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

1. Residential battery backup system site survey

A customer who is connected to the grid would like to install a battery system. They have experienced a few unexpected power outages and want to make sure that the next time an outage happens they have backup energy supply for the most important loads. They have expressed a desire for up to 6 hours of backup (one evening equivalent) and have identified the following loads for backup and expected maximum usage time.

i) Complete the load table to calculate the required backup load, max demand, and surge demand.

ii) What happens to the energy load, max demand and surge demand if the following energy efficiency measures are implemented: The existing incandescent lights swapped with 25W compact fluorescent lights (CFL), with a power factor of 0.9, the existing plasma TV swapped with equivalent size LCD TV at 120W, and the microwave taken off the backup loads list (fill out the second table provided).

Table 1: Backup loads given by customer

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		1		1	
Bedroom 2 lights	1	75	1		1		1	
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		0.7		1.3	
Total energy load								
Maximum demand								
Surge demand (VA)								

Note: the fridge is assumed to have a 50% duty cycle, ie during the 6 hours of backup, it is assumed the fridge compressor is operating only half of the time.

Table 2: Adjusted backup load list swapping incandescent lights for CFLs and removing microwave use from list.

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	25	5	2 x 25W x 5h = 250Wh	0.9	2 x 25÷0.9 = 55.6VA	1	150VA x 1 = 55.6VA
Bedroom 1 lights	1	25	1		0.9		1	
Bedroom 2 lights	1	25	1		0.9		1	
Bathroom lights	1	25	1		0.9		1	
Fridge	1	150	3		1		1	
Television	1	120	3		0.8		1.3	
Laptop computer	2	60	2		0.8		1	
Pedestal fan	1	60	6		0.8		2	
Total energy load								
Maximum demand								
Surge demand (VA)								

All the following questions are based on Table 2

2. Residential battery energy requirement

Calculate the total design energy required from the battery (E_{TOT})

Use the equation: $E_{TOT} = E_{AC} \div \eta_{INV}$

Assume η_{INV} value of 0.9

What is the total design energy required from the battery for the load list shown in Table 2? __________ Wh

3. Deriving residential battery capacity required

Use the equation: Battery Capacity (Ah) = $E_{TOT} \div (V_{dc} \times DOD)$

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

Note: DOD value can vary from 0.25 to 0.9 depending on battery technology and expected cycling frequency. For lead-acid batteries, the more times it's expected to cycle, the lower the DoD value should be.

What is the total design battery capacity for the energy requirement calculated? __________ Ah

4. Deriving the discharge current

4.1: Calculate the required discharge current from the battery for the maximum demand calculated.

Use the equation: Discharge current (A) = Demand (VA) $\div (V_{dc} \times \eta_{INV})$

Assume the system is 12V and η_{INV} is 0.9 (90%)

What is the required discharge current for the maximum demand calculated for Table 2? ____________ A

4.2: Calculate the potential surge current.

Use the equation: Surge current (A) = Surge demand (VA) ÷ (V_{dc} × η_{INV})

Assume the system is 12V and η_{INV} is 0.9 (90%)

What is the surge current calculated? ___________ A

5. Selecting the battery

Use the datasheet provided to select the battery banks required for the backup system. Assuming the battery capacity is based on the C_{10} rating.

Example: if required capacity is 500Ah, the battery model selected at C_{10} must be 500Ah or higher.

The selected battery must be capable of providing:

- The maximum demand current at C_5
- The surge demand current at C_1

Check the discharge current of the battery by dividing the capacity by the C hour rating. For example, the discharge current of a 400Ah@ C5 is 400/5 = 80A. Conversely, if a maximum demand discharge current of 200A is required at C5, then a battery with a capacity of 200 x 5, i.e. 1000Ah, must be selected. Similar check must be made for the surge current.

These checks ensure that the battery voltage does not drop to the point it trips the inverter.

5.1: Battery model and capacity suitable for battery capacity determined in Question 3?

Model ___________________________, Ah capacity____________________________

5.2: What is the minimum battery capacity required at C_5 to provide maximum demand discharge current determined in Question 4.1?

__________________________________Ah capacity____________________________

5.3: Battery model and capacity (at C_5) suitable for maximum demand discharge current determined in Question 4.1?

Model ____________________________, Ah capacity____________________________

5.4: What is the minimum battery capacity required at C_1 to provide surge demand discharge current determined in Question 4.2?

__________________________________Ah capacity____________________________

5.5: Battery model and capacity (at C_1) suitable for surge demand discharge current determined in Question 4.2?

Model _____________________________, Ah capacity____________________________

5.6: Based on the three battery models determined in 5.1, 5.3 and 5.5 which model would you select and why?

Model ____________________________, Ah capacity____________________________

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

6. Commercial grid connected PV system with battery backup site survey

An owner of a small business wants to safeguard against loss of power from occasional planned and unplanned outages. They are thinking of installing a battery backup system.

The owner would like one day's worth of backup, as planned outages sometimes last from 8am to 5pm, which overlaps with the business hours. If unplanned outages last longer than one business day, the owner would reduce trading hours or obtain a back-up generator.

The surveyed load for the business is as follows:

Please complete the empty columns

Table 3: Backup load list identified at the small business

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Building lights (fluorescent)	10	36	8	10 x 36W x 8h = 2880 Wh	0.9	10 x 36÷0.9 = 400 VA	1	400VA x 1 = 400VA
Printer (Printing)	1	550	1		1		1	
Printer (standby)	1	7	7		1		1	
Kettle	1	1500	0.5		1		1	
Fridge	1	150	4		1		1	
Desktop computer and monitor	2	200	8		0.8		1.3	
Laptop computer	1	60	8		0.8		1	
Pedestal fan	3	180	8		0.8		2	
Mobile phone/ laptop charger	1	60	1		1		1	
Total energy load								
Maximum demand								
Surge demand (VA)								

Note: duty cycle of the fridge is assumed to be 50%.

7. Commercial battery energy requirement

Calculate the total design energy required from the battery (E_{TOT})

Use the equation: $E_{TOT} = E_{AC} \div \eta_{INV}$

Assume η_{INV} value of 0.9

What is the total design energy required for the load list shown? ___________ Wh

8. Deriving Commercial battery capacity required

Calculate the total battery capacity required for the two scenarios outlined by Table 3

Use the equation: Battery Capacity (Ah) = $E_{TOT} \div (V_{dc} \times DOD)$

Assume the system is 48V and depth of discharge (DOD) value of 0.6 (i.e. 60%).

Note: DOD value can vary from 0.25 to 0.9 depending on battery technology and expected cycling frequency. For lead-acid batteries, the more times it's expected to cycle, the lower the DoD value should be.

What is the total design battery capacity for the energy requirement calculated? ___________ Ah

9. Deriving the discharge current

9.1: Calculate the required discharge current from the battery for the maximum demand calculated in Table 3

Use the equation: Discharge current (A) = Demand (VA) $\div (V_{dc} \times \eta_{INV})$

Assume the system is 48V and η_{INV} is 0.9 (90%)

What is the required discharge current for the maximum demand calculated for Table 3? ___________ A

9.2: Calculate the potential surge current.

Use the equation: Surge current (A) = Surge demand (VA) $\div (V_{dc} \times \eta_{INV})$

Assume the system is 48V and η_{INV} is 0.9 (90%)

What is the surge current calculated for Table 3? ___________ A

10. Selecting the battery

Use the datasheet provided to select the battery banks required for the backup system. Assuming the battery capacity is based on the C_{10} rating.

Example: if the required capacity is 500Ah, the battery model selected at C_5 must be 500Ah or higher.

The selected battery must be capable of providing:

- The maximum demand current at C_5
- The surge demand current at C_1

Check the discharge current of the battery by dividing the capacity by the C hour rating. For example, the discharge current of a 400Ah@ C5 is 400/5 = 80A. Conversely, if a maximum demand discharge current of 200A is required at C5, then a battery with a capacity of 200 x 5, i.e. 1000Ah, must be selected. Similar check must be made for the surge current.

These checks ensure that the battery voltage does not drop to the point it trips the inverter.

10.1: Battery model and capacity suitable for battery capacity determined in Question 8?

Model ________________________________, Ah capacity__________________________

10.2: What is the minimum battery capacity required at C_5 to provide maximum demand discharge current determined in Question 9.1?

__________________________________, Ah capacity____________________________

10.3: Battery model and capacity (at C_5) suitable for maximum demand discharge current determined in Question 9.1?

Model ____________________________________, Ah capacity____________________________

10.4: What is the minimum battery capacity required at C_1 to provide surge demand discharge current determined in Question 9.2?

__________________________________, Ah capacity____________________________

10.5: Battery model and capacity (at C_1) suitable for surge demand discharge current determined in Question 9.2?

Model __________________________________, Ah capacity____________________________

10.6: Based on the three-battery models determined in 10.1, 10.3 and 10.5 which would you select and why?

Model ____________________________, Ah capacity____________________________

Reason: ____

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
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A602/1960C SOLAR	867	1222	1371	1593	1803	1942	2016	1957	1994
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A602/3270 SOLAR	1309	1935	2227	2530	2846	3090	3249	3184	3266
A602/3920 SOLAR	1571	2322	2673	3036	3415	3708	3899	3821	3919

Supplementary Questions

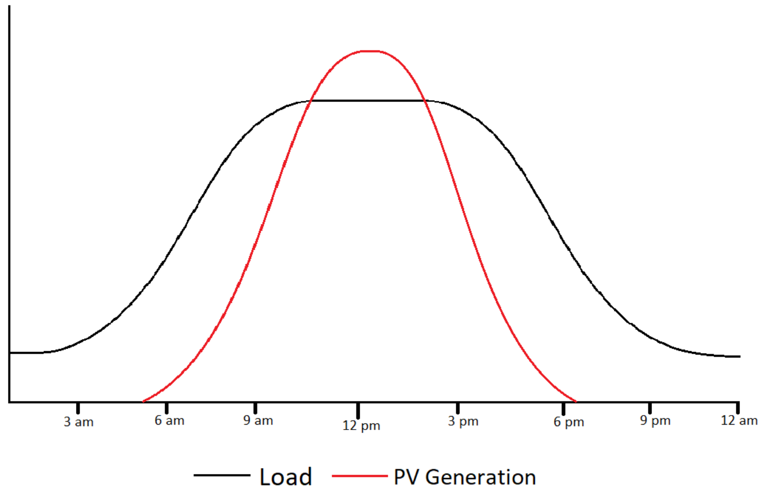
Note: These 2 questions are undertaken in your own time. Go to Question 11.

A. What could be done to reduce the battery size?

B. What if the backup hours are reduced to 4 hours only? What would be the result?

11. Sizing the battery for zero export

You have been tasked with sizing a battery for a commercial building with zero export. An approximate load and generation curve has been provided for the day of the year with the highest PSH.



The building has a 10kW PV system installed with a system efficiency of 80% (this includes all the losses between STC rated PV array and the load). It has been determined that the PV generation exceeds the load for approximately 3 hours. The total irradiation during this time is 3.8kWh/m^2.

11.1: If the load during this period is a constant 8kW, calculate the excess PV generation.

11.2: Using the following information, determine the minimum battery capacity (in kWh and Ah). to store the excess PV generation: The system will be in a.c. bus configuration with an interactive inverter

- Battery voltage: 24V
- Maximum DoD: 60%
- Interactive Inverter, efficiency in charger mode: 90%

12: Assume an average load of 3 kW after 6pm (close of business) and a battery with a 550Ah capacity has been chosen. How long can the battery provide backup to the system assuming it starts at full charge?

Assume

- Battery voltage: 24V
- Maximum DoD: 60%
- Inverter efficiency: 90%

Practice load tables

Appliance	No.	Power (W)	Usage time (hour)	Energy (Wh)	Power factor	Potential max demand (VA)	Surge factor	Potential surge demand (VA)
Building lights (fluorescent)		36			0.9		1	
Printer (Printing)		550			1		1	
Printer (standby)		7			1		1	
Kettle		1500			1		1	
Fridge		150			1		1	
Desktop computer and monitor		200			0.8		1.3	
Laptop computer		60			0.8		1	
Pedestal fan		180			0.8		2	
Mobile phone/ laptop charger		60			1		1	
Total energy load								
Maximum demand								
Surge demand (VA)								

Inverter efficiency η_{INV}: ___________

Depth of discharge (%): ___________

System voltage (V): ___________

Battery capacity required (Ah): ___________

Battery maximum demand current(A): ___________

Battery surge demand(A): ___________