Photon Exchange



# Small Solar Power Systems

# PHOTON EXCHANGE

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# Introduction to Solar Power System Design

*Five billion years of fuel remaining in our sun. What is the best way you can think of to use some of it?*

Photovoltaic power systems installed in remote locations are a form of distributive power generation where the energy is consumed in the same area it is generated. Photovoltaic power systems also have proven to be a reliable and cost effective solution in supplementing grid power and powering remote locations where the grid is not accessible. There are no consumable fuels that need to be transported and they require minimal maintenance. One barrier to photovoltaic power systems is the high capital cost associated with the solar panels, batteries, and electronics. Installing photovoltaic power systems requires paying up front for years of usable energy.

ICON KEY

- ✏ Design calculations
- 🕮 Important information
- ⚒ Maintenance
- 🗀 Notes
- ✹ Warning

This document was written not just for an individual design, but also as a learning tool to explain the design process for photovoltaic power systems in general.

The "icon key" on the left clarifies the type of information being presented. For example; all of the information given after the ✏ symbol is Design Calculations methodology.



The "icon key" was designed to highlight the type of information presented. Included in the key were the categories deemed essential in this type of document. There are some generic maintenance topics discussed within, but not to the detail required to perform required maintenance. Therefore, the detailed steps required to maintain a specific design will need to be included within the operational manual for that design.

## Socio-Economics of Photovoltaic Systems

The key element required for a nation to advance technologically or industrially is the access to reliable cost-effective energy. Readily available and inexpensive energy sources allowed developed societies to go through their industrial revolutions. These energy sources were first coal and then were expanded to include oil based sources. This development was further expanded by importing energy sources from under developed countries that lacked the science and technology to fully utilize these resources. We all know the era of low cost fossil fuels is over. In the 1960s, the cost of a barrel of oil was in the $2USD range. Oil producing counties have learned that oil is a limited resource and have pushed the price of oil to over $100USD per barrel.

The argument has been made that individuals and industry in developing countries have to pay more for their energy cost than their counterparts in developed nations. This inequity is a large barrier for personnel and national development. This argument is invalid. In the highly developed European nations, electric prices range from $0.19-0.43USD/kWh compared to 0.22USD/kWh in Rwanda. European's pricing for a liter of fuel is in the $2.00-2.40USD/l range with the highest per liter price I have seen in Rwanda of $1.63USD/l. There are two very valid arguments that can be made. First, expanding the energy sources and the infrastructure required to distribute this energy is a tremendous hurdle for developing nations. And second, the public and private sector not serviced by the existing infrastructure pay extremely high energy prices.

Individuals, public institutions, and the commercial and industrial sectors of developed nations have close to 100% access to a reliable energy infrastructure. This electric, fuel, and gas infrastructure was build during the era of low-cost fossil fuels. Economic growth requires additions, but they are small compared to the overall generation capability. If you add a 100MW electric generation to the United States' 4,400TWh yearly combustion rate, that is an increase of 0.02%.

Developing nations do not have the established infrastructure or the generation capacity to provide access to everyone. Presently about 6% of Rwanda's population is connected to the grid. Most of these individuals are centralized near cities. To expand the electric distribution network to 100% of the population would be an increase of over 94%, not to mention the required additional generation capability. Nevertheless, adding 100MW of electric generation would be enough energy to power 3 – 800W CFL all night in 2.5 million homes. The point is what would be a small change in a developed nation can make huge impact in a developing nation.

Individuals who do not have access to the national electrical grid get their required energy from biomass, kerosene, candles, and/or batteries. Kerosene is the most prevalent for lighting. Each year between 37-38 billion USD is spent on kerosene lighting. Stated figures for individual household spending a year on kerosene are in the $60-114USD per year range.

A kerosene lantern consumes about 0.05 liters of kerosene per hour. At this rate of consumption, its output is about 10 lumens. Kerosene costs about $1USD per liter. Therefore, 3 hours of light per night costs about $54USD and 4 hours coast about $73USD per year. The 0.05_l/h consumption rate and 10_lm output are based on a quality kerosene lantern and home-made lanterns will have a higher consumption rate and lower output. Also, the below calculation assumes that the lantern is turned on for 4 hours then off. It is my understanding that some households run the lantern for 3-4 hours at night, then turn the lantern down and let it run throughout the night. Nevertheless, the stated figures of $60-114USD per year on kerosene lighting do seem to be reasonable figures.

4_h/day * 365_day * 0.05_l/h * $1USD = $73.00USD on kerosene per year.

Standard figures quoted for how inefficient kerosene is for lighting are; incandescent is 325 more efficient, compact florescent is 1625 times more efficient, and LED is 2350 times more efficient. Using standard figures does give a very good idea of effect, but let's test the standard figures for Rwanda.

1_l * 0.05_l/h = 20_h

The above equation states that 1 liter of kerosene burned at 0.05 liters per hour would last 20 hours. At a cost of $1USD per liter, it would cost $1USD to provide 20 hours of 10 lumens of light.

20_h * 13_W * $0.22/kWh = $0.0572USD

The above equation states that at $0.22USD per kilowatt of electricity you can run a 13_W CFL and get 800 lumens of light for 20 hours at a cost of $0.0572USD. Putting these two statements for kerosene and electric grid lighting into the same format;

Kerosene => $1.00USD to provide 20 hours of 10 lumens of light.

Electric Grid => $0.057USD to provide 20 hours of 800 lumens of light.

An individual in Rwanda with access to the national electric grid is getting 80 times the light at 1/17.5 the cost over an individual without access to the grid. This equates to compact florescent being 1400 times more efficient than kerosene for lighting. Today, In Rwanda, incandescent is 280 times more efficient, compact florescent is 1400 times more efficient, and LED is 2025 times more efficient than kerosene for lighting.

Fuel based lighting has more problems than being expensive and wasteful. Toxic fumes from fuel-base lighting are equivalent to smoking two packs of cigarettes a day. It is estimated that over 1.5 million people die and over 2 million children are diagnosed with respiratory and eye problems due to exposure from indoor air pollution. Each kerosene lantern emits an average of six tons of carbon dioxide into the atmosphere. This is roughly 244 million tons of carbon dioxide going into the atmosphere.

None of the above information is new. For years organizations have been developing and promoting programs to improve lighting and access to electricity with renewable energy and energy efficient technologies. These programs have one or more of the following objectives:

- Higher quality of light for students to read.
- Replace unhealthy, dangerous, wasteful, and expensive energy sources with an environmentally friendly solution.
- Allow women more time for self-empowering activates.
- Extend working hours.
- Extend selling and shopping hours.
- Improve the standard of living for the rural poor.
- Lessen rural to urban migration stresses.
- Improve political stability by correcting regional imbalances.
- Improve information and communications.

If there is a desire to start a solar lighting/electrification project, objectives for this project are probably clearly defined. There have been many solar lighting/electrification programs implemented utilizing environmentally friendly energy solutions. These programs have had some degree of success and failure. What might be very useful is to look at the reasons similar programs were not completely successful. The problems associated with these programs are listed below. Not every program had every problem listed. One problem on the list can make the attended beneficiary's life difficult. One clear objective to any program should be to make the beneficiary's life better not worse.

- Did not fill the needs of the customer.
- Did not meet the expectations of the customer.
- System had been modified.
- System not maintained.
- System improperly installed.
- High component failure rate or low product life.

The most prominent failure with solar lighting/electrification projects has been the system did not fill the needs of the customer. These systems were funded through micro-loan programs. The main concept of the programs has been, that if a household is spending $6-8USD per month on kerosene, a solar lighting system could be installed and $5-6USD could be used to pay off a micro-loan. If the solar lighting system does not fill the lighting needs of the household and kerosene is still being used, the cost of both the kerosene and micro-loan places a high financial burden on the intended beneficiary. Most of the reasons why the solar lighting systems did not fill the needs have been listed above and explained below.

Not meeting expectations. There has been a belief by some individuals using kerosene and other forms of lighting that if you get electricity, you can run anything. A lot of implemented programs have had steps where the intended beneficiary was trained on how the product works and how to maintain the product. Nevertheless, after the system was installed and running, the beneficiary expected that it would do more than what it was designed to do. A prototype system installed in a local shop, teacher's house, church, etc where an individual could see how it works before committing to a program would be very beneficial.

If the system did not meet their expectations, some of the systems were modified. Most of the modifications were the addition of low quality wires to power a device the system was not designed to power. These wires were improperly installed by twisting wires together. Adding the energy losses associated with the low quality wires and the extra drain from the device makes an under powered system. Thus, there is not enough power to fill the household lighting needs.

Most of the solar lighting/electrification systems are basically maintenance free. The only real maintenance is keeping the solar panels clean. If the solar panels are dirty, the dirt prevents the solar panel from collecting the sun's energy. Keeping the solar panels clean does sound like a simple task, but it has been listed as one of the main reasons for system performance problems.

A key objective in development programs has been to utilize local labor. Hiring and training local labor to install and maintain solar lighting/electrification systems are essential for the long-term success of a project. All of these programs have had steps where the installation and maintenance personnel were trained. Nevertheless, program evaluations have listed that some of the systems were improperly installed. Adding a step in the program where an individual is responsible for periodic inspections of newly installed systems would be very beneficial. Additional training would need to be implemented if problems in the inspected installation were found.

The number one problem with solar lighting/electrification systems has been low quality components. These components include solar panels, inverters, batteries, wires, connectors, switches, and plugs. Low quality components are generally cheaper. Cheap components have a higher cost in the long run associated with the replacement part, labor to replace the part, and frustration for the customer. Any component used in the system needs to be a high quality part that is designed to last for years.

## Grid-Tie Micro Solar Power Systems

Grid-tie solar power systems collect energy from the sun and supply any extra energy to the grid. This type of system is good for peak load leveling. Hydro, thermal, and gas electric generators used to power the grid need to have an output capacity greater than the peak load (max power consumed). If the load is greater than the electrical generation capability, the grid will suffer from brown-outs or grid shut-downs. One benefit of grid-tie solar power systems is that peak load occurs right when the solar panels are outputting their energy. Every watt of energy outputted by the solar panels lowers the peak generation requirement of the electric generators.

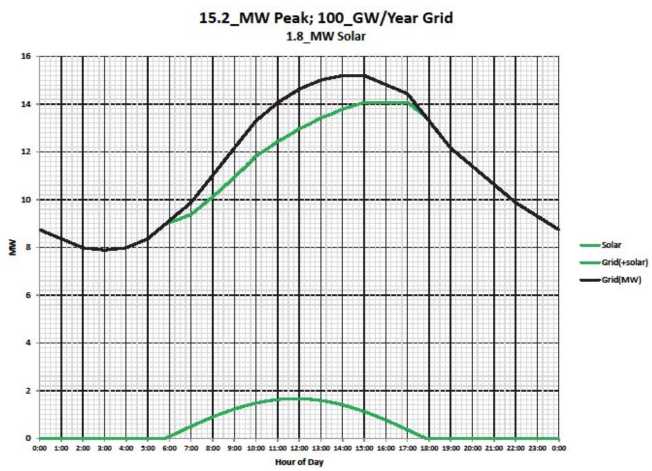


Figure 5: Peak Load Leveling

Figure 5 show a distribution grid with a peak load of 15.2_MW with a total yearly energy consumption of about 100_GWh (Rwanda used 438_GWh in 2010). Adding 1.8_MW of micro grid solar power systems to the distribution grid lowers the peak load generation requirement from 15.2_megawatts to 14.0_megawatts. The solar irradiance used for the calculations was the lowest estimate on the web for Kigali, 4.3 equivalent sun hours. Actual solar irradiance data collected at the Kigali Airport, the lowest is for May at 4.94 equivalent sun hours.

The hourly grid power graph in Figure 5 does not represent the power consumption in Rwanda. This chart was only used to demonstrate the peak load leveling concept. Grids that are heavily commercial loads have a peak load between 1-3PM. Heavier residential loads have a distinctive increase in power early in the morning and extend the peak later in the day. We did not have actual grid data for Rwanda. With actual data from the grid or sub-section of the grid in Rwanda, this chart can be redone.

## System Over-view

Grid-tie micro inverter systems include a solar panel and a micro inverter. The solar panel is connected directly to the micro inverter. The input of the micro inverter utilizes a MPPT (Maximum Power Point Tracking) controller to track the maximum power point of the solar panel through the course of the day. Then the micro inverter converts the DC electricity to AC electricity and synchronizes this AC output with the voltage and frequency of the grid. This output is connected to the consumer's side of the power meter or their AC Main panel.

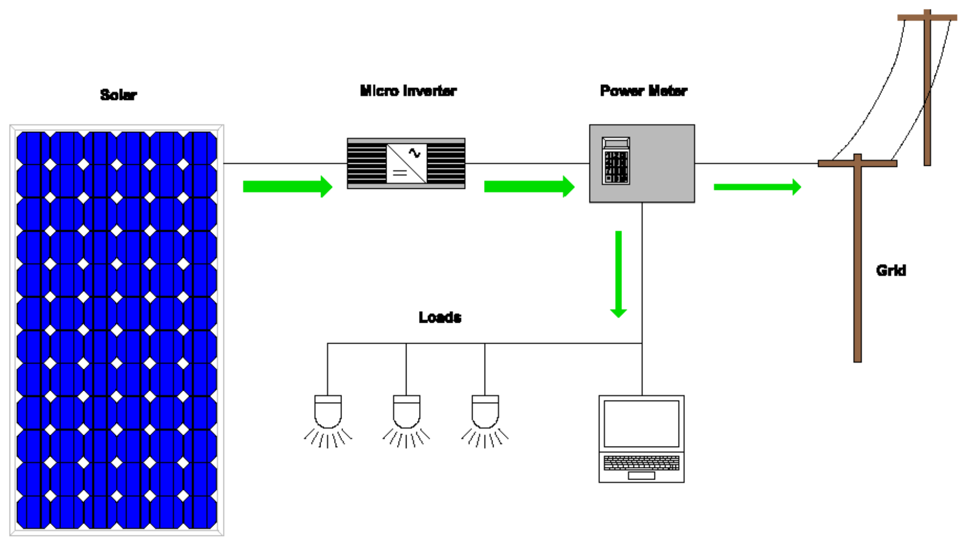


Figure 6: Micro-Grid Solar Power System

In Figure 6, energy collected from the solar panel is converted to AC electricity. This AC electricity is used to power any loads (computer, lights, etc.). Any excess energy is transmitted onto the grid.





Micro grid solar power systems are a form of distributed energy where the energy is generated in the same physical location that it is to be used. Connecting a micro grid solar power system to the local grid requires a power meter with net metering. This allows the meter to run in a forward direction when the consumer pulls energy off the grid and run backwards when the consumer puts energy on to the grid.

If the consumer uses less energy than generate each day, they will be net exporter of power. A credit for the extra energy will build up in the power meter. At regular intervals yearly or quarterly, the power company will need to issue the consumer a credit/payment for the extra energy the consumer has supplied to the grid.

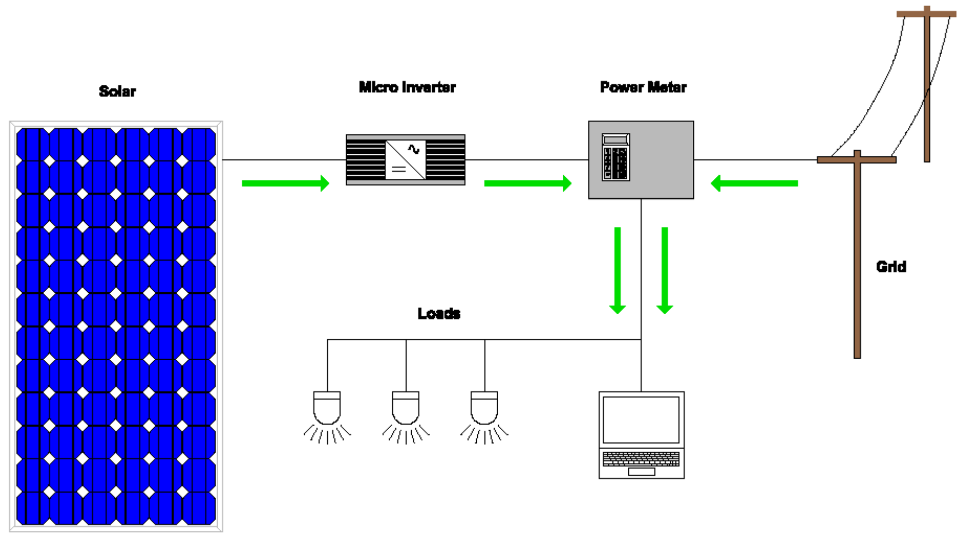


Figure 7: Micro-Grid Solar Power System

Figure 7 shows when the load is greater than the power generated from the solar panel, the load's extra power is supplied by the grid.

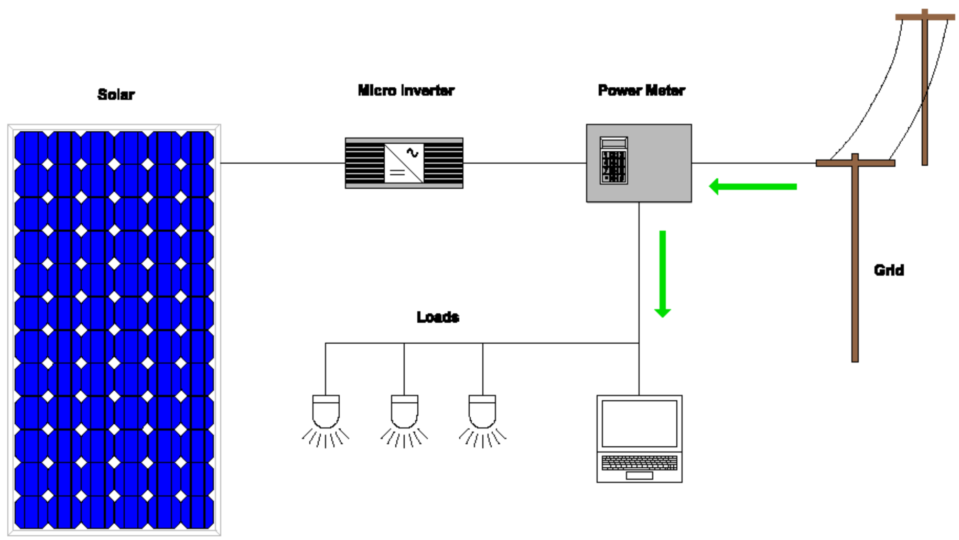


Figure 8: Micro-Grid Solar Power System

When there is no solar energy available, all power is delivered by the grid.

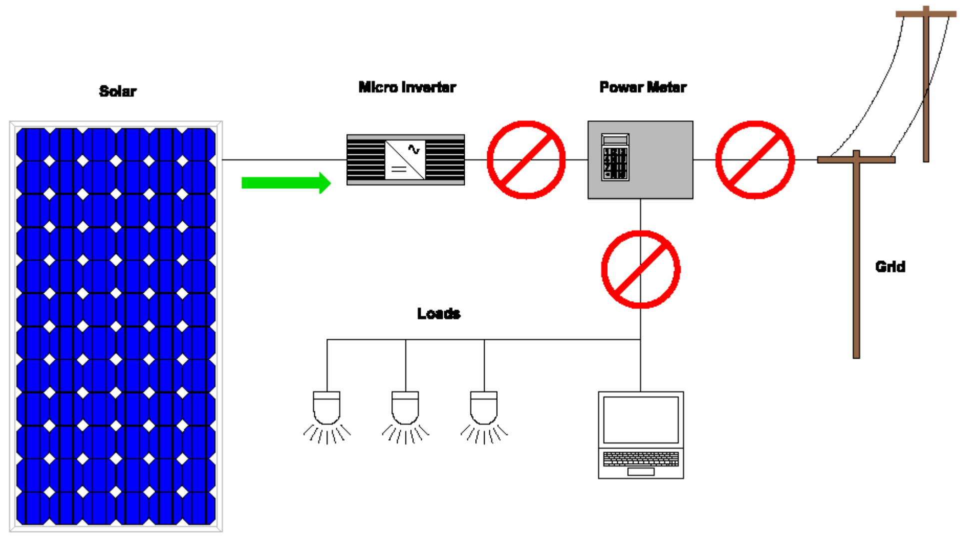


Figure 9: Micro-Grid Solar Power System

Anti-islanding is an important concept for distributive energy systems including micro-grid solar power systems. Figure 8 demonstrates that when the grid is down, all output from the micro inverter is off. The micro inverter will not turn on even if there is adequate power from the solar panel. This is a safety issue. Islanding is a condition where a distributive energy system continues to supply energy to the grid when the grid is down. This condition is dangerous for utility workers who believe the grid is no longer energized, but a distributive system is keeping the grid powered.

## Off-Grid Solar Power Systems

Off-grid power systems are beneficial in areas where there are desired loads (lights, computers, radio, etc.) and the electrical grid infrastructure is not available and too cost prohibitive to build.

### System Over-view

In off-grid solar power systems, the solar panel is connected directly to a charge controller. A charge controller can have many functions. Its output is connected to the battery to perform its primary function of protecting the battery from over-charge which will weaken and eventually destroy the battery. Some charge controllers have secondary functions for controlling a load. One type of load control for a charge controller is and over-discharge protection. DC loads like inverters and DC lighting can be connected to the charge controller's load output and the charge controller prevents the load from over-discharging the battery. A second type of load control is dusk to dawn lighting control. A charge controller with this type of load control will turn on a light at dusk and turn the light off at dawn. Finally, there is an inverter to convert the DC electricity to AC electricity. If the inverter has over-discharge protection, it can be connected directly to the battery. If the inverter does not have over-discharge protection, it must be connected to the output of a charge controller with load control.

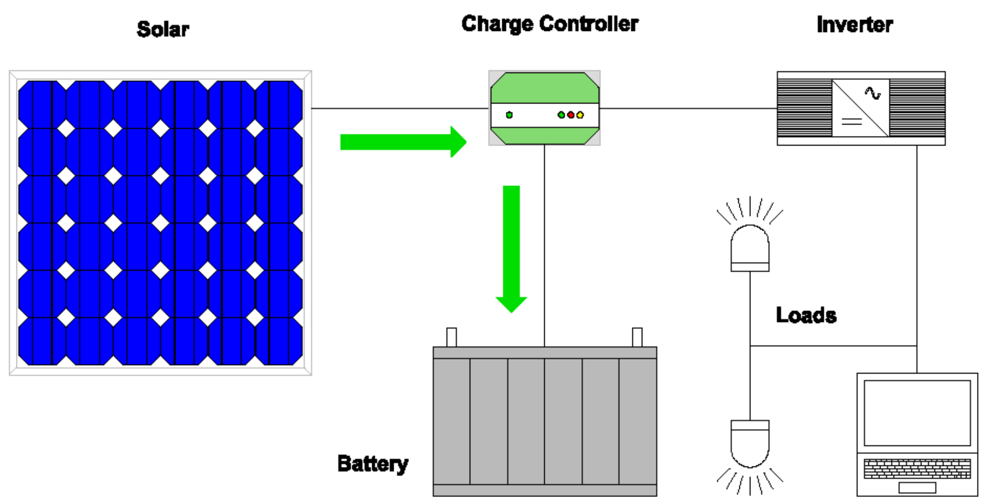


Figure 1: Off-Grid Solar Power System

In Figure 1, energy collected from the solar panel is stored in the battery to be used at a later time.

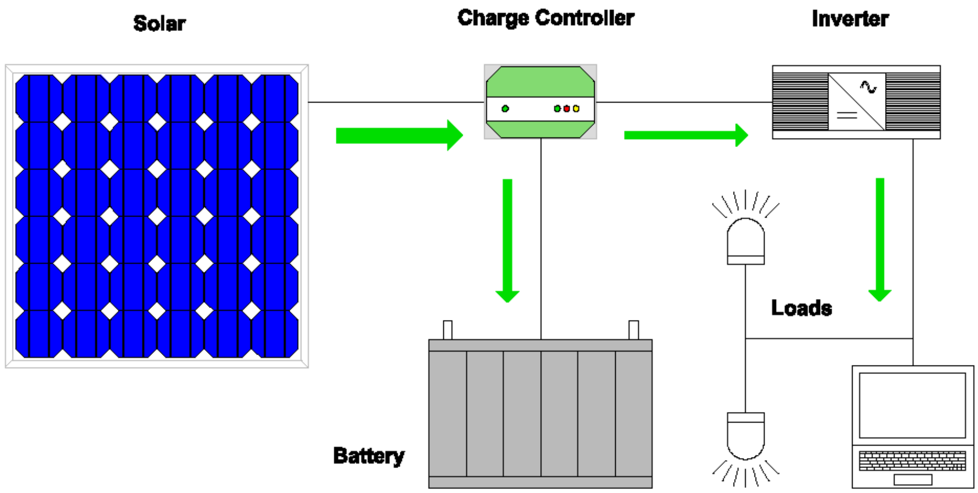


Figure 2: Off-Grid Solar Power System

In Figure 2, as the loads (lights, computer, etc.) are turned on, they consume energy collected from the solar panel. Any excess energy generated is stored in the battery.

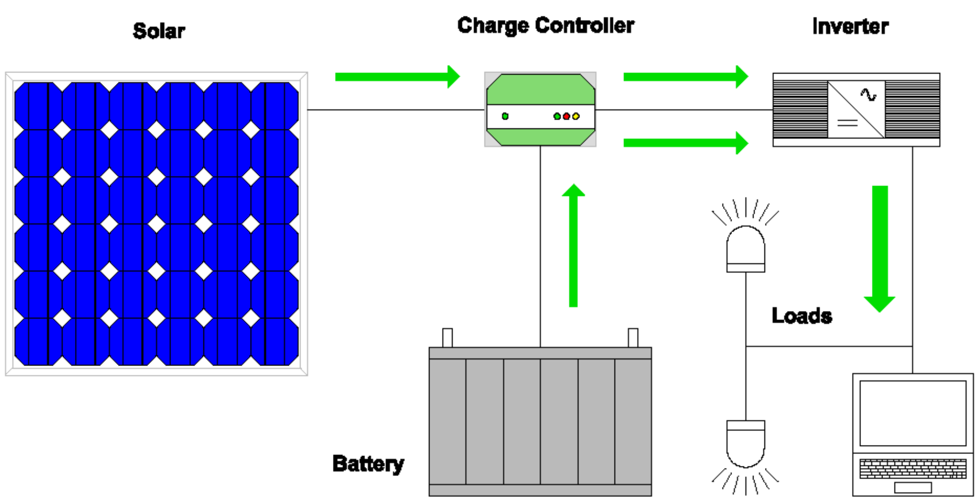


Figure 3: Off-Grid Solar Power System

In Figure 3, when the load demand is greater than the amount of energy collected from the solar panel, the extra energy is supplied by the battery.

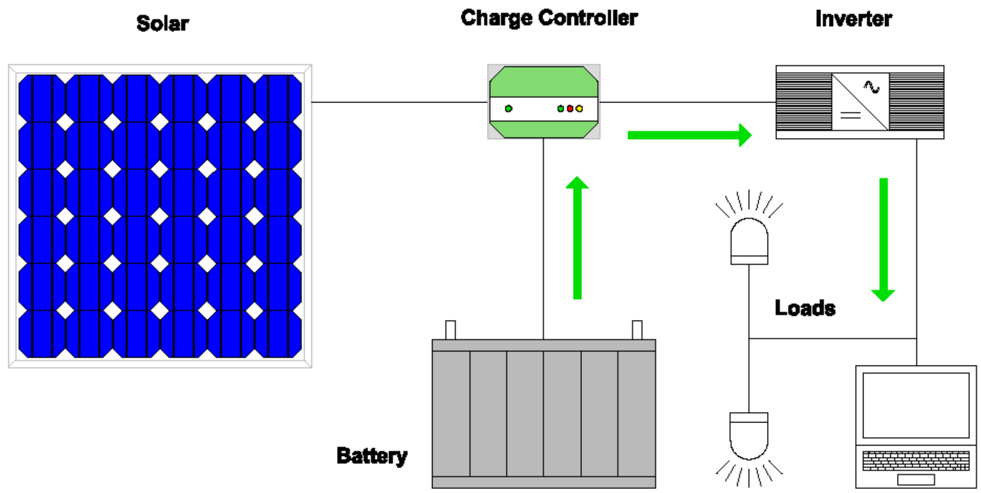


Figure 4: Off-Grid Solar Power System

In Figure 4, when there is a load and no energy being collected from the solar panel, the energy for the load is supplied by the battery. The charge controller and/or inverter will disconnect an empty battery from the load preventing over-discharge and battery damage.



There is a third type of solar power system that is a combination of the grid-tie and off-grid systems. This system is the same as the micro-grid solar power system except that the system uses a battery to power the loads when the grid is down. It uses an automatic or manual disconnect for anti-islanding. The problem with this type of system is cost. The electronics for small systems like this are over 5 times the cost of the micro inverter systems. Furthermore, there is the added cost associated with the battery. Even though the battery requirement is lowered to hours of autonomy instead of days for an off-grid system, it still makes this type of system cost prohibitive for small systems.

## Electronic Loads (Devices)

If we are looking at installing a photovoltaic power system, there are electronic devices (loads) that we would like to power. The first pillar of environmentally friendly systems is energy efficiency: getting the most done with the least amount of work.

A good starting point in designing a photovoltaic power system is specifying what the system is required to accomplish. Then for each desired task, pick a device that will accomplish the goal with a high energy efficiency rating and a good unit price.



Let's say a goal is to provide 3 lights with an 800_lm (60_W eq.) for 6 hours a day. Let's also say we can get 60_W incandescent bulbs for free and an equivalent 13_W CFL costs $10 each. Finally, the micro grid system has a deliverable energy rating of $1.35/Wh ($2.88/Wh for off-grid).

Incandescent $1.35*[(3*60_W)*6_hr] + $0*3 = $1,458USD ($3,110.40USD)

CFL $1.35*[3*13_W)*6_hr] + $10*3 = $345.90USD ($703.92USD)

A micro grid solar power system to power 3 – 60_W incandescent bulbs for 6 hours a day would cost $1,458USD ($3,110.40 for an off-grid system). Replacing the light with CFLs would lower the cost of the system to $315.90USD + the cost of the CFL bulbs ($673.92 for an off-grid system). Those free incandescent bulbs turn out to cost $380.7 each ($812.16 each for off-grid); very expensive!

### CFL Compact Fluorescent Lighting

Compact fluorescent lights (CFLs) are a matured product with high reliability. CFL have a luminous efficacy between 50-60_lm/W compared to 11-14_lm/W for incandescent lamps. Luminous efficacy (lm/W) is the measure of the number of lumens produced for each watt consumed by a light source. Also, the rated life for CFLs is between 6,000-12,000 hours. Incandescent lamps have a rated live of 750-1000 hours, giving the CFLs an 8-12 times life rating advantage.

### LED Lighting

With a luminous efficacy between 100-120_lm/W and a rated life between 25,000-50,000 hours, LED lighting will be the lighting choice of the future. For now, two factors must be overcome. First is cost; LED light cost between 10-12 times that of an equivalent CFL. Second is reliability; the last group of AC LED lights tested had a 65% failure rate within the first two weeks.

LED lights are still being tested in-house. When the price and reliability have been addressed, LED lights will be the lighting source of choice.

## Computers/Laptops/Tablets

To say that you would like to run a computer for 6 hours a day is a little ambiguous. Different computer systems can consume anywhere from less than 8_watts, like the OLPC, to over 1200_watts, like a workstation. The difference in daily energy usage is 48_Wh compared to 7200_Wh. Another way to state this is, one workstation would require the same energy as 150 OLPC laptops. Therefore, if we were to design a system to run one OLPC Laptop for 6 hours and then replace the OLPC Laptop with a workstation, the workstation would run for less than 2 ½ minutes.

Laptops can consume anywhere for 20-90_W of power. My HP Pavilion tx1000 will consume 34_W in power saving mode and 68_W in high performance mode as long as it is plugged in. The newer essential type laptops can run in the 20_W range in power saving mode.

None of the three models listed below have been tested for actual power performance. The listed power consumption is based on data from the manufacture's webpage. Actual lab testing should be done once the type of device is picked out and the types of accessories are included. The HP 2000x laptop can have extra memory added or a faster processor which will increase the power consumption.

| Laptop: HP 2000z series $350USD about 20Watts | |
|---|---|
| Operating System | Windows 7 Home Premium |
| CPU | AMD Dual-core E-300, 1.6GHz, 1MB L2 |
| Memory | 2GB, DDR3 |
| Storage | 250GB, Serial ATA |
| Optical Drive | DVD-Writer |
| Display | 15.6" High Definition LED 1366 x 766 |
| Networking | WiFi, 802.11b/g/n |
| | Fast Ethernet (Rj-45) |
| Input/Output | 3-USB 2.0, VGA, RJ-45, webcam, microphone |

| Notebook: HP; Mini 110 series $280USD 15Watts | |
|---|---|
| Operating System | Windows 7 |
| CPU | Intel Atom N455 1.66GHz, 512KB L2, 32bit |
| Memory | 1GB, DDR3 |
| Storage | 250GB |
| Display | 10.1" WSVGA LED 1024 x 600 |
| Networking | WiFi, 802.11b/g/n |
| | Fast Ethernet (Rj-45) |
| Input/Output | 3-USB 2.0, VGA, RJ-45, webcam, microphone |

| Tablet: Flytouch V10 10” Android Tablet $140USD about 7Watts | |
|---|---|
| Operating System | Andriod 2.3 |
| CPU | Flytouch3, ARMv7, 1GHz, 32bit |
| Memory | 512MB |
| Storage | 4GB (add $25USD for 16G) |
| | Support TF Card, 32G Max (a 16G Card is about $36USD) |
| Display | 10.1” Touch screen, TFT LCD, 600 x 1024 |
| Networking | WiFi 802.11b/g |
| | Fast Ethernet (RJ-45) |
| Input/Outputs | RJ45, HDMI, USB ports, 2.5mm earphone, 2-speakers. |
| GPS | Built in GPS module |
| Camera | 0.3 Mega Pixel |
| Video output/record | 1080p HD video @ 30fps |
| Audio | MP3/WMA/APE/FLAC/AAC/AC3/WAV |
| Browser | Webpage, WAP, MPLAYER |
| Networking | QQ, MSN, Skype |
| Office tools | Word, Excel, Powerpoint, PDF reader and email |

The Android Tablet has TV/Radio capabilities if there is internet access available.

### Printing

There are no printers added into any of the systems. Nevertheless:

An HP Deskjet 3000 Printer is about 10_W while printing.

An Epson Artisan 50 Ink Jet Printer is about 13_W while printing.

## Power Requirements

Designing a system that generates energy that never will be used is a waste of valuable resources. Designing a system that does not generate enough energy will not allow you to perform the desired tasks. Underpowered photovoltaic power systems can be major source of irritation for the user/owner.

As stated, determining the power requirements of the system is a critical component for a new photovoltaic power system. All of the energy consumed needs to be generated and stored by the system. Therefore, we need to add up the energy consumption for the loads (devices to be powered). This is accomplished by taking the power, in watts, of each load and multiplying it by the number of hours the load is to be used each day to get the daily energy consumption, in watt-hours (Wh) for each load. Adding up all the watt-hours will give us the daily power requirements for the system.

Power is the rate work is performed. In electronics, power (watts) is defined by the potential difference (voltage) across a load multiplied by the flow of electrons through the load. Power can be calculated by multiplying the voltage of a load (in Volts) by the current through the load (in Amps).

A device that uses 230VAC that draws 0.087_Amps would consume 230_VAC x 0.087_Amps = 20_Watts of power.

Energy is the amount of work done. In electronics energy (Wh), is defined by watts (power) over a given amount of time (hours). Energy can be calculated by multiplying power (W) by time (h) to give watt-hours (Wh).

A device that draws 20_watts (W) of power for 6 hours (h) would consume 20_W x 6.0_h = 120_Wh of energy.

## Daily Power Consumption

| System 2: Laptop, 3-800_lm CFL | | | | | |
|---|---|---|---|---|---|
| Qty. | Description | Watts | Hours per Day | Total Watts | Wh |
| 3 | CFL Lights | 13 | 5.0 | 39 | 195 |
| 1 | Laptop | 20 | 6.0 | 15 | 120 |
| 1 | Cell Phone Charge | 2 | 2.0 | 2 | 4 |
| | | | TOTALs | 43 | 319 |

| System 3: Tablet, 3-800_lm CFL | | | | | |
|---|---|---|---|---|---|
| Qty. | Description | Watts | Hours per Day | Total Watts | Wh |
| 3 | CFL Lights | 13 | 5.0 | 39 | 195 |
| 1 | Tablet | 7 | 6.0 | 7 | 42 |
| 1 | Cell Phone Charge | 2 | 2.0 | 2 | 4 |
| | | | TOTALs | 43 | 241 |

| System 4: Tablet, 3-800_lm LED | | | | | |
|---|---|---|---|---|---|
| Qty. | Description | Watts | Hours per Day | Total Watts | Wh |
| 3 | LED Lights | 6 | 5.0 | 18 | 90 |
| 1 | Tablet | 7 | 6.0 | 7 | 42 |
| 1 | Cell Phone Charge | 2 | 2.0 | 2 | 4 |
| | | | TOTALs | 43 | 136 |

Not all the energy collected by the solar panels will make it to the loads (devices) being powered. There are power losses in the wires, charge controller, batteries, and inverter. Therefore, the solar panels must collect enough energy each day to power the loads plus extra energy to cover any losses within the system.

For grid-tie micro solar power systems, this step is a simple calculation. The micro inverter converts the DC power from the solar panel to the AC power required to run the loads and supply energy to the grid. The micro inverter selected has an efficiency of >88%.

319_Wh / 88% = 362.5_Wh needs to be collected each day

Off-grid solar power systems are more complex with more inefficiencies. The solar panel is connected to the charge controller to convert the solar panel's output to the desired battery voltage. Solar charge controllers have efficiencies between 70-96% efficient. The selected charge controller is 94% efficient.

Small pure sine wave off-grid inverters convert the battery's DC voltage to the desired AC load voltage. These inverters have efficiencies between 75-90%. Larger pure sine inverters can have efficiencies of +96%. The 200W pure sine wave inverter selected has an efficiency of >88%.

The overall efficiency from the system; from the solar panel to the output of the inverter, is calculated by multiplying together all the individual efficiencies of the system. For example, system 2:

94% * 88% = 82.7% efficiency

320_Whr / 82.7% = 386.9_Whrs needs to be collected each day.

System 1 was added to the Required Energy Table. For System 1; 320_Wh per day for all the equipment listed in System 2 plus some extra energy for other equipment not listed.

| Required Energy Table | | | |
|---|---|---|---|
| SYSTEM | Load | Grid-Tie | Off-Grid |
| System 1 | 425_Wh | 483_Wh | 514_Wh |
| System 2 | 320_Wh | 364_Wh | 387_Wh |
| System 3 | 240_Wh | 272_Wh | 290_Wh |
| System 4, LED | 136_Wh | 155_Wh | 165_Wh |
| NOTE: Off-grid systems have more losses with the battery. | | | |

For grid-tie micro inverter solar power systems, we have the required energy (Wh) needed to be collected each day to run the desired loads. Off-grid solar power systems have more losses associated with storing energy in the battery. These losses will be covered in the next section.

# Battery Bank Design

Off-grid solar power systems require a battery to store energy. Batteries convert the chemical energy contained in its electrodes directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction. This reaction is reversed to recharge the battery.

## Flooded (Liquid Vented)

The main advantage to Flooded Lead Acid batteries is long life. Flooded batteries can last 4 – 15 years depending on the thickness of the electrodes, the depth of discharge (DOD), and how well they are maintained. A 30-50% DOD is recommended to achieve the rated battery life.

Flooded Lead-Acid batteries require periodic maintenance. During charging, the batteries vent water and gases. This water loss requires the cells to be re-filled. Also, the batteries must be stored in a ventilated area to prevent the buildup of Hydrogen gas, which is very explosive. During discharge, crystals of lead sulfate form on the electrodes. This process is called sulfation and its symptoms are: loss of capacity, longer charge time, and higher battery charge temperature.

An equalization charge needs to be performed every 30 to 90 days to reverse sulfation. Desulfation requires a charge with a minimum of 5_Amps of current for every 100_Ah of battery storage. For an 80_Ar battery, it will take 4_A of charge current to break up any crystallized lead sulfate. For a 24 volt system; 24_V * 4_A = 96_watt solar array. Or, drag a generator out to each site every 30 – 90 days.

## VRLA (Sealed)

VRLA (Valve Regulated Lead-Acid battery) Lead Acid batteries are maintenance free because the battery is completely sealed and spill-proof. The electrolyte cannot be accessed so electrolyte will not be spilled, even if the battery case is broken.

The life expectance of a VRLA battery is lower than a Flooded. A VRLA battery expected life depends on the quality of the battery and the depth of discharge. To get a quality battery to last 6 years (2,100 cycles), a DOD of 33% is recommended. A quality VRLA discharged to a DOD of 15% can last 5,700 cycles.

## Battery Bank Sizing

A battery's energy storage capacity (C) is listed in Amp-hours (Ah). Batteries are rated by discharging at a C-Rate. There are two standard C-rates used to measure the capacity of Lead-Acid batteries; C/20 and C/100. We will use the C/20 c-rate. The C/20 C-rate is the discharge current in Amps (A) it would take to fully discharge a battery in 20_hours.

If you have a battery with a C/20 capacity rating of 100_Ah;

C-Rate => 100_Ah/20_hours = 5_A

Therefore; if you were to discharge a battery at 5_A with a capacity of 100_Ah at C/20, it would take 20 hours.

SOC (State Of Charge): 0% SOC means the battery is completely empty; 60% SOC means the battery has 60% of its energy remaining; and 100% SOC means the battery is completely full. SOC term is generally used during charging.

DOD (Depth Of Discharge): 0% DOD means the battery is completely full; 40% DOD means the battery has 40% of its energy removed; and 100% DOD means the battery is completely empty. DOD term is generally used during discharge.

The DOD on a battery will affect the life of the battery. For VRLA; 80% DOD will last for about 600 cycles (~2 years); 33% DOD ~2100 cycles (6 years); 10% DOD ~5700 cycles (16 years).

All the calculations used in the design of a system are in the energy term of watt-hours (Wh) and not capacity (Ah). To convert the capacity of the battery into energy, you need to multiply the capacity by the battery voltage. We are using a 24_V system, Therefore;

24_V * 100_Ah = 2.4_kWh of energy storage.

The four main factors in determining the size and type of battery bank to use are autonomy, price, life, and maintenance. We will assume about two days of autonomy, 10 year battery life, and very low maintenance in the following calculations.

Autonomy is the amount of time the batteries will supply power to the system without being recharged by the solar panels. The main factors in determining the appropriate amount of autonomy are the importance of the loads, area weather patterns, and the price of the battery. A good reference of autonomy is 1 to 3 days for non-critical loads and 5 – 7 days for critical loads.

In the Power Consumption section, we calculated the energy requirements for the off-grid systems. Based on the daily energy required, we can determine the battery size for one day of autonomy.

To obtain 6 years of battery life on a low maintenance VRLA battery, we can only remove 33% of its available energy, or 33% DOD.

387_Wh / 33% DOD = 1,173_Wh.

Now we have the amount of energy the battery bank needs to store. Batteries are rated by capacity in Ah. Converting the energy storage capability (Wh) of the battery into a capacity (Ah), we need to divide the Wh by the system voltage.

1,170_Wh / 24_V = 48.875_Ah.

| Required Energy Storage Table; One Day Autonomy. | | | |
|---|---|---|---|
| SYSTEM | Off-Grid | Battery Size | |
| System 1 | 514_Wh | 1,558_Wh | 65_Ah |
| System 2 | 387_Wh | 1,173_Wh | 49_Ah |
| System 3 | 290_Wh | 879_Wh | 37_Ah |
| System 4, LED | 165_Wh | 500_Wh | 21_Ah |

| Required Energy Storage Table; Two Days Autonomy. | | | |
|---|---|---|---|
| SYSTEM | Off-Grid | Battery Size | |
| System 1 | 514_Wh | 3,116_Wh | 130_Ah |
| System 2 | 387_Wh | 2,346_Wh | 98_Ah |
| System 3 | 290_Wh | 1,758_Wh | 74_Ah |
| System 4, LED | 165_Wh | 1,000_Wh | 42_Ah |

Lead-Acid batteries are manufactured in different voltages and amp-hour (Ah) ratings. Each cell inside the battery is about 2-volts. Therefore, a 6-volt battery has 3-cells inside and 12-volt battery has 6-cells inside. To increase the voltage of a battery bank, you can connect the multiple batteries in series. Two 12-volt batteries connected in series would have a battery bank voltage of 24-volts.

Batteries can also be connected in parallel to increase the available amp-hours. Two batteries with a 100_Ahr capacity connected in parallel will deliver 200_Ahr.

We need to find a battery with a capacity rating of about 98_Ahr and determine how many batteries are needed to make up our 24-volt battery bank.

There is a 12-volt, 97.6_Ahr VRLA battery available;

24_V / 12_V = 2 Batteries.

Therefore, 2 of the 12-volt 97.6_Ah VRLA batteries connected in series will give us a 24-volt battery bank with 2.3_kWh of energy storage and 772_Wh of usable energy at a 33% DOD.

| Battery Table; Usable Energy | | | | | |
|---|---|---|---|---|---|
| SYSTEM | Off-Grid | Battery Selection | | Usable Energy | Autonomy |
| | | Amp-hour | Watt-hour | | |
| System 1 | 514_Wh | 125_Ah | 3,000_Wh | 990_Wh | 1.9 days |
| System 2 | 387_Wh | 97.6_Ah | 2,342_Wh | 772_Wh | 2.0 days |
| System 3 | 290_Wh | 73.6_Ah | 1,766_Wh | 583_Wh | 2.0 days |
| System 4, LED | 165_Wh | 48.8_Ah | 1,171_Wh | 387_Wh | 2.3 days |

Batteries recharge by converting electrical energy into chemical energy stored in its electrodes. How efficient a battery converts electrical energy into chemical energy is called charge acceptance. Lead-Acid batteries have an Amp hour (Ah) charge acceptance of about 90% and a Watt hour (Wh) charge acceptance of about 75%.

System 2: We previously calculated it would take 387_Wh to deliver 320_Wh to the loads. This extra energy is to over-come the losses associated with the charge controller and inverter. Now we need to determine how much energy we need to deliver to the battery to account for the battery's charge acceptance.

387_Wh / 75% = 516_Wh needs to be delivered to the battery.

| Off-Grid Energy Table | | | |
|---|---|---|---|
| SYSTEM | Load | Delivered Power | Over-come Battery Charging losses |
| System 1 | 425_Wh | 514_Wh | 685_Wh |
| System 2 | 320_Wh | 387_Wh | 516_Wh |
| System 3 | 240_Wh | 290_Wh | 387_Wh |
| System 4, LED | 136_Wh | 165_Wh | 219_Wh |

SYSTEM 2: In the above calculations, we calculated the power requirements and losses for the inverter and charge controller then added in the battery. We can go through the system linearly, from solar panel to load, and look how the results compare.

Solar panel's energy through the charge controller at 94%.
516_Wh * 94% = 485_Wh. Energy to battery.

Energy to the battery to stored energy in the battery at 75% charge acceptance.
485_Wh * 75% = 364_Wh. Stored in the battery.

Stored battery energy converted to AC by the inverter at 88% efficiency.
364_Wh * 88% = 320_Wh. Delivered to the load.

We have calculated System 2 two different ways and determined that 516_Wh of energy generation will over-come all the losses of the system and deliver 320_Wh to the loads.

The last energy generation calculation we need to do is determine how much energy should be collected to account for cloudy and rainy days. Large battery banks with many days of autonomy can sit in a low SOC (State of Charge) for extended periods of time. This can cause the batteries to degrade and lower the expected battery life. Therefore, you need to add extra wattage on the solar panels to insure that the batteries will be recharged within a 2 to 7 day period.

2 Days; 516_Wh / 2 days = 258_Wh. Extra Solar.

7 Days; 516_Wh / 7 days = 74_Wh. Extra Solar.

| Required Daily Energy Table | | | | |
|---|---|---|---|---|
| SYSTEM | Grid Tie | Off-Grid; Recovery Days | | |
| | | 7 | 3 | 2 |
| System 1 | 483_Wh | 783_Wr | 913_Wh | 1,028_Wh |
| System 2 | 364_Wh | 590_Wh | 688_Wh | 774_Wh |
| System 3 | 272_Wh | 442_Wh | 516_Wh | 581_Wh |
| System 4, LED | 155_Wh | 250_Wh | 292_Wh | 329_Wh |

The Required Daily Energy Table gives us the energy generation requirements for different recovery days. In the next section we will look at solar irradiance and how we can collect this much energy with solar panels.

# Photovoltaic System Calculations

Insolation is the term used to describe the sun's power that reaches the earth. The amount of insolation on the earth's surface is about 1,000_watts for every square meter. For every hour of clear sky, there is one kilowatt-hour of energy hitting every square meter. In fact, enough sunlight reaches land every 6 hours to supply humanity's hunger for energy for an entire year.

## Solar Array Sizing



Insolation is also called irradiation and has units of Wh/m^2. Photovoltaic calculations utilize insolation expressed in equivalent sun hours where on sun equals 1000 W/m^2. A location that receives 4.94 hours of equivalent suns in one day (4.94_h/day), has 4940_Wh/m^2 of solar radiation.



Dividing the daily energy requirement by the equivalent suns will determine the size of solar panel required.

589_Wh / 4.94_h/day = 119.2_W. Solar Panel

The lowest irradiance data shows a 4.94_h/day for May in Kigali, Rwanda. The Minimum Solar Panel Required Table was generated utilizing 4.94 equivalent suns per day.

Below is a chart of monthly insolation data for Kigali and a yearly average for a few other cities in Rwanda. Also, a Minimal Solar Panel table is listed for the different recovery days.

Off-Grid Solar Power Systems Specifications is the final tally for each of the four systems. In these designs, we used a 2 day recovery for a no-sun day.

| Kigali, Rwanda | |
|---|---|
| Month | Eq. Suns |
| January | 5.31 |
| February | 5.47 |
| March | 5.34 |
| April | 5.06 |
| May | 4.94 |
| June | 5.47 |
| July | 5.68 |
| August | 5.72 |
| September | 5.52 |
| October | 5.44 |
| November | 5.11 |
| December | 5.16 |
| AVERAGE | 5.34 |

| Rwanda | |
|---|---|
| City | Eq, Suns |
| Kigali | 5.34 |
| Butare | 5.48 |
| Kamembe | 4.93 |
| Gisenyi | 5.19 |
| Gikongoro | 5.52 |
| Kibungo | 5.13 |
| AVERAGE | 5.269 |

| Minimum Solar Panel Required | | | | |
|---|---|---|---|---|
| SYSTEM | Grid Tie | Off-Grid, Recovery Days | | |
| | | 7 | 3 | 2 |
| System 1 | 97.8_Wh | 159_Wh | 185_Wh | 208_Wh |
| System 2 | 73.5_Wh | 119_Wh | 139_Wh | 156_Wh |
| System 3 | 55.5_Wh | 90_Wh | 104_Wh | 118_Wh |
| System 4 | 31.4_Wh | 51_Wh | 59_Wh | 67_Wh |

| Off-Grid Solar Power System Specifications | | | | | | |
|---|---|---|---|---|---|---|
| SYSTEM | Daily Load Energy | Solar Panel Power | System Daily Energy Gen. | Battery | | |
| | | | | Amp-Hour | Watt-Hours | Days Recovery |
| System 1 | 425_Wh | 185_W | 968_Wh | 125_Ah | 3,000_Wh | 2.4 |
| System 2 | 320_Wh | 150_W | 785_Wh | 97.6_Ah | 2,342_Wh | 1.9 |
| System 3 | 240_Wh | 100_W | 523_Wh | 73.6_Ah | 1,766_Wh | 2.8 |
| System 4 | 136_Wh | 60_W | 314_Wh | 48.8_Ah | 1,171_Wh | 2.3 |

A reliable and cost effective LED light used for the calculations in System 4 does not exist. Therefore, System 4 was not been quoted. The calculations were done to demonstrate how utilizing energy efficient components lower the requirements for the system.

# Simulation of the Off-Grid Battery SOC

The off-grid solar power system's battery stores the energy generated by the sun during the day and releases the energy at night. This battery has extra storage capability to deliver energy to the load during clouding or rainy days (low irradiance). The more extra storage capacity, the more days of autonomy the system has.

System number 2 was designed to have a daily load of 320_Wh, at least 2 days of autonomy, 1.9 days to recover from 1 No-Sun day, and good cycle life on the battery. We will simulate the System 2 to look at its SOC on the battery. These calculations use 4.94 equivalent suns, May in Kigali. We will also assume the worst case scenario where all the solar energy is stored in the battery and then the battery supplies all energy to the load. This means that there are NO loads during the day when the sun is out.

## Normal Operation

The battery is at 100% SOC or fully charged with 2,342_Wh in battery.

320_Wh used to run the loads at night. To determine how much energy has been removed from the battery, we need to divide the energy used by the efficiency of the inverter;

320_Wh / 88% = 364_Wh out of battery.

2,342_Wh - 364_Wh = 1,978_Wh in battery or 84.5% SOC.

During the next day, the 150_W solar panels generate energy to recharge the batteries. The amount energy generated is the solar panel's wattage times the equivalent sun hours.

150_W * 4.94_h = 741_Wh generated.

Not all of this 741_Wh generated will be stored in the battery. Some of the energy will be lost in the inefficiency of the charge controller and the batteries ability to accept a charge, charge acceptance. To determine how much energy will be stored into the battery, we need to multiply the energy generated by the efficiency of the charge controller and then multiply that result by the battery's charge acceptance.

741_Wh * 96% = 711_Wh through the charge controller.

711_Wh * 75% = 533_Wh to the battery. We only removed 364_Wh from the battery, thus the extra energy will be used to maintain a full charge on the battery. By the end of day 2, we are at 100% SOC or fully charged with 2,342_Wh in battery.

Normal operation for system number 2 will be cycling the battery between 100% SOC and 84.5% SOC. This low 15.5% DOD (Depth of Discharge) on the battery will result in a >10 year cycle life.

## Cloudy/Rainy or No-Sun Days

In the Battery State Of Charge table on the next page is the battery's SOC simulation for different amounts of irradiance. The 320_Wh/Daily Load column has the HIGH and LOW SOC for the battery. Day 2 is a No-Sun day with 1% irradiance. It takes just over 2 days for the system to recover from this one day with No-Sun.

Days 6 & 7 simulate 2 consecutive days without sun. It is not until day 12 that the system recovers from these 2 No-Sun Days. A better simulation is on days 15 – 21. This is one week of clouds and/or rain. The week takes 8 days of full sun to recover.

The LED column indicates the LED status during the HIGH and LOW states on the battery. Normal operation, the LED will remain GREEN. When there are multiple days of clouds and/or rain, the LED will turn YELLOW during the night and back to GREEN during the day. This daily cycling between GREEN and YELLOW is not bad.

On Day 21 the LED cycles between YELLOW and RED. This is an indication that the batteries are being over-discharged. If the LED continues to cycle daily between YELLOW and RED or just stays RED, loads need to be removed from the system.

## Over-Loaded System

In the Battery State Of Charge table on the next page is a column with 470_Wh/Daily Load. The system was only designed to handle a daily load of 320_Wh. This shows what would happen if too large of load was placed on the system.

In the table, Day 2 is a No-Sun day and the system never recovers from it. The LED status toggles between GREEN and YELLOW. Any other cloudy or rainy days just lowers the SOC on the battery. Eventually, the LED status cycles between YELLOW and RED then just stays RED.

Days 7 – 14, the system would shut down at night. During days 15 – 21, it might not even come back ON. Days 22 on, the system would come ON during the day then shut OFF during the night.

A system that is not recovering from cloudy/rainy days is a sign that the system is over-loaded. It will have symptoms of the LED status of YELLOW during the day, RED at night and the system shutting down at night. If the system is consciously run this way, the battery will fail within 2 years.

| Battery State Of Charge | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 320_Wh/Daily Load | | | 470_Wh/Daily Load | | |
| | | Battery SOC | | | Battery SOC | | |
| Day | Solar Irradiation | HIGH | LOW | LED | HIGH | LOW | LED |
| 1 | 100% | 100.0% | 84.5% | | 100.0% | 77.2% | |
| 2 | 1% | 84.7% | 69.2% | | 77.4% | 54.6% | |
| 3 | 100% | 92.0% | 76.4% | | 77.4% | 54.6% | |
| 4 | 100% | 99.2% | 83.7% | | 77.4% | 54.6% | |
| 5 | 100% | 100.0% | 84.5% | | 77.3% | 54.5% | |
| 6 | 1% | 84.7% | 69.2% | | 54.8% | 32.0% | |
| 7 | 1% | 69.4% | 53.9% | | 32.2% | 9.4% | |
| 8 | 100% | 76.7% | 61.1% | | 32.2% | 9.4% | |
| 9 | 100% | 83.9% | 68.4% | | 32.1% | 9.3% | |
| 10 | 100% | 91.2% | 75.6% | | 32.1% | 9.3% | |
| 11 | 100% | 98.4% | 82.9% | | 32.1% | 9.3% | |
| 12 | 100% | 100.0% | 84.5% | | 32.1% | 9.3% | |
| 13 | 100% | 100.0% | 84.5% | | 32.0% | 9.2% | |
| 14 | 100% | 100.0% | 84.5% | | 32.0% | 9.2% | |
| 15 | 50% | 95.9% | 80.3% | | 20.6% | 0.0% | |
| 16 | 25% | 86.0% | 70.5% | | 5.7% | 0.0% | |
| 17 | 25% | 76.2% | 60.7% | | 5.7% | 0.0% | |
| 18 | 25% | 66.4% | 50.8% | | 5.7% | 0.0% | |
| 19 | 25% | 56.5% | 41.0% | | 5.7% | 0.0% | |
| 20 | 25% | 46.7% | 31.2% | | 5.7% | 0.0% | |
| 21 | 50% | 42.6% | 27.0% | | 11.4% | 0.0% | |
| 22 | 100% | 49.8% | 34.3% | | 22.8% | 0.0% | |
| 23 | 100% | 57.1% | 41.5% | | 22.8% | 0.0% | |
| 24 | 100% | 64.3% | 48.8% | | 22.8% | 0.0% | |
| 25 | 100% | 71.6% | 56.1% | | 22.8% | 0.0% | |
| 26 | 100% | 78.8% | 63.3% | | 22.8% | 0.0% | |
| 27 | 100% | 86.1% | 70.6% | | 22.8% | 0.0% | |
| 28 | 100% | 93.3% | 77.8% | | 22.8% | 0.0% | |
| 29 | 100% | 100.0% | 84.5% | | 22.8% | 0.0% | |
| 30 | 100% | 100.0% | 84.5% | | 22.8% | 0.0% | |
| 31 | 100% | 100.0% | 84.5% | | 22.8% | 0.0% | |

## System Performance Simulation

Solar power systems performance degrades over time. In the 220_W Grid Tie System 20 Year Performance charts, the yearly kWh generated was lowered each year to get an idea how the system would perform over its intended life. Each system was designed to run 5 hours of 2400 lumens of light and a laptop computer or tablet for 6 hours every night for 20 years. All extra energy generated is delivered to the grid and is listed in the Energy to the Grid (kWh) Grid column. At a grid electric cost of $0.22USD/kWh, the $0USD/Year Profit column indicate the yearly value for this energy. A $150USD charge was added into year 10 for an unexpected failure.

Earlier we estimated that it would cost about $73USD a year to run a kerosene lantern for 4 hours a night. In the $50-$75-$100USD/Year columns these savings were added to the value of the electricity supplied to the grid. This comparison is between 10 lumens for 4 hours a night -TO- 2400 lumens for 5 hours plus running a laptop/tablet for 6 hours a day: not a direct comparison.

Adding all the expenditures and dividing it by the total energy delivered gives an energy cost of $0.15USD/kWh ($0.18USD/kWh for the 185_W solar grid-tie system).

| 220_W Grid Tie System 20 Year Performance: 425_Wh / Day Load | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Money saved on Kerosene | | | | $0USD/Year | | $50USD/Year | | $75USD/Year | | $100USD/Year | |
| Year | kWh Generation | Expenditures | Energy to the Grid (kWh) | Profit | Account | Profit | Account | Profit | Account | Profit | Account |
| 1 | 372 | $ (870.58) | 217 | $ 47.64 | $ (822.94) | $ 97.64 | $ (772.94) | $ 122.64 | $ (747.94) | $ 147.64 | $ (722.94) |
| 2 | 368 | | 213 | $ 46.83 | $ (776.11) | $ 96.83 | $ (676.11) | $ 121.83 | $ (626.11) | $ 146.83 | $ (576.11) |
| 3 | 364 | | 209 | $ 46.01 | $ (730.10) | $ 96.01 | $ (580.10) | $ 121.01 | $ (505.10) | $ 146.01 | $ (430.10) |
| 4 | 361 | | 205 | $ 45.19 | $ (684.91) | $ 95.19 | $ (484.91) | $ 120.19 | $ (384.91) | $ 145.19 | $ (284.91) |
| 5 | 357 | | 202 | $ 44.37 | $ (640.53) | $ 94.37 | $ (390.53) | $ 119.37 | $ (265.53) | $ 144.37 | $ (140.53) |
| 6 | 353 | | 198 | $ 43.56 | $ (596.98) | $ 93.56 | $ (296.98) | $ 118.56 | $ (146.98) | $ 143.56 | $ 3.02 |
| 7 | 349 | | 194 | $ 42.74 | $ (554.24) | $ 92.74 | $ (204.24) | $ 117.74 | $ (29.24) | $ 142.74 | $ 145.76 |
| 8 | 346 | | 191 | $ 41.92 | $ (512.32) | $ 91.92 | $ (112.32) | $ 116.92 | $ 87.68 | $ 141.92 | $ 287.68 |
| 9 | 342 | | 187 | $ 41.10 | $ (471.21) | $ 91.10 | $ (21.21) | $ 116.10 | $ 203.79 | $ 141.10 | $ 428.79 |
| 10 | 338 | $ (150.00) | 183 | $ 40.29 | $ (580.93) | $ 90.29 | $ (80.93) | $ 115.29 | $ 169.07 | $ 140.29 | $ 419.07 |
| 11 | 335 | | 179 | $ 39.47 | $ (541.46) | $ 89.47 | $ 8.54 | $ 114.47 | $ 283.54 | $ 139.47 | $ 558.54 |
| 12 | 331 | | 176 | $ 38.65 | $ (502.81) | $ 88.65 | $ 97.19 | $ 113.65 | $ 397.19 | $ 138.65 | $ 697.19 |
| 13 | 327 | | 172 | $ 37.83 | $ (464.98) | $ 87.83 | $ 185.02 | $ 112.83 | $ 510.02 | $ 137.83 | $ 835.02 |
| 14 | 323 | | 168 | $ 37.01 | $ (427.96) | $ 87.01 | $ 272.04 | $ 112.01 | $ 622.04 | $ 137.01 | $ 972.04 |
| 15 | 320 | | 165 | $ 36.20 | $ (391.77) | $ 86.20 | $ 358.23 | $ 111.20 | $ 733.23 | $ 136.20 | $ 1,108.23 |
| 16 | 316 | | 161 | $ 35.38 | $ (356.39) | $ 85.38 | $ 443.61 | $ 110.38 | $ 843.61 | $ 135.38 | $ 1,243.61 |
| 17 | 312 | | 157 | $ 34.56 | $ (321.83) | $ 84.56 | $ 528.17 | $ 109.56 | $ 953.17 | $ 134.56 | $ 1,378.17 |
| 18 | 309 | | 153 | $ 33.74 | $ (288.08) | $ 83.74 | $ 611.92 | $ 108.74 | $ 1,061.92 | $ 133.74 | $ 1,511.92 |
| 19 | 305 | | 150 | $ 32.93 | $ (255.16) | $ 82.93 | $ 694.84 | $ 107.93 | $ 1,169.84 | $ 132.93 | $ 1,644.84 |
| 20 | 301 | | 146 | $ 32.11 | $ (223.05) | $ 82.11 | $ 776.95 | $ 107.11 | $ 1,276.95 | $ 132.11 | $ 1,776.95 |

| 220_W Grid Tie System 20 Year Performance: 320_Wh / Day Load | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Money saved on Kerosene | | | | $0USD/Year | | $50USD/Year | | $75USD/Year | | $100USD/Year | |
| Year | kWh Generation | Expenditures | Energy to the Grid (kWh) | Profit | Account | Profit | Account | Profit | Account | Profit | Account |
| 1 | 372 | $ (870.58) | 255 | $ 56.08 | $ (814.50) | $ 106.08 | $ (764.50) | $ 131.08 | $ (739.50) | $ 156.08 | $ (714.50) |
| 2 | 368 | | 251 | $ 55.26 | $ (759.24) | $ 105.26 | $ (659.24) | $ 130.26 | $ (609.24) | $ 155.26 | $ (559.24) |
| 3 | 364 | | 247 | $ 54.44 | $ (704.80) | $ 104.44 | $ (554.80) | $ 129.44 | $ (479.80) | $ 154.44 | $ (404.80) |
| 4 | 361 | | 244 | $ 53.62 | $ (651.18) | $ 103.62 | $ (451.18) | $ 128.62 | $ (351.18) | $ 153.62 | $ (251.18) |
| 5 | 357 | | 240 | $ 52.81 | $ (598.38) | $ 102.81 | $ (348.38) | $ 127.81 | $ (223.38) | $ 152.81 | $ (98.38) |
| 6 | 353 | | 236 | $ 51.99 | $ (546.39) | $ 101.99 | $ (246.39) | $ 126.99 | $ (96.39) | $ 151.99 | $ 53.61 |
| 7 | 349 | | 233 | $ 51.17 | $ (495.22) | $ 101.17 | $ (145.22) | $ 126.17 | $ 29.78 | $ 151.17 | $ 204.78 |
| 8 | 346 | | 229 | $ 50.35 | $ (444.87) | $ 100.35 | $ (44.87) | $ 125.35 | $ 155.13 | $ 150.35 | $ 355.13 |
| 9 | 342 | | 225 | $ 49.53 | $ (395.33) | $ 99.53 | $ 54.67 | $ 124.53 | $ 279.67 | $ 149.53 | $ 504.67 |
| 10 | 338 | $ (150.00) | 221 | $ 48.72 | $ (496.61) | $ 98.72 | $ 3.39 | $ 123.72 | $ 253.39 | $ 148.72 | $ 503.39 |
| 11 | 335 | | 218 | $ 47.90 | $ (448.71) | $ 97.90 | $ 101.29 | $ 122.90 | $ 376.29 | $ 147.90 | $ 651.29 |
| 12 | 331 | | 214 | $ 47.08 | $ (401.63) | $ 97.08 | $ 198.37 | $ 122.08 | $ 498.37 | $ 147.08 | $ 798.37 |
| 13 | 327 | | 210 | $ 46.26 | $ (355.37) | $ 96.26 | $ 294.63 | $ 121.26 | $ 619.63 | $ 146.26 | $ 944.63 |
| 14 | 323 | | 207 | $ 45.45 | $ (309.92) | $ 95.45 | $ 390.08 | $ 120.45 | $ 740.08 | $ 145.45 | $ 1,090.08 |
| 15 | 320 | | 203 | $ 44.63 | $ (265.30) | $ 94.63 | $ 484.70 | $ 119.63 | $ 859.70 | $ 144.63 | $ 1,234.70 |
| 16 | 316 | | 199 | $ 43.81 | $ (221.48) | $ 93.81 | $ 578.52 | $ 118.81 | $ 978.52 | $ 143.81 | $ 1,378.52 |
| 17 | 312 | | 195 | $ 42.99 | $ (178.49) | $ 92.99 | $ 671.51 | $ 117.99 | $ 1,096.51 | $ 142.99 | $ 1,521.51 |
| 18 | 309 | | 192 | $ 42.18 | $ (136.32) | $ 92.18 | $ 763.68 | $ 117.18 | $ 1,213.68 | $ 142.18 | $ 1,663.68 |
| 19 | 305 | | 188 | $ 41.36 | $ (94.96) | $ 91.36 | $ 855.04 | $ 116.36 | $ 1,330.04 | $ 141.36 | $ 1,805.04 |
| 20 | 301 | | 184 | $ 40.54 | $ (54.42) | $ 90.54 | $ 945.58 | $ 115.54 | $ 1,445.58 | $ 140.54 | $ 1,945.58 |

| 220_W Grid Tie System 20 Year Performance: 240_Wh / Day Load | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Money saved on Kerosene | | | | $0USD/Year | | $50USD/Year | | $75USD/Year | | $100USD/Year | |
| Year | kWh Generation | Expenditures | Energy to the Grid (kWh) | Profit | Account | Profit | Account | Profit | Account | Profit | Account |
| 1 | 372 | $ (870.58) | 284 | $ 62.50 | $ (808.08) | $ 112.50 | $ (758.08) | $ 137.50 | $ (733.08) | $ 162.50 | $ (708.08) |
| 2 | 368 | | 280 | $ 61.68 | $ (746.40) | $ 111.68 | $ (646.40) | $ 136.68 | $ (596.40) | $ 161.68 | $ (546.40) |
| 3 | 364 | | 277 | $ 60.86 | $ (685.53) | $ 110.86 | $ (535.53) | $ 135.86 | $ (460.53) | $ 160.86 | $ (385.53) |
| 4 | 361 | | 273 | $ 60.05 | $ (625.48) | $ 110.05 | $ (425.48) | $ 135.05 | $ (325.48) | $ 160.05 | $ (225.48) |
| 5 | 357 | | 269 | $ 59.23 | $ (566.26) | $ 109.23 | $ (316.26) | $ 134.23 | $ (191.26) | $ 159.23 | $ (66.26) |
| 6 | 353 | | 266 | $ 58.41 | $ (507.84) | $ 108.41 | $ (207.84) | $ 133.41 | $ (57.84) | $ 158.41 | $ 92.16 |
| 7 | 349 | | 262 | $ 57.59 | $ (450.25) | $ 107.59 | $ (100.25) | $ 132.59 | $ 74.75 | $ 157.59 | $ 249.75 |
| 8 | 346 | | 258 | $ 56.78 | $ (393.47) | $ 106.78 | $ 6.53 | $ 131.78 | $ 206.53 | $ 156.78 | $ 406.53 |
| 9 | 342 | | 254 | $ 55.96 | $ (337.51) | $ 105.96 | $ 112.49 | $ 130.96 | $ 337.49 | $ 155.96 | $ 562.49 |
| 10 | 338 | $ (150.00) | 251 | $ 55.14 | $ (432.37) | $ 105.14 | $ 67.63 | $ 130.14 | $ 317.63 | $ 155.14 | $ 567.63 |
| 11 | 335 | | 247 | $ 54.32 | $ (378.05) | $ 104.32 | $ 171.95 | $ 129.32 | $ 446.95 | $ 154.32 | $ 721.95 |
| 12 | 331 | | 243 | $ 53.51 | $ (324.55) | $ 103.51 | $ 275.45 | $ 128.51 | $ 575.45 | $ 153.51 | $ 875.45 |
| 13 | 327 | | 239 | $ 52.69 | $ (271.86) | $ 102.69 | $ 378.14 | $ 127.69 | $ 703.14 | $ 152.69 | $ 1,028.14 |
| 14 | 323 | | 236 | $ 51.87 | $ (219.99) | $ 101.87 | $ 480.01 | $ 126.87 | $ 830.01 | $ 151.87 | $ 1,180.01 |
| 15 | 320 | | 232 | $ 51.05 | $ (168.94) | $ 101.05 | $ 581.06 | $ 126.05 | $ 956.06 | $ 151.05 | $ 1,331.06 |
| 16 | 316 | | 228 | $ 50.23 | $ (118.70) | $ 100.23 | $ 681.30 | $ 125.23 | $ 1,081.30 | $ 150.23 | $ 1,481.30 |
| 17 | 312 | | 225 | $ 49.42 | $ (69.28) | $ 99.42 | $ 780.72 | $ 124.42 | $ 1,205.72 | $ 149.42 | $ 1,630.72 |
| 18 | 309 | | 221 | $ 48.60 | $ (20.68) | $ 98.60 | $ 879.32 | $ 123.60 | $ 1,329.32 | $ 148.60 | $ 1,779.32 |
| 19 | 305 | | 217 | $ 47.78 | $ 27.10 | $ 97.78 | $ 977.10 | $ 122.78 | $ 1,452.10 | $ 147.78 | $ 1,927.10 |
| 20 | 301 | | 213 | $ 46.96 | $ 74.06 | $ 96.96 | $ 1,074.06 | $ 121.96 | $ 1,574.06 | $ 146.96 | $ 2,074.06 |

Off-grid systems require a battery for energy storage. This battery and the charge control electronics associated with it make off-grid solar power systems more expensive. Also, cost effective batteries do not last 20 years. In the expenditures column, an unexpected $150USD failure was included in year 10 and a battery replacement was included in year 11. The batteries should last a little longer than 10 years. Nevertheless, for 20 years of performance, a battery replacement will be required.

Looking at the same $50-$75-$100/year savings on kerosene, none of the three systems will really ever pay for themselves. We are doing a little more than supplying 10 lumens of light per night. An extra column was added with the cost required to repay for the systems in 10 years. An added change for the cost associated for a micro-loan program will need to be added. Small off-grid solar power systems are only good for areas where there is no access to a local grid.

The cost of electricity for the Off-Grid Systems was done a little differently than normal. Most of these types of calculations use the amount of energy generated by the system. The following calculations use the amount of usable (to the loads) energy over the 20 year life of the system. Also included is the cost associated with maintaining the system for 20 years. System 1 (185_W), $0.84USD/kWh; System 2 (150_W), $0.94USD/kWh; System 3 (100_W), $1.07USD/kWh.

| SYSTEM 1: 185_W Off-Grid System 20 Year Performance: 425_Wh / Day Load | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Money saved on Kerosene | | $50USD/Year $4.25/Month | | $75USD/Year $6.25/Month | | $100USD/Year $8.33/Month | | $259.61USD/Year $21.63/Month | |
| Year | Expenditures | Payment | Account | Payment | Account | Payment | Account | Payment | Account |
| 1 | $ (1,675.82) | $ 50.00 | $ (1,625.82) | $ 75.00 | $ (1,675.82) | $ 100.00 | $ (1,575.82) | $ 259.61 | $ (1,416.21) |
| 2 | | $ 50.00 | $ (1,575.82) | $ 75.00 | $ (1,600.82) | $ 100.00 | $ (1,475.82) | $ 259.61 | $ (1,156.60) |
| 3 | | $ 50.00 | $ (1,525.82) | $ 75.00 | $ (1,525.82) | $ 100.00 | $ (1,375.82) | $ 259.61 | $ (896.99) |
| 4 | | $ 50.00 | $ (1,475.82) | $ 75.00 | $ (1,450.82) | $ 100.00 | $ (1,275.82) | $ 259.61 | $ (637.38) |
| 5 | | $ 50.00 | $ (1,425.82) | $ 75.00 | $ (1,375.82) | $ 100.00 | $ (1,175.82) | $ 259.61 | $ (377.77) |
| 6 | | $ 50.00 | $ (1,375.82) | $ 75.00 | $ (1,300.82) | $ 100.00 | $ (1,075.82) | $ 259.61 | $ (118.16) |
| 7 | | $ 50.00 | $ (1,325.82) | $ 75.00 | $ (1,225.82) | $ 100.00 | $ (975.82) | $ 259.61 | $ 141.45 |
| 8 | | $ 50.00 | $ (1,275.82) | $ 75.00 | $ (1,150.82) | $ 100.00 | $ (875.82) | $ 259.61 | $ 401.06 |
| 9 | | $ 50.00 | $ (1,225.82) | $ 75.00 | $ (1,075.82) | $ 100.00 | $ (775.82) | $ 259.61 | $ 660.67 |
| 10 | $ (150.00) | $ 50.00 | $ (1,325.82) | $ 75.00 | $ (1,150.82) | $ 100.00 | $ (825.82) | $ 259.61 | $ 770.28 |
| 11 | $ (770.25) | $ 50.00 | $ (2,046.07) | $ 75.00 | $ (1,846.07) | $ 100.00 | $ (1,496.07) | | $ 0.03 |
| 12 | | $ 50.00 | $ (1,996.07) | $ 75.00 | $ (1,771.07) | $ 100.00 | $ (1,396.07) | | $ 0.03 |
| 13 | | $ 50.00 | $ (1,946.07) | $ 75.00 | $ (1,696.07) | $ 100.00 | $ (1,296.07) | | $ 0.03 |
| 14 | | $ 50.00 | $ (1,896.07) | $ 75.00 | $ (1,621.07) | $ 100.00 | $ (1,196.07) | | $ 0.03 |
| 15 | | $ 50.00 | $ (1,846.07) | $ 75.00 | $ (1,546.07) | $ 100.00 | $ (1,096.07) | | $ 0.03 |
| 16 | | $ 50.00 | $ (1,796.07) | $ 75.00 | $ (1,471.07) | $ 100.00 | $ (996.07) | | $ 0.03 |
| 17 | | $ 50.00 | $ (1,746.07) | $ 75.00 | $ (1,396.07) | $ 100.00 | $ (896.07) | | $ 0.03 |
| 18 | | $ 50.00 | $ (1,696.07) | $ 75.00 | $ (1,321.07) | $ 100.00 | $ (796.07) | | $ 0.03 |
| 19 | | $ 50.00 | $ (1,646.07) | $ 75.00 | $ (1,246.07) | $ 100.00 | $ (696.07) | | $ 0.03 |
| 20 | | $ 50.00 | $ (1,596.07) | $ 75.00 | $ (1,171.07) | $ 100.00 | $ (596.07) | | $ 0.03 |

| SYSTEM 2: 150_W Off-Grid System 20 Year Performance: 320_Wh / Day Load | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Money saved on Kerosene | | $50USD/Year $4.25/Month | | $75USD/Year $6.25/Month | | $100USD/Year $8.33/Month | | $220.71USD/Year $18.39/Month | |
| Year | Expenditures | Payment | Account | Payment | Account | Payment | Account | Payment | Account |
| 1 | $ (1,401.94) | $ 50.00 | $ (1,351.94) | $ 75.00 | $ (1,326.94) | $ 100.00 | $ (1,301.94) | $ 220.71 | $ (1,181.23) |
| 2 | | $ 50.00 | $ (1,301.94) | $ 75.00 | $ (1,251.94) | $ 100.00 | $ (1,201.94) | $ 220.71 | $ (960.52) |
| 3 | | $ 50.00 | $ (1,251.94) | $ 75.00 | $ (1,176.94) | $ 100.00 | $ (1,101.94) | $ 220.71 | $ (739.81) |
| 4 | | $ 50.00 | $ (1,201.94) | $ 75.00 | $ (1,101.94) | $ 100.00 | $ (1,001.94) | $ 220.71 | $ (519.10) |
| 5 | | $ 50.00 | $ (1,151.94) | $ 75.00 | $ (1,026.94) | $ 100.00 | $ (901.94) | $ 220.71 | $ (298.39) |
| 6 | | $ 50.00 | $ (1,101.94) | $ 75.00 | $ (951.94) | $ 100.00 | $ (801.94) | $ 220.71 | $ (77.68) |
| 7 | | $ 50.00 | $ (1,051.94) | $ 75.00 | $ (876.94) | $ 100.00 | $ (701.94) | $ 220.71 | $ 143.03 |
| 8 | | $ 50.00 | $ (1,001.94) | $ 75.00 | $ (801.94) | $ 100.00 | $ (601.94) | $ 220.71 | $ 363.74 |
| 9 | | $ 50.00 | $ (951.94) | $ 75.00 | $ (726.94) | $ 100.00 | $ (501.94) | $ 220.71 | $ 584.45 |
| 10 | $ (150.00) | $ 50.00 | $ (1,051.94) | $ 75.00 | $ (801.94) | $ 100.00 | $ (551.94) | $ 220.71 | $ 655.16 |
| 11 | $ (655.20) | $ 50.00 | $ (1,657.14) | $ 75.00 | $ (1,382.14) | $ 100.00 | $ (1,107.14) | | $ (0.04) |
| 12 | | $ 50.00 | $ (1,607.14) | $ 75.00 | $ (1,307.14) | $ 100.00 | $ (1,007.14) | | $ (0.04) |
| 13 | | $ 50.00 | $ (1,557.14) | $ 75.00 | $ (1,232.14) | $ 100.00 | $ (907.14) | | $ (0.04) |
| 14 | | $ 50.00 | $ (1,507.14) | $ 75.00 | $ (1,157.14) | $ 100.00 | $ (807.14) | | $ (0.04) |
| 15 | | $ 50.00 | $ (1,457.14) | $ 75.00 | $ (1,082.14) | $ 100.00 | $ (707.14) | | $ (0.04) |
| 16 | | $ 50.00 | $ (1,407.14) | $ 75.00 | $ (1,007.14) | $ 100.00 | $ (607.14) | | $ (0.04) |
| 17 | | $ 50.00 | $ (1,357.14) | $ 75.00 | $ (932.14) | $ 100.00 | $ (507.14) | | $ (0.04) |
| 18 | | $ 50.00 | $ (1,307.14) | $ 75.00 | $ (857.14) | $ 100.00 | $ (407.14) | | $ (0.04) |
| 19 | | $ 50.00 | $ (1,257.14) | $ 75.00 | $ (782.14) | $ 100.00 | $ (307.14) | | $ (0.04) |
| 20 | | $ 50.00 | $ (1,207.14) | $ 75.00 | $ (707.14) | $ 100.00 | $ (207.14) | | $ (0.04) |

| SYSTEM 3: 100_W Off-Grid System 20 Year Performance: 240_Wh / Day Load | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Money saved on Kerosene | | $50USD/Year $4.25/Month | | $75USD/Year $6.25/Month | | $100USD/Year $8.33/Month | | $188.22USD/Year $15.89/Month | |
| Year | Expenditures | Payment | Account | Payment | Account | Payment | Account | Payment | Account |
| 1 | $ (1,194.58) | $ 50.00 | $ (1,144.58) | $ 75.00 | $ (1,119.58) | $ 100.00 | $ (1,094.58) | $ 188.22 | $ (1,006.36) |
| 2 | | $ 50.00 | $ (1,094.58) | $ 75.00 | $ (1,044.58) | $ 100.00 | $ (994.58) | $ 188.22 | $ (818.14) |
| 3 | | $ 50.00 | $ (1,044.58) | $ 75.00 | $ (969.58) | $ 100.00 | $ (894.58) | $ 188.22 | $ (629.92) |
| 4 | | $ 50.00 | $ (994.58) | $ 75.00 | $ (894.58) | $ 100.00 | $ (794.58) | $ 188.22 | $ (441.70) |
| 5 | | $ 50.00 | $ (944.58) | $ 75.00 | $ (819.58) | $ 100.00 | $ (694.58) | $ 188.22 | $ (253.48) |
| 6 | | $ 50.00 | $ (894.58) | $ 75.00 | $ (744.58) | $ 100.00 | $ (594.58) | $ 188.22 | $ (65.26) |
| 7 | | $ 50.00 | $ (844.58) | $ 75.00 | $ (669.58) | $ 100.00 | $ (494.58) | $ 188.22 | $ 122.96 |
| 8 | | $ 50.00 | $ (794.58) | $ 75.00 | $ (594.58) | $ 100.00 | $ (394.58) | $ 188.22 | $ 311.18 |
| 9 | | $ 50.00 | $ (744.58) | $ 75.00 | $ (519.58) | $ 100.00 | $ (294.58) | $ 188.22 | $ 499.40 |
| 10 | $ (150.00) | $ 50.00 | $ (844.58) | $ 75.00 | $ (594.58) | $ 100.00 | $ (344.58) | $ 188.22 | $ 537.62 |
| 11 | $ (537.60) | $ 50.00 | $ (1,332.18) | $ 75.00 | $ (1,057.18) | $ 100.00 | $ (782.18) | | $ 0.02 |
| 12 | | $ 50.00 | $ (1,282.18) | $ 75.00 | $ (982.18) | $ 100.00 | $ (682.18) | | $ 0.02 |
| 13 | | $ 50.00 | $ (1,232.18) | $ 75.00 | $ (907.18) | $ 100.00 | $ (582.18) | | $ 0.02 |
| 14 | | $ 50.00 | $ (1,182.18) | $ 75.00 | $ (832.18) | $ 100.00 | $ (482.18) | | $ 0.02 |
| 15 | | $ 50.00 | $ (1,132.18) | $ 75.00 | $ (757.18) | $ 100.00 | $ (382.18) | | $ 0.02 |
| 16 | | $ 50.00 | $ (1,082.18) | $ 75.00 | $ (682.18) | $ 100.00 | $ (282.18) | | $ 0.02 |
| 17 | | $ 50.00 | $ (1,032.18) | $ 75.00 | $ (607.18) | $ 100.00 | $ (182.18) | | $ 0.02 |
| 18 | | $ 50.00 | $ (982.18) | $ 75.00 | $ (532.18) | $ 100.00 | $ (82.18) | | $ 0.02 |
| 19 | | $ 50.00 | $ (932.18) | $ 75.00 | $ (457.18) | $ 100.00 | $ 17.82 | | $ 0.02 |
| 20 | | $ 50.00 | $ (882.18) | $ 75.00 | $ (382.18) | $ 100.00 | $ 117.82 | | $ 0.02 |

## Component Specifications

All materials and components used in the design have a country of origin of the US. The only exception to this is the solar panels. The cells used in the solar panels were manufactured in the US, but the final assembly of the solar panels is done in Mexico.

### Solar Panels

| | | | |
|---|---|---|---|
| Panel Technology | Monocrystalline | | |
| Standard Test Conditions | 1000 W/m$^2$, AM 1.5, 25° C | | |
| Maximum Power ($P_{max}$) | 100 W | 150 W | 185 W |
| Voltage at Pmax ($V_{mp}$) | 34.6 V | 34.6 V | 34.6 V |
| Current at Pmax ($I_{mp}$) | 2.9 A | 4.35 A | 5.35 A |
| Short-circuit Current ($I_{sc}$) | 3.2 A | 4.77 A | 5.89 A |
| Open-circuit Voltage ($V_{oc}$) | 43.2 V | 43.2 V | 43.2 V |

### Inverter: Micro Grid-Tie

| | |
|---|---|
| DC Input Voltage | 23-60 VDC |
| Continuous Power Rating | 220 W |
| AC Voltage/Frequency | 230 VAC, 50 Hz, Pure Sine |
| Efficiency | >86% |
| Over-load protection | >230 W |
| Water proof | IP67 |
| Short-circuit protection | |
| Under voltage protection | |
| Over voltage protection | |
| Over temperature protection | |

### Inverter: Off-Grid

| | |
|---|---|
| DC Input Voltage | 19.8 – 29.5 |
| Continuous Power Rating | 220 W |
| AC Voltage/Frequency | 230 VAC, 50 Hz, Pure Sine |
| Efficiency | >86% |
| Over-load protection | >230 W |
| Short-circuit protection | |
| Under voltage protection | |
| Over voltage protection | |
| Over temperature protection | |

## Charge Controller: Off-Grid Systems

| | |
|---|---|
| Technology | MPPT max power point tracking |
| Max Solar Array | 400 W |
| Solar Array Voltage | 12 – 75 VDC |
| Power Conversion Efficiency | 96-98% |
| Charging Regulation | 4 Stages |

## Battery Bank

| Battery Specifications | | | |
|---|---|---|---|
| Battery Technology | VRLA Solar Gel | | |
| Battery Life @ 33% DOD | +2100 cycles | | |
| Battery Life @ 15% DOD | 5700 | | |
| Battery Voltage (V) | 12 | 12 | 12 |
| Battery Capacity (Ah) | 73.6 | 97.6 | 125 |
| **Battery Bank Specifications** | | | |
| Number of Batteries | 2 | 2 | 2 |
| Bank Voltage (V) | 24 | 24 | 24 |
| Bank Energy Storage (Wh) | 1,766 | 2,342 | 3,000 |

## Compact Fluorescent Lights (CFL)

| | |
|---|---|
| Input Voltage | 230 VAC |
| Output | 800_lm |
| Color Temperature | Cool White 8000k |
| | White 6500k |
| | Warm White 3000k |
| Rated Life | 8,000_h |