ENCH 648L – PHOTOVOLTAICS
FINAL PROJECT
FALL 2018

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The PV module provided has the following properties under AM1.5 Conditions:

Property	**Data**
Number of Solar Cells	60
Maximum Power Voltage	30.9 V
Maximum Power Current	8.32 A
Maximum Power	257.088 W
Open Circuit Voltage	38.0 V
Short Circuit Current	-8.88 A
Effective Module Area	1 m^2

We consider the cells to have no series resistance and to have a very large shunt resistance. This allows us to find the photocurrent and the dark saturation current. Also the cells can be considered to be maintained at 298K under the AM1.5 conditions.

Property	**Data**
Series Resistance	0Ω
Shunt Resistance	∞
Temperature of the cells	298 K

Under short circuit conditions:

$$V = 0$$

Hence,

$$I_{ph} = -I_{sc} = 8.88\ A$$

Under Open Circuit conditions,

$$I = 0$$

Hence,

$$I_o = \frac{I_{ph}}{\left[\exp\left(\frac{qV_{oc}}{\beta k_B T}\right) - 1\right]} = 1.7617 * 10^{-10}\ A$$

Since the system properties have been evaluated at AM1.5 conditions (E_G = 1000 W/m^2), the properties will vary with the insolation data since at each time frame due to the energy available to the solar cells is never exactly equal to 1000 W/m^2. This leads us to conclude that the system properties must be evaluated using the concentrating factor.

Concentrating Factor for each data point can be evaluated as:

$$X = \frac{Insolation}{1000}$$

The changing insolation would mean that the maximum power for the cells would vary with the time of the day. Using the iterative method we can evaluate the maximum power voltage and current and hence the maximum power.

$$V_{oc} = \frac{\beta k_B T}{q}\left(\frac{XI_{ph}}{I_o} + 1\right)$$

$$V_{mp}^{i+1} = V_{oc} - \frac{\beta \mathrm{k_B} T}{q} \ln\left[\left(\frac{qV_{mp}^{i}}{\beta k_B T}\right) + 1\right]\ (V)$$

Corresponding Maximum power current is evaluated as:

$$I_{mp} = -\left(X * I_{ph}\right) + I_o \exp\left[\left(\left(\frac{qV_{mp}}{\beta k_B T}\right) - 1\right)\right]\ (A)$$

Hence the maximum power generated,

$$P_{mp} = I_{mp} * V_{mp}\ (W)$$

Assuming that the cells work at the maximum power at all times, the efficiency of the cells for each insolation data point can be calculated as:

$$\eta = \frac{P_{mp}}{Insolation}$$

The electrical load requirements of the house have been noted as:

Time Period	**Total Hours**	**Load**
Midnight – 1AM	1 hour	0 kW
1AM – 9AM	8 hours	1.5 kW
9AM – 5PM	8 hours	0 kW
5PM – Midnight	7 hours	1 kW
	24 hours	19 kWhr

The charge in the house primary battery system available for the next time period can be evaluated as:

$$C_{i+1} = C_i + \eta \Delta t \left[\frac{E_{G(ti+1)} + E_{G(ti)}}{2}\right] - \Delta t(load\ requirements)$$

Hence for the conditions provided:

$$C_{i+1} = C_i + \Delta t \left[\frac{P_{mp(ti+1)} + P_{mp(ti)}}{2}\right] - \Delta t\left(Load_{t(i+1)} - Load_{ti}\right)$$

Where,

$\eta - efficiency\ of\ the\ cell$

$\Delta t - The\ reference\ time\ intervals\ between\ two\ data\ points.$

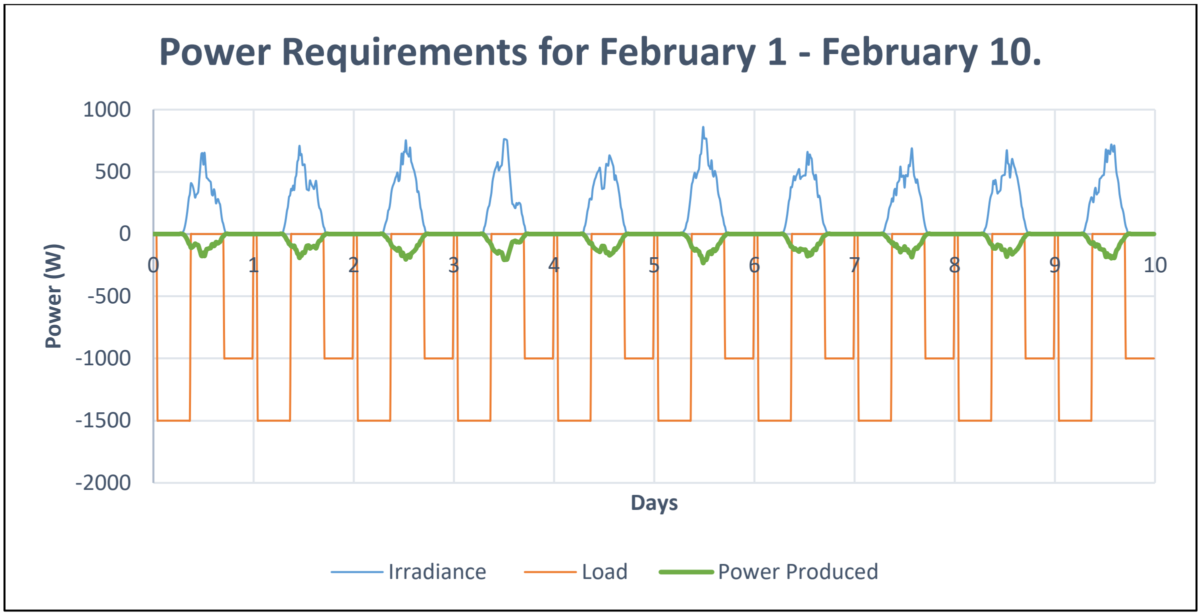
$C_i - Initial\ battery\ storage\ (kWhr)$

We can assume each module to have an effective area of the cells to be **1m²**.

This would give us the work requirements and power produced for the insolation.

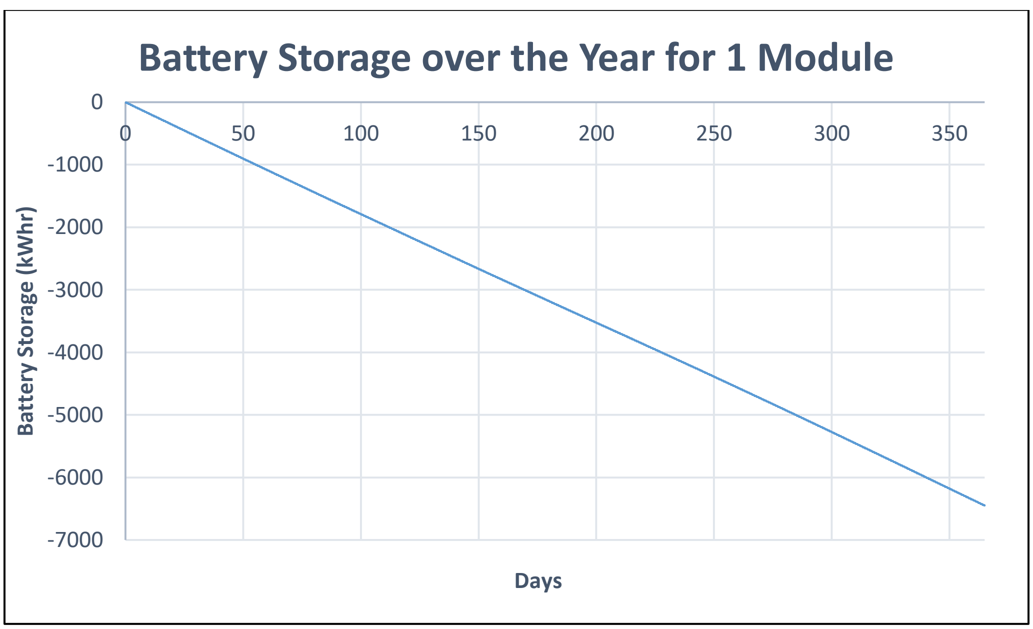
PART A.

Power requirements for the first 10 days of February for a single module:



PART B:

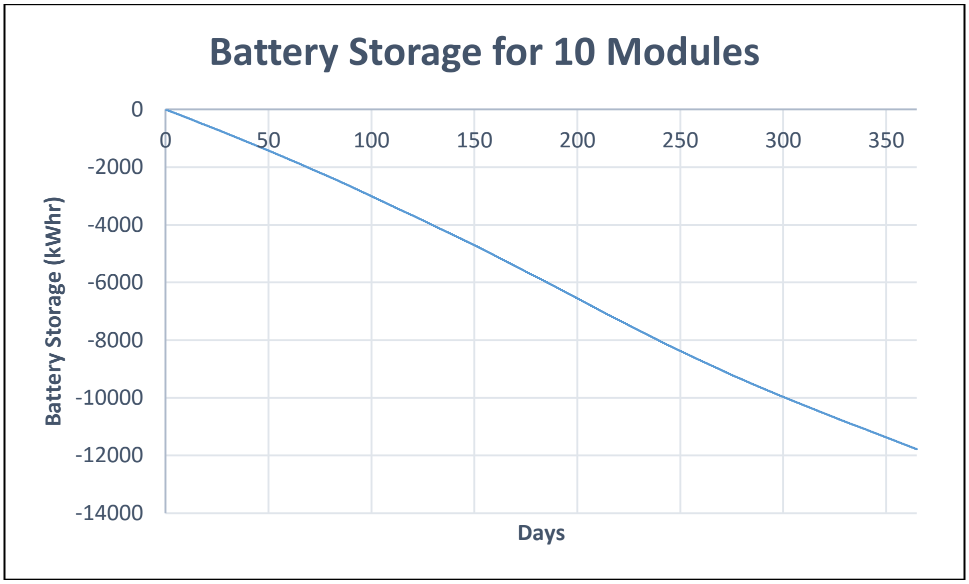
For a single module starting at no initial condition:

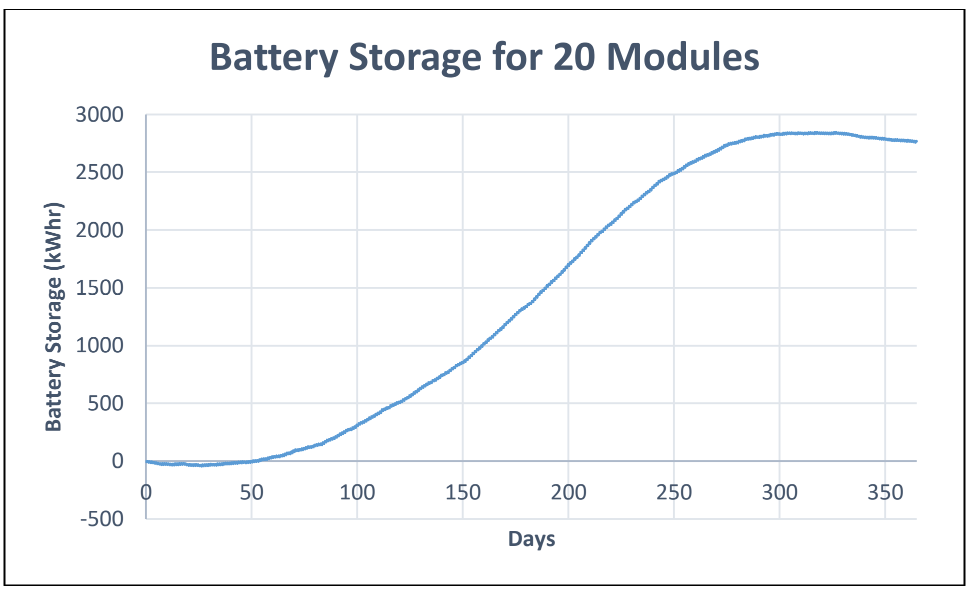


The above plot tells us that a single module can never meet the power demands of the house even if we use a battery with very high initial storage. It would eventually drain out and give power failure since then. Evaluating the storage for a system containing N modules:

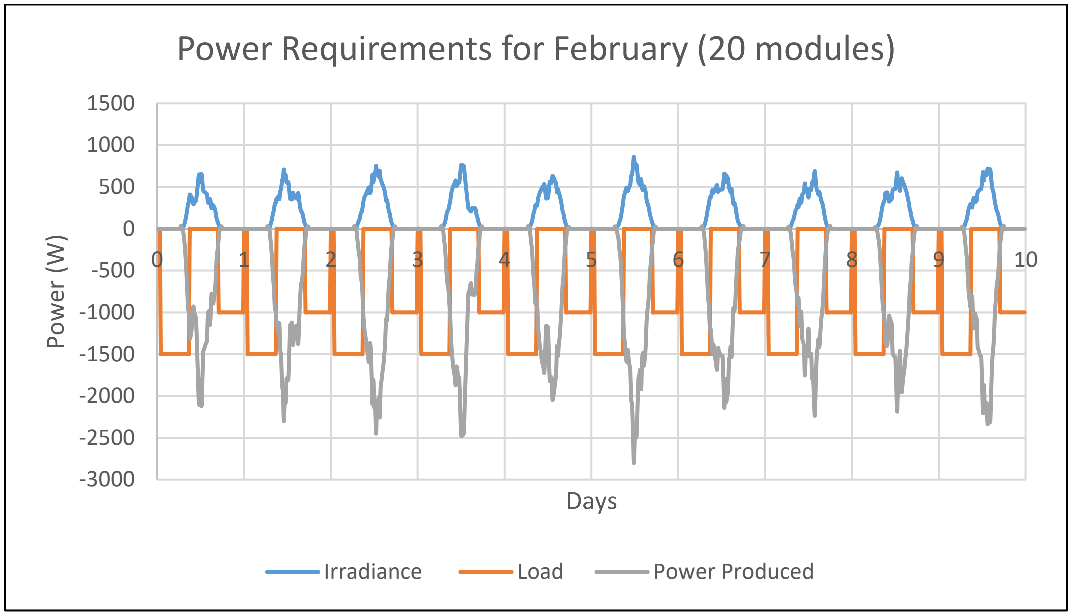
$$C_{i+1} = C_i + N\Delta t\left[\frac{P_{mp(ti+1)} + P_{mp(ti)}}{2}\right] - \Delta t\left(Load_{t(i+1)} - Load_{ti}\right)$$

For no initial battery charge:





From the above plots, it is clear that the load demands of the house are not met by 10 modules and hence we require more than 10 modules. Also, a system of 20 modules gives us net positive power storage over the course of the year although the initial 60 days would be without energy. To compensate for the initial condition, a battery with initial charge can be used to compensate for the energy loss. The minimum energy point on the plot is at (-56.67 kWhr), hence, a battery with an initial storage of 60 kWhr would be sufficient to compensate for the loss battery drainage.

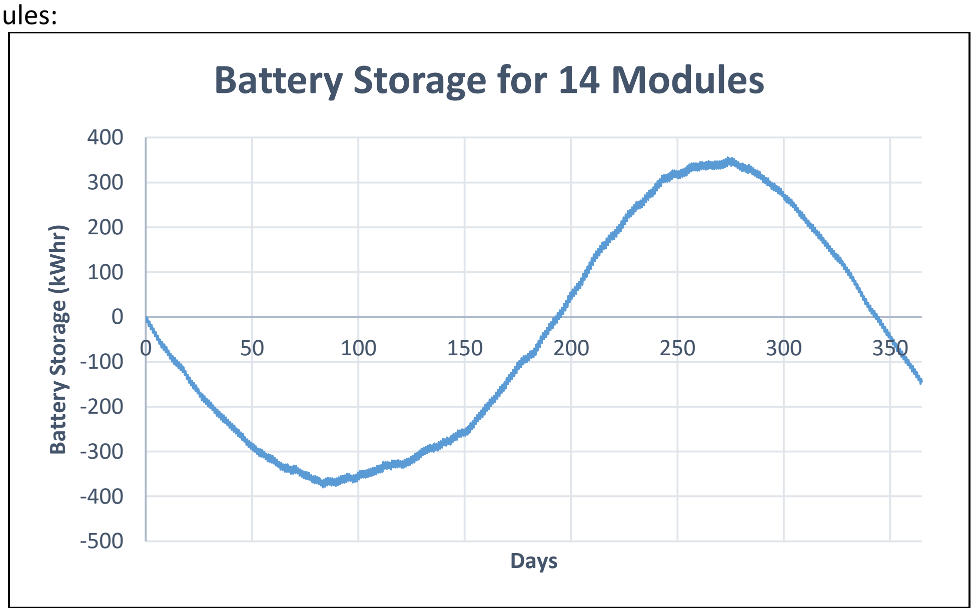


The above plot shows us that the power production by a system of 20 modules is very large compared to the load requirements.

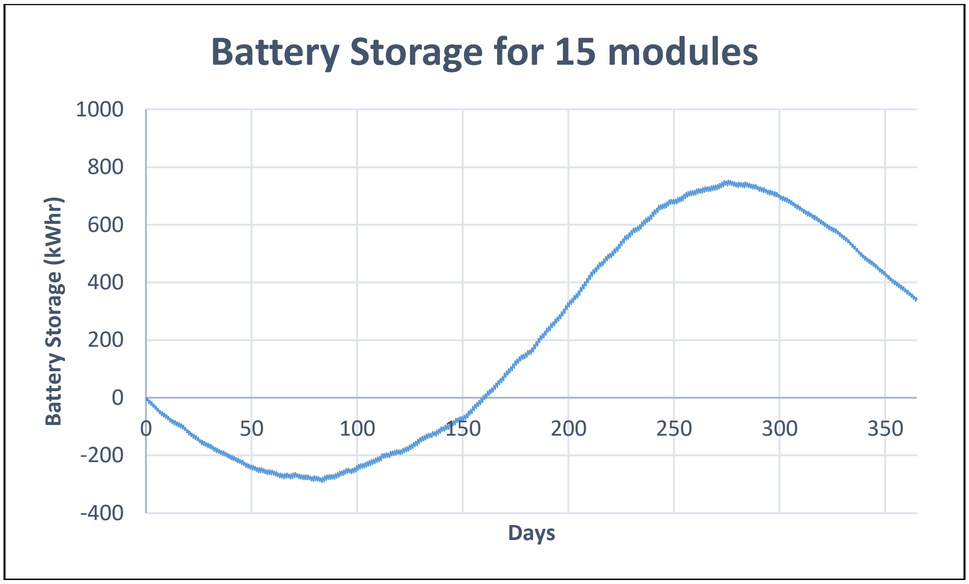
PART C.

The above problem can be optimized by considering the number of modules required to be between 10 and 20 modules such that less than 10 failure events occur.

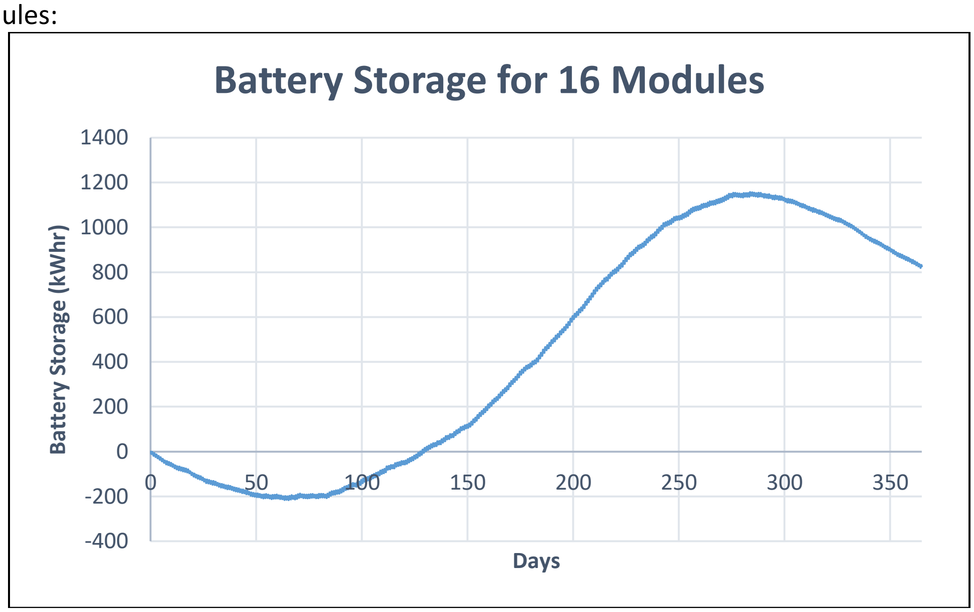
For 14 modules:



For 15 modules:

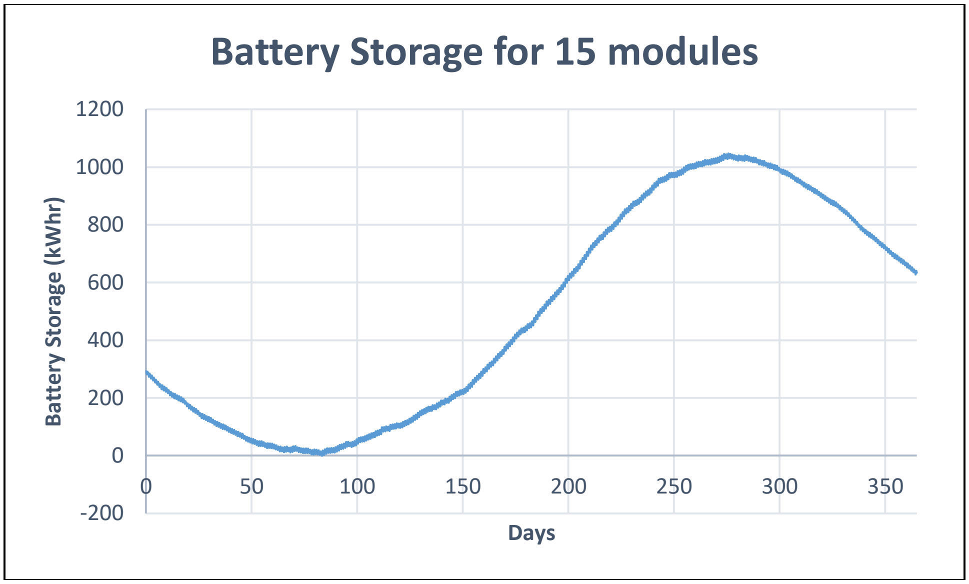


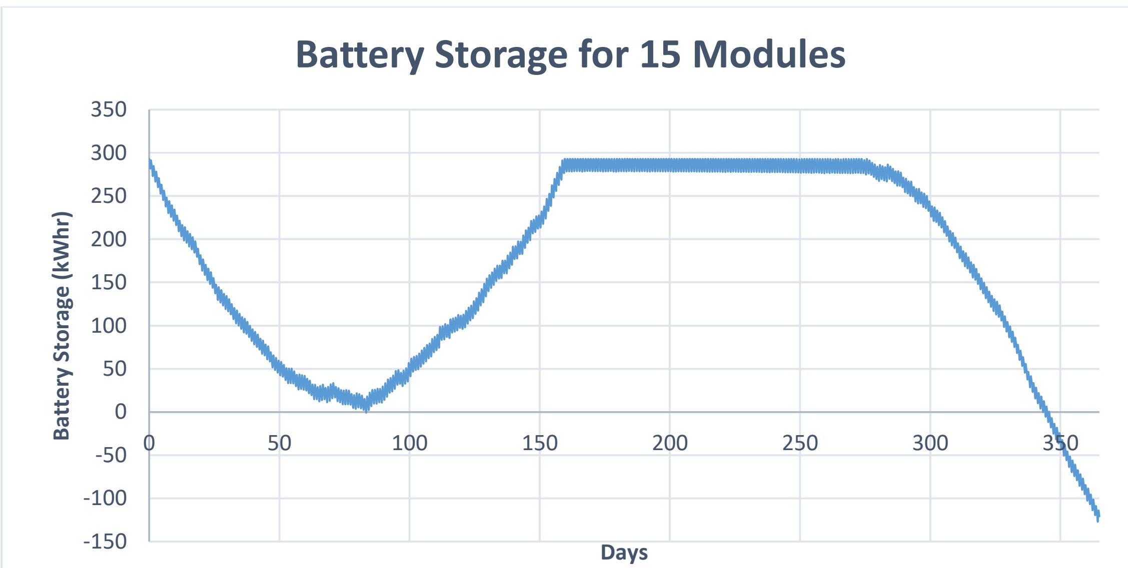
For 16 modules:



The best results are obtained for 15 modules which does not overcompensate for the energy requirements and also has net positive power at the end of the year. This system of 15 modules must be used with a battery having an initial storage of 293.5kWhr which would result in approximately 9 failures throughout the year. The system with 14 modules are not sufficient to compensate the energy requirements whereas the system of 16 modules gives a large amount of surplus energy.

The initial battery charge for this system is 293.5kWhr and the battery must have a capacity of about 1100 kWhr.

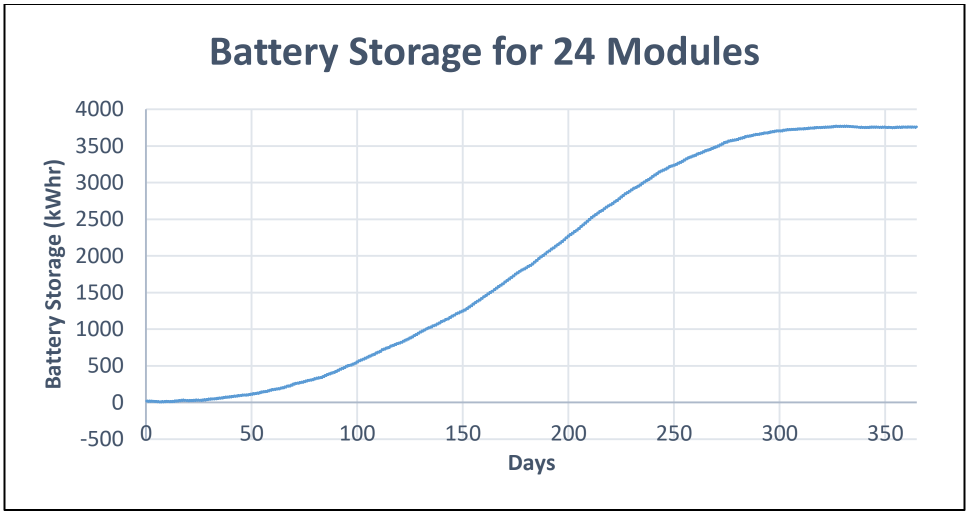




Although this seems to be the most feasible option, the capacity of the battery is very large and requires a very large initial battery storage, a battery with a capacity of 293kWhr is very large and would be unreasonable. Also, the above plot confirms that the battery is not sufficient enough as it would drain out during winter and would not be ready for use.

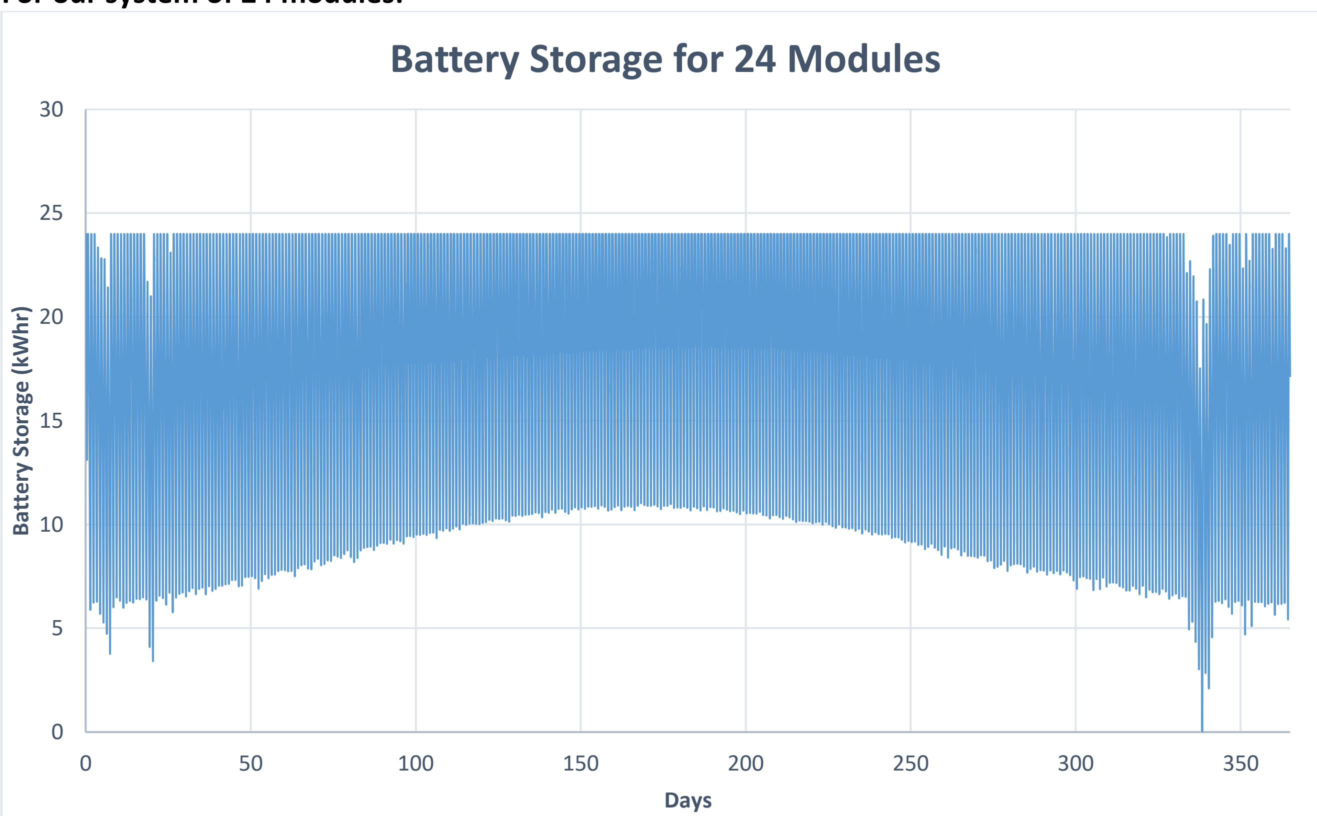
Evaluating the requirements of the house, we find that the house requires about 19kWhr of power for an entire day. So we need a battery with an initial storage such that it could power the house for an entire day without any power generation from the sun.

For this, we can work with a system which requires a battery capacity of over 19kWhr. Optimising this problem we find that 24 modules of solar cells in combination with a battery of capacity of 24kWhr would ensure that the house would be powered throughout the year with only about 6 failures.



The above system ensures that the requirements of the house are met throughout the year. Also, the battery capacity is not very large and is nearly completely charged at all times and provides sufficient power requirements even in the absence of sunlight as seen in the plot below. It would also provide be sufficient to provide energy for over a day in case of any failures and the excess energy could be transmitted and could be used for other purposes through integration.

For our system of 24 modules:



CONCLUSION:

Properties of the battery and the PV cell arrays required to meet the energy demands of the house:

Property	Data
Number of Modules	24
Battery Capacity	24 kWhr
Initial Charge	24 kWhr