Determining the required battery capacity for a household/commercial grid connected PV system with batteries

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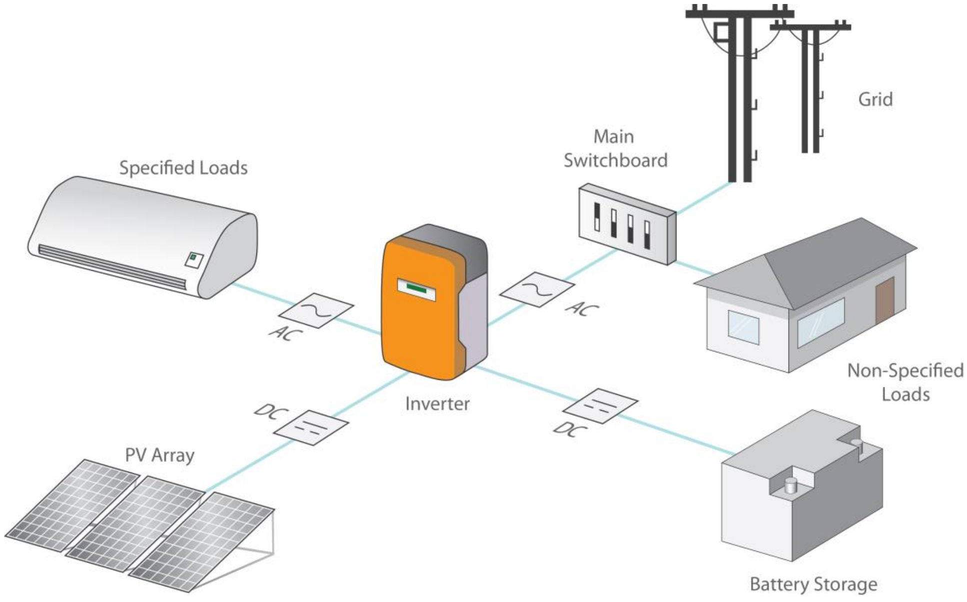
Overview

- Grid-connected PV systems can be installed with batteries to provide a source of backup power during grid downtime.
- Beneficial for locations that experience short but frequent blackouts.
- No generators, therefore battery bank is the only source of energy.
- Customer should be surveyed about the loads they will be using during grid downtime, also known as the 'specified loads'



Steps to battery sizing

- Site visit for survey of loads and available space
- Calculate required energy, max demand and surge demand
- Calculate battery capacity required to meet energy, max demand and surge demand
- Match battery required discharge current with product capability

Sizing a Battery Bank for Back-up

Site inspection/customer interview:

- Ask how long the backup is needed and why?
- Create a Loads survey to find out:
    - Total amount of energy required
    - Surge demand
    - Peak demand

Site visit and using the Loads Survey Form

Survey form is similar to the offgrid design form, but without weather factor and shorter (for backup loads only

Site visit is helpful to find out the actual power rating of the appliances described and likely backup energy usage.

Where unsure of appliance behaviour, take photos of label and look up its datasheet. You may also find characteristics of similar appliances online.

When onsite, record columns 2, 3, and 4. Column 6 and 8 can be read off labels or be looked up later.

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Fluorescent Light	2	75	5	2 x 75W x 5h = 750Wh	1	2 x 75÷1 = 150VA	1	150VA x 1 = 150VA
Load #2				No. x Power x Duration		No. x Power ÷ Power factor		Power factor x Surge factor
Load #3								
…								
Total energy load (Wh)								
Maximum demand (VA)								
Surge demand (VA)								

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Example Exercise: Site Survey Form

- A customer who is about to install grid-connected PV system is also looking for a backup battery system for when they have blackouts. They have identified the following list of load for if they need battery backup for up to 6 hours during the evening (6 hours)
- Tips for identifying loads:
  - Need to ask customer to identify only what would be used during backup
  - Fridge and aircon have duty cycles (when compressor is running). Typical values are 30%-50%. In this example, the fridge's cycle is 50%, i.e. for a 6 hours backup, the fridge compressor will be on for 3 hours.

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Lounge room lights	2	75	5	2 x 75W x 5h = 750Wh	1	2 x 75÷1 = 150VA	1	150VA x 1 = 150VA
Bedroom 1 lights	1	75	1	75	1	75	1	75
Bedroom 2 lights	1	75	1	75	1	75	1	75
Bathroom lights	1	75	1		1		1	
Fridge	1	150	3		1		1	
Television	1	250	3		0.8		1.3	
Laptop computer	2	60	2		0.8		1	
Pedestal fan	1	60	6		0.8		2	
Microwave	1	1200	0.5	600	0.7	1714.3	1.3	2228.59
Total energy load				3375Wh				
Maximum demand						2776.8 VA		
Surge demand (VA)								3459.84 VA

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Completed Site Survey Form

- A customer who is about to install grid-connected PV system is also looking for a backup battery system for when they have blackouts. They have identified the following list of load for if they need battery backup for up to 6 hours during the evening (6 hours)
- Tips for identifying loads:
  - Need to ask customer to identify only what would be used during backup
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Bedroom 1 lights	1	75	1	75	1	75	1	75
Bedroom 2 lights	1	75	1	75	1	75	1	75
Bathroom lights	1	75	1	75	1	75	1	75
Fridge	1	150	3	450	1	150	1	150
Television	1	250	3	750	0.8	312.5	1.3	406.25
Laptop computer	2	60	2	240	0.8	150	1	150
Pedestal fan	1	60	6	360	0.8	75	2	150
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System characteristics

- Duration of operation: 6 hours
- Energy required: 3375 Wh
- Maximum demand: 2776.8 VA
- Surge demand: 3459.8 VA

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Lounge room lights	2	75	5	2 x 75W x 5h = 750Wh	1	2 x 75÷1 = 150VA	1	150VA x 1 = 150VA
Bedroom 1 lights	1	75	1	75	1	75	1	75
Bedroom 2 lights	1	75	1	75	1	75	1	75
Bathroom lights	1	75	1	75	1	75	1	75
Fridge	1	150	3	450	1	150	1	150
Television	1	250	3	750	0.8	312.5	1.3	406.25
Laptop computer	2	60	2	240	0.8	150	1	150
Pedestal fan	1	60	6	360	0.8	75	2	150
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Calculate Energy Demand from Battery

- Assume battery inverter/charger efficiency (η_{INV}) is 90%
- Assume no other losses in the system
- Energy required from the battery is

$$E_{TOT} = E_{AC} \div \eta_{INV}$$

Where:

E_{TOT} = total energy required from battery

E_{AC} = AC energy required from the system

From the example:

E_{TOT} = 3375 Wh ÷ 0.9

= 3750 Wh

Calculate Battery Capacity Required

Battery capacity is calculated by the formula

$$\text{Battery Capacity (Ah)} = E_{TOT} \div (V_{dc} \times DOD)$$

The battery system voltage V_{dc} and battery depth of discharge (DOD) are design choices.

- DOD can vary depending on usage frequency and battery technology
- V_{dc} depends on power demand. Higher voltages (24V, 48V etc.) should be selected for systems with high max demand to reduce current draw

Example:

Assume the system is 12V and DOD value of 0.6 (i.e. 60%).

The design battery capacity required is:

Battery Cap(Ah) = 3750 Wh ÷ (12 x 0.6)

= 520.8 Ah

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Calculating Discharge Current

- Discharge current is the amount of current the battery releases as it discharges
- Discharge current varies depending on power draw
- Need to calculate:
  - Maximum discharge current
  - Surge discharge current
- Equation:

$$\text{Discharge current (A)} = \text{Demand (VA)} \div (V_{dc} \times \eta_{INV})$$

Calculate Maximum Discharge Current

From survey form:

- Maximum demand: 2776.8 VA
- Surge demand: 3459.8 VA

Design spec:

- V_{dc} = 12V
- η_{INV} = 90%

Therefore:

Maximum discharge current

= 2776.8 VA ÷ (12V × 0.9)

= 257.1 A

Discharge current is too high! Increase system voltage to 24V and redesign system.

Calculate Maximum Discharge Current

From survey form:

- Maximum demand: 2776.8 VA
- Surge demand: 3459.8 VA

Design spec:

- Vdc = **24**V
- η_{INV} = 90%

Therefore:

Maximum discharge current

= 2776.8 VA ÷ (**24**V × 0.9)

= 128.6 A

Surge discharge current

= 3459.8 VA ÷ (**24**V × 0.9)

= 160.2 A

Sizing Batteries to Load

- Designer must verify with battery manufacturer that chosen battery is capable of meeting maximum and surge demand.
- Maximum discharge, based on the continuous rating of the inverter, should be less than or equal to the 5 hour (C_5) discharge rate current.
- Maximum surge discharge, based on the surge rating of the inverter, should be less than or equal to the 1 hour (C_1) discharge rate current.

Battery Capacity Rating

- Battery capacity is related to its discharge rate. The higher the discharge current, the smaller the capacity
- The capacity rating is commonly described with the annotation "C_x" and given in Amp-hour (Ah).
- C_x rating = discharge current × number of hours (x) the battery can provide this current
- Therefore: Discharge current of battery = C_x rating ÷ number of hours (x) the battery can provide this current

Example:

A battery with C_{10} rating of 200Ah can provide 20Amp discharge current for 10 hours

Discharge current (A) = 200Ah/10h = 20A

Battery Discharge Rate

- Battery capacity needs to meet max demand current at C_5 and surge demand current at C_1
  - Maximum demand current = 128.6 A
  - C_5 rating required to meet max demand

    = 128.6A × 5 h

    = 642.8Ah
  - Surge demand current = 160.2 A
  - C_1 rating required to meet surge demand

    = 160.2A x 1 h

    = 160.2A

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Selecting a Battery Model

From previous slide

- C_5 rating required to meet max demand: 642.8Ah
- C_1 rating required to meet surge demand: 160.7 A

Suitable model: A602/1130 (2V cells)

Number of cells required = 12 cells

Capacities C_1 - C_{120} (20 °C) in Ah

Type	C_1 1.67 Vpc	C_3 1.75 Vpc	C_5 1.77 Vpc	C_{10} 1.80 Vpc	C_{24} 1.80 Vpc	C_{48} 1.80 Vpc	C_{72} 1.80 Vpc	C_{100} 1.85 Vpc	C_{120} 1.85 Vpc
A602/295 SOLAR	124	167	193	217	248	273	289	285	294
A602/370 SOLAR	155	209	241	272	310	342	362	357	367
A602/440 SOLAR	186	251	289	326	372	410	434	428	440
A602/520 SOLAR	229	307	342	379	435	471	503	505	519
A602/625 SOLAR	275	369	410	455	523	565	604	606	623
A602/750 SOLAR	321	431	479	531	610	659	705	707	727
A602/850 SOLAR	368	520	614	681	729	782	827	822	845
A602/1130 SOLAR	491	694	818	908	973	1043	1102	1096	1126
A602/1415 SOLAR	614	867	1023	1135	1216	1304	1378	1370	1408
A602/1695 SOLAR	737	1041	1228	1362	1459	1565	1654	1644	1689
A602/1960C SOLAR	867	1222	1371	1593	1803	1942	2016	1957	1994
A602/2600 SOLAR	1047	1548	1782	2024	2276	2472	2599	2547	2613
A602/3270 SOLAR	1309	1935	2227	2530	2846	3090	3249	3184	3266
A602/3920 SOLAR	1571	2322	2673	3036	3415	3708	3899	3821	3919

Discussion: Battery Size and Energy Efficiency

- Battery is oversized due to microwave driving up demand
  - Battery can be reduced if customer promise to not use microwave (or other energy intensive loads) during blackout
- Energy efficiency
  - Battery can be further reduced if lights were swapped out with energy efficient model
  - Good time for client to think about appliance upgrade, which is cheaper than a big battery bank

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Lounge room lights	2	75	5	2 x 75W x 5h = 750Wh	1	2 x 75÷1 = 150VA	1	150VA x 1 = 150VA
Bedroom 1 lights	1	75	1	75	1	75	1	75
Bedroom 2 lights	1	75	1	75	1	75	1	75
Bathroom lights	1	75	1	75	1	75	1	75
Fridge	1	150	3	450	1	150	1	150
Television	1	250	3	750	0.8	312.5	1.3	406.25
Laptop computer	2	60	2	240	0.8	150	1	150
Pedestal fan	1	60	6	360	0.8	75	2	150
Microwave	1	1200	0.5	600	0.7	1714.3	1.3	2228.59
Total energy load				3375Wh				
Maximum demand						2776.8 VA		
Surge demand (VA)								3459.84 VA

Discussion: Max Demand and Staggering Load

- Battery size can be reduced if not all loads are on at the same time
  - E.g. Client to not turn on lounge lights while bedroom lights are on
  - TV to be off while laptop is being charged
  - Etc.

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Lounge room lights	2	75	5	2 x 75W x 5h = 750Wh	1	2 x 75÷1 = 150VA	1	150VA x 1 = 150VA
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Fridge	1	150	3	450	1	150	1	150
Television	1	250	3	750	0.8	312.5	1.3	406.25
Laptop computer	2	60	2	240	0.8	150	1	150
Pedestal fan	1	60	6	360	0.8	75	2	150
Microwave	1	1200	0.5	600	0.7	1714.3	1.3	2228.59
Total energy load				3375Wh				
Maximum demand						2776.8 VA		
Surge demand (VA)								3459.84 VA

Discussion: Runtime Variation

- What might the load list look like if it's for a 4 hour backup? Do all the appliance need to be on there?

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Lounge room lights	2	75			1		1	
Bedroom 1 lights	1	75			1		1	
Bedroom 2 lights	1	75			1		1	
Bathroom lights	1	75			1		1	
Fridge	1	150			1		1	
Television	1	250			0.8		1.3	
Laptop computer	2	60			0.8		1	
Pedestal fan	1	60			0.8		2	
Microwave	1	1200			0.7		1.3	
Total energy load								
Maximum demand								
Surge demand (VA)								

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What is Zero Export?

- Zero Export device enable solar system owners & operators to limit the amount of solar power that their systems export to the electricity grid.

- Export limitation means that the amount of solar energy in the system is controlled by adjusting the set point of the inverters in the system. The integrated power analyzer measures the total power at the point of coupling and compares this with the adjustable set point of the controller. When the consumption from the grid is above this set point, the solar energy will be increased, when the consumption is below this set point, the solar energy will be reduced.

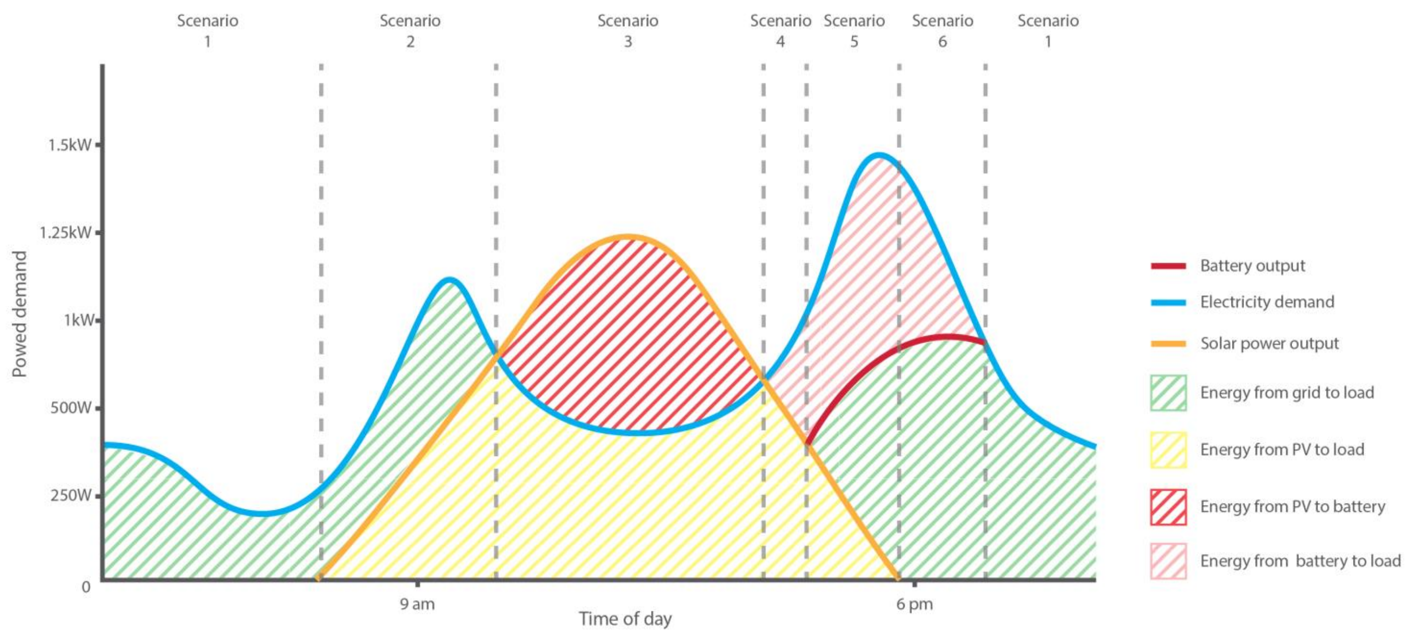
Benefits of Zero export

- Non-exporting commercial PV systems reduce a utility's risk associated with issues such as:
  - voltage rise
  - substation/transformer loading
  - and potentially Neutral Voltage Displacement (NVD)
- Zero export control can allow for:
  - larger PV systems to be installed
  - oversizing becomes more cost effective
  - potentially avoid NVD
  - standardised commercial PV system offering
- A battery can be used to store the excess generation

Why do I need Zero Export Device for my plant?

- With Zero Export device you can run your PV plant without net metering.

What the Grid, PV and Battery are doing to Supply the Load



Note: Battery is not charged via the grid in normal operation

Note: it is assumed that the battery inverter is grid-interactive i.e. can sync and operate in parallel with the grid

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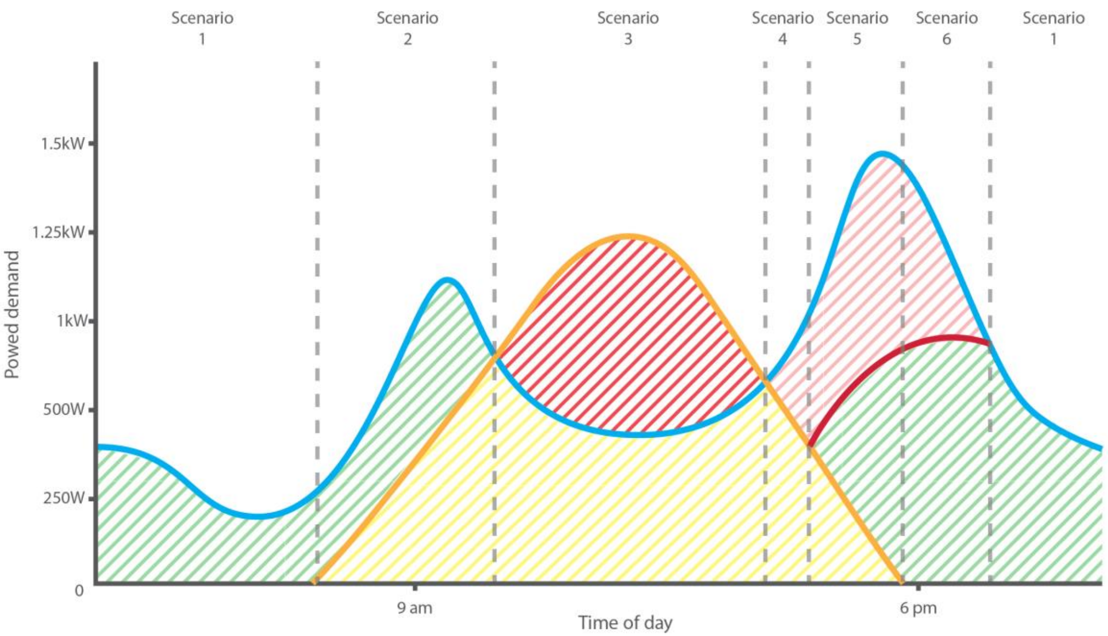
What the Grid, PV and Battery are doing to Supply the Load



- Scenario 1: Only grid used to meet the load
- Scenario 2: Grid and direct PV used to meet the load
- Scenario 3: Direct PV used to meet the load, excess PV used to charge battery
- Scenario 4: Direct PV and battery storage used to meet the load
- Scenario 5: Direct PV, grid and battery storage used to meet the load
- Scenario 6: Grid and battery storage to meet the load

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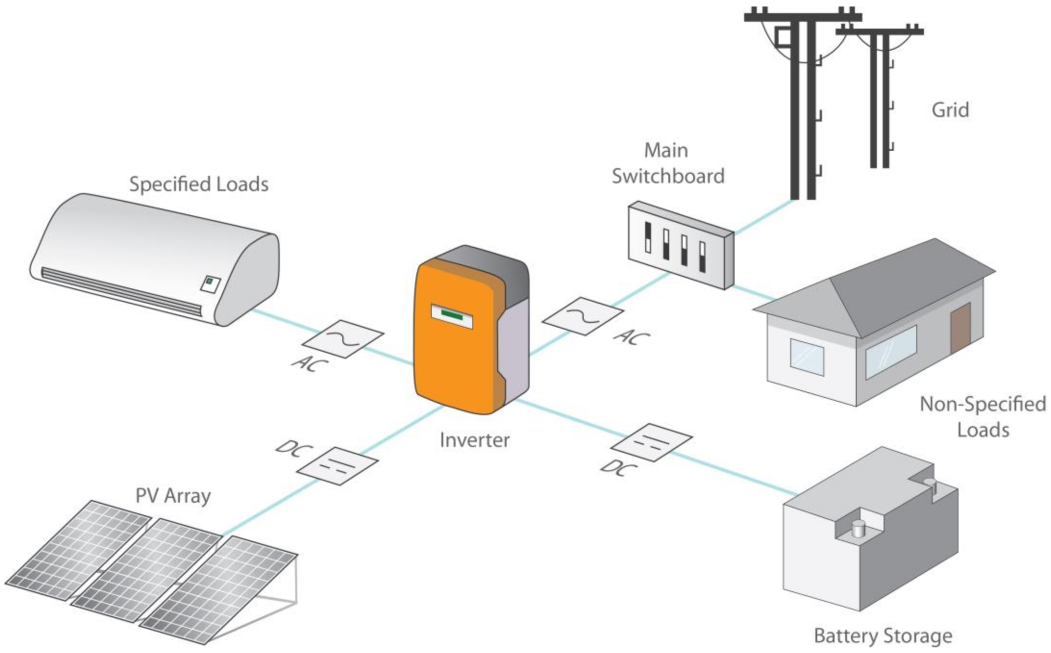
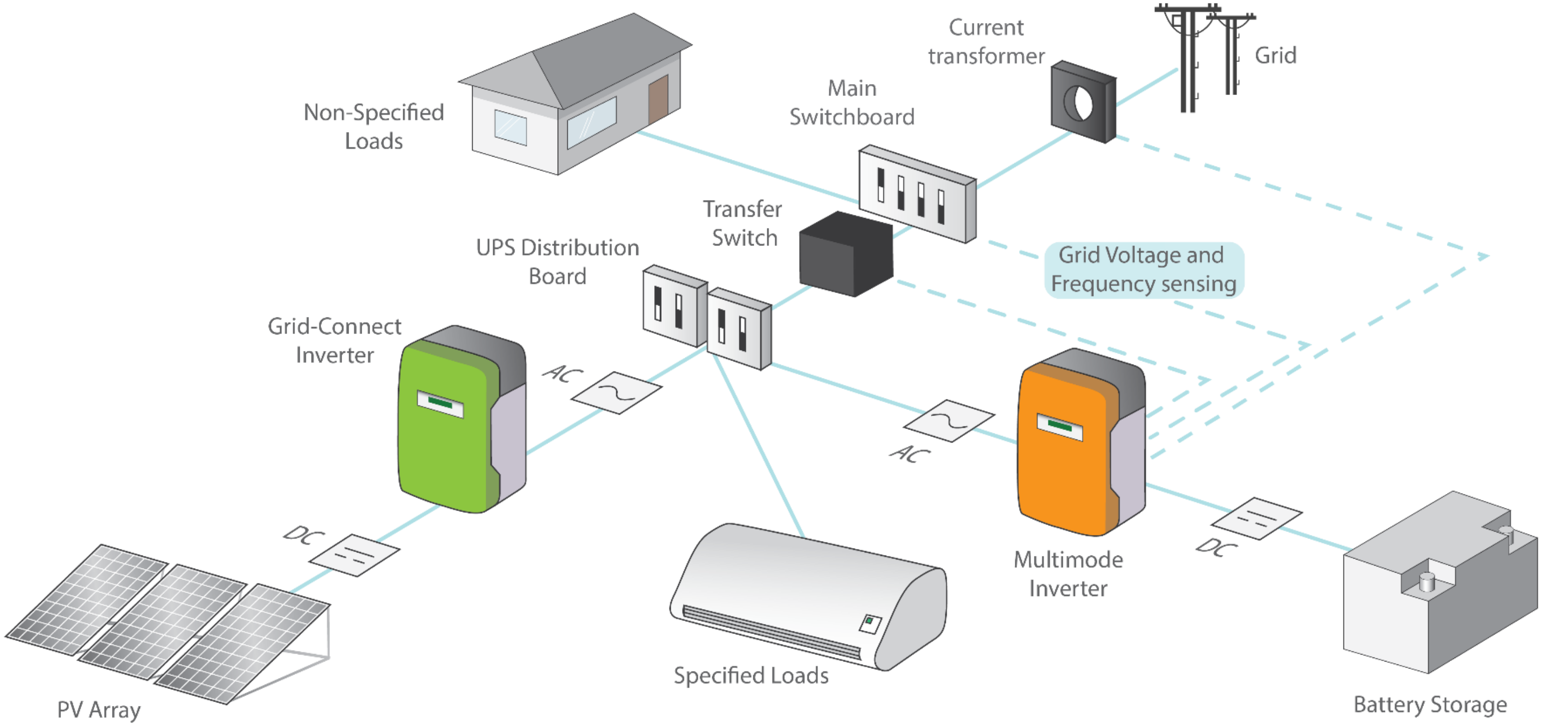
Single Multimode Inverter



AC Bus Configuration



Transfer switch will connect the grid-connect inverter, the multimode inverter, the specified loads and the normal loads in parallel with the grid under normal operation. During grid outage the transfer switch isolates the normal loads and the incoming grid supply from the grid-connect inverter, multimode inverter and specified loads so that backup operation can take place.

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Sizing a Battery Bank for Zero Export

Site inspection/customer interview:

- Estimate the maximum excess PV generation to be expected (this should prevent any wastage of PV).
- Determine if the customer wants backup functionality during blackouts
- Create a Loads survey to find out:
  - Total amount of energy required and when it is used
  - Surge demand
  - Peak demand

Site Information

- Assuming that the customer that is about to install a zero export grid-connected PV system with batteries, and wants to use excess PV generated electricity during the evening period.
- An assessment of average PSH for the site becomes handy.
- For Samoa, assuming the following PSH at tilt of 13 degrees.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
5.3	5.01	5.12	5.31	5.06	4.99	5.23	5.6	5.83	5.74	5.65	5.44	5.36

- Highest PSH is used to determine maximum excess PV electricity.

PV Generation

- Assume the array will be 7kW on roof of the building with a tilt angle of 13 degrees

- 20% System losses including :
  - array derating due to temperature, dirt and manufacturers
  - Inverter efficiency
  - Cable Voltage drop

- The daily output of the PV system would be 7 x 5.83 x 0.80 = 32.65 kWh.

Daytime Load Survey

- To find the excess PV energy, the daytime load should be subtracted from the daily generation
- Fridge and aircon have duty cycles (when compressor is running). Typical values are 30%-50%. In this example, the fridge's cycle is 50%, i.e. for a 4 hours backup, the fridge compressor will be on for 2 hours.

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Room 1 Lights	10	25	8	2000	0.9	(10 x 25)÷0.9 = 278VA	1	277.78VA x 1 = 278VA
Room 2 Lights	10	25	8	2000	0.9	278	1	278
Bathroom Light	4	15	1	60	0.9	66.67	1	66.67
Air Conditioner	1	1800	4	7200	0.85	2117.6	2	4235.2
Computers	6	250	8	12,000	0.9	1666.7	1.3	2166.7
Security Cameras	3	15	8	360	0.95	47	1	47
Fridge	1	200	6	1200	0.85	235.3	1.5	352.9
Microwave	1	1200	0.8	960	0.7	1714.3	1.2	2057.2
Kettle	1	1500	0.3	450	1	1500	1	1500
Total energy load				26,230Wh				
Maximum demand						7903.6 VA		
Surge demand (VA)								10981.6 VA

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Discussion

- PV System is only 7kW and with system losses could possible be only providing 7 x 0.8 = 5.6kW (kVA).

- While the maximum demand has been calculated 7.9kVA - thereby showing that some of the day time load must be supplied from the grid.

- Accurate interval analysis comparing the energy usage to PV generation in 5 minute intervals (or less) would be required to know exactly how much daily load is being supplied by the PV array.

- At other times the PV array output would be in excess of the actual loads and that is when storage would occur.

Estimating Excess PV generation

For the sake of the exercise we will assume that all the daily energy is being supplied by the PV array but in reality it might only be 50% to 80%

Month	Peak sun hours at 13° tilt	Maximum daily energy production (kWh)	Daytime load requirement (kWh)	Excess (kWh)
September (Highest PSH)	5.83	32.65	26.23	6.42

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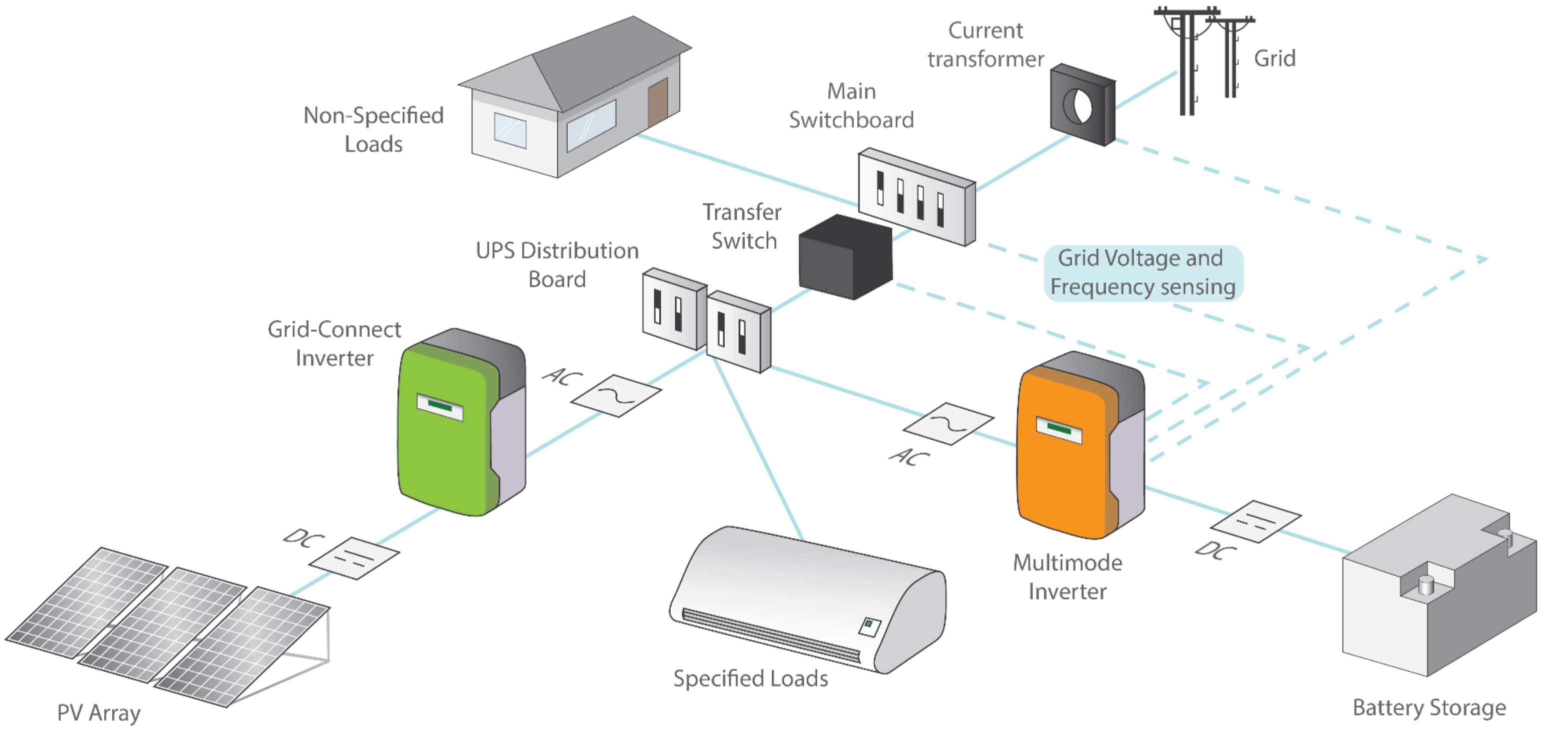
Assume configuration is:



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Calculate Energy To be Stored in Battery

- Assume battery inverter/charger efficiency (η_{INV}) is 90% when charging
- Assume no other losses in the system
- Total PV energy available to be stored by the battery is

$$E_{PV\text{-}Batt} = E_{Excess} \times \eta_{INV\text{-}CHG}$$

Where:

$E_{PV\text{-}Batt}$ = total energy to be stored in battery

E_{Excess} = excess energy generated from the system

From the example:

$E_{PV\text{-}Batt}$ = 6.42 kWh x 0.9

= 5.78 kWh or 5780Wh

Calculate Battery Capacity Required (Wh)

Battery capacity is calculated by the formula:

$$\text{Battery Capacity (Wh)} = E_{PV\text{-}Batt} \div \text{Max DOD}$$

Example:

Assume the system has a Maximum DOD value of 0.7 (i.e. 70%).

The design battery capacity required is:

Batt Cap (Ah) = 5.78 kWh ÷ 0.7

= 8.25 kWh

Calculate Battery Capacity Required (Ah)

Battery capacity is calculated by the formula:

$$\text{Battery Capacity (Ah)} = E_{PV\text{-}Batt} \div (V_{dc} \times DOD)$$

Example:

Assume the system is 24V and DOD value of 0.7 (i.e. 70%).

The design battery capacity required is:

Batt Cap (Ah) = 5780Wh ÷ (24 x 0.7)

= 344 Ah

Battery Backup

- In a zero export system, the battery can also be used as backup
- However if the battery remains the same sized as that calculated to absorb excess energy then it can only back up to that amount of energy.
- If black-outs are a concern then the battery should be sized as covered earlier in the presentation.

Questions?

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