Designing a Battery-Based System Step-by-Step

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Introduction

Disclaimer

AEE Solar is a distributor of goods and services used in the deployment of PV and wind distributed power systems. We are not accountants, attorneys or Code-making experts. The information presented here represents the equipment, rules and best practices that we are aware of. However, local and project-specific requirements can vary widely.
Types of Battery-Based Systems

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

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

AC-only
- All loads run on AC power from an inverter or AC generator
- Most common type of Off-Grid system used for homes

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

Hybrid
- Derives energy from more than one source
- i.e. PV and wind, PV and utility grid, or PV and a generator
Designing a Battery-Based System Step-by-Step

System Sizing
User Data 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**
  - How many days in a row will the loads need to run with little or no sun
  - Don’t neglect heavy snows

• **Sun-Hours per day during 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

- Load Worksheet –
  - 2016 AEE Solar Design Guide and Catalog – Page 9

**Worksheet: Off-Grid Load**
Determine the total amp-hours per day used by the AC and DC loads.

**Step 1:** List all AC loads, wattage and hours of use per week in the table below. (If there are no AC loads, skip to Step 5.)
Multiply watts by hours/week to get AC watt-hours per week (Wh/Wk). Add up all the watt hours per week to determine total AC watt-hours per week.

**NOTE:** 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 VAC) to find watts.

**Calculate AC loads** (If there are no AC loads, skip to Step 5)

<table>
<thead>
<tr>
<th>Description of AC loads run by inverter</th>
<th>watts</th>
<th>hours/week</th>
<th>=</th>
<th>watt-hours/week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**Step 2:** Convert to DC watt-hours per week by multiplying the result of Step 1 by 1.15 to correct for inverter loss.

**Step 3:** List the inverter DC input voltage; usually 12, 24 or 48 VDC. This is DC system voltage.

**Step 4:** Divide the DC Watt-hours per week by the DC system voltage to get the total DC amp-hours per week used by the AC loads.
Don’t Forget “Stand-by” 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>$.27</td>
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<tr>
<td>Multi function printer/scanner/copier</td>
<td>6</td>
<td>$.80</td>
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<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>
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<tr>
<td>Garage door opener</td>
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<td>$1.60</td>
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<tr>
<td>Microwave oven</td>
<td>3</td>
<td>$.40</td>
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<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 24hrs = 2964Wh = 3kWh/day
System Options You Will Need to Choose

- **Battery Type: Flooded, AGM, Gel or Advanced**
  - Consider: Maintenance, shipping and storage requirements

- **Battery bank DC voltage**: 12, 24, 48 VDC (or high-voltage)
  - Consider: Voltage of DC loads, size of system, available inverters
  - 48VDC is generally most efficient and cost-effective for AC systems over 2kW

- **Charge controller type: PWM or MPPT**
  - Pulse Width Modulated (PWM) controllers
    - Pros: Inexpensive and compact
    - Cons: Low capacity (up to 60A), input voltage limitations (12/24/48VDC array)
  - Maximum Power Point Tracking (MPPT) controllers
    - Pros:Maximized energy harvest, wider input voltage range (48 to 600VDC), higher capacity (up to 100A)
    - Cons: More Expensive, physically larger

- **Module Type: 36-cell, 60-cell or 72-cell**
  - PWM controllers require 36-cell (12 VDC nominal) or 72-cell (24 VDC nominal) modules
  - Consider transportation and mounting limitations as well as module cost per watt
PV arrays for Off-Grid systems are based on the peak sun-hours during the darkest month of the year, not the yearly average.

Most Off-Grid systems require some sort of back-up power, usually a generator, for extended cloudy weather.
### PV Array Sizing

#### Peak Sun-Hours

**NREL Red Book**

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**Honolulu, HI**

**WBAN NO. 22521**

- **Latitude:** 21.33° N
- **Longitude:** 157.92° W
- **Elevation:** 5 meters
- **Mean Pressure:** 1016 millibars
- **Station Type:** Primary

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#### Variability of Latitude Fixed-Tilt Radiation

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#### Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

<table>
<thead>
<tr>
<th>Tilt (°)</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
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<td>3.2</td>
<td>2.2</td>
<td>1.5</td>
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<td>2.6/3.6</td>
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<td>1.4/1.5</td>
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<td>2.6/3.0</td>
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<td>3.3/4.7</td>
<td>3.3/4.9</td>
<td>2.6/3.1</td>
</tr>
</tbody>
</table>
### PV Array Sizing

#### Peak Sun-Hours

**PV Watts Calculator**

**Results**

<table>
<thead>
<tr>
<th>Month</th>
<th>Solar Radiation (kWh/m²/day)</th>
<th>AC Energy (kWh)</th>
<th>Energy Value ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.83</td>
<td>110</td>
<td>39</td>
</tr>
<tr>
<td>February</td>
<td>5.25</td>
<td>107</td>
<td>37</td>
</tr>
<tr>
<td>March</td>
<td>5.63</td>
<td>127</td>
<td>44</td>
</tr>
<tr>
<td>April</td>
<td>6.69</td>
<td>124</td>
<td>43</td>
</tr>
<tr>
<td>May</td>
<td>5.71</td>
<td>127</td>
<td>44</td>
</tr>
<tr>
<td>June</td>
<td>5.75</td>
<td>124</td>
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</tr>
<tr>
<td>July</td>
<td>5.85</td>
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</tr>
<tr>
<td>August</td>
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<td>48</td>
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<tr>
<td>September</td>
<td>6.10</td>
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<td>47</td>
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<tr>
<td>October</td>
<td>5.51</td>
<td>121</td>
<td>42</td>
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<td>November</td>
<td>5.06</td>
<td>111</td>
<td>39</td>
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<tr>
<td>December</td>
<td>4.72</td>
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<tr>
<td>Annual</td>
<td>5.52</td>
<td>1,459</td>
<td>$511</td>
</tr>
</tbody>
</table>

*Download Results: Monthly | Hourly*
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
For PWM Controllers

- **Find the current the array must produce**
  
  \[
  \frac{\text{Daily consumption (Ah)} \times 1.2}{\text{kWh per m}^2\text{per day}} = \text{Required Array Amps}
  \]

- **Select a PV module**
  - Find the peak current rating \((I_{mp})\) on the module data sheet

- **Determine the number of parallel strings required**
  
  \[
  \frac{\text{Required Array Amps}}{\text{Module } I_{mp}} = \text{Total strings}
  \]

- **Determine the number of modules per string**
  
  - 12 VDC modules (36-cell):
    - 12 VDC system = 1 per string
    - 24 VDC system = 2 per string
  
  - 24 VDC modules (72-cell):
    - 12 VDC system = NA
    - 24 VDC system = 1 per string

- **Determine the total number of modules**
  
  \[
  \text{Total strings } \times \text{String length} = \text{Total modules}
  \]
MPPT Charge Controllers

- **Charge controllers for modern 60 cell modules must be MPPT type**
  - MPPT = Maximum Power Point Tracking

- **An MPPT controller** will convert the input voltage to the correct voltage for charging the battery

- **Array voltage** must be higher than the battery voltage

- **MPPT Charge controllers are current limited**
  A 4kW array will need one 80 A change controller for a 48 VDC battery, but will require two controllers for a 24 VDC battery
    - $80 \text{ A} \times 48 \text{ VDC} = 3,840 \text{ W}$
    - $80 \text{ A} \times 24 \text{ VDC} = 1,920 \text{ W}$

- The **PV array** will rarely put out full rated power except at high altitude sites
  - Reasonable oversizing of array vs. charge controller can minimize cost
  - Always have overcurrent protection between array and controller
Charge Controllers
String Sizing (MPPT)

• String operating voltage must be between battery charging voltage and controller limit (usually 150 VDC)
  - Power will drop off dramatically if the charge point of the array falls below the battery voltage

• A 48 VDC battery charges at 56 VDC or more
  ➢ Requires at least **three 60-cell modules** to charge correctly
    2 modules x 27 VDC = 54 VDC
    2 modules in series will typically not charge a 48 VDC battery at full power in hot weather

• Most 60 cell modules will exceed 150 VDC in strings of 4 in most locations

• A 48 VDC battery requires 3 modules in series only

• A 24 VDC battery can typically use either 2 or 3 modules in series
PV Array Combiner Boxes

- *Each* parallel string of modules must have circuit protection
  - Most modules have a 15 A circuit rating
  - Under fault conditions, the array can be exposed to full short circuit current of the battery bank

- The breakers in these circuits must be rated for the maximum voltage
  - Maximum voltage for many of these systems will be 150 VDC

- High-voltage charge controllers require higher voltage breakers or fuses and a proper combiner box for them.

- 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
Balance of System: Charge 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 **150 VDC PV input circuits** to controller:
  - This breaker must be sized for 156% (125% x 125%) of $I_{sc}$ 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.

- 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.
  - For OutBack systems, this is typically the GFDI breaker.
  - If the charge controller will be operated near its limit, oversize the battery breaker slightly to avoid nuisance tripping.
Balance of System: 
Ground and Arc Fault Protection

• Ground fault detection and disconnect (GFDI) is required for most residential systems
  – DC-GFDI or “DC-GFP” assemblies

• A DC-GFDI is simply a small breaker’s pole connected to larger breaker poles
  – The smaller breaker pole (usually 0.5A) connects the negative array conductor to ground
  – This connection is the DC negative-to-ground bond
  – If the GFDI breaker trips from current flowing between negative and ground, it also disconnects the PV array and/or charge controller

• The GFDI is traditionally installed between the array breaker and charge controller
  – OutBack also uses it between the charge controller and battery, serving as the charge controller disconnect

• The 2011 NEC code also requires Arc Fault detection in the PV system
  – Stand-alone arc fault detectors are not available at this time
Designing a Battery-Based System Step-by-Step

Charging Batteries
Flooded Cell
(Deep Cycle Type)

Pros

- Lower initial cost than VRLA in smaller sizes
- Excellent cycle life
- Electrolyte loss is replaceable
- Less sensitive to overcharging

Cons

- Not sealed
  - Cannot be mounted on its side
  - Cannot be shipped by air
  - Requires isolation & ventilation
- Maintenance required
  - Water must be added ~monthly
  - Regular equalization charge
  - Reduced life at higher temperatures
- Less efficient
  - Higher self discharge,
    Much higher float current >1kWh per day likely.
- Sensitive to shock and vibration
Gel-Cell VRLA

Pros

• Low maintenance

• Sealed
  o Can often be installed on its side
  o Can often be shipped by air

• Very good cycle life

• High efficiency
  Low self discharge and float current

• Shock and vibration resistant

Cons

• Sensitive to overcharging

• Reduced life at higher temperatures

• Lower charge & discharge rates

• Slightly higher cost than AGM

• Lower capacity units available than flooded cell or AGM
Absorbed Glass Mat (AGM) VRLA

Pros

• Low maintenance

• Sealed
  o Can be installed on its side
  o Can often be shipped by air

• High efficiency
  Low self discharge and float current

• Shock and vibration resistant

• Works in high-power applications

• Large capacity batteries available

Cons

• Sensitive to overcharging

• Reduced life at higher temperatures

• Electrolyte cannot be replaced

• Higher initial cost in smaller sizes than flooded
AGM with Carbon

- Carbon is added to the negative plate of lead acid batteries, either sealed or flooded, to improve partial state of charge performance.

- Extended partial state of charge (PSoC)
  - Sulfation on the negative plate is minimized
  - Much less need for regular full charge
  - Excellent for self-consumption or off-grid systems
  - No advantage for standby backup systems

- Longer cycle life in real conditions
  - Can be cycled in mid state of charge
  - Up to 44% improvement in cycle life
  - Only about 15% higher price

- Available in AGM or Flooded
  - OutBack Energy Cell Nano-Carbon AGM, in a wide range of sizes
  - Trojan SmartCarbon flooded commercial and industrial
Aqueous Hybrid Ion (Aquion)

Pros

• High cycle life at high cycle depth
  o Up to 3,000 cycles @ 100% DoD
  o Up to 6,000 cycles @ 50% DoD
  o Operates from -5°C to 40°C with full life

• Durable and abuse tolerant
  o Completely tolerant of partial state of charge
  o Self balancing in parallel strings
  o Can be completely depleted without harm
  o No active management necessary

• Very safe
  o Limited power output to shorts
  o Will not support flame
  o Will not explode
  o No thermal runaway issues

• Cradle to Cradle certified
  o All common non-toxic materials
  o Sodium, and a little Lithium, salt water electrolyte

Cons

• Moderately expensive
  o 2 to 3 X price of lead-acid batteries
  o Available in 48 V blocks only

• Low power and energy density
  o Requires more space for the same capacity
  o Wider voltage range ~40 V to 57 V
  o Low rate of charge and discharge
  o Limited capacity at higher rates of charge and discharge
Pros

• High power and energy density
  o 6.4 kWh daily version or 9.1 kWh weekly version
  o High voltage to substantially reduce current and wire size
  o Takes up little space, wall hung

• High cycle life at high cycle depth
  o Up to 3,000 cycles @ 100% DoD
  o High round trip efficiency up to 92.5%
  o Control of thermal issues
  o Use between -20°C to 50°C with internal cooling and heating

• Easy to install
  o Integrates to solar inverters, SolarEdge to start
  o Light weight
  o Touch safe
  o Outdoor rated
  o Multiple units for larger capacity up to 7 units

• Pleasing design
  o Decorative cover

Cons

• Moderately expensive
  o 2 to 3 X price of lead-acid batteries
  o May have limited calendar life ~10 years

• Availability
  o Installers must complete special training and legal agreements before selling
  o Limited to two parallel units to start
  o Limited inverter compatibility
Lithium Ion

**Pros**

- Widely used in laptops, EVs and handheld devices
- High power and energy density
  - Discharge rates up to 40X nominal Ah capacity
  - Up to ~40 Wh/lb
- High cycle life at high cycle depth
  - Up to 3,000 cycles @ 80 to 90% DoD

**Cons**

- Expensive
  - 2 to 5 X price of lead-acid batteries
  - May have limited calendar life ~10 years
- Thermal management challenges
  - Operates between ~32 °F and 100 °F
  - Risk of thermal runaway → fire or explosion
  - LiFePO and related chemistries less prone to thermal runaway risk, but more expensive and less energy density
- Requires sophisticated battery management system
  - Adds to cost
  - Adds significant design complexity
- Non-recyclable and hazardous
  - Disposal costs not typically included in price
  - Shipping restrictions
  - Will support combustion in a fire
# Nickel Based Batteries

## NiCd, NiFe, NiMH

### Pros

- **Good energy and power density**
  - About 60% of Lithium-ion

- **High cycle life at high cycle depth**
  - Up to 11,000 cycles or more @ 80% DoD for flooded NiFe
  - Up to 5,000 cycles or more @ 80% DoD for flooded NiCd

- **Robust**
  - Flooded cells only, not sealed
  - No sudden failures
  - Tolerant of under and overcharging
  - Very wide operating temperature range

- **Flat voltage vs. state of charge curve**

- **Less hazardous materials**

### Cons

- **Very Expensive**
  - 3 - 5 X price of lead-acid batteries
  - Heavy metals, Nickel and/or Cadmium

- **Low cell voltage**
  - Low cell voltage (~1.2 VDC)
  - More cells required per system

- **High self-discharge rate**

- **Memory effect in sealed NiCd cells**
  - Need to fully cycle about once per month
  - Limited reconditioning is possible

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Battery Capacity

- Capacity = Ampere-hours provided to the load(s)
  - Changes according to discharge rate, temperature, age, etc.
  - 20-hour rating = 100% capacity = C_{20}
  - 8-hour rating = 88% of C_{20}
  - 6-hour rating = 84% of C_{20}
  - 3-hour rating = 74% of C_{20}
  - 1-hour rating = 59% of C_{20}

- Batteries deliver less than 100% rated capacity when new.
  - Poor maintenance will affect capacity

- Batteries self discharge if stored for long periods of time without being charged.
  - The hotter the temperature the more self discharge
Battery Wiring

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

• **Parallel: Capacity is additive; 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 12 VDC, 220 Ah batteries in parallel will a 12 VDC, 440 Ah battery
Battery Charging

• Lead Acid Batteries should be charged after every use to ensure they are never stored in a discharged condition (May not be as necessary for added Carbon batteries)
  – If batteries are stored for extended periods of time they should be charged approximately every 6 weeks
  – Between 105-120% of previously discharged capacity must be returned for full charge
  – No need to fully discharge prior to charging
  – Charging should be temperature corrected
  – Always use charge controller’s temperature sensor when available

• Flooded Batteries need to be overcharged to ensure proper mixing of the electrolyte and avoid stratification
  – “Equalization” - deliberate, periodic overcharge to prevent electrolyte stratification
  – Most charge controllers have an equalize charge setting
Recommended Flooded/Wet Charging Profile

Voltage (per cell)
2.45V to 2.70V (@25°C, 77°F)
2.35V

Current (Amps)
10-13% C<sub>20</sub>
1-3% C<sub>20</sub>

Charge Current

Charge Voltage

State of Charge (%)
20% 90% 100%
### Battery Voltages

<table>
<thead>
<tr>
<th>Condition (@77°F)</th>
<th>12 VDC</th>
<th>24 VDC</th>
<th>48 VDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully charged – no load</td>
<td>12.7 VDC</td>
<td>25.4 VDC</td>
<td>50.8 VDC</td>
</tr>
<tr>
<td>20% charged – no load</td>
<td>11.6 VDC</td>
<td>23.2 VDC</td>
<td>46.4 VDC</td>
</tr>
<tr>
<td>90% charged – charging</td>
<td>15 VDC</td>
<td>30 VDC</td>
<td>60 VDC</td>
</tr>
<tr>
<td>Fully charged - equalizing</td>
<td>&gt;15 VDC</td>
<td>&gt;30 VDC</td>
<td>&gt;60 VDC</td>
</tr>
<tr>
<td>Fully charged – under heavy load</td>
<td>11.5 VDC</td>
<td>23 VDC</td>
<td>46 VDC</td>
</tr>
<tr>
<td>20% charged – under heavy load</td>
<td>10.2 VDC</td>
<td>20.4 VDC</td>
<td>40.8 VDC</td>
</tr>
</tbody>
</table>

- Charging voltage must increase as temperature falls
  - Charging voltage must be higher in cold weather and lower in hot weather
- A battery monitor keeps track of amp-hours, voltage and temperature to determine state of charge
  - OutBack FlexNet DC, Magnum BMK, Schneider Battery Monitor, Bogart Trimetric
- Check battery voltages or specific gravity during any maintenance call
  - This is often the first indication that something could be wrong
Depth of Discharge

- Deep Discharging will shorten battery life

- Most lead-acid batteries designed for 50% DoD

- Deep-Cycle Batteries designed for up to 80% DoD
  - Shallower cycles will enable longer life

- Never leave batteries discharged for more than 1-2 days!
  - Sulfating of electrodes will permanently decrease capacity (much less so for Nano-Carbon)
Watering Flooded Batteries

- Add distilled water to cells *AFTER* charging
  - Never add acid/electrolyte to cells
  - Fill to 1/8” below the bottom of the fill well or to maximum level indicator

- Do not overfill the batteries

- If the plates are exposed, add water to discharged batteries to just above the plates
  - Do not fill all the way!

- Never add water to discharged batteries if the electrolyte is visible above the plates!
  - This will cause the batteries to spill over when they are charged

- Single-point watering systems can make it much easier and safer
  Be sure system is compatible with batteries used
Battery Safety

- Always wear personal protective equipment when handling batteries
  - Chemical-resistant gloves, goggles or face shield, acid-resistant apron and boots

- Keep flames, sparks or metal objects away from batteries
  - Use insulated tools
  - Do not smoke near batteries
  - No metal jewelry

- Neutralize acid spills with baking soda immediately

- Ensure that vent caps are securely in place before charging

- Provide proper ventilation to prevent gas build up
Periodic Inspection and Cleaning

- Keep batteries clean and dry
- Check that all vent caps are tight
- Check that all connections are tight
- Terminal protector should be applied to terminals to reduce corrosion
- Use a solution of baking soda and water to clean any acid residue on batteries or corrosion on the terminals
Battery Enclosures

- Batteries must be properly housed and sited
- Keep batteries in temperature-controlled space
  - Basements or garages are typical
- Battery enclosure must be ventilated
  - Active ventilation may be required for flooded batteries in hot or tightly enclosed spaces
- Protect terminals from people, pets and falling objects
- Ensure that battery rack/enclosure meets any applicable seismic requirements for your region
- Breakers/Switches help improve safety when using and servicing batteries
Battery Bank Sizing

- **Daily energy consumption**
  \[ Ah = \frac{Wh}{VDC_{battery\ bank}} \]
  - Sum the DC loads and convert to Ah
  - Sum the AC Loads and convert to Ah, then divide by inverter efficiency

- **Required Battery Bank Capacity**
  \[ \text{Required Battery Bank Capacity} = (\text{Ave Daily Consumption}) \times (\text{Days of Autonomy}) \times \text{Temp multiplier} \]
  \[ \frac{(\text{Recommended Depth of Discharge})}{\text{(Recommended Depth of Discharge)}} \]

- **Required Battery Bank Capacity**
  \[ \frac{\text{Unit Battery Capacity}}{\text{Unit Battery Capacity}} = \text{Total Parallel Battery Strings} \]
  - Limit total strings to 3 or less (for common lead-acid batteries)

- **Battery Bank Voltage**
  \[ \frac{\text{Battery Bank Voltage}}{\text{Unit Battery Voltage}} = \text{Batteries per String} \]

- **Batteries per String \times Total Parallel Battery Strings = Total Batteries**

- May need to try multiple different battery sizes
Designing a Battery-Based System Step-by-Step

Inverters: Making AC from Batteries
Battery-Based vs. Grid-tie Inverters

**Battery-Based Inverters**

- Voltage sourced
  - Inverter builds its own waveform
- Fixed low-voltage input
  - Inverter fed from steady 12/24/48VDC from batteries
- PV array MPPT provided by charge controller
  - Charge controller dictates string size
- Modest efficiency: 75-90%
  - Low-voltage single-phase 120 or 240VAC output

**Grid-tie Inverters**

- Current sourced
  - Inverter uses grid waveform
- Actively controlled voltage input
  - Inverter uses MPPT and accepts wide range of voltages
- Inverter provides PV array MPPT
  - String sizing dictated by inverter
- High efficiency: 95-98%
- Range of outputs
  - 240VAC or 208/277/480VAC 3-phase
Inverter Sizing

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

- Identify any loads with high start-up or surge current draws
  - Motors in compressors, fans and appliances
  - Gauss rifles/rail guns, electromagnets and other large inductive loads
  - Largest surge load determines minimum inverter surge rating

- Identify any loads that may require 240 VAC
  - 240 VAC often requires transformer or dual inverters

- Be sure to consider inverter’s no-load-draw when sizing battery system and array
Inverter Selection Considerations

• Will there be an AC generator in the system?
  – Be sure inverter has generator input for battery charging
  – Be sure that inverter and generator are compatible

• Will the system connect to the utility grid?
  – Inverter must be “grid interactive” – these inverters have internal transfer switches to comply with UL 1741/IEEE 1547 anti-islanding requirements

• Will the inverter be mounted outdoors?
  – Most battery-based inverters are only rated for indoor use (NEMA 1)

• Do the loads include sensitive electronics or audio equipment?
  – Modified sine wave inverters may damage certain electronics and will interfere with most speakers
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 Monitoring
Balance of System (BOS): Power Panels
Balance of System (BOS): Power Panels

• A central location is desired 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

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

• The main DC breaker for these inverters is 125 A to 250 A
  • The inverter manufacturer or supplier will generally specify breaker sizes
  • Breaker size is generally max power output in watts divided by battery voltage x 1.5, but sometimes larger

• Wire size for battery and inverter circuits will commonly be 2/0 or 4/0 AWG
  • Keep connection as short as possible to minimize voltage drop
  • Under 10 ft is best
Balance of System (BOS): Power Systems

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

- Pre-wired power systems include:
  - Inverter(s)
  - Controller and networking devices
  - Battery monitor
  - Integration hardware and BOS
  - Enclosures, Breakers, GFDI, Bypass, etc.
  - Charge controllers
Balance of System (BOS): System Controllers

- Automate battery management
  - Float and equalization charge timing

- Turn on/shut off inverters and/or generators according to time of day or battery state of charge

- Remote monitoring/control via Internet
Example: AC-Only System

- Off-Grid house outside of Moab, UT
  - Full-time residence
  - Typical 2-3 bedroom house
  - Propane available for water and space heating

- Involuntary loads
  - Refrigerator & Freezer
  - HVAC Air handler
  - Bathroom/kitchen vent fans
  - Water pump

- Voluntary loads
  - Lights
  - Computer/entertainment system
  - Washer/gas dryer
  - Microwave oven
  - Toaster
  - Hair dryer
  - Battery chargers

- Other considerations
  - Snow may reduce output for up to 2 days at a time
  - Well is separate PV-direct system, but house pressure is from AC pump
### Descriptions of AC loads run by inverter

<table>
<thead>
<tr>
<th>Description</th>
<th>Watts</th>
<th>X</th>
<th>Hours/Week</th>
<th>X</th>
<th>Watt-Hrs/Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>furnace blower or pumps</td>
<td>250</td>
<td>5</td>
<td></td>
<td></td>
<td>1250</td>
</tr>
<tr>
<td>well pump</td>
<td>250</td>
<td>5</td>
<td></td>
<td></td>
<td>1250</td>
</tr>
<tr>
<td>septic pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>lights</td>
<td>130</td>
<td>42</td>
<td></td>
<td></td>
<td>5460</td>
</tr>
<tr>
<td>computer &amp; monitor</td>
<td>50</td>
<td>15</td>
<td></td>
<td></td>
<td>750</td>
</tr>
<tr>
<td>router and network</td>
<td>25</td>
<td>168</td>
<td></td>
<td></td>
<td>4200</td>
</tr>
<tr>
<td>printer &amp; peripherals</td>
<td>100</td>
<td>1</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>tv &amp; dvd player or similar</td>
<td>135</td>
<td>35</td>
<td></td>
<td></td>
<td>4725</td>
</tr>
<tr>
<td>satellite dish</td>
<td>110</td>
<td>28</td>
<td></td>
<td></td>
<td>3080</td>
</tr>
<tr>
<td>stereo</td>
<td>15</td>
<td>35</td>
<td></td>
<td></td>
<td>525</td>
</tr>
<tr>
<td>refrigerator</td>
<td>400</td>
<td>250</td>
<td></td>
<td></td>
<td>7692</td>
</tr>
<tr>
<td>freezer</td>
<td>500</td>
<td>250</td>
<td></td>
<td></td>
<td>9615</td>
</tr>
<tr>
<td>fans</td>
<td>134</td>
<td>28</td>
<td></td>
<td></td>
<td>3752</td>
</tr>
<tr>
<td>microwave</td>
<td>1000</td>
<td>1.9</td>
<td></td>
<td></td>
<td>1900</td>
</tr>
<tr>
<td>Washer</td>
<td>240</td>
<td>10</td>
<td></td>
<td></td>
<td>2400</td>
</tr>
<tr>
<td>Dryer</td>
<td>240</td>
<td>10</td>
<td></td>
<td></td>
<td>2400</td>
</tr>
<tr>
<td>Phone &amp; device chargers</td>
<td>25</td>
<td>32.5</td>
<td></td>
<td></td>
<td>813</td>
</tr>
<tr>
<td>Toaster</td>
<td>850</td>
<td>0.5</td>
<td></td>
<td></td>
<td>425</td>
</tr>
<tr>
<td>Hair dryer</td>
<td>850</td>
<td>1</td>
<td></td>
<td></td>
<td>850</td>
</tr>
<tr>
<td>Inverter no-load draw</td>
<td>30</td>
<td>28</td>
<td></td>
<td></td>
<td>840</td>
</tr>
<tr>
<td>Loads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

#### Total AC Wh/Week

- Total AC Wh/Week: 52027 Watt-Hrs
- Adjusted for inv. eff.: 59801 Watt-Hrs

#### Inverter efficiency

- Inverter efficiency: 87%
- Inverter no-load draw: 5671 Watt-Hrs
- Adjusted for inv. eff.: 59801 Watt-Hrs

#### Average daily DC watt-hours

- Divide by 7 days to get average daily DC watt-hours: 8543 Watt-Hrs
System Data

- Daily consumption (Watt-hours from worksheet) 8543 Wh
- Peak load (Watts) and characteristics (VDC/VAC/Hz) 5671 W @ 120VAC
- Days of Autonomy 2 Days

![Diagram of energy consumption](image.png)
Finding Solar Resource

Example system location: Moab, UT

Site Latitude: 38.6°N

Be sure to set the correct Tilt Angle and Orientation that the PV array will actually have

Peak Sun-Hours during darkest month (December) is 4.7

<table>
<thead>
<tr>
<th>Month</th>
<th>Solar Radiation (kWh/m²/day)</th>
<th>AC Energy (kWh)</th>
<th>Energy Value ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.83</td>
<td>113</td>
<td>8</td>
</tr>
<tr>
<td>February</td>
<td>5.45</td>
<td>116</td>
<td>8</td>
</tr>
<tr>
<td>March</td>
<td>5.93</td>
<td>135</td>
<td>9</td>
</tr>
<tr>
<td>April</td>
<td>7.16</td>
<td>156</td>
<td>11</td>
</tr>
<tr>
<td>May</td>
<td>7.00</td>
<td>151</td>
<td>10</td>
</tr>
<tr>
<td>June</td>
<td>7.03</td>
<td>141</td>
<td>10</td>
</tr>
<tr>
<td>July</td>
<td>6.57</td>
<td>133</td>
<td>9</td>
</tr>
<tr>
<td>August</td>
<td>6.74</td>
<td>139</td>
<td>10</td>
</tr>
<tr>
<td>September</td>
<td>6.16</td>
<td>126</td>
<td>9</td>
</tr>
<tr>
<td>October</td>
<td>5.42</td>
<td>119</td>
<td>8</td>
</tr>
<tr>
<td>November</td>
<td>5.17</td>
<td>117</td>
<td>8</td>
</tr>
<tr>
<td>December</td>
<td>4.74</td>
<td>112</td>
<td>8</td>
</tr>
<tr>
<td>Annual</td>
<td>6.02</td>
<td>1,557</td>
<td>$108</td>
</tr>
</tbody>
</table>
System Options

- **Battery Type: Flooded, AGM or Gel**
  - Considerations: Large system, user on-site
  - Flooded battery likely to be most cost effective, but AGM may be better for the user

- **Battery bank DC voltage: 12, 24, or 48 VDC**
  - Considerations: large system, all loads go through inverter
  - 48 VDC battery bank likely to be most cost-effective

- **Charge controller type: PWM or MPPT**
  - Considerations: Large system, 48 VDC battery bank
  - MPPT controller only type large enough

- **Module Type: 36-cell, 60-cell or 72-cell**
  - Considerations: MPPT charge controller, multi-kW sized array
  - 60-cell modules likely most cost effective
Battery Bank Sizing

- **Daily energy consumption** \( Ah = \frac{Wh}{VDC_{\text{battery bank}}} = \frac{8543 \, Wh}{48 \, VDC} = 178 \, Ah \)

- **Required Battery Bank Capacity** =

\[
\frac{(\text{Total Daily Consumption}) \times (\text{Days of Autonomy})}{(\text{Recommended Depth of Discharge})} \times \text{Temp multiplier}
\]

\[
\text{Required Battery Bank Capacity} = \frac{(178) \times (2)}{(50\%)} \times 1.0 = 712 \, Ah
\]

- **What battery to use?**

  3-string configuration:

  \[
  \text{Minimum battery rating} = \frac{\text{Required Capacity}}{3 \, \text{strings}} = \frac{712 \, Ah}{3} = 237 \, Ah
  \]

  2-string configuration:

  \[
  \text{Minimum battery rating} = \frac{\text{Required Capacity}}{2 \, \text{strings}} = \frac{712 \, Ah}{2} = 356 \, Ah
  \]

  1-string configuration:

  \[
  \text{Minimum battery rating} = \frac{\text{Required Capacity}}{1 \, \text{strings}} = \frac{712 \, Ah}{1} = 712 \, Ah
  \]
## Battery Bank Sizing

<table>
<thead>
<tr>
<th>Battery</th>
<th>Volts</th>
<th>Ah</th>
<th>#/string</th>
<th>Strings</th>
<th>QTY</th>
<th>Unit $</th>
<th>Total $</th>
</tr>
</thead>
<tbody>
<tr>
<td>IND9-6V</td>
<td>6 VDC</td>
<td>445</td>
<td>8</td>
<td>2</td>
<td>16</td>
<td>$1,250</td>
<td>$20,000</td>
</tr>
<tr>
<td>IND13-6V</td>
<td>6 VDC</td>
<td>673</td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>$1,705</td>
<td>$13,640</td>
</tr>
<tr>
<td>EnergyCell 800RE</td>
<td>2 VDC</td>
<td>672</td>
<td>24</td>
<td>1</td>
<td>24</td>
<td>NA</td>
<td>$14,161</td>
</tr>
<tr>
<td>EnergyCell 1100RE</td>
<td>2 VDC</td>
<td>960</td>
<td>24</td>
<td>1</td>
<td>24</td>
<td>NA</td>
<td>$18,345</td>
</tr>
</tbody>
</table>

*String length* = \( \frac{\text{Battery bank voltage}}{\text{Battery unit voltage}} \)
PV Array Sizing

- Loads consume 8543 Wh/day and site receives ~ 4.7 kWh/m²/day in winter

\[
\text{Required Array Watts} = \frac{\text{Daily consumption (Wh) } \times 1.2}{\text{kWh per m}^2\text{ per day}} = \frac{8543 \text{ Wh} \times 1.2}{4.7 \text{ kWh}} = \frac{10252}{4.7} = 2182 \text{ W}
\]

- Select a PV Module
  Considerations: 60-cell, MPPT charge controller, standard roof-mount racking
PV Array Sizing

• Minimum required PV array wattage = 2182 W

• Determine the number of modules required
  
  - Minimum number of modules required = \( \frac{PV \text{ array size}}{\text{Module Nameplate}} = \frac{2182 \text{ W}}{255 \text{ W}} = 8.6 \)

  - Most MPPT charge controllers only accept 3 modules per string for a 48 VDC system

    \[ 3 \text{ modules} \times 4 \text{ strings} = 9 \text{ modules} \checkmark \]

  Always round up when determining number of modules!

  ➢ Recommend oversizing to 12 modules
Charge Controller Selection

- **System Requirements**
  - Compatible with sealed AGM batteries, array size is 3,060 W
  - Note input voltage limit is 150 VDC
  - Maximum charge current for the EnergyCell 1100RE is 212 A
  - 4 strings of 3 modules each

<table>
<thead>
<tr>
<th>Model</th>
<th>Max output current</th>
<th>Maximum recommended PV array size</th>
<th>Max PV array voltage ($V_{OC}$)</th>
<th>Item code</th>
</tr>
</thead>
<tbody>
<tr>
<td>OutBack FLEXmax 60</td>
<td>60 A</td>
<td>750 W 1,500 W 3,000 W</td>
<td>150 VDC</td>
<td>020-02017</td>
</tr>
<tr>
<td>OutBack FLEXmax 80</td>
<td>80 A</td>
<td>1,000 W 2,000 W 4,000 W</td>
<td>150 VDC</td>
<td>020-02020</td>
</tr>
</tbody>
</table>
Inverter Selection

- System requirements
  - 5,671 W Peak AC Load, All loads 120 VAC/60 Hz, 48 VDC battery bank
  - Maximum surge load (Washer motor startup): 12 A (1,440 W)
  - AC generator?

### OutBack Radian Inverters

<table>
<thead>
<tr>
<th>Model</th>
<th>Continuous output</th>
<th>Battery voltage</th>
<th>AC out volts/Hz</th>
<th>No load draw</th>
<th>Charger output</th>
<th>AC surge output</th>
<th>Weight</th>
<th>Item code</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS4048A</td>
<td>4,000 W</td>
<td>48 VDC</td>
<td>124/240 V 60 Hz</td>
<td>N/A</td>
<td>57 A</td>
<td>6,000 W</td>
<td>84 lbs</td>
<td>030-04058</td>
</tr>
<tr>
<td>GS8048</td>
<td>8,000 W</td>
<td>48 VDC</td>
<td>124/240 V 60 Hz</td>
<td>30 W</td>
<td>115 A</td>
<td>12,000 W</td>
<td>125 lbs</td>
<td>030-04039</td>
</tr>
</tbody>
</table>

### FLEXpower TWO Pre-Wired

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Inverter</th>
<th>Item code</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP2 VFX3524</td>
<td>Pre-wired dual inverter system, 7.0 kW 120/240 VAC, 24 VDC</td>
<td>VFX3524</td>
<td>033-04231</td>
</tr>
<tr>
<td>FP2 VFX3648</td>
<td>Pre-wired dual inverter system, 7.2 kW 120/240 VAC, 48 VDC</td>
<td>VFX3648</td>
<td>033-04230</td>
</tr>
<tr>
<td>FP2 FX2524T</td>
<td>Pre-wired dual inverter system, 5.0 kW 120/240 VAC, 24 VDC</td>
<td>FX2524T</td>
<td>033-04233</td>
</tr>
<tr>
<td>FP2 FX3048T</td>
<td>Pre-wired dual inverter system, 6.0 kW 120/240 VAC, 48 VDC</td>
<td>FX3048T</td>
<td>033-04232</td>
</tr>
<tr>
<td>FP2 GVFX3524</td>
<td>Grid-tied pre-wired dual inverter system, 7.0 kW 120/240 VAC, 24 VDC</td>
<td>GVFX3524</td>
<td>033-04241</td>
</tr>
<tr>
<td>FP2 GVFX3648</td>
<td>Grid-tied pre-wired dual inverter system, 7.2 kW 120/240 VAC, 48 VDC</td>
<td>GVFX3648</td>
<td>033-04240</td>
</tr>
<tr>
<td>FP2 GTXF3048</td>
<td>Grid-tied pre-wired dual inverter system, 6.0 kW 120/240 VAC, 48 VDC</td>
<td>GTXF3048</td>
<td>033-04244</td>
</tr>
<tr>
<td>FP2 GTXF3048HI</td>
<td>Grid-tied pre-wired dual inverter system, state of HI only, 6 kW 120/240, 48 VDC</td>
<td>GTXF3048HI</td>
<td>033-04243</td>
</tr>
</tbody>
</table>
System Components

AEE Solar
Delivering Success

X 4

Solar Panels

OutBack Power System

Battery Storage

Inverter

Electric Panel
Designing a Battery-Based System Step-by-Step

Grid-tie Battery Backup: Backing up the Grid
Types of Grid-tie Battery Systems

- Backup system separate from the solar grid-tied system

- Grid-tied solar systems with battery backup and protected loads panel
  - Basic DC coupled grid-tie w/ Battery Backup (GTBB)
  - GTBB using 120VAC only inverters with 120VAC loads
  - GTBB using 120VAC only inverters and transformer for 120/240VAC loads
  - GTBB using 120/240VAC inverters

- Grid-tied solar systems with battery backup for whole house backup
  - GTBB for whole house using a 4 pole manual transfer switch
  - GTBB for whole house using line side tap and manual transfer switch
  - GTBB for whole house using an automatic transfer switch

- Grid-tied solar systems using AC coupling
  - GTBB using AC coupling and protected loads panel
This is a simple grid-tie system without any backup power.
When the grid power goes out, the PV system is useless.
The backup system can be separate from the solar system
This could also be a generator only or have both inverter and generator
DC-Coupled Grid-Tie w/ Battery Backup (GTBB)

- The original and most common arrangement for grid-tie with backup
- DC coupled with low voltage array, charge controller, and battery-based grid-tie inverter
- Protected loads panel for loads to be backed up
• Some grid-tie battery inverters just provide a single 120 VAC leg
• These inverters also have only one AC input
  – Transfer switch needed for running with a generator
GTBB Using 120 VAC Inverters with 120/240 VAC Loads

- GTBB 120 VAC system w/protected load panel and transformer for 240 VAC loads
- Use standard US house wiring at 120/240 VAC
- Grid connection and generator input is still only 120 VAC
• Using a 120/240 VAC split phase inverter with separate generator input is the most versatile and easy to use system
• 120/240 VAC protected loads sub-panel is used
• Grid connection and generator input are both 120/240 VAC
Whole House Backup Issues

- NEC 702 5(B) requires a system that can power all loads if an automatic transfer switch is used,
  - Exception for loads that are automatically disconnected
  - A 200A service would require six Radian 8kW inverters

- A Manual transfer switch only requires the system to power chosen loads
  - User must manually shut off non-critical circuits before switching
  - Manual transfer will leave the house in the dark until someone does the transfer

- If the inverter cannot power all the loads it will be overloaded and shut off, requiring a manual restart

- The input/grid-feed and output of the inverter must never be connected together
  - This will irreparably damage the inverter and may cause a fire
  - Connecting the input to the utility side of the meter is most common approach
Using a Line Tie Connection for a Whole House Backup System

- Line tie connection with fused disconnect and two pole transfer switch
- Transfer switch must be manually activated to meet code
  - Non-critical circuits must be disconnected first
- Power from the utility must be disconnected to install the transfer switch
Whole house backup with an automatic transfer switch requires a backup system capable of powering all loads, or having loads automatically disconnected NEC 702 5(B)

- 200A service requires six Radian 8kW inverters unless automatic circuit disconnects are used
- Requires a line tie connection to the utility
AC coupled GTBB system

- Normally uses a protected loads panel
- Uses both a direct grid-tie inverter and a battery-based inverter
- Is useful when retrofitting an existing system
- A kWh production meter can still be used
- More expensive and complex, not all equipment is compatible
Battery Based Grid-Tie Inverters
Battery Based Inverters for Grid-tie

- All battery-based inverters must have a battery bank to function

- OutBack FXR and SMA Sunny Island inverters are 120 VAC input and output only
  - An autotransformer can be used with a single inverter to produce 120/240 VAC split phase output, or 240 VAC input, but not both with a single transformer
  - Two inverters can be stacked to produce 120/240 VAC split phase output

- OutBack Radian and Schneider XW+ inverters are 120/240 VAC split phase input and output
  - Up to 10 Radian inverters can be stacked for an 80 kW system
  - Up to 4 Schneider XW+ inverters can be stacked for 27.2 kW system

- FXR and Sunny Island inverters have a single AC input
  - External transfer switch required for use with a generator

- Radian and XW+ inverters have two AC input circuits
  - Compatible with most generators
Battery Based Inverters

• Size inverter for the larger of maximum load or for array size
  • During an outage, the inverter must be large enough to run all of the loads that will run at the same time
  • The inverter must be large enough to process the full solar array into the grid

• Per 2011 NEC 705.12(D)(2), the grid connection circuit is rated at the maximum inverter grid feed current x 1.25.
  • The grid intertie breaker can be larger than the intertie circuit rating so that the intertie breaker can handle the maximum pass-through current
  • 50 A or 60 A is a common breaker size for pass-through

• When a single 120 VAC inverter is used, the current for the grid intertie will be double that for a given system size compared to a direct grid-tie inverter running at 240 VAC
  • This may be a problem to meet 2008 NEC 690 64(B)(2), or 2011 NEC 705 12(D)(2)
Use Sealed Batteries

- The battery must be large enough to support the backup loads for the time desired
  - The battery bank must be large enough to power the inverter adequately
  - Also consider: depth of discharge; temperature; inverter efficiency; degradation over lifetime
- The battery bank may be the single largest cost in the system
- Sealed batteries require an enclosure, but not special containment.
  - A garage or basement is ideal
Load Analysis: Talk to your Customer

- Protected vs. non-protected loads: what do they really need
  - Refrigerator/freezer, lights, ventilation, TV/computer, cell phone charger, alarms

- Heating systems vary widely and may or may not be practical to back up
  - Air handlers can be a very large energy load, even if the heat source is gas

- How long do they really need the backup to last?
  - Batteries drive the total system cost more than the PV or inverter
  - The larger the loads and the longer they run, the more expensive the system will be
  - A 100 kWh battery bank (50 kWh/day for 2 days), is likely to cost about $40,000

- Can they add a generator if the backup needs to be larger or last longer?

- Manage the customer’s expectations!
  - “A protected loads panel is far more convenient and cost-effective than whole-house backup”
  - Accurate load analysis is worth the time and will result in more satisfied customers
  - Ensure your customer understands how much energy they can expect from their backup system and the risks of overloading it
Load Analysis

- Sum the protected loads as you would if they were in a separate off-grid system

<table>
<thead>
<tr>
<th>Descriptions of AC loads run by inverter</th>
<th>Watts</th>
<th>Run time/ hr</th>
<th>Watt-Hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>furnace blower or pumps</td>
<td>1800</td>
<td>12</td>
<td>21600</td>
</tr>
<tr>
<td>well pump</td>
<td>1200</td>
<td>0.2</td>
<td>240</td>
</tr>
<tr>
<td>septic pump</td>
<td>1500</td>
<td>0.2</td>
<td>300</td>
</tr>
<tr>
<td>lights</td>
<td>350</td>
<td>4</td>
<td>1400</td>
</tr>
<tr>
<td>computer &amp; monitor</td>
<td>50</td>
<td>3</td>
<td>150</td>
</tr>
<tr>
<td>router and network</td>
<td>15</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>printer &amp; peripherals</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>tv &amp; dvd player or similar</td>
<td>150</td>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>satellite dish</td>
<td>25</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>stereo</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>refrigerator</td>
<td>400</td>
<td>877</td>
<td>1096</td>
</tr>
<tr>
<td>(annual kWh from energy guide above)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>freezer</td>
<td>500</td>
<td>1096</td>
<td>1370</td>
</tr>
<tr>
<td>(annual kWh from energy guide above)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Sizing the PV array for GTBB systems is similar to a grid-tie system

• Limits to array size:
  • 100% offset of electrical use
  • Available space
  • Budget

• At minimum the array should power the backup loads for an extended outage

• Sizing for an extended outage needs to account for winter solar production unless the system will also have a generator
Inverter Sizing Considerations

- Inverter must meet the larger of array size or load size
  - The inverter needs to be large enough to power all of the loads that will be put on it during a power outage
  - A grid-tied inverter also must handle entire PV array power
  - This connection does not exist for off-grid systems

- Will any loads require 240 VAC power?
  - Same as for off-grid systems

- Wire the protected loads panel for normal North American distribution of 120/240 VAC split phase or just 120 VAC?

- Will the installation use a backup generator?
  - will it be 120 VAC only or 240 VAC?
Battery Sizing

- Battery sizing minimum for inverter power

- From OutBack Radian manual:
  - “To prevent the inverter’s charger from overcharging, the minimum recommended battery bank size is 350 amp-hours for every Radian inverter/charger installed on the system”
  - “Systems intended to bridge short-term outages can use smaller battery banks. In these cases, the bank can be as low as 200 amp-hours per inverter However, the charge rate must be decreased to half the inverter’s maximum using the MATE3”
  - One of the following conditions must also be true:
    - “The system is equipped with a backup generator that is programmed for automatic start, or typical grid loss is 30 minutes or less, or the loads are less than 2 kW”

- Other inverters have similar requirements
Thank you!

support@aeesolar.com