Off Grid System Design

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San Diego, CA
What is an “Off-Grid” system?

- No access to the utility electrical grid, or limited or no use of the utility grid
- Batteries used to provide for loads when it’s dark or cloudy
  - Often referred to as Battery-Based systems
- Modules and racking are usually the same as used in grid-tie systems
- Most other components are specialized
Types of Off-Grid systems

- **PV direct**
  - Loads are run directly from the solar source
  - No energy storage (batteries)
  - Loads typically motors (pumps, fans, etc.) that run directly from the solar array

- **DC-Only**
  - All loads run on DC from a battery
  - Batteries charged by PV, engine generator, wind, hydro etc.

- **AC-only**
  - All loads run on AC power from an inverter or AC generator

- **AC/DC**
  - Both AC and DC loads are powered by the system

- **Hybrid**
  - Derives energy from more than one source
    - i.e. PV and a generator, PV and wind and/or hydro
  - Most common type of Off-Grid system used for homes
Load is run directly from solar array, without energy storage (batteries).

Generally used only with motors, like pumps and fans, which can run directly from a DC energy source. Well pumps are the most common load.

Loads can only run when energy is available from the production source since there is no energy storage.

Very simple systems—minimal equipment needed, such as solar array, direct drive controller, and the load.

Loads run at variable speed depending on energy available from source: PV-direct systems do not work at night.

Current limited: only the amount of current that is directly produced by the energy source is present. Often means that overcurrent devices are not needed as long as the conductors are sized to handle full current.
DC-Only Systems

- Load size & voltage drives design
  - DC load current and run time determines system size
  - No AC loads or inverter

- PV used to charge the battery bank
  - Constant power from intermittent source
  - Sometimes with generator backup

- Common applications include lighting, communications, telemetry, signage and data logging

- Example: Weather station
  - PV array and mounting structure
  - 12 VDC Battery
  - PWM Charge controller
  - Weather sensors and data logger/transmitter
AC–Only systems

- AC from an inverter powers all of the electrical loads
  - Any type of AC load can be powered
  - Inverter output limits total load draw
  - Appliances and wiring are standard and easy to find

- Inverter draws from battery bank
  - PV array charges batteries as in DC-only system
  - PV Arrays and other charging sources are connected to charge controller(s) rather than inverter
  - Most inverters can enable battery-charging from an AC generator
Both AC and DC loads are powered by the off-grid power system
- DC loads powered directly from battery output
- AC loads powered by inverter or generator

Requires separate AC & DC electrical circuits

Most common in Boats and RV’s
- Note that mobile inverters have special grounding requirements
- Mobile inverters fall under a different UL listing
Hybrid systems

- Energy is produced by more than one source, for instance PV and wind, or PV and hydro, or PV and a generator.
How does Off-Grid system design differ from Grid-Tie system design?

<table>
<thead>
<tr>
<th>Grid-Tie (Net-Metered)</th>
<th>Off-Grid</th>
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</thead>
<tbody>
<tr>
<td>• Energy production and PV array size based on annual consumption</td>
<td>• Energy production based on daily or weekly consumption</td>
</tr>
<tr>
<td>• Some energy used directly as it’s produced, and some energy is sent to the grid (stored as credit)</td>
<td>• Some energy used directly as it’s produced, and some energy is stored in batteries</td>
</tr>
<tr>
<td>• Inverter size matches array size</td>
<td>• PV array sized based on energy production during the darkest time of year</td>
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<tr>
<td>• Simple – few long lasting components</td>
<td>• Inverter size based on peak AC load, not on array size</td>
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<tr>
<td>• If the system fails, the lights stay on</td>
<td>• More complex – many components</td>
</tr>
<tr>
<td></td>
<td>• If the system fails, the lights go out</td>
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</tbody>
</table>
Off-Grid System Components

- PV array, engine generator, wind turbine, micro-hydro turbine, etc
- PV array combiner box (rapid shutdown system)
- Charge controller(s)
- Battery bank
- Battery-based inverter(s)
- DC switchgear and over-current protection
- AC switchgear and over-current protection
- Battery monitor and other system controllers
Off-Grid System Diagram
Off-Grid System Sizing

The purpose of the off-grid power system is to provide power to run loads.

System design begins with an analysis of the loads that need to be powered.
User Information That You Will Need to Collect

• **Daily consumption (Watt-hours)**
  – How much energy will the application consume each day? Is it seasonal?
  – For each load, multiply the power draw by the hours it is used per day
  – For appliances, divide the Energy Star annual consumption kWh by 365

• **Peak load (Watts) and characteristics (VDC/VAC/Hz)**
  – Sum of all loads that may be run simultaneously
  – Separate AC and DC Loads
  – Voltage and frequency the loads require

• **Days of Autonomy (Energy storage)**
  – How many days in a row will the loads need to run with little or no sun
  – Don’t neglect to account for snow

• **Sun-Hours per day during the darkest month (kWh/day)**
  – This is the available solar resource
  – Use Winter Solstice time frame rather than annual average if loads will be run during winter
Load Analysis

Loads Worksheet – From the AEE Solar Off Grid quote request form

**List your AC loads:**
List all AC loads, wattage and hours of use per day in the spaces provided. Wattage of appliances can usually be determined from tags on the back of the appliance or from the owner's manual. If an appliance is rated in amps, multiply amps by operating voltage (120 or 240) to find watts.

<table>
<thead>
<tr>
<th>Descriptions of AC loads run by inverter</th>
<th>Voltage</th>
<th>Watts</th>
<th>Hours/Day</th>
<th>Watthours/Day</th>
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<td>Spring</td>
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<td>Heating system</td>
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<td>Mar-Apr</td>
<td>May-Aug</td>
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<td>well pump (1200)</td>
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<td>computer &amp; monitor (120)</td>
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<td>router and network (50)</td>
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<td>printer &amp; peripherals (100)</td>
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<td>DVD &amp; DVD player or similar (100)</td>
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<td>Dryer, Gas only (600)</td>
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<td>Vacuum (1300)</td>
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<tr>
<td>Inverter efficiency 87%</td>
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<td>Total AC load</td>
<td>Total AC load w/inverter eff.</td>
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</tbody>
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**List your DC loads:**
List all DC loads, wattage and hours of use per day in the spaces provided.

<table>
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<tr>
<td>Inverter tie</td>
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<td>DC load</td>
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</table>
# Load Analysis

## Loads Worksheet – Refrigerators and Freezers

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</thead>
<tbody>
<tr>
<td>Inverter take</td>
<td>48</td>
<td>24</td>
<td>840</td>
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<tr>
<td>DC load</td>
<td>35</td>
<td>24</td>
<td>840</td>
</tr>
</tbody>
</table>

Use kWh per year figure for Watt-hour calculation.

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*Image source: AEE Solar, Delivering Success [Link to original source]*
### Load Analysis

#### Loads Worksheet – Inverter tare loss

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<th>Voltage</th>
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<th>Summer May-Aug</th>
<th>Autumn Sept-Oct</th>
<th>Winter Nov-Feb</th>
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<tr>
<td>Heating system</td>
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<td>Lights</td>
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<td>router and network (50)</td>
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<td>Refrigerator/freezer (annual kWh from energy guide)</td>
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<tr>
<td>Inverter efficiency 87%</td>
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<td>Total AC load</td>
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<td>0</td>
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<td>0</td>
</tr>
</tbody>
</table>

#### List your DC loads:

List all DC loads, wattage and hours of use per day in the spaces provided.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>

Inverter tare loss is a DC load.
Load Analysis

Loads Worksheet – Total AC loads for inverter

List your AC loads:
List all AC loads, wattage and hours of use per day in the spaces provided. Wattage of appliances can usually be determined from tags on the back of the appliance or from the owner’s manual. If an appliance is rated in amps, multiply amps by operating voltage (120 or 240) to find watts.

<table>
<thead>
<tr>
<th>Description of AC loads run by inverter</th>
<th>Voltage</th>
<th>Watts</th>
<th>Spring Mar-Apr</th>
<th>Summer May-Aug</th>
<th>Autumn Sept-Oct</th>
<th>Winter Nov-Feb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>well pump (1200)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>septic pump (1200)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lights</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>computer &amp; monitor (120)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>router and network (50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>printer &amp; peripherals (100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tv &amp; dvd player or similar (200)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>satellite dish (50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stereo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>microwave (1500)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>washing machine (600)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dryer, Gas only (600)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum (1500)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air conditioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Refrigerator/freezer                    |         |       |                |                |                 |               |
| (annual kWh from energy guide)          |         |       |                |                |                 |               |
| Refrigerator/freezer                    |         |       |                |                |                 |               |
| (annual kWh from energy guide)          |         |       |                |                |                 |               |
| Inverter efficiency                     |       | 87%   |                 |                |                 |               |
| Total AC load                           |         |       |                |                |                 |               |
| Total AC load w/ inverter eff.         |         |       |                |                |                 |               |
| Total AC loads - Wh/day                 |         |       |                |                |                 |               |

List your DC loads:
List all DC loads, wattage and hours of use per day in the spaces provided.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Watts</th>
<th>Hours/Daily</th>
<th>Watts/hours/Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>35</td>
<td>24</td>
<td>840</td>
</tr>
<tr>
<td>DC load</td>
<td></td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

Total AC loads that will be powered by the inverter. This will determine the inverter size.
Don’t Forget “Phantom” Loads

## Phantom load

Some devices draw power even when they are not in use or are switched off. It’s called phantom load. The chart shows power costs if device is off the entire month.

<table>
<thead>
<tr>
<th>Appliance or device</th>
<th>Typical load when off but plugged in</th>
<th>Power cost per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desktop PC (computer and LCD monitor)</td>
<td>5</td>
<td>$.67</td>
</tr>
<tr>
<td>Computer speakers</td>
<td>2</td>
<td>$.27</td>
</tr>
<tr>
<td>Wireless router</td>
<td>2</td>
<td>$.27</td>
</tr>
<tr>
<td>Multi function printer/scanner/copier</td>
<td>6</td>
<td>$.80</td>
</tr>
<tr>
<td>LCD television</td>
<td>1.5</td>
<td>$.20</td>
</tr>
<tr>
<td>Plasma television</td>
<td>3</td>
<td>$.40</td>
</tr>
<tr>
<td>Digital cable box</td>
<td>35</td>
<td>$4.66</td>
</tr>
<tr>
<td>TiVo or digital video recorder</td>
<td>35</td>
<td>$4.66</td>
</tr>
<tr>
<td>Satellite cable box</td>
<td>12</td>
<td>$1.60</td>
</tr>
<tr>
<td>Cellphone charger (when not charging)</td>
<td>1</td>
<td>$.13</td>
</tr>
<tr>
<td>Video game console (Xbox 360)</td>
<td>1</td>
<td>$.13</td>
</tr>
<tr>
<td>Cordless phone</td>
<td>2</td>
<td>$.27</td>
</tr>
<tr>
<td>Garage door opener</td>
<td>12</td>
<td>$1.60</td>
</tr>
<tr>
<td>Microwave oven</td>
<td>3</td>
<td>$.40</td>
</tr>
<tr>
<td>Coffee pot</td>
<td>1</td>
<td>$.40</td>
</tr>
<tr>
<td>Clock radio</td>
<td>2</td>
<td>$.27</td>
</tr>
</tbody>
</table>

(Source: U.S. Department of Energy, California Energy Commission)

123.5W x 24 hrs = 2964 Wh/day
**Load Analysis**

**Loads Worksheet – Total AC loads for inverter**

**List your AC loads:**
List all AC loads, wattage and hours of use per day in the spaces provided. Wattage of appliances can usually be determined from tags on the back of the appliance or from the owner's manual. If an appliance is rated in amps, multiply amps by operating voltage (120 or 240) to find watts.

<table>
<thead>
<tr>
<th>Descriptions of AC loads run by inverter</th>
<th>Voltage</th>
<th>Watts</th>
<th>Hours/Day</th>
<th>Wetthours/Day</th>
<th>Rotational Peak W</th>
<th>Full AC Power Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system</td>
<td></td>
<td></td>
<td>Spring</td>
<td>Summer</td>
<td>Autumn</td>
<td>Winter</td>
</tr>
<tr>
<td>well pump (1200)</td>
<td></td>
<td></td>
<td>Mar-Apr</td>
<td>May-Aug</td>
<td>Sept-Oct</td>
<td>Nov-Feb</td>
</tr>
<tr>
<td>septic pump (1200)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>lights</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>computer &amp; monitor (120)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>router and network (50)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>printer &amp; peripherals (100)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>tv &amp; dvd player or similar (200)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>satellite dish (50)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stereo</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>microwave (1500)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>washing machine (600)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dryer, Gas only (600)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>phone</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vacuum (1500)</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air conditioning</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Loads</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Loads</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Loads</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Refrigerator/freezer (annual kWh from energy guide)</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Refrigerator/freezer (annual kWh from energy guide)</td>
<td>0</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>inverter efficiency 67%</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total AC load</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total AC load w/inverter eff.</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**List your DC loads:**
List all DC loads, wattage and hours of use per day in the spaces provided.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Watts</th>
<th>Hours/Day</th>
<th>Wetthours/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter tire</td>
<td>48</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>DC load</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Total AC energy kWh needed to be supplied by the system. Each column for a season. This is what the solar and battery are sized to meet.
Load Analysis

Loads Worksheet – Example

<table>
<thead>
<tr>
<th>Description</th>
<th>Voltage</th>
<th>Watts</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system</td>
<td>2400</td>
<td>2</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Pump (1200)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Septic pump (1200)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lights (48)</td>
<td></td>
<td>2</td>
<td>2.5</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Computer &amp; monitor (120)</td>
<td>2400</td>
<td>2.5</td>
<td>1.43</td>
<td>1.43</td>
<td>1.43</td>
<td>1.43</td>
</tr>
<tr>
<td>Printer &amp; peripherals (100)</td>
<td>200</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TV &amp; DVD player or similar (100)</td>
<td>200</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Satellite dish (30)</td>
<td>80</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Stereo</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Microwave (1500)</td>
<td>120</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
</tr>
<tr>
<td>Washing machine (800)</td>
<td>350</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dish, Gas only (600)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phone</td>
<td>200</td>
<td>1.43</td>
<td>1.43</td>
<td>1.43</td>
<td>1.43</td>
<td>1.43</td>
</tr>
<tr>
<td>Vacuum (1500)</td>
<td>200</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Garage door</td>
<td>40</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Fridge</td>
<td>40</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Toaster oven</td>
<td>1100</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Pump station</td>
<td>300</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Refrigerator/Freezer</td>
<td>365</td>
<td></td>
<td>365</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigerator/Freezer (annual kWh)</td>
<td>365</td>
<td></td>
<td>365</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Daily energy consumption -
7397 Wh in winter
8511 Wh in summer
8776 Wh in autumn

Peak load -
7153 W from the inverter
8256 W from the battery
Site Analysis

• What is the solar energy potential at the site?
  – Insolation in kWh/m²/day (aka: Peak sun-hours) for each month
  – PV arrays for Off-Grid systems are based on the month with the largest load to solar resource ratio
  – Generally this will be peak during the darkest month of the year, not the yearly average
  – Sometimes the greatest load will be in the summer for A/C
  – Shade or orientation issues
  – Mounting space

• Are there any other possible energy sources other than PV?
  – Wind or Hydro turbines can produce power when sunlight is not available and can add greatly to the energy production reliability of off-grid systems
  – Recently it may be less expensive to simply add more solar

• How many cloudy days in a row should the design be based on?
  – Most Off-Grid systems require some sort of back-up power, usually a generator, for extended cloudy weather or when snow covers the array.
  – How large a battery is affordable and how much generator run time is acceptable?
Out of print but charts are available online  http://rredc.nrel.gov/solar/pubs/redbook/
PV Array Sizing
AEE Solar Catalog Maps

- In Reference Section in the back of the Catalog
- These maps show the Peak Sun-Hours for the **darkest month** of the year
  - NOT the yearly average
- They are useful for sizing off-grid systems, not grid-tie systems
PV Array Sizing
PV Watts

http://pvwatts.nrel.gov/

Use the Solar Radiation data – Use the energy production figures only with correct de-rates

Tilt and Azimuth can be adjusted

Yearly Average – 4.66

December average – 3.22
• The Off-Grid Sizing Worksheets in the AEE Catalog is one method of doing system sizing.

• Using a spreadsheet that you put together will make the task easier and faster
  – If you build your own spreadsheet you will understand how to use it

• There are third party sizing programs available
  – Some of these have complex financial models also

---

Worksheet: Off-Grid Solar Array Sizing
Determine how much energy (kWh) the solar array must produce to size the PV array and determine the total number of solar modules required for the system.

Step 1: List the total average watt-hours per day needed to power the electrical loads.
Obtain this number from the Off-Grid Loads Worksheet on the previous page.

Step 2: Calculate the minimum watt-hours needed per day.
Multiply the watt-hours per day needed by 1.25 to compensate for PV array and battery charge/discharge losses. This is the minimum total watt-hours that the PV array needs to produce, on average, each day. However, increasing the array size further will allow the system to provide some additional charging during cloudy weather and catch up more quickly after a cloudy period. Increasing the array size can also allow for reduced battery storage requirements.

Step 3: List the average sun-hours per day at the system’s location.
Choose local weather data, look at the map below, or find a city on the Solar Insolation Table in the Reference Section that has similar latitude and weather to your location. If you want year-round autonomy, use the lower winter insolation. If you want 100% autonomy only in summer, use the higher summer insolation. If you have a utility grid-tie system with net metering, use the yearly average figure.

Step 4: Determine the minimum nameplate capacity.
Divide the result of Step 2 by the average sun-hours per day from Step 3 to determine the minimum nameplate capacity of the PV array.

NOTE: Sizing Solar Arrays with PWM or MPPT Charge Controllers
If you are planning a small low-cost system with a PWM charge controller, with 12 or 24VDC “nominal” PV modules (36 or 72 cells), continue to Step 5 below. If you are planning a system with an MPPT charge controller, go to Step 5 in “Sizing Solar Arrays with MPPT Charge Controllers”. Information on the different types of PV charge controllers can be found in the Charge Controller Section.

Step 5: Calculate peak amps.
Divide the total solar array wattage required from Step 4 by the system’s DC battery voltage (usually 12, 24, or 48 VDC) to get the total peak amps (A) that the PV array must produce.

Step 6: Find the peak-power current (I_{mp}) of the module you will be using from its specifications or Data Sheet.

Step 7: Calculate the number of parallel strings.
Divide the result of Step 5 by the result of Step 6. Round up to the next whole number. This is the total number of parallel module strings required to produce the total array current needed.

Step 8: Use the table below to determine the number of modules in each series string needed to match the DC battery voltage of the power system.

<table>
<thead>
<tr>
<th>Nominal System Voltage</th>
<th>Number of Modules Connected per String</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 V Module</td>
<td>1</td>
</tr>
<tr>
<td>24 V Module</td>
<td>2</td>
</tr>
<tr>
<td>48 V Module</td>
<td>4</td>
</tr>
</tbody>
</table>

Step 9: Calculate the minimum number of solar modules.
Multiply the number of strings from Step 7 by the number of modules per string from Step 8 to get the total minimum number of solar modules required with a PWM charge controller.

Step 10: Calculate minimum PWM charge controller rating.
Multiply the number of strings from Step 7 by the module’s short-circuit current (I_{SC}) and then by a 1.25 Code-required safety factor. The current rating of the selected PWM charge controller must exceed this number.
PV Array Sizing
De-rate factors

• Module power tolerance
  – Though most modules are now -0/+3% tolerance, some are still up to -5%

• Module temperature de-rate
  – This will vary through the year, but is usually in the 10% range. Less in the winter and more in hot areas

• Array soiling
  – Solar modules will gather dust, soot, moss, leaves, pollen, etc. Extremely variable, but even when the large stuff is cleaned off there may still be commonly an average of 5% reduction in power.

• Battery round trip efficiency
  – For a lead acid type of battery round trip efficiency is commonly 80% at best. For lithium batteries it can be over 92%.
  – The limiting of solar production when the battery has a full charge should also be considered, but when the battery is full generally the loads have been satisfied, so there is little need to characterize it.
Daily energy consumption – with inverter efficiency taken into account for the AC loads (87%)

- 7397 Wh in winter
- 8511 Wh in summer
- 8776 Wh in autumn

Peak load -
- 7153 W from the inverter
- 8256 W from the battery
PV Array Sizing
Sample Calculations

• Power for a load of 7397 Wh/day is needed from the PV array, on average, in the winter months
  – Calculate the base array size using December insolation
  – Performance factor of 1.4 used, this is a very poorly defined number
  – Inverter efficiency was calculated in the load sheet (87% typical)
  – Traditional Performance factor, aka; array to load ratio, 1.2 when solar cost more

<table>
<thead>
<tr>
<th>Dec. Daily average load Wh/day</th>
<th>Dec. Daily average insolation kWh/sqm/day</th>
<th>Performance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>7397</td>
<td>2.19</td>
<td>1.4</td>
</tr>
</tbody>
</table>

\[(7397 / 2.19) \times 1.4 = 4729 W\]

• The 4729 Watt base size is multiplied by de-rates for final array
  – Calculate the array using all of the de-rates

<table>
<thead>
<tr>
<th>Base array size</th>
<th>Module Tolerance</th>
<th>Temp derate</th>
<th>Soiling derate</th>
<th>Battery efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>4729</td>
<td>1</td>
<td>90%</td>
<td>95%</td>
<td>75%</td>
</tr>
</tbody>
</table>

\[4729 / (1 \times 0.9 \times 0.95 \times 0.75) = 7374 W\]
The results can be calculated for the full year and graphed

- This graph is showing calculations for monthly totals
Battery Sizing
Design Considerations

- The battery needs to store enough energy to power the loads during periods of low energy production – to average out weather conditions
  - This is called “days of autonomy”
- Typically 2 to 3 days autonomy is used for most of the USA for residential systems, more for industrial systems without backup
  - Old school when PV was expensive this was often 5 to 7 days or more
  - With only 2 or 3 days autonomy the use of a backup generator will be needed for extended cloudy periods, or when the array is covered with snow
  - In a system without generator backup this needs to be much longer
  - How much longer depends on what part of the country and if conservation can be put into effect during cloudy periods
- As little as 1 day autonomy can be used but it will be hard on the battery and will require substantial generator use
  - A battery must be chosen that can handle the maximum array current
  - The battery will be cycled heavily so may have a shortened life
- A larger PV array can compensate for days of autonomy to some extent
  - This is where the “Performance Factor” comes into play
  - The battery is likely to be a large part of the cost of the system
  - It might be less expensive to substantially oversize the PV array
  - There are limited models to accurately figure how well this works or how to calculate it
Battery Sizing
Depth of Discharge (DoD)

- Most batteries will last longest with a shallower daily DoD
  - Most lead acid batteries will have a shorter life if cycled daily more than 50% DoD, and will last longer with less DoD
  - 80% DoD is considered ok for occasional discharges
  - Days of autonomy can be calculated to 80% DoD or 50% DoD
  - The daily DoD can also be used as an alternative method

- Lithium batteries are intended to be cycled up to 90% daily
  - More often they last longest if cycled only 80% DoD
  - For off grid this heavy daily cycling would require extensive use of a backup generator
Battery Sizing
Capacity

• Battery capacity is measured in Amp-hours (Ah)
  – Lithium batteries are often measured in kWh

• Capacity varies with rate of discharge
  – At a higher discharge rate a battery has less capacity
  – At a lower discharge rate a battery has higher capacity
  – Very deep cycle batteries may be more effected
  – Lithium batteries do not change much

• Residential systems have extremely variable loads
  – Generally the 20 hour rate is used
  – When a battery is sized for more than 3 days autonomy the 100 hour rate can be used

• Parallel strings of batteries
  – Best practice is no more than 3 parallel strings for lead-acid
  – One string is best. If retrofit a 24V system 2 strings allows conversion to 48V system later
  – Lithium can be parallels in higher numbers depending on the Battery Mgmt System
Battery Sizing
Maximum charge and discharge rates

• Maximum charging current
  – Batteries can only absorb a charge at a certain rate
  – There is a large variation between battery types
  – Lead Acid - low to high
  – Lithium - high to very high
  – Nickel Iron – very low

• A battery with a higher rated maximum charging current will usually also handle a higher peak load
  – Batteries with lower internal resistance will have higher charge and load rates

• The battery needs to be able to supply the peak load
  – A discharge rate that is too high will cause the voltage to drop and the inverter to shut down
  – This maximum current is also time dependent, shorter length draws can be higher current, longer draws must be at a lower rate

• Generally for an off-grid system the battery is large enough that the battery can handle both maximum charge and discharge
  – For one day autonomy these may need to be considered
Battery Sizing
Temperature effects

• Temperature and capacity
  – Capacity is reduced with lower temperature
  – Maximum charge and discharge rates are reduced at lower temperatures

• Low temperature limits
  – Lead Acid batteries can withstand -40° when fully charged
  – Lead Acid batteries will freeze at the freezing point of water when fully discharged, and must be operated at higher state of charge at lower temperatures
  – Flooded, AGM, or gel batteries makes little difference, they do not survive freezing
  – Lithium batteries generally should not be charged when below 32°F, but discharged at somewhat lower temperatures

• High temperature limits
  – Lead Acid batteries lose ½ their life for every 13°F higher average operating temperature
  – Lithium batteries are rated at up to 113°F, but have the longest life if kept between 59°F and 77°F
Battery Sizing
Sample Calculations

• Power for a load of 7397 Wh/day is needed from the battery bank
  • Calculate the base capacity with days of autonomy, DoD, and temperature de-rate
  • Inverter efficiency was calculated in the load sheet (87% typical)

<table>
<thead>
<tr>
<th>Daily load Wh/day</th>
<th>Days of autonomy</th>
<th>Depth of Discharge</th>
<th>Temp de-rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>7397</td>
<td>3</td>
<td>80%</td>
<td>90%</td>
</tr>
</tbody>
</table>

\[ \frac{7397 \times 3}{0.8 \times 0.9} = 30821 \text{ Wh} \]

• The 30821 Watt-hour size is converted to Amp-hours (Ah)
  • Divide the Ah capacity by the battery nominal voltage
  • Generally for residential the 20 hour rate is used
  • 48 volts is used for this example and is most common
  • The Watt-hour capacity is used to size a Lithium battery

<table>
<thead>
<tr>
<th>Base Capacity Wh</th>
<th>Battery voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>30821</td>
<td>48</td>
</tr>
</tbody>
</table>

\[ \frac{30821}{48} = 642 \text{ Ah} \]
Off-Grid Inverter Sizing

• Maximum AC load
  – Identify and sum all loads that may run simultaneously
  – Sum up total Watts – this is the minimum inverter continuous power rating required

• Identify any loads with high start-up or surge current draws
  – Motors in pumps, compressors, and other appliances with large inductive loads
  – Largest surge load determines minimum inverter surge rating

• Identify any loads that may require 240VAC
  – Most inverters used now have standard 120/240 VAC split phase output
Choosing System DC Voltage

• Selecting the best DC system voltage depends on a variety of factors:
  – Peak load - 12VDC is fine for peak loads up to about 1500W, 24VDC is fine for peak loads up to 3000W, 48VDC is best for peak loads over 3000W

• Size of PV array
  – A single MPPT 80A charge controller will handle up to 1000W of PV in a 12V system, but will handle up to 2000W in a 24V system, and up to 4000W in a 48V system

• Battery bank
  – Higher system voltage means more 2V cells in series so fewer parallel strings will be needed to gain the same amount of energy storage

• Voltage of any DC loads
  – If there are DC loads, that may define what the system voltage should be, or DC-DC converters can be used to supply power to those loads
Equipment – Modules and Racking

• Module Type: 36-cell, 60-cell or 72-cell
  – Cost, availability
  – Ease of installation how well they fit the installation space
  – Effect on equipment choices, 60-cell modules work best with some common charge controllers

• Racking
  – Roof mount – may not have the best tilt angle, but may have the best exposure
  – Ground mount – Easier access, better tilt angle
  – Pole mount – Good access, tilt can be adjusted and can be made steep enough to help shed snow in the winter
PV array combiner boxes

- Each parallel string of modules must have circuit protection
  - Most modules have a 15 A or 20 A max fuse rating
  - Under fault conditions, the array can be exposed to full current of the array breaker
  - 600V charge controllers generally have only one or two strings and will not require circuit protection

- The fuses or breakers in these circuits must be rated for the maximum voltage
  - Breakers are available in 150 V or 300 V ratings, fuses up to 600 V

- All array circuits going to each charge controller must have a separate and isolated feeder to that charge controller

- Some combiner boxes have the capacity for two separate circuits
  - Multiple combiners may be more convenient for wire management

- Some combiner boxes will also have rapid shutdown and arc fault protection
Rapid Shutdown

• Required in 2014 National Electric Code for all PV systems
  – Section 690.12 says “PV circuits installed on or in buildings shall include a rapid shutdown function...”
  – 690.12(1) states that “Requirements for controlled conductors shall only apply to PV system conductors of more than 5 ft in length inside a building, or more than 10 ft from a PV array.”
  – 690.12(2) states that “Controlled conductors shall be limited to not more than 30V and 240 VA within 10 seconds of rapid shutdown initiation.”

• Modified in 2017 NEC:
  – 690.12(B)(1) changes the definition of “array boundary” to 1 ft from the array.
  – Requires that “Controlled conductors located outside the boundary or more than 1 m (3 ft) from the point of entry inside a building shall be limited to not more than 30V within 30 seconds of rapid shutdown initiation.”
  – 690.12(B)(2) Starting Jan 2019 conductors within the array boundary will be limited to 80V essentially mandating module level shutdown
  – By 2019 entirely new rapid shutdown equipment may take over the market

Exception: Ground mounted PV system circuits that enter buildings, of which the sole purpose is to house PV system equipment, shall not be required to comply with 690.12.
Rapid Shutdown Components

• **OutBack ICS+ system**
  - Includes Arc Fault protection in the combiner box
  - Remote operated breaker to disconnect the charge control end of the circuit

• **MidNite Solar’s Birdhouse**, disconnecting combiners, and remote-trip breakers
Arc-Fault and Ground Fault Protection

• The 2017 NEC, 690.11, requires that “Photovoltaic systems... operating at 80V or greater shall be protected by a listed DC arc-fault circuit interrupter”
  - The 2017 NEC does provide for an exception for certain types of ground mounted array and solar power shed.

• The OutBack ICS Plus system is currently the only equipment listed to UL 1699B for arc-fault detection and interruption for battery systems
  - Some charge controllers have built-in arc-fault protection but are not currently listed to the applicable UL Standard.

• The 2017 NEC, 690.41, requires that “DC PV arrays shall be provided with DC ground-fault protection...”
  - DC ground-fault protection can be in the charge control or a separate DC-GFDI breaker or device
  - The 2017 NEC does provide for an exception for certain types of ground mounted arrays and solar power shed.
Controller type
PWM or MPPT

• **Charge controller type: PWM**
  - Pulse Width Modulated (PWM) charge controllers, inexpensive, compact
  - Array must match battery voltage, 12V nominal modules = 36-cell, 24V nominal modules = 72-cell, multiples in series are used for 48V systems
  - Does not track the maximum power of the array, does not change the array voltage which is the same as the battery voltage

• **Charge controller type: MPPT**
  - Maximum Power Point Tracking (MPPT) charge controllers use any modules, but 60 cell modules work better than 36 cell or 72 cell modules for 150 V controllers
  - MPPT maximize energy production up to 30% in winter
  - Operates array at maximum power point voltage. Array voltages up to 150, 200, 250, 300, or 600 VDC
  - Converts the higher array voltage to battery voltage
• String operating voltage must be between battery charging voltage and the controller upper limit

• Power will drop off dramatically if the peak power point of the array falls below the battery charging voltage

• 150VDC limited charge controls
  – A 48 VDC battery charges at 56 VDC or more
  – Two 60-cell modules x 27.5 VDC (at high temperature) = 55 VDC, not counting voltage drop or module degradation which will make it worse, so two 60-cell modules in series will typically not do well to charge a 48 VDC battery.
  – Most 60 cell modules will exceed 150 VDC in strings of 4 at low temperatures
  – Some charge controls will take higher than rated voltage, but will usually not be operating when over voltage

• Higher voltage charge controls
  – 200V controllers will take up to four 60-cell modules in series
  – 250V controllers will take up to five 60-cell modules in series
  – 300V controllers will take up to six 60-cell modules in series
  – 600V controllers will take up to 13 60-cell modules in series depending on power
• Total power should generally not exceed what the charge controller can process
  – The solar array will rarely be able to put out more than 87% of the nameplate rating
  – High altitude sites may have to downsize the array per charge controller
  – Some charge controllers can have larger array power and will simply limit the output and leave the balance unprocessed
  – Some charge controllers are not tolerant of higher array power
Charge Controller BOS
Controller Circuit Protection

• Disconnects and circuit protection are required between the PV array and the charge controller, and between the charge controller and the battery

• A circuit breaker is normally used for up to 300 VDC PV input circuits to controller
  – This breaker must be sized for 156% (125% x 125%) of Isc of array (STC)
  – Breaker not to exceed the maximum input amperage rating for the charge controller
  – Wire between breaker and the combiner box must meet or exceed the current rating of the breaker used

• A DC rated disconnect is used for 600 VDC rated circuits
  – This is sized for 156% (125% x 125%) of Isc of array (STC)
  – Often these have only two strings so the code exception can be used and no circuit protection is needed

• The charge controller breaker and disconnect serves as the battery breaker
  – If it matches the charge controller output rating it must be rated for continuous duty
  – If not rated for continuous duty at full amperage, size to 125% of max current
  – If the charge controller will be operated near its limit, oversize the battery breaker to avoid nuisance tripping
Battery Options

Lead-Acid types

• Flooded Lead-Acid
  - Robust for Lead Acid
  - High maintenance
  - Isolation, spill containment and ventilation required
  - Must be regularly fully charged
  - Carbon enhanced better at partial state of charge operation

• VRLA Lead-Acid – AGM or Gel
  - Sealed - very low maintenance
  - Can have cycle life that matches flooded
  - Must be regularly fully charged

• VRLA Lead-Acid AGM Carbon enhanced
  - Nano-carbon is used in the negative plate
  - Substantially reduces the effect of sulfation
  - Good partial state of charge operation

• VRLA Lead-Acid Gel tubular plate
  - DIN standard is OPzV
  - Sealed – very low maintenance
  - Very high cycle life, 2500 to 3000 cycles at 50% DoD
  - Must be regularly fully charged
Battery Options
Lithium and Others

• Lithium Iron Phosphate (LiFePO)
  - Resistant to thermal runaway or fire
  - High energy density up to ~35 Wh/lb
  - High efficiency up to 92% round trip
  - Partial state of charge operation
  - Long life at high cycle depth
  - Over 4200 cycles @ 90% DoD
  - Works with most 48 volt nominal inverters
  - Expensive but long life tradeoff
  - Operates between 32°F and 113°F, preferred between 59°F and 77°F
  - Some have Canbus or Xanbus communications

• Lithium-ION NMC
  - Mostly made for grid tie with energy management
  - May not be approved for off grid use
  - More complex battery management system for safety
  - Less expensive than LiFePO

• Others
  - Other Lithium-ION
  - Nickel Cadmium
  - Nickel Iron
  - Aquion
**Battery Bank Wiring**

**Series and Parallel**

- **Series connection:**
  - Voltage is additive - rated Ah capacity remains same
    - Positive of Battery 1 is connected to negative of Battery 2 and so on
    - Example: Two 12V, 220Ah batteries in series will yield a **24V / 220Ah battery bank**

- **Parallel connection:**
  - Capacity is additive - DC voltage remains same
    - The positives are connected to each other, same for negatives
    - Output leads must be from first and last battery for electrical balance
    - Manufacturers typically limit maximum number of parallel strings to three
    - Example: Two 12V, 220Ah batteries in parallel will yield a **12V / 440Ah battery bank**
Types of Off-Grid Inverters

• Modified Square-Wave (Modified Sine-Wave)
  - Inverters are inexpensive, but have a non-sinusoidal wave form
  - Very efficient, but some loads cannot be run on them
  - Typically have a total distortion of up to 30%

• Sine-Wave inverters
  - The most commonly used in residential and commercial systems.
  - Have very clean power output that will run almost any AC load.
  - Typically have a total distortion of less than 5%

• Residential inverters
  - Designed for stationary installations, such as homes and businesses.
  - Should be Listed to UL 1741

• Mobile inverters
  - Designed for RV and marine use.
  - Have “ground switching” which allows for the system’s neutral/ground bond to either be inside the inverter, or outside in the “shore power” connection.
  - Should be Listed to UL 458

• Inverters may or may not have built-in battery chargers for charging batteries from an AC source, such as a generator.
Inverter Systems
Points to Consider

• A central location is needed to connect wiring and install breakers
  ‒ There needs to be a DC load center and an AC load center, or one load center for both AC and DC.
  ‒ These systems are for **indoor mounting** only

• A battery-based inverter can have a very large current draw
  ‒ Especially when battery voltage is lower

• The main DC breaker for these inverters are rated for 125A to 250A
  ‒ The inverter manufacturer or supplier will generally specify breaker sizes
  ‒ Breaker size is generally maximum power output in watts divided by battery voltage \( \times 1.5 \), but sometimes larger

• Wire size for battery and inverter circuits will commonly be AWG 2/0 or AWG 4/0 cable
  ‒ Keep connection as short as possible to minimize voltage drop
  ‒ Under 10ft is best
  ‒ If over 5ft the 2014 code requires a disconnect and circuit protection at the battery
Integration Hardware

- Over-current devices – breakers and fuses
- DC Ground-Fault Protection (GFP)
- Bus Bars
- Combiner boxes
- Grounding
- Generator Start Controls
- Amp-Hour Meters
- System Control and Monitoring
System Monitors & Controllers

• Automate battery management
  – Allows you to adjust the bulk, absorption, float and equalization charge timing and voltage set-points

• Turn on/shut off generators according to time of day or battery state of charge

• May allow for remote monitoring/control via Internet

• May track battery state-of-charge through amp-hour metering

Every off-grid system should have an amp-hour meter or battery monitor installed!
Pre-Assembled Power Systems

• Factory pre-wired power systems simplify design and installation
  − Several common sizes & configurations are available

• Most Power Systems include:
  − Inverter(s)
  − Controller and networking devices
  − Battery monitor
  − Integration hardware and BOS
    - Enclosures, Breakers, GFDI, Bypass, etc.
  − Charge controller(s)
System Example

• Using our previous example
  – Array size 7.4kW
  – Battery size 642Ah at 48V
  – Inverter size 7.2kW

• Module and racking choices
  – 300 watt 60-cell modules are what you can get at a good price and availability
  – 7400 Watts / 300W modules = 24.67 modules
  – Since 24 modules is a nice number for both racking and stringing, and the performance factor is generous, I’d choose that number of modules
  – Array needs to be installed 250 feet away from the power system
  – System will be in a snow zone in Vermont so a steep tilt will be needed
  – A ground mount or pole mount will be needed
  – An easily adjustable-tilt pole mount will allow a vertical setting for snow storms and can be adjusted to a lower tilt to optimize seasonally
Using our previous example - Array size 7.4kW - Battery size 642Ah at 48V - Inverter size 7.2kW

Charge controller choice

- Array is 250 feet from the power system
- Trade off between cost of high voltage charge control and cost of wire
- A 7.4kW array 250ft away with one string of 12 modules in series, operating at 320+ volts to each 600V charge controller, will only need two circuits using #10 copper wire at ~$200
- That array with two parallel strings of 6 modules in series, operating at 160+ volts into each 300V charge controller, will need two circuits using #4 copper wire at ~$800
- That array with four parallel strings of 3 modules in series, operating at 80+ volts to each 150V charge controller, will need two circuits using #2/0 copper wire at ~$2400
- Which inverter is used may have an effect on the choice of charge controller and vice versa.
System Example

• Using our previous example - Array size 7.4kW - Battery size 642Ah at 48V - Inverter size 7.2kW

• Inverter choice
  – Iterations between inverter, charge controller, array
  – Using the same inverter and charge controller will allow for one monitor and control and potentially coordination between them
  – In an off grid system coordination between charge control and inverter is less important than for a grid tied system
  – Looks like an OutBack 8kW Radian inverter is just right
  – If not all the loads need to run at the same time, maybe only 6kW is needed, then the Schneider XW+6848 would be fine
  – If more power might be needed in the future, maybe two Schneider XW+5548 inverters could be used
  – If a more economical system is desired maybe two Magnum MS4448PAE inverters could be used
  – Does one of these choices work better with a charge controller that is better suited to the array?
System Example

- **Using our previous example** - Array size 7.4kW - Battery size 642Ah at 48V - Inverter size 7.2kW

- **BOS choices**
  - Combiner – If the power equipment is in or on a building (other than a PV power shed) it will need rapid shutdown, arc fault and ground fault protection. Either the ICS+ or Midnite system can be used. Only the OutBack system currently has listed arc-fault
  - Power center – Is one or more enclosures with DC and/or AC breakers, wiring bus bars, and monitoring equipment. Many inverter mfg have ones that match up with their inverters and charge controllers
  - Control panel – Many inverters have a separate control panel or remote control that will work with, and set up communications with, the inverter and charge controllers
  - Battery meter – Some inverter mfg have a battery state of charge meter that works with their system. Third party meters can also be used. The customer is blind to the overall system operation without this meter
  - Generator start – There is a built in generator start function in some inverters that will work directly (or with a relay) with a two wire start generator that has its own starting logic. If starting logic is needed to run a three wire start generator, a generator start control is needed, either from the inverter company or a third party unit.
System Example

- **Using our previous example** - Array size 7.4kW - Battery size 642Ah at 48V - Inverter size 7.2kW

- **Battery choices**
  - Price and availability
  - Flooded only recommended if customer can handle it or if the system is small enough so that the inexpensive L-16 sized battery can be used. For this system two parallel strings of L-16 would give the needed capacity at the lowest cost. These are 6V each so 8 are needed in series, for 16 total batteries. An industrial flooded battery could be used for much longer life, but at a cost near that of the industrial AGM or gel.
  - To get this capacity with AGM or gel batteries requires the use of industrial grade batteries which will be more expensive, but are likely to last much longer than the L-16 type. They have a small footprint and come with racking and interconnects.
  - The nano-carbon batteries can handle higher charge current, and do not need to be fully charged all the time, but this system has plenty of PV so that should not be an issue. Also the NC has a gap in sizing at this capacity without too many parallel strings or going up to a larger size. The industrial versions have the same advantages as the other industrial AGM batteries.
  - The OPzV tubular gel batteries would work well depending on availability, probably with a longer life than any battery except LiFePO. These may take more floor space to install than the industrial AGM type, similar to a flooded battery.
  - LiFePO batteries would work very well, but the cost is very high ~$19000 for a smaller capacity, with deeper daily cycling. They may possibly last 20 years.
Off-Grid System Sample
Three line wiring diagram
Off-Grid System Sample
One line wiring diagram
Off-Grid System Design

Questions?

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