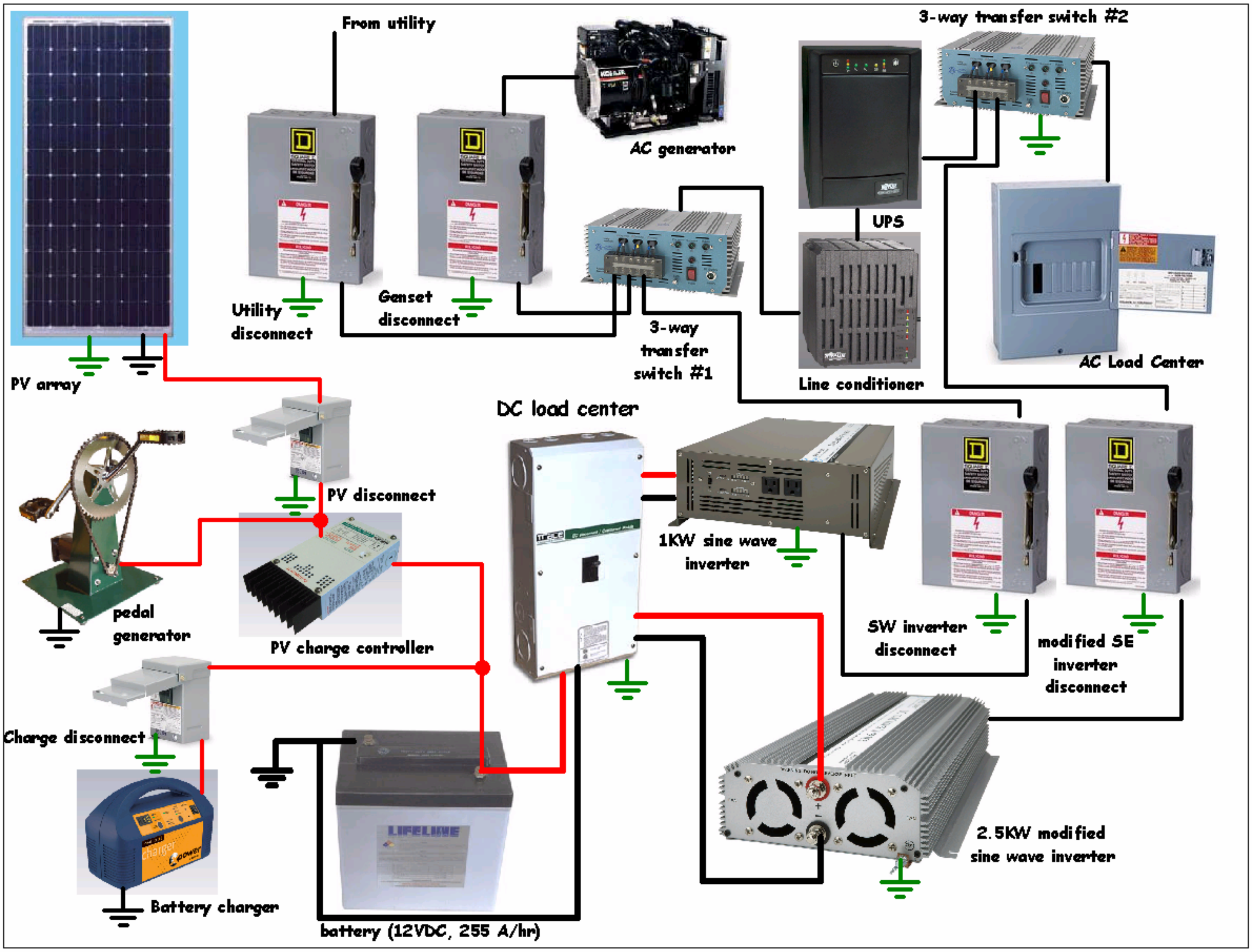
It's always a good idea to include a disconnect (DC or AC) for each generating component of your system. The disconnect should be as physically close to the generating component as practical. If the disconnect will be located outdoors, then ensure that the enclosure is rated for exposure to the weather. Some typical AC and DC disconnects are shown below.

Also note that if your PV panels will be mounted above the ground (roof mounted for instance), then a ground fault circuit and lightning protection circuit will also need to be installed.

Systems

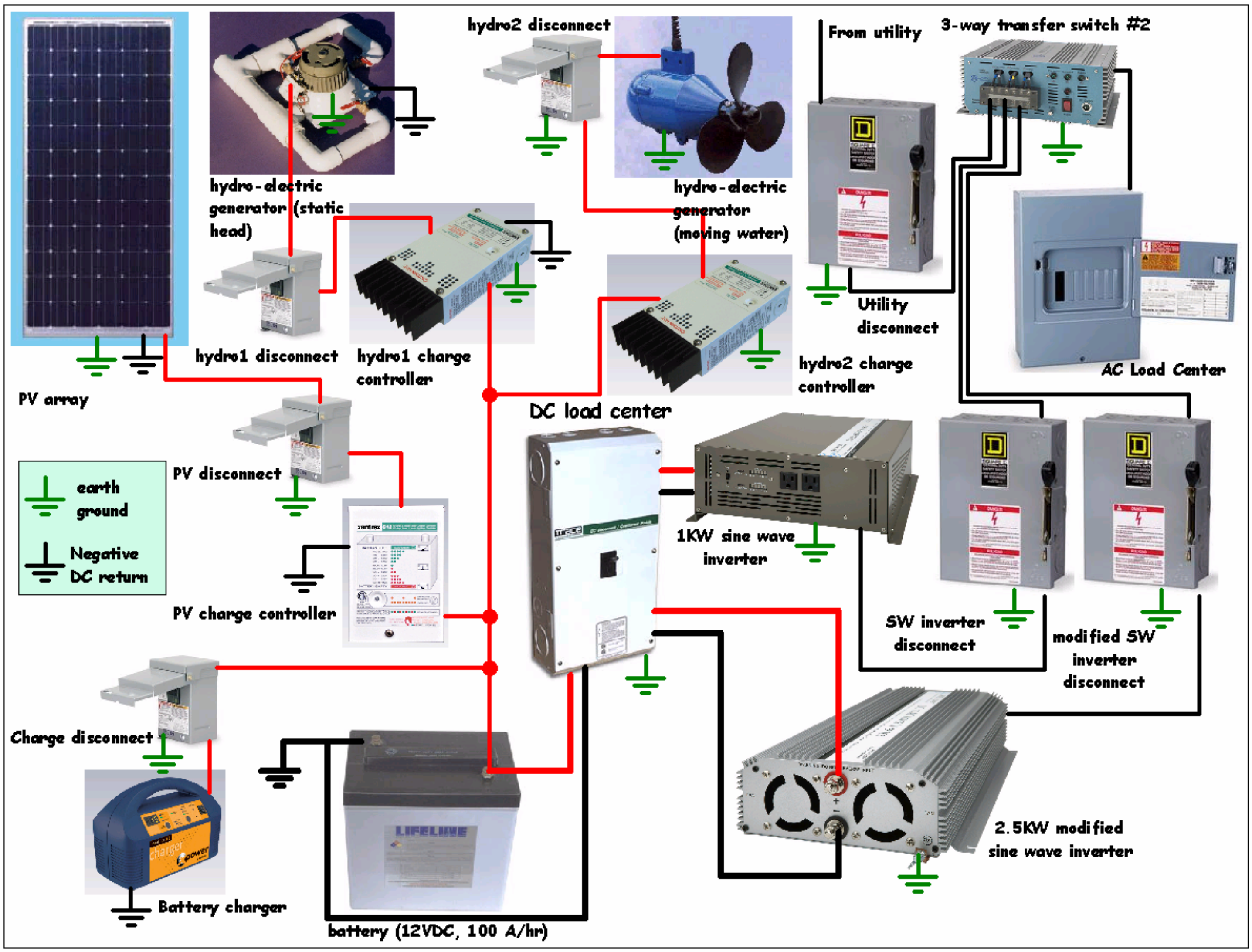
A couple of systems are illustrated below. Note that these represent only two of countless hookup possibilities with the components discussed thus far. Note also that wind generation wasn't discussed, as our area isn't conducive to any appreciable power generation from wind. Note also that although the hydroelectric generators shown are hooked up to provide DC, the same can be ordered to directly produce AC. Each system also has a hookup to your local utility but isn't depicted to enable selling excess generation capacity back to the utility grid. For off-grid type applications, the utility disconnect and associated wiring may be omitted.

The first system relies mainly on AC type generation devices to provide the bulk of the service while allowing DC to provide limited AC during brief power outages and to allow the gasoline or diesel generator to start and warm up prior to supplying the AC loads.

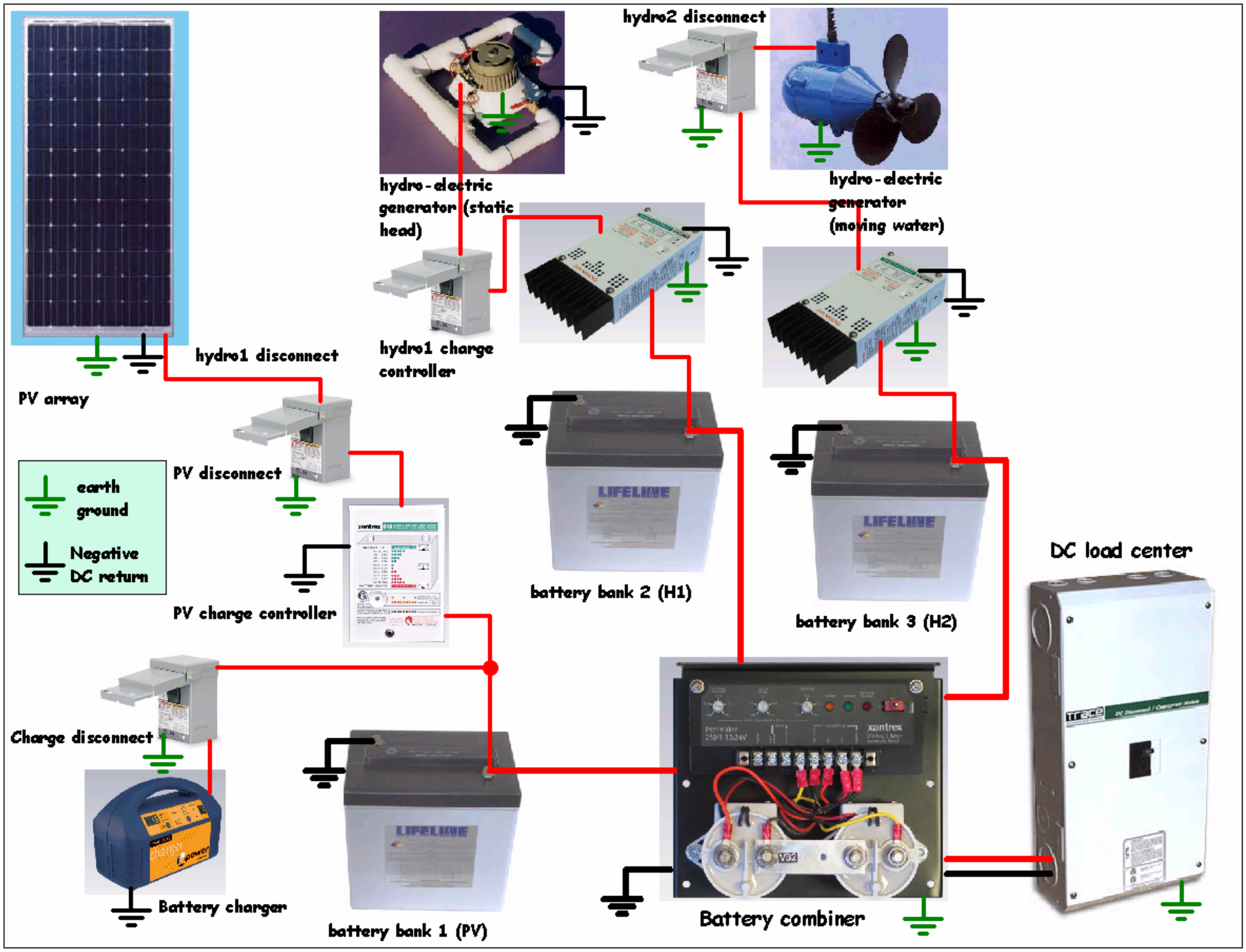


Note that the load center is separate from the main AC load center for your home. This load center should be wired to run only your essential electrical needs. These can generally be added by an experienced electrician without the need to go into the walls. Existing outlets can be split in the box and another set of wires run to the essential load center. These loads will then run continuously during a power outage from either the inverter or the generator. Also note that most modern inverters can run continuously as their idle power consumption is only a few watts. This allows the system to operate as a large UPS until you either start the generator manually or you generator controller starts the generator automatically. Note also the UPS and line conditioner illustrated above. These are optional components that are in place if you choose to not have your inverters running continuously (which will decrease the lifetime of the inverter). Here, the UPS supplies the essential loads until you can start the inverter and / or generator. The line conditioner also provides spike and surge protection (as well as brownout protection without having to start the generator or inverter) for all your AC sources since a compressor can generate a spike even when you aren't connected to the utility grid. Also note that only one DC charge controller is used for your PV system and another DC source (a manual pedal type generator is shown in the example). Battery capacity can also be small, especially if the main power source during a power outage will be a generator. Here, the battery capacity should be large enough to supply your essential loads for five to ten minutes and also large enough to store about two days of output from your PV array. However, increasing the battery array size and PV array output can enable your system to run from the battery for more extended periods, such as when you need to perform routine maintenance on your generator during an extended power outage. Lastly, the battery voltage and amp-hour ratings as depicted in the diagram are just an example and probably will not meet the requirements of your particular home.

The second system depicted below relies mainly on several DC type sources to provide AC. A utility connection is present but a generator can be hooked up for true off-grid applications. Again, the battery specifications depicted are for example only and aren't representative of what your particular requirements will be.



Note here that each DC source now has it's own DC charge controller. The above illustration allows the use of only one DC source at a time. A more flexible DC hookup arrangement is shown below. Here, each DC source has not only its own DC charge controller but also its own battery (or battery bank). Note also that the battery combiner can be replaced with a simple three or four-way battery switch. If you use a battery switch instead of the combiner, you should ensure that each battery bank is identical in size (amp-hours) and battery type. The battery combiner allows you the flexibility of using different size battery banks depending upon the DC source and can allow you to save money by allowing you to optimize the battery bank to each source as opposed to having three identical battery banks sized to the largest DC source requirements.



Note that connections on the other side of the DC load center are the same as in the single battery bank setup.

A Note About Inverters

The inverters illustrated above are just two of the many types and sizes of inverters available. Usually, the higher the power rating, the more expensive and heavy the inverter is. Also note that pure sine wave inverters are larger, heavier, more expensive, and less efficient than their modified sine wave counterparts of equivalent power rating, but operate inductive type loads (motors or any appliance that contains a transformer) much more efficiently than a modified sine wave inverter. Also note that modified sine wave inverters can actually damage some types of sensitive equipment, especially medical equipment.

My inverter system is perhaps a little different than most; both in terms of complexity and purpose. I have one of the Aims 1KW sine wave inverters and your no-frills 2.5KW inverter as well. The 2.5KW inverter is hooked up on the DC side to a 250-amp DC breaker while the 1KW inverter is hooked up to a 100-amp DC breaker. The large inverter has an AC disconnect along with a small 30-amp load center. I re-wired the inverter to bypass the installed outlets and installed a 5R-30 30-amp receptacle as this allows the full output to be utilized by a single large load or several smaller loads. A mating plug runs from the disconnect. For the 1KW sine wave inverter, I also have an AC disconnect which is hooked up using the installed outlet on the front panel. The loads plug into a Tripplite line conditioner, which gives the inverted output boost-buck capability. The system is designed to allow the use of most appliances (except heating / AC) in the event of a power outage. The 2500-watt inverter is used for luxury items, such as the microwave and toaster oven. It's nice to be able to use these things when the lights go out for everyone else and still have lights too! The 1KW sine wave inverter is used to run a TV and is used in conjunction with a UPS, which keeps a light and the TV going until I can start the inverter and transfer the load with a manual transfer switch. The DC side of things is a little more involved as well. I have three of the Optima 34M batteries, which are hooked up to a Xantrex battery combiner and a Xantrex system monitor. I also have a small PV panel with a Xantrex C-12 charge controller that can be used to charge the batteries in addition to the Xantrex battery charger. Although everything is kind of spread out in a spare room, I plan on mounting all the components and batteries on a cart, which I can then role to where it's needed. I also plan to add one of your 3-way automatic bus transfer switches to the system in the near future. The basic system is pictured below.