Renewable Energy and Distributed Generations

Lecture 12

Sizing and Designing the Off-grid and Grid Connected PV System

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Lecture learning outcomes:

At the end of this lecture, you will be able to:

i. Understand the sizing and designing of off-grid and grid connected PV systems

ii. Identify how to estimating an electric load

iii. Knows the software application on grid connected and off-grid PV systems

iv. Develop design project using Homer optimization

Outlines

1. Sizing and Designing the Grid Connected System

2. Designing and sizing Off-grid system

3. Estimating an Electric load

4. Software's used for PV/RE simulation

5. Design Project Example

6. Solution of the Design Project

Summary

References

1. Sizing and Designing the Grid Connected System

The following steps are needed:

1. Select site, efficiency of PV modules used, array layout and budget.

Determining the maximum array power output.

2. Selecting one or more inverters with a combined rated power output 80% to 90% of the array maximum power rating at STC.

3. Inverter string sizing determines the specific number of series-connected modules permitted in each source circuit to meet voltage requirements.

4. The inverter power rating limits the total number of parallel source circuits.

5. Estimating system energy production based on the local solar resource and weather data.

6. The sizing of interactive PV systems is centered on the inverter requirements

- The solar modules constitute the input of your solar system; therefore, you need to include the system inefficiencies in order to estimate the number of solar panels you need.
- Normally, a common grid-tie solar system may have losses about 14-22%.
- Accordingly, consider these losses while designing your system .

Thus, calculate the number of solar panel needs the following things:

- Considering a well-designed solar system with good efficiency >85%, divide the solar system size (AC) in step 4

❖ Select the solar module with standard nominal name plate from manufacturer

❖ If the power calculated at step 4 is known and calculate the number of panels using power output divided by the selected panel rating

❖ In this case, number of modules should cover 100% of your energy needs.

2. Designing and sizing Off-grid system

- The main **objective of sizing** stand-alone PV system is: a critical balance between energy supply and demand.

It involves the following key steps[1]:

- Determine the average daily load requirements of each month
- Conduct a critical design analysis to determine the month with the highest load to solar insolation ratio
- Size the battery banks for system voltage and required energy storage capacity
- Size PV array to meet the average daily load requirements for the period with lowest sunlight and highest load (usually winter)

Designing Cont.…

- Calculate the necessary energy before establishing a solar PV system, it is necessary to calculate the total energy requirements of all applications that the system will need to power.
- Every day, determine how many watt-hours each piece of equipment uses. For the purpose of calculating the total Watt-hours that is added to the Watt-hours needed for all of the equipment taken together, which can be supplied to the goods.
- Determine the number of Watt-hours that the solar system generates on a daily average.
- The daily total of equipment Watt-hours must be divided by to get the amount of electricity that the panels must produce.

Designing Cont.…

The System Sizing is given by: generally, involves a Six-step process which will allow the photovoltaic system designer:

- Estimating the Electric Load
- Sizing and Specifying Batteries
- Sizing and Specifying an Inverter
- Sizing and Specifying an Array and specifying A Controller
- Sizing the cablings between each PV components

Designing Cont….

- Thus, the following steps help you determine the array size for your off-grid or grid tie solar photovoltaic stem
- Find you monthly average electricity usage from your energy bill: This is the total kWh you pay for in a single month.
- Find your daily average electricity usage: Divide your monthly average kWh found in step 1 by 30 days.
- Find the daily average peak sun hours for your location : it’s also possible to visit NASA data
- Calculate the solar system size (AC) to generate 100% of your electricity consumption : can be achieved by dividing the daily average energy usage by the average sun peak hours in your location.

3. Estimating an Electric load(EEL)

- **Power calculation:** the total power or energy requirement that needs to design the PV system depends on your daily energy requirements and future energy requirements
- To determine the daily energy requirement, it's recommended to fill out the load sizing worksheet, considering the standard efficiency and voltage of Inverter and battery as presented in Table.1

Table. 1 Battery voltage and Inverter efficiency[2]

A	Inverter efficiency	0.88 to 0.98
B	Battery bus voltage	12V, 24V, 48V
C	Inverter AC Voltage	120V or 408 V

EEL Cont…..

Table. 2 the electric load datasheet

D= Rating of each Item (I). (W)	**I.1 I. 2 I.3 I.4……………………………………………..I.n**		
E=Adjustment factor(A.F)	A.F=1 for DC item	A.F=A for AC	<=1
F_i=Adjusted rating of each appliance	D/E		In watt
G= operating time of each item per day	Number of hours		Hrs.
H_i=Energy usage per day/item	F*G		Watt-hr.
I=total energy in Watt-hours	Summation of the total item energy in Watt-hour s= sum(Hi), i=1…..n		Watt-hr.
J= Total Amp-hr./day	I/B		Amp-hr
K= Maximum AC power requiring	Sum (Fi), i=1…..n(for AC only)		Watt
L= Maximum DC power requiring	Sum (Fi), i=1…..n(for DC only)		Watt
M= total Power	K+L		Watt

EEL Cont.….

Battery Rating/sizing

The battery capacity required depends on the following:

a. Desired days of storage to meet system loads with no recharge from PV

b. Maximum allowable depth-of-discharge

c. Temperature and discharge rates

d. System losses and efficiencies

e. The system voltage defines the number of series-connected battery cells required.

f. The number of parallel battery strings required

Cont.….

Table 3. Standard worksheet for Battery Sizing is given by:

Items	Parameters	Required values	Description
B.1	Day of storage	Days	It is required to provide power (3-5 days is recommended)
B.2	Depth discharge	0.8	Maximum fraction of capacity that can be withdrawn from battery
B.3	Required Battery capacity (A-hrs.)	(J*B.1)/B.2	It is the product of total A-hrs per day and day of autonomy per depth of discharge
B.4	Amp-hr. capacity of selected battery	Select the battery type	The battery cell can be selected from different manufacturer

EEL Cont.….

B.5	**Number of battery in Parallel**	**B.3/B.4**	**The sum of batter in parallel =total amp-hr**
B.6	Battery in series	B/selected battery Volt.	Batteries achieve maximum required voltage by connecting N-Batteries -radial
B.7	Total number of Batteries	B.5*B.6	Parallel battery *series Batteries
B.8	Total Amp-hr. capacity	B.4*B.6	Battery Amp-hr. capacity

Cont.….

C. PV Array Sizing

Solar array size is determined by the following parameters:

a. The PV array for stand-alone systems is sized to meet the average daily load during the critical design month.

b. Solar insolation received in the site

c. System losses, soiling and higher operating temperatures are factored in estimating array output.

EEL Cont…..

d. Characteristics of the PV modules

e. The system voltage determines the number of series-connected modules required per source circuit

f. The system power and energy requirements determine the total number of parallel source circuits required

g. Then, knowing the requirements of the load and the output of a single module, the array can be size

h. Higher system availability can be achieved by increasing the size of the PV array and/or battery

EEL Cont.….

Table 4. The Sample Worksheet for PV Array sizing

Item	Parameter	Value	Description
C1	Total energy demand per day(watt-hrs.)	I	The energy demand per hour (watt-hrs.)
C2	Battery round trip efficiency	0.7-0.85	Use 0.85 if selected battery is efficient
C3	Required solar array output power	C1/C2	Divide the total energy demand per day by the battery trip efficiency
C4	Select the PV module max- power voltage at stc(Volt)	P_{max}*0.85	Which is determined from the manufacturer data sheet
C5	PV guaranteed output power	Refer manufacturer data	Refer the manufacturer data sheet based on the module type selected

EEL Cont…..

C6	Peak-sun hour at designed tilt for designed months	Hours	It's a peak sun hour at optimal tilt. Normally determined from the solar radiation data of a given location based on the average-day of lowest month
C7	Energy output per module per day	C5*C6	The energy determined per-array for worst months
C8	Module energy output at operating temperature (watt-hrs.)	DF*C7	Consider the effect of constraints. It's different for hot and cold days . 0.8 for hot and critical, whereas 0.9 is considered for moderate
C9	Number of module required for required energy	C3/C8	Divide the required power per day by the module energy o/p

EEL Cont…..

C10	Number of module required per string	B/C4	Divide the battery bus voltage by the module operating voltage
C11	Number of sting required in parallel	C9/C10	Refer the manufacturer data sheet based on the module type selected
C12	Number of module to be purchased	C10*C11	It's a peak sun hour at optimal tilt. Normally determined from the solar radiation data of a given location
C13	Nominal rated PV O/P power	Manufacturer data	Select your PV type
C14	Nominal array output power	C12*C13	

Cont…..

D. Sizing the Charge Controller:

- The function of a charge controller is to regulate the charge going into your batteries bank from your solar array and prevent overcharging and reverse current flow at the night.
- Most used charge controllers are Pulse width modulation (PWM) or Maximum power point tracking (MPPT)
- The voltage at which PV module can produce maximum power is called maximum power point (or peak power voltage).
- Maximum power varies with solar radiation, ambient temperature and solar cell temperature.
- Typical PV module produces power with maximum power voltage of around 17V when measured at a cell temperature of 25°C, it can drop to around 15V on a very hot day and it can also rise to 18V on a very cold day

EEL Cont…..

- MPPT solar charge controller allows users to use PV module with a higher voltage output than the operating voltage of battery system.
- If PV module has to be placed far away from charge controller and battery, its wire size must be very large to reduce voltage drop.
- With a MPPT solar charge controller, users can wire PV module for 12,24 or 48 V and bring power into 12, 24 V or 48 V battery system.
- Which reduces the wire size needed while retaining full output of PV module.
- The charge controller current input rating is equal to the product of the short circuit current of the PV module, number of PV modules in parallel, and safety factor, where safety factor, normally 1.25.

$$I_{c(cont)} = 1.25 * (N_{PV(par)} * I_{sc}) \qquad \text{eqn.(1)}$$

EEL Cont.….

e. Selecting an Inverter sizing

- It is required to convert direct current to alternating current based on the demand.
- Stand-alone inverters are typically voltage-specific, the inverter must have the same nominal voltage as your battery
- The input rating of the inverter should never be lower than the total watt required power, inverter capacity > P_t
- The input rating of the inverter should be ideally 25-30% more than the rated wattage of your appliances
- Then, you can select the inverter specifications from manufacturing data

Cont.….

f. Cable Sizing

- It is required to estimate the size and the type of wire that needs to connect;
- between PV modules and Batteries
- between the Battery Bank and the Inverter
- between the Inverter and Load. The equation needs to determine the size is given by:

$$A = \frac{2 * \rho * L * I}{V_d} \qquad \text{eqn.(2)}$$

The voltage V_d is typically:

a. For cabling between PV modules and Batteries = 12V, 24 V or 48V

b. For cabling between the Battery Bank and the Inverter = 12V, 24V or 48V

c. For cabling between the Inverter and Load is equivalent to the load voltage

4. Software's used for PV/RE simulation

- There are many software's that have been used for optimal renewable energy, generation, operation and control , and hence its integration to the Grid.

Some of commonly used software's are :

1. HOMER Micro grid and Hybrid Power Modeling Software

2. PSAT

3. Windographar

4. Renewable Resource Assessment Platform

5. Data Management Dashboard

Software's Cont.…
4.1 HOMER optimization

- HOMER[3] the micro-power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications.

When you design a power system, you must make many decisions about the configuration of the system:

- What components does it make sense to include in the system design?
- How many and what size of each component should you use?
- The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult.

Software's Cont.…

- HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.
- To use HOMER, **you provide the model with inputs**, which describe technology options, component costs, and resource availability

How does HOMER work?

- Simulation
- Optimization
- Sensitivity analysis . The steps are:

Step one: Formulate a question that HOMER can help answer

- HOMER can answer a wide range of questions about the design of small power systems.

Software's Cont.…

- It is useful to have a clear idea of a question that you want HOMER to answer before you begin working with HOMER.

kinds of questions that HOMER can answer are:

- Is it cost-effective to add a wind turbine to the diesel generator in my system?
- How much will the cost of diesel fuel need to increase to make photovoltaic cost effective?
- Will my design meet a growing electric demand?
- Is it cost-effective to install a system to produce electricity and heat for my grid-connected system?

Software's Cont.…

How does new model work

Steps to do new model are:

1. install the HOMER software using installation guideline

2. open the software after installation

3. go to file and open new model

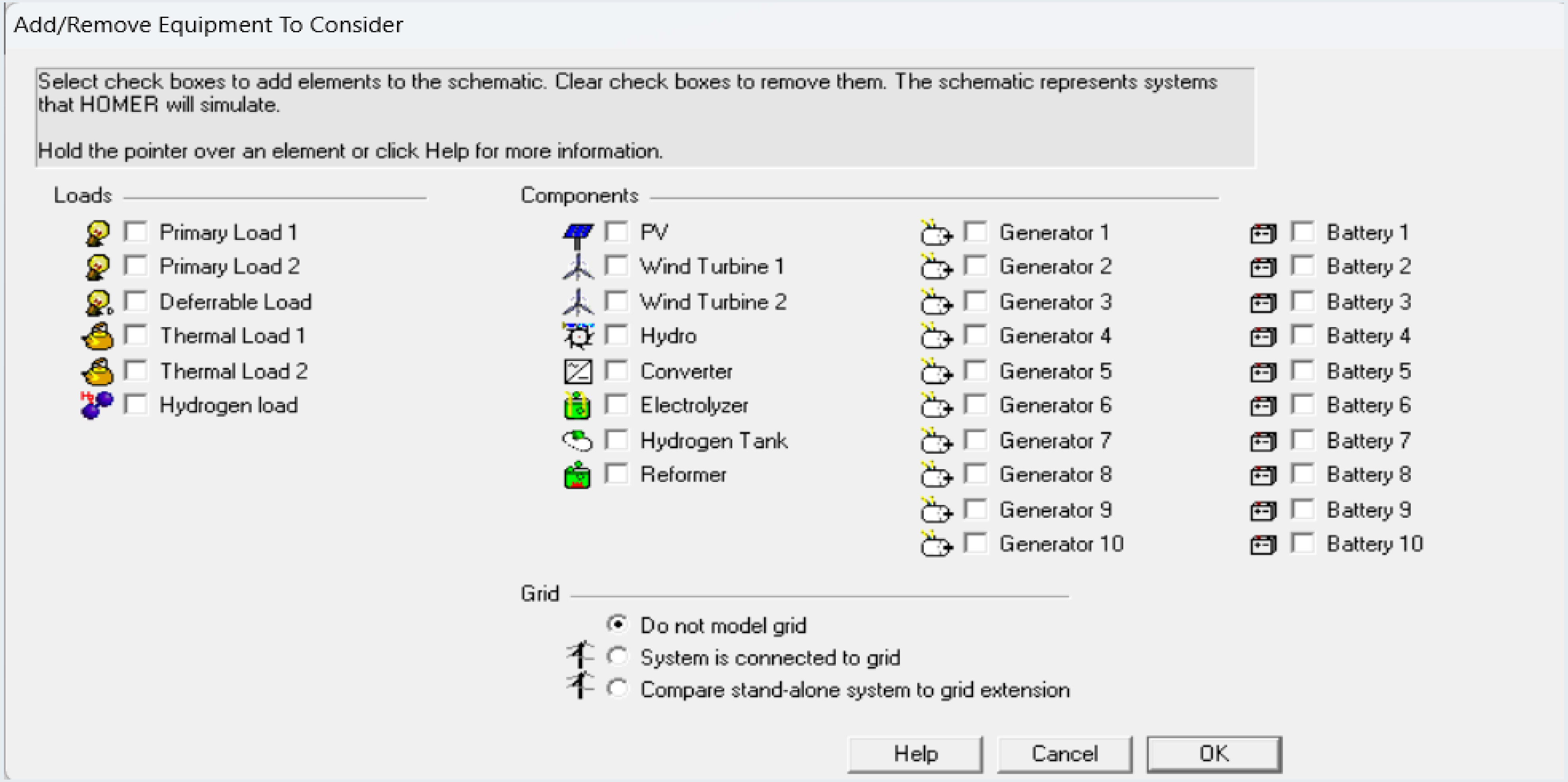
4. Click Add/remove

5. Select the component and loads based on the design , which is given in Fig.1

6. select the don’t model the grid for off-grid system and select the system with grid connected system for grid integration

7. Then, select compare the stand alone with grid extension for comparing tow systems

Software's Cont.…



Add/Remove Equipment To Consider

Select check boxes to add elements to the schematic. Clear check boxes to remove them. The schematic represents systems that HOMER will simulate.

Hold the pointer over an element or click Help for more information.

Loads

- ☐ Primary Load 1
- ☐ Primary Load 2
- ☐ Deferrable Load
- ☐ Thermal Load 1
- ☐ Thermal Load 2
- ☐ Hydrogen load

Components

- ☐ PV
- ☐ Wind Turbine 1
- ☐ Wind Turbine 2
- ☐ Hydro
- ☐ Converter
- ☐ Electrolyzer
- ☐ Hydrogen Tank
- ☐ Reformer

- ☐ Generator 1
- ☐ Generator 2
- ☐ Generator 3
- ☐ Generator 4
- ☐ Generator 5
- ☐ Generator 6
- ☐ Generator 7
- ☐ Generator 8
- ☐ Generator 9
- ☐ Generator 10

- ☐ Battery 1
- ☐ Battery 2
- ☐ Battery 3
- ☐ Battery 4
- ☐ Battery 5
- ☐ Battery 6
- ☐ Battery 7
- ☐ Battery 8
- ☐ Battery 9
- ☐ Battery 10

Grid

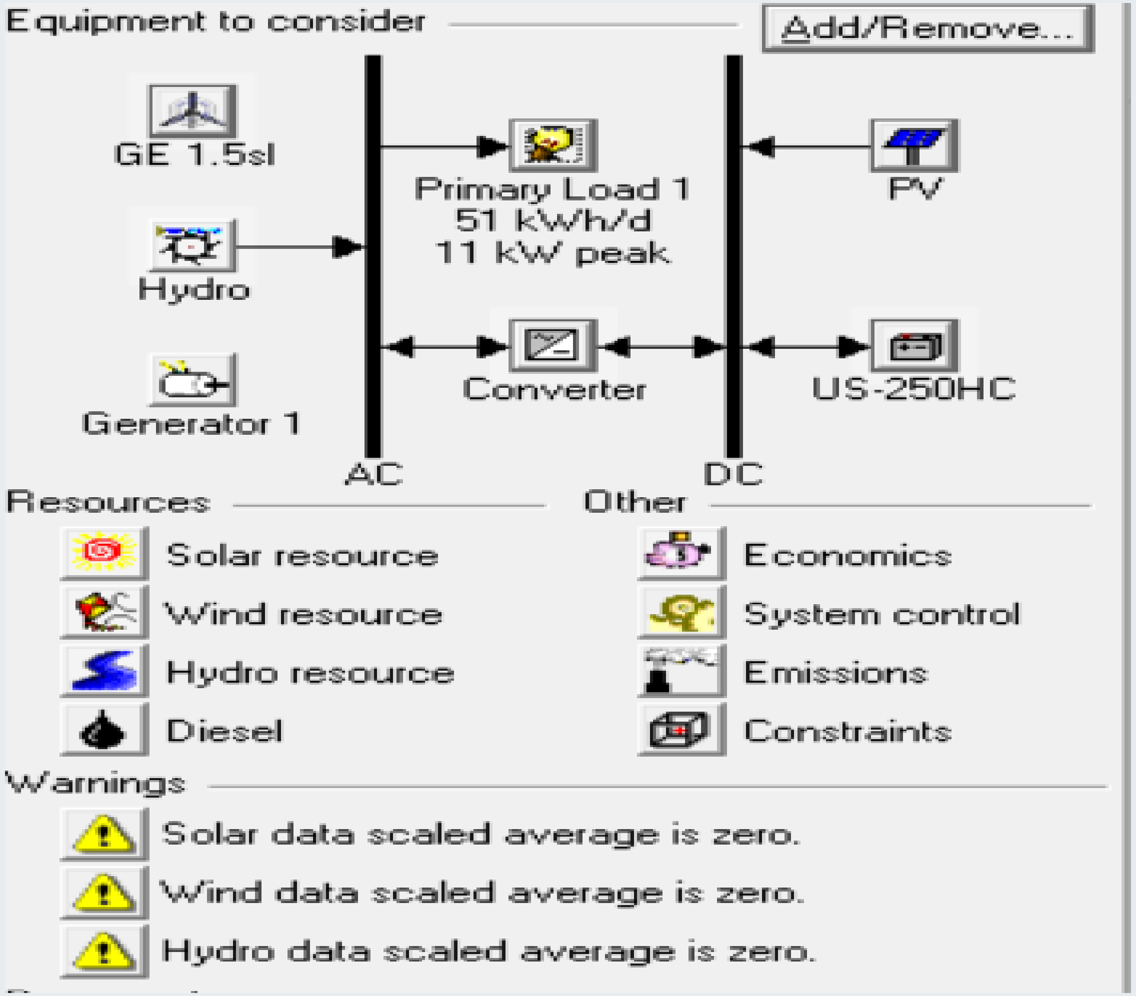
- ● Do not model grid
- ○ System is connected to grid
- ○ Compare stand-alone system to grid extension

Figure 1. Developing the new model using HOMER software

Software's Cont.…

- Then, select the types of wind turbine, solar PV , hydro-turbine etc by clicking each parameter.
- Insert resources : Solar, wind, Hydro, and others
- Provide other necessary data based on your system model and you will get the sample model as given in Fig.2.
- Then, you will get the sample results in Fig.3 while clicking the calculate

Software's Cont.…



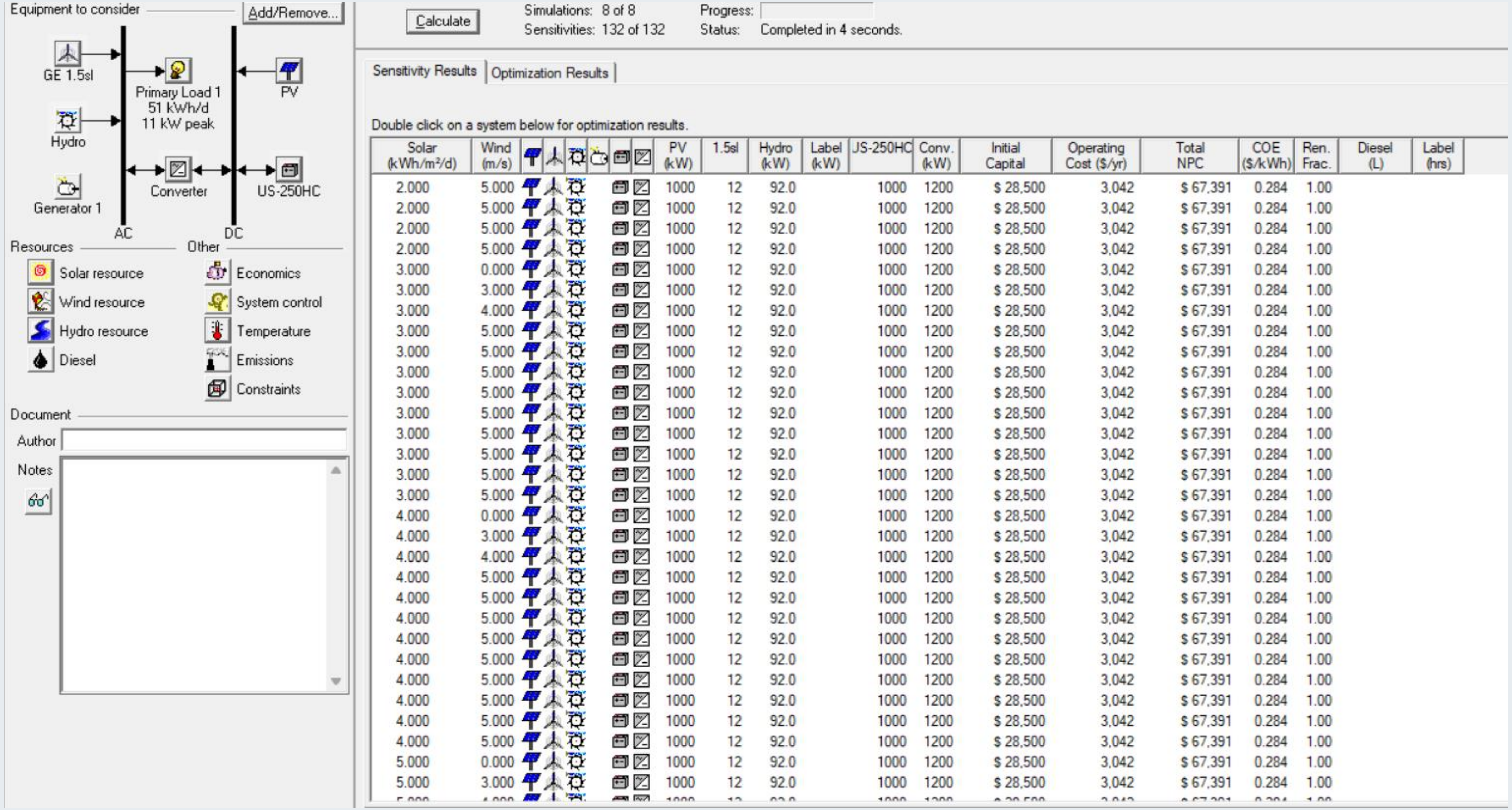
Solar data scaled average is zero.

Wind data scaled average is zero.

Hydro data scaled average is zero.

Figure 2. Sample Off-grid RE model using HOMER

Software's Cont….



Simulations: 8 of 8
Sensitivities: 132 of 132
Progress:
Status: Completed in 4 seconds.

Double click on a system below for optimization results.

Solar (kWh/m²/d)	Wind (m/s)							PV (kW)	1.5sl	Hydro (kW)	Label (kW)	JS-250HC	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
2.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
2.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
2.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
2.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
3.000	0.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
3.000	3.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
3.000	4.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
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3.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
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4.000	0.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
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4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
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4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
4.000	5.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
5.000	0.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		
5.000	3.000	✓	✓	✓		✓	✓	1000	12	92.0		1000	1200	$ 28,500	3,042	$ 67,391	0.284	1.00		

Figure 3. Sample results using HOMER software

5. Design Project Example

1. Assume University K is constructing three big hostels that aims to accommodate the postgraduate students so that they can only concentrate on their education while living in the proposed hostels. The load data per hostel is given in **Appendix A.** As an Energy engineer, the University needs you to design the required system from the off-grid and grid connected PV energy systems. Accordingly;

A. Design the off-grid solar photovoltaic system that needs to satisfy the required demand using: **hand-calculation and Homer optimization software**. Then, compare the results and give your engineering conclusion. NB: you are recommended to extract the solar resource data from NASA, IAEA, World Bank or other necessary data resource sites.

Design Project Cont.…

b. Design the optimal Grid connected PV systems with all necessary components. Extract the results, discus it and compare it with the results extracted in case-a.

Hint: For hand calculation use the following steps:

Estimate the Electric Load

1. Compute the total connected watts for both AC and DC.
2. Compute the Average Daily Load for Both AC and DC
3. Compute the Total AC connected watts.
4. Specify an Inverter to supply the AC Total connected watts.

Design Project Cont.…

Battery Sizing

5. Establish the Inverter Losses.

6. Divide the AC Average Daily Load by the Inverter efficiency.

7. Add the result in 6 to the DC Average Daily Load.

8. Divide the result in 7 by system voltage to get ‘Average Amp-hr. day load’.

9. Divide the result in 8 by the Days of Autonomy.

10. Divide the result In 9 to get the’ Total Amp Hour Capacity’ of the System.

11. Specify a battery and divide the Total Connected watts by the battery’s rated its Amp-hour to get the Batteries needed to be connected in Parallel.

Design Project Cont.…

12. Divide the DC system voltage by the battery voltage to get the batteries wired in series.

13. Take the product of 11 and 12 to get the total number of batteries needed.

Array Sizing

14. Establish the battery energy efficiency.

15. Divide the Amp hour day Load by the battery efficiency.

16. Divide the result in (15) by the ’Peak Sun Hours’ to get ‘Total Array Peak Amps’.

Design Project Cont.…

17. Specify a module and divide the Array peak amps by the Peak amps produced by each module to get the Modules needed in parallel.

18. Divide the Dc system voltage by the nominal module voltage to get the Modules in Series.

19. Multiply the results of 17 and 18 to get the total number of modules.

Specifying a Controller

20. Multiply the module short circuit current by the total number of module to get the minimum Amp rating for the Charge Controller.

6. Solution of the Design Project

A. solution of Hand-calculation:

Steps from 1-20 are used to come up with the hand calculation design. Then, the result is given in Table 5.

Table 5. Electrical load estimation results

	A	**Inverter efficiency**				**0.85**
	B	Battery bus voltage				24
	C	Inverter AC voltage				120
No.	Appliance	Unit (Watt)	Adjustment factor	Adjusted power	usage (hr.)	Energy usage /day/item
1	Coffee pot	200	0.85	235.29	0.25	58.82
2	coffee maker	800	0.85	941.18	0.25	235.29
3	Toaster	1150	0.85	1352.94	0.25	338.24
4	Blender	300	0.85	352.94	0.15	52.94

Load Estimation Result Cont.…

No.	Appliance	Unit (Watt)	Adjustment factor	Adjusted power	usage (hr.)	Energy usage /day/item
5	Microwave	1050	0.85	1235.29	0.3	370.59
6	hot plate	1200	0.85	1411.76	0.3	423.53
7	washing machine automatic	500	0.85	588.24	0.25	147.06
8	washing machine manual	300	0.85	352.94	0.25	88.24
9	vacuume cleaner upright	450	0.85	529.41	0.25	132.35
10	vacuume cleaner hand	100	0.85	117.65	0.25	29.41
11	sewing machine	100	0.85	117.65	0.25	29.41

Load estimation Result Cont….

12	**Iron**	**1000**	**0.85**	**1176.47**	**0.25**	**294.12**
13	Clothes dryer electric	400	0.85	470.59	0.25	117.65
14	water pump	375	0.85	441.18	0.25	110.29
15	cealing fan	30	0.85	35.29	0.25	8.82
16	table fan	17.5	0.85	20.59	0.25	5.15
17	Electric blanket	200	0.85	235.29	0.25	58.82
18	Blow dryer	1000	0.85	1176.47	0.25	294.12

Load estimation Result Cont.…

19	**Shaver**	**15**	**0.85**	**17.65**	**0.15**	**2.65**
20	Computer Laptop	35	0.85	41.18	5	205.88
21	Computer Pc	115	0.85	135.29	5	676.47
22	Computer Printer	100	0.85	117.65	0.25	29.41
23	Typewriter	140	0.85	164.71	0.3	49.41
24	TV 25'' Color	150	0.85	176.47	4	705.88
25	TV19'' Color	70	0.85	82.35	4	329.41

Load estimation Result Cont….

26	1 TV 2" B&W	20	0.85	23.53	4	94.12
27	VCR	40	0.85	47.06	0.2	9.41
28	Clock Radio	1	0.85	1.18	0.3	0.35
29	Sateliite Dish	30	0.85	35.29	2	70.59
30	CB Radio	5	0.85	5.88	0.3	1.76
31	Electric Clock	3	0.85	3.53	24	84.71
32	Light : 100w Incadescent	100	0.85	117.65	4	470.59

Load estimation Result Cont.…

33	**Light : 25w Compact Florescent**	**28**	**0.85**	**32.94**	**4**	**131.76**
34	Light : 50w Dc Incandescent	50	1	50.00	4	200.00
35	Light : 40w Dc Halogen	40	1	40.00	4	160.00
36	Light : 20w Compact Florescent	22	0.85	25.88	4	103.53
37	Compact Florescent Incandescent 40w equivalent	11	0.85	12.94	4	51.76
38	Compact Florescent Incandescent 60w equivalent	16	0.85	18.82	4	75.29
39	Compact Florescent Incandescent 75w equivalent	20	0.85	23.53	4	94.12
40	Compact Florescent Incandescent 100w equivalent	30	0.85	35.29	4	141.18

Load estimation Result Cont.…

41	**1/4" Drill**	**250**	**0.85**	**294.12**	**4**	**1176.47**
42	1/2" Drill	750	0.85	882.35	4	3529.41
43	1" Drill	1000	0.85	1176.47	0.5	588.24
44	9" Disc Sander	1200	0.85	1411.76	0.5	705.88
45	3" Belt Sander	1000	0.85	1176.47	0.5	588.24
46	12" Chain Saw	1100	0.85	1294.12	0.5	647.06
47	14" Band Saw	1100	0.85	1294.12	0.5	647.06
48	7-1/4" circular Saw	900	0.85	1058.82	0.5	529.41
49	8-1/4" circullar Saw	1400	0.85	1647.06	0.5	823.53

Load estimation Result Cont.…

50	**Refrigerator/Freezer 20cf 1.8Kwh per day**	**540**	**0.85**	**635.29**	**15**	**9529.41**
51	Refregerator/Freezer 16cf 1 .6Kwh per day	475	0.85	558.82	13	7264.71
52	Sun frost 16cf Dc	112	1	112.00	7	784.00
53	Sun frost 12cf Dc	70	1	70.00	7	490.00
54	Freezer 14cf	440	0.85	517.65	15	7764.71
55	Freezer 14cf	350	0.85	411.76	14	5764.71
56	Sun Frost-Freezer 19cf	112	0.85	131.76	10	1317.65

Load estimation Result Cont….

57	**Energy demand (W.hr./d)**	**Total energy demand per day**	**48633.62**
58	Amp-hr.	Total amp-hour demand per day	2026.40
59	AC- power(W)	Maximum Ac Power requiremen	20530.5
60	DC-power (W)	Maximum Dc Power requirement	182

Battery Sizing Result

Table 6. Battery sizing Results

Item	Parameters	Value
B.1	Day of storage desired/required(autonomy)	3 day
B.2	Allowable depth of discharge limit(decimal)	0.8
B.3	Required battery capacity(amp-hour)	(Amp.hr*B.1)/B.2=(2026.40*3)/0.8= 17731.00
B.4	Amp-hour capacity of selected battery	478
B.5	Number of battery in parallel	B.3/B.4=37
B.6	Number of battery in series	B(Buttery bus voltage)/selected battery voltage=24/12=2
B.7	Total number of battery	B.5*B.6=37*2=74
B.8	Total battery amp-hour capacity	B.5*B.4=478*37=17686

PV Array Sizing Result

Table 7. PV array sizing Results

Item	Parameter	value
C.1	Total energy demand per day(w/day)	48633.62
C.2	Battery round trip efficiency	0.85
C.3	Required array output per day(Amp-hr.)	C.1/C.2=57216.02
C.4	Selected PV module Max power voltage at STC(V)	Vmax*0.85=14.8
C.5	Selected Pv module max guaranteed power output at STC(watt)	53*.9= 47.7
C.6	Peek sun hours at design tilt fo design month	3.62
C.7	Energy output per module per day (watt-hour)	C.5*C.6=173

PV Array Sizing Result Cont……

C.8	**Module energy output at operating temperature(watt-hour)**	**DF*C.7=156**
C.9	Number of modules required to meet energy requirements(module)	C3/C8=366.769
C.10	Number of modules required per string rounded to the next highest integer	B/C.4=2
C.11	Number of strings in parallel rounded to the next higher integer	C.9/C.10=226.17
C.12	Number of module to be purchased	C.10*C11=358
C.13	Nominal rated PV module output(watt)	53
C.14	Nominal rated array output(watt)	C.12*C.13=18874

Summery of Hand calculation results

Step 1 :- Electrical load	Value
• Total energy demand per day	= 48633.62 Wh
• Total amp-hour demand per day	= 2026.40 Ah
• Maximum Ac Power requirement	= 20530.5w
• Maximum Dc Power requirement	=182w
• Total power per day	= 20712.5w
Step 2 :- Battery Selection	
• Total required battery capacity	= 17686Ah
• Number of battery	= 74
Step 3:- Solar panel selection	
• Power required from solar panel	= 18874w
• Number of solar panel required	= 358
• Nominal module rating	=53 W
Step 4:- Inverter selection	
• Total power required per day	= 20712.5w
• The required inverter power	= (Total power required per day * safety factor)/(inverter efficiency) = 20712.5*1.25/0.85 = 30,459.55 W Approximate 30.5KW
Step 5:- Charger Controller Selection Charge controller current	= (total solar panel power)/(Battery bank voltage) = 18874/24 = 786 A

A.2 Homer Optimization Design(HOD)

- Here, the calculated data are used as an input for HOMER optimization and Addis Ababa, Ethiopia is considered to extract the solar resource data extraction, which is an input for solar PV panel.

The solar radiation data of Addis Ababa, Ethiopia is given by:

- Project: Addis Ababa, Ethiopia
- Geographical coordinates: 9.035829°, 38.752413° (09°02'09", 038°45'09")
- Generated by: Global Solar Atlas

Map link https://globalsolaratlas.info/map?s=9.035829,38.752413,10

- Accordingly, the solar radiation data of Addis Ababa (A.A) is presented in Table 8

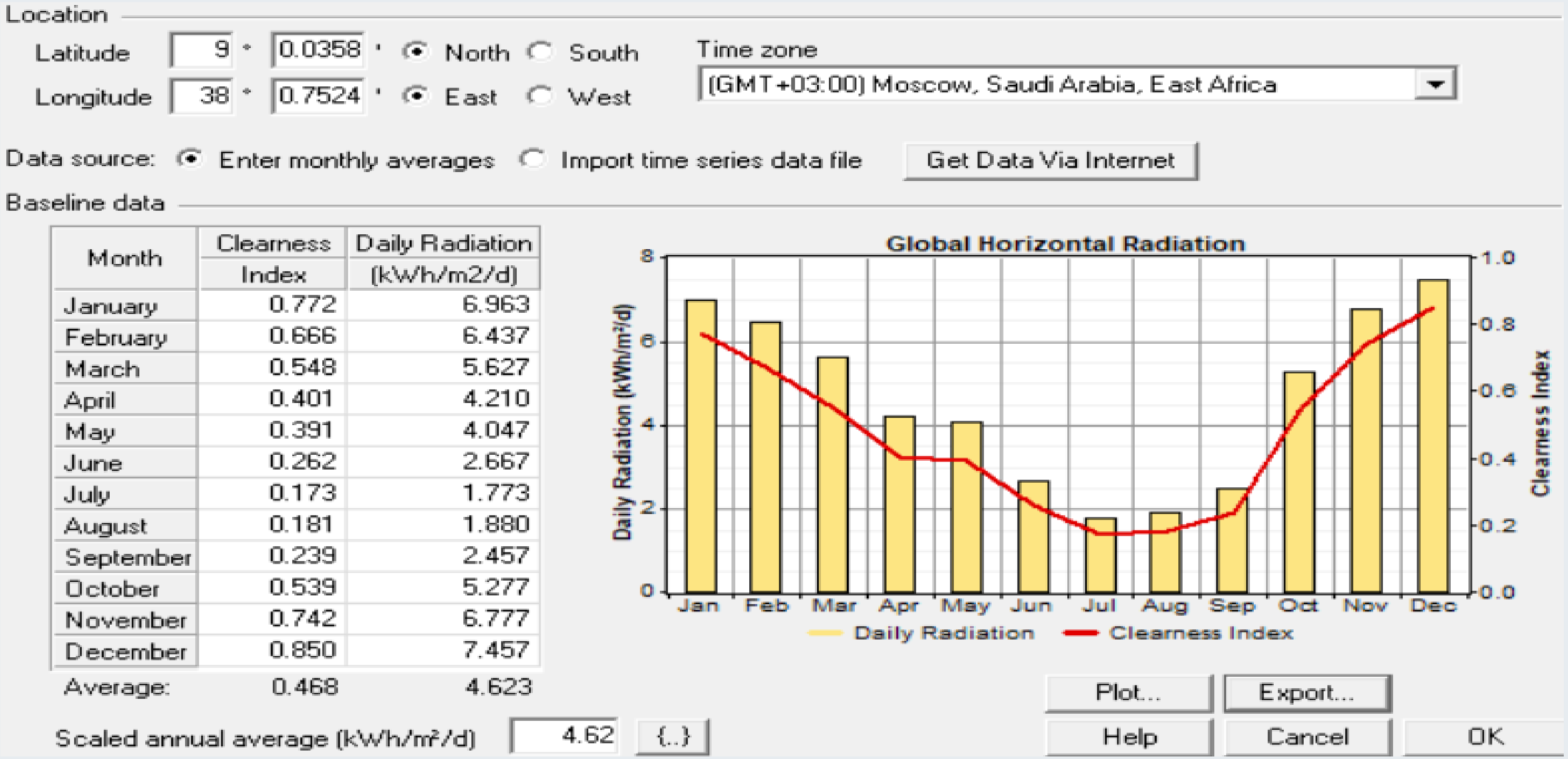
HOD Cont.….

Table 8: Monthly and Daily energy solar irradiation data of A.A

Months	Monthly data energy (kWh/m²)	Daily data energy (kWh/m²)
Jan	208.9	6.96
Feb	193.1	6.44
Mar	168.8	5.67
Apr	126.3	4.21
May	121.4	4.05
Jun	80	2.67
Jul	53.2	1.77
Aug	56.4	1.88
Sep	73.7	2.46
Oct	158.3	5.28
Nov	203.3	6.78
Dec	223.7	7.46

HOD Cont…..

- The daily radiation in kwh/m2.day for A.A using the radiation and coordinate data presented above is given in Fig.4



Location

Latitude 9 ° 0.0358 ' ● North ○ South

Longitude 38 ° 0.7524 ' ● East ○ West

Time zone: (GMT+03:00) Moscow, Saudi Arabia, East Africa

Data source: ● Enter monthly averages ○ Import time series data file

Baseline data

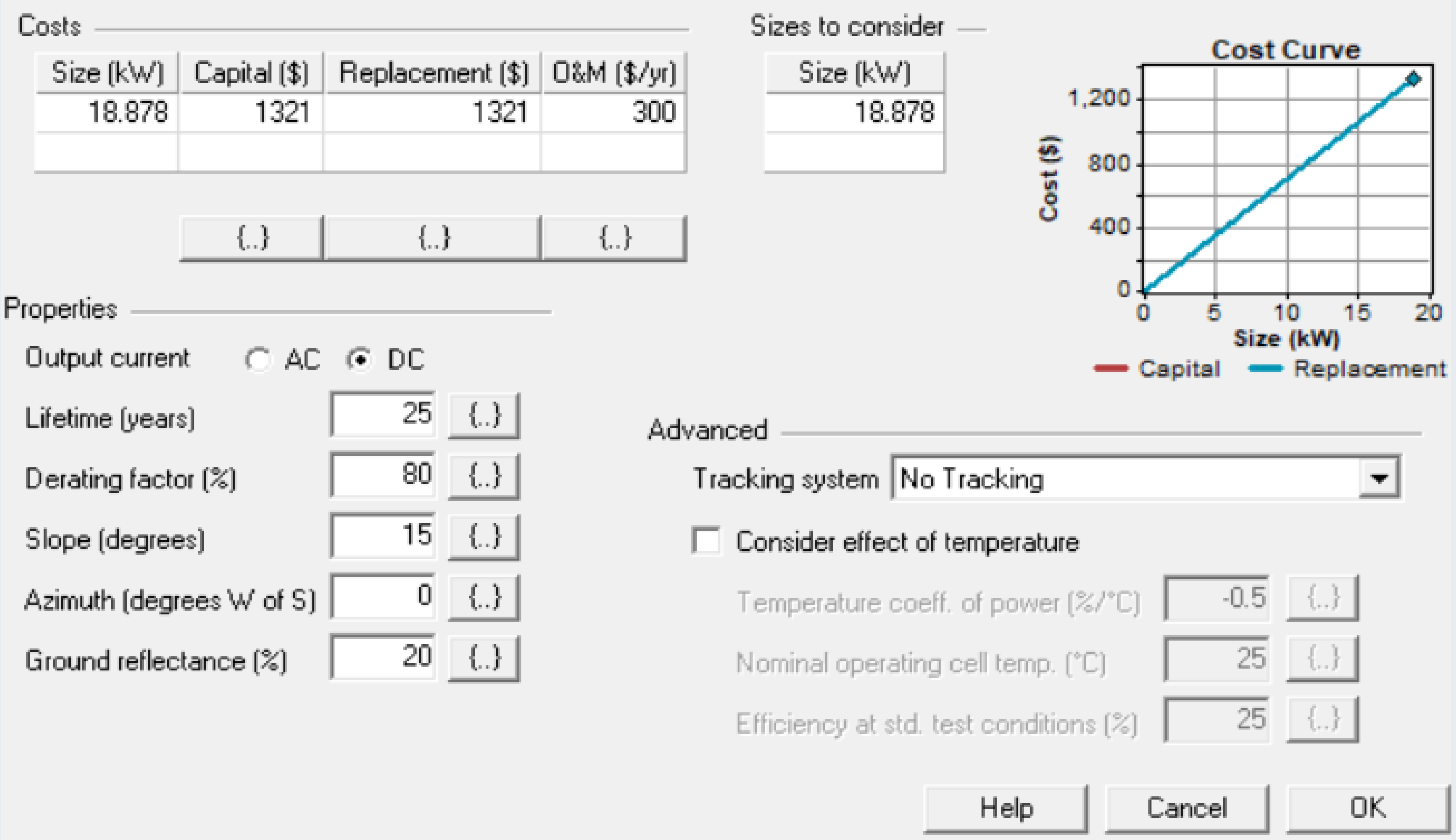
Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.772	6.963
February	0.666	6.437
March	0.548	5.627
April	0.401	4.210
May	0.391	4.047
June	0.262	2.667
July	0.173	1.773
August	0.181	1.880
September	0.239	2.457
October	0.539	5.277
November	0.742	6.777
December	0.850	7.457
Average:	0.468	4.623

Scaled annual average (kWh/m²/d) 4.62

Figure 4. The daily radiation in kwh/m2/day of A.A with cleanness index

HOD Cont.….

- Therefore, the cost of designed maximum power for the required 18.878 kw is presented in Fig.5



Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
18.878	1321	1321	300

Sizes to consider

Size (kW)
18.878

Properties

Output current ○ AC ● DC

Lifetime (years)	25
Derating factor (%)	80
Slope (degrees)	15
Azimuth (degrees W of S)	0
Ground reflectance (%)	20

Advanced

Tracking system: No Tracking

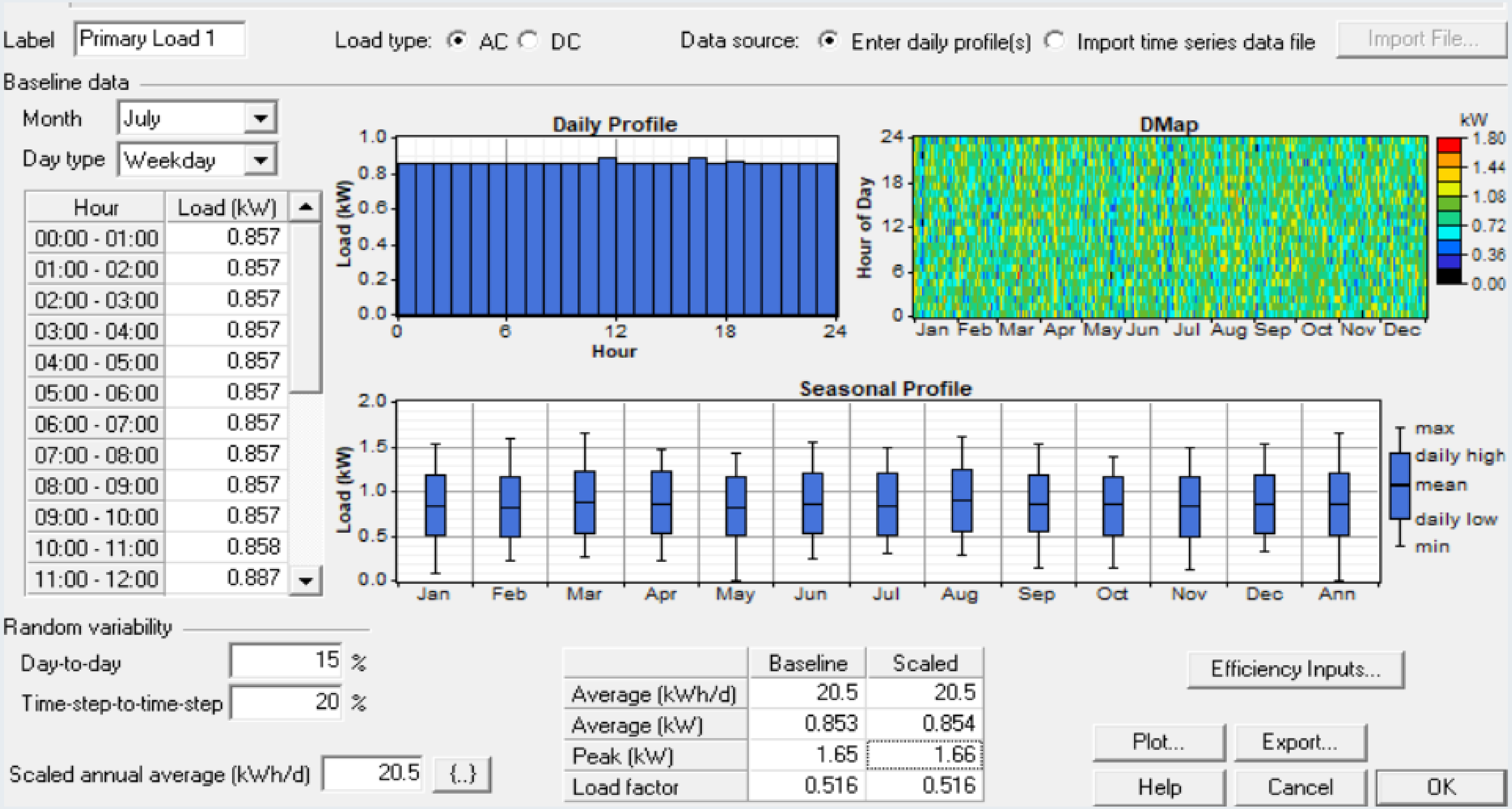
☐ Consider effect of temperature

Temperature coeff. of power (%/°C)	-0.5
Nominal operating cell temp. (°C)	25
Efficiency at std. test conditions (%)	25

Figure 5. The input data for PV cost for the required demand.

HOD Cont.….

The AC load input data based on the given input in kw/day is presented in Fig.6



Label: Primary Load 1

Load type: ● AC ○ DC

Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data

Month: July

Day type: Weekday

Hour	Load (kW)
00:00 - 01:00	0.857
01:00 - 02:00	0.857
02:00 - 03:00	0.857
03:00 - 04:00	0.857
04:00 - 05:00	0.857
05:00 - 06:00	0.857
06:00 - 07:00	0.857
07:00 - 08:00	0.857
08:00 - 09:00	0.857
09:00 - 10:00	0.857
10:00 - 11:00	0.858
11:00 - 12:00	0.887

Random variability

Day-to-day: 15 %

Time-step-to-time-step: 20 %

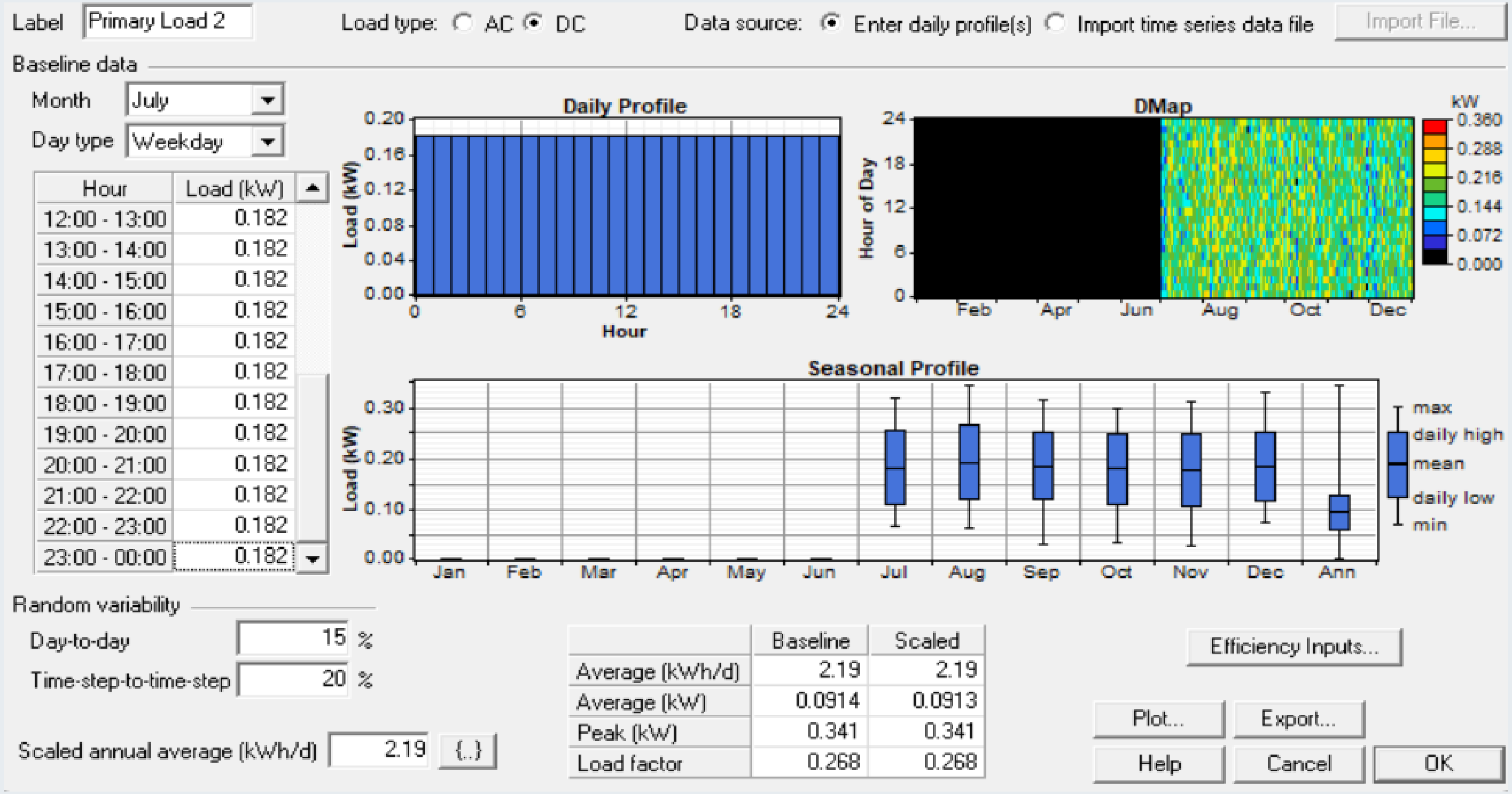
Scaled annual average (kWh/d): 20.5

	Baseline	Scaled
Average (kWh/d)	20.5	20.5
Average (kW)	0.853	0.854
Peak (kW)	1.65	1.66
Load factor	0.516	0.516

Figure 6. The AC load input data in kw/day

HOD Cont…..

The DC load input data based on the given input in kw/day is presented in Fig.7



Label: Primary Load 2

Load type: ○ AC ● DC

Data source: ● Enter daily profile(s) ○ Import time series data file

Baseline data

Month: July

Day type: Weekday

Hour	Load (kW)
12:00 - 13:00	0.182
13:00 - 14:00	0.182
14:00 - 15:00	0.182
15:00 - 16:00	0.182
16:00 - 17:00	0.182
17:00 - 18:00	0.182
18:00 - 19:00	0.182
19:00 - 20:00	0.182
20:00 - 21:00	0.182
21:00 - 22:00	0.182
22:00 - 23:00	0.182
23:00 - 00:00	0.182

Random variability

Day-to-day: 15 %

Time-step-to-time-step: 20 %

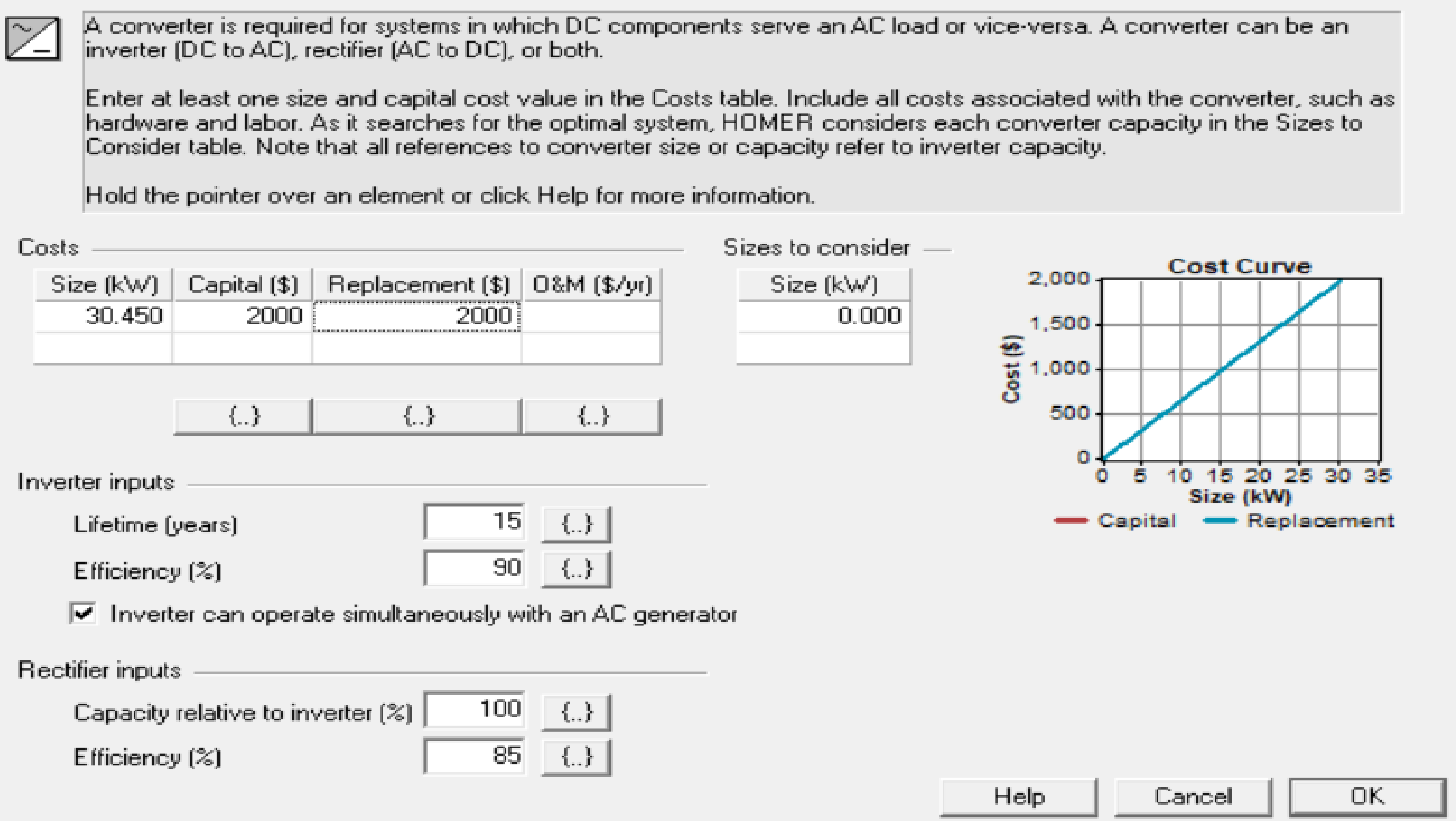
Scaled annual average (kWh/d): 2.19

	Baseline	Scaled
Average (kWh/d)	2.19	2.19
Average (kW)	0.0914	0.0913
Peak (kW)	0.341	0.341
Load factor	0.268	0.268

Figure 7. The DC load input data in kw/day

HOD Cont….

- Then, the converter cost data based on the rated capacity and market value is presented in Fig.8


A converter is required for systems in which DC components serve an AC load or vice-versa. A converter can be an inverter (DC to AC), rectifier (AC to DC), or both.

Enter at least one size and capital cost value in the Costs table. Include all costs associated with the converter, such as hardware and labor. As it searches for the optimal system, HOMER considers each converter capacity in the Sizes to Consider table. Note that all references to converter size or capacity refer to inverter capacity.

Hold the pointer over an element or click Help for more information.

Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
30.450	2000	2000	

Sizes to consider

Size (kW)
0.000

Inverter inputs

Lifetime (years) 15

Efficiency (%) 90

☑ Inverter can operate simultaneously with an AC generator

Rectifier inputs

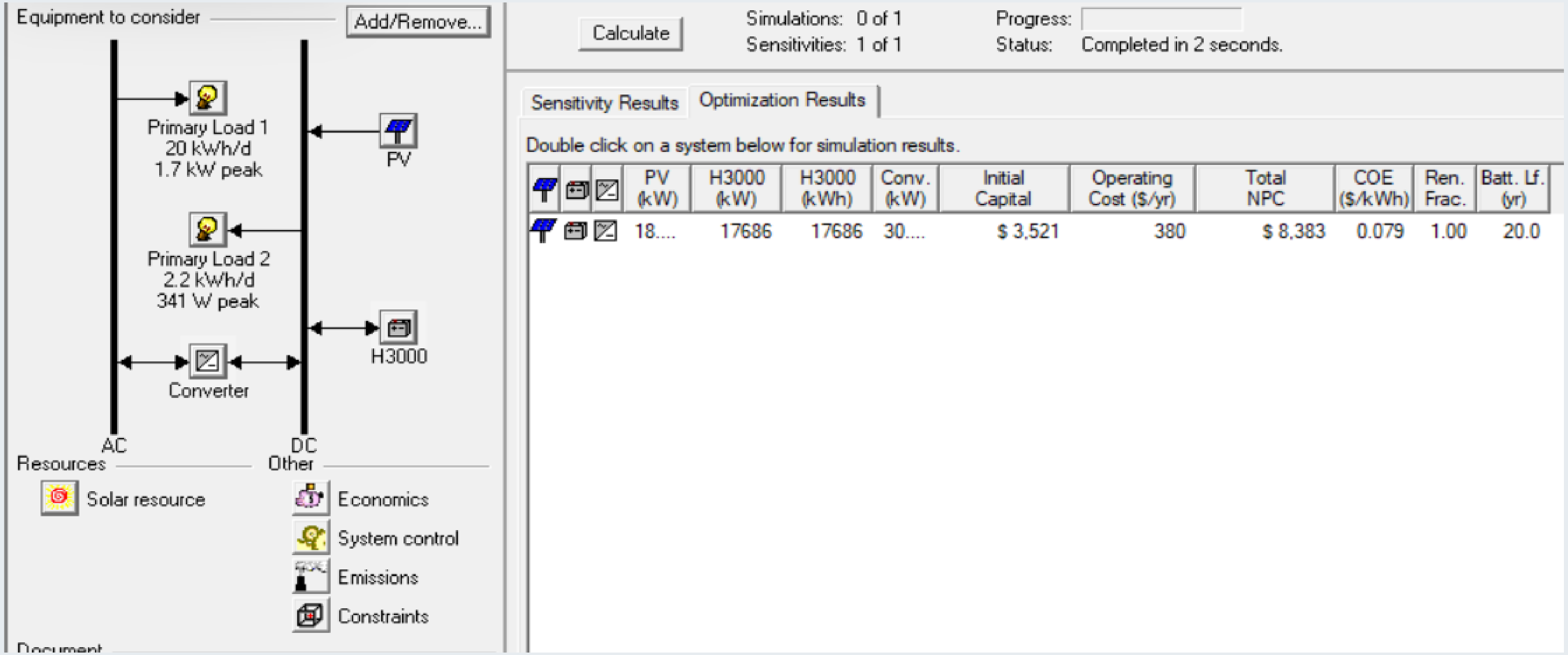
Capacity relative to inverter (%) 100

Efficiency (%) 85

Figure 8 The Converter rating and its cost in kw/day

HOD Cont.….

- Finally, the homer optimization overall model and results for initial estimation is given in Fig.9



Simulations: 0 of 1
Sensitivities: 1 of 1

Progress:
Status: Completed in 2 seconds.

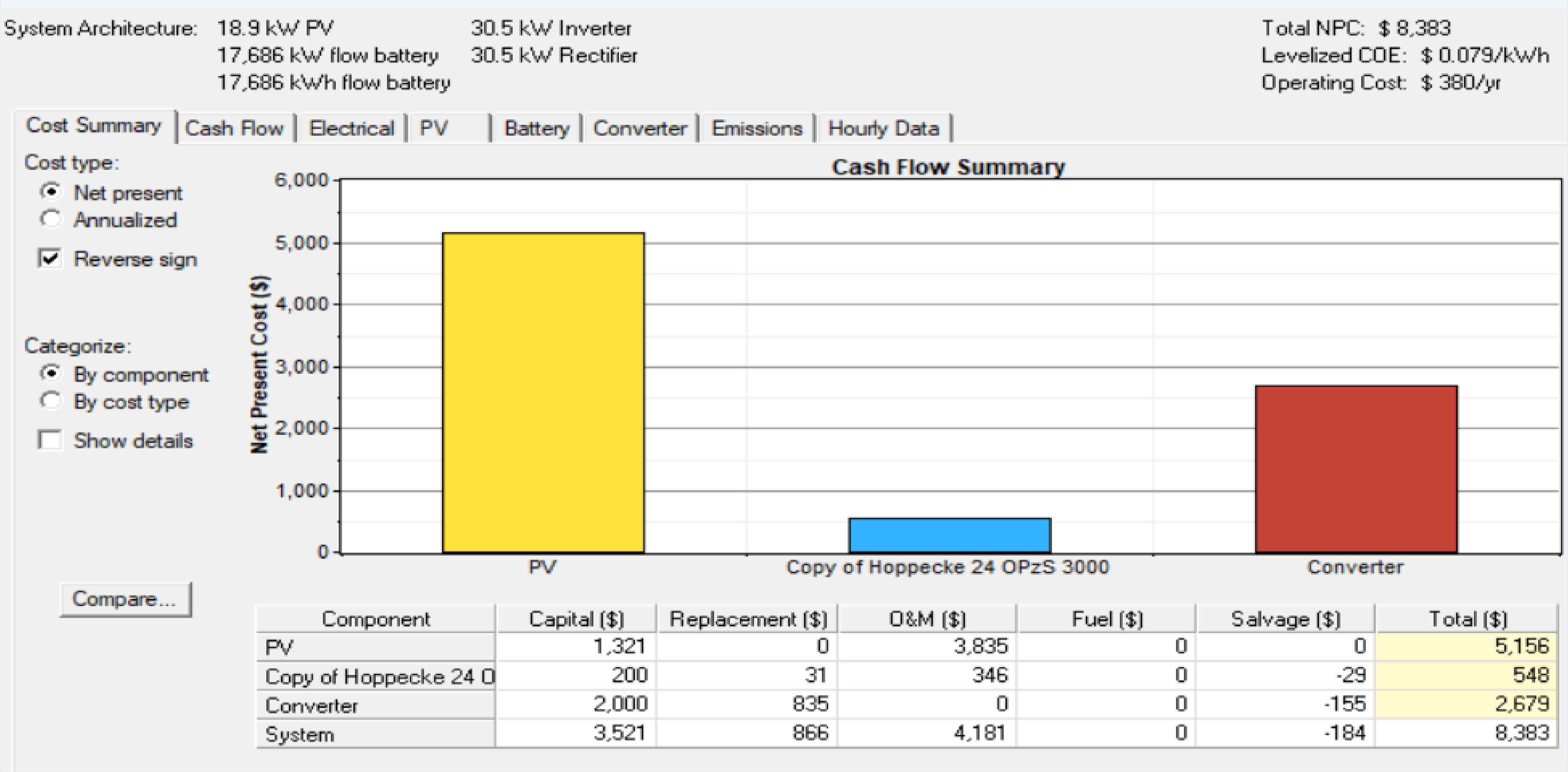
Double click on a system below for simulation results.

			PV (kW)	H3000 (kW)	H3000 (kWh)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
			18....	17686	17686	30....	$ 3,521	380	$ 8,383	0.079	1.00	20.0

Figure 9 The overall HOMER model and results for initial case

Homer optimization Solution(HOS)

a. Optimal Cost summary. The optimal cost summary is presented in Fig.10



System Architecture: 18.9 kW PV, 17,686 kW flow battery, 17,686 kWh flow battery, 30.5 kW Inverter, 30.5 kW Rectifier

Total NPC: $ 8,383
Levelized COE: $ 0.079/kWh
Operating Cost: $ 380/yr

Cost type:
● Net present
○ Annualized
☑ Reverse sign

Categorize:
● By component
○ By cost type
☐ Show details

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,321	0	3,835	0	0	5,156
Copy of Hoppecke 24 O	200	31	346	0	-29	548
Converter	2,000	835	0	0	-155	2,679
System	3,521	866	4,181	0	-184	8,383

Figure 10 Cost summary of Off-grid PV system

HOS Cont……

b. Cash flow summary of life span. The cash flow summary is presented in Fig.11

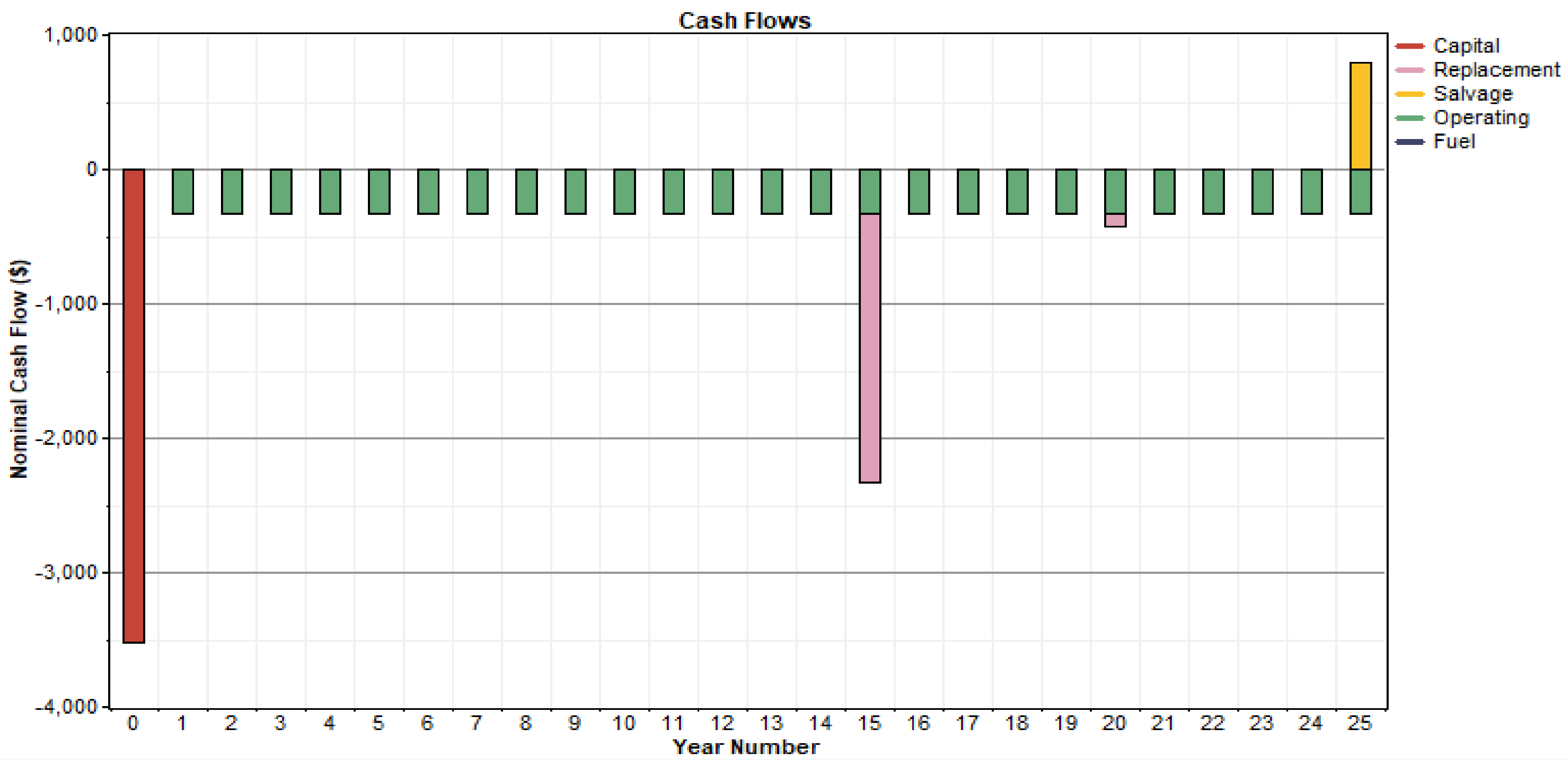
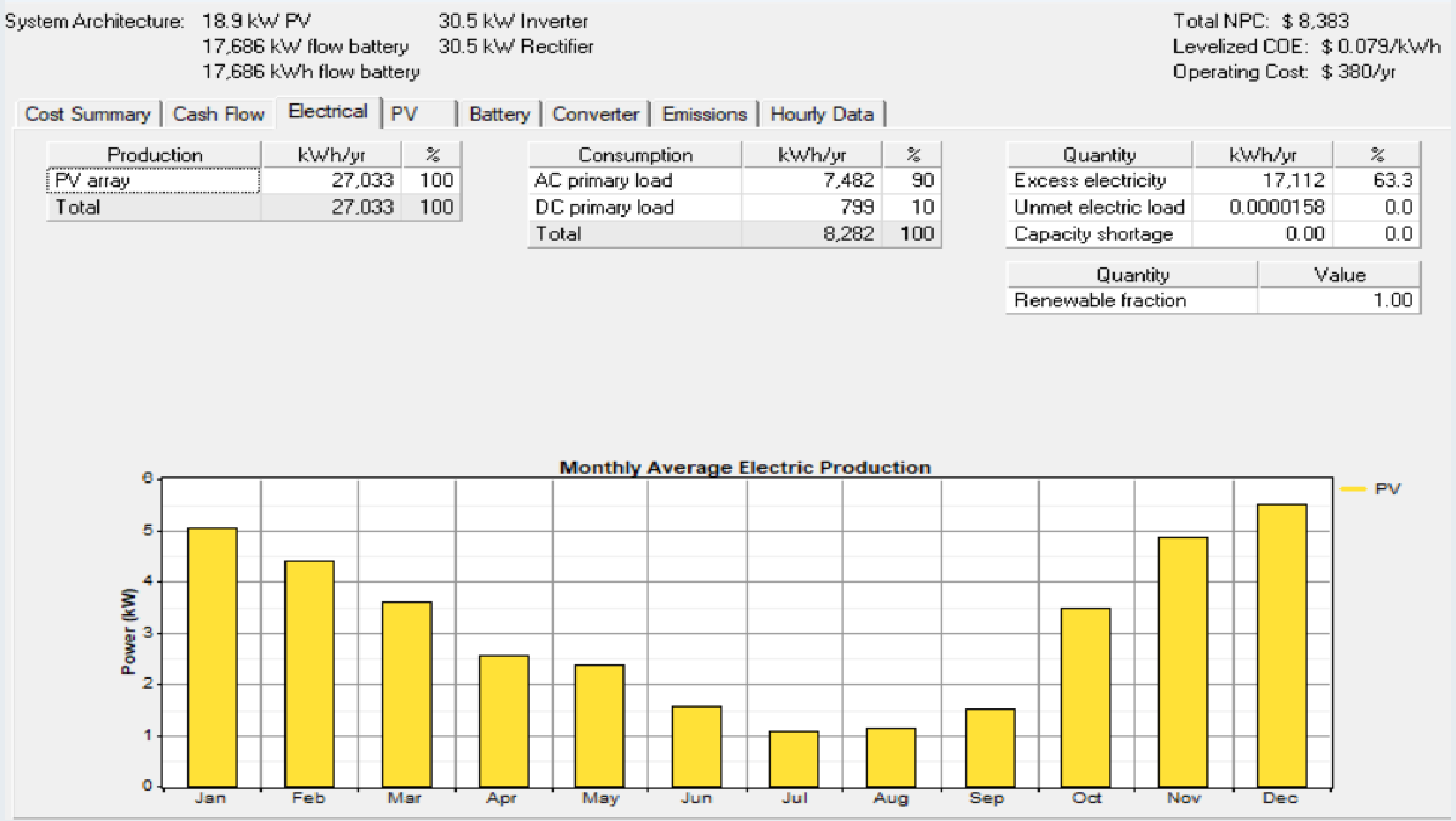


Figure 11 Cash flow summaries of Off-grid system

HOS Cont……

- The monthly average electricity production is presented in Fig.12



System Architecture: 18.9 kW PV 30.5 kW Inverter
17,686 kW flow battery 30.5 kW Rectifier
17,686 kWh flow battery

Total NPC: $ 8,383
Levelized COE: $ 0.079/kWh
Operating Cost: $ 380/yr

Production	kWh/yr	%
PV array	27,033	100
Total	27,033	100

Consumption	kWh/yr	%
AC primary load	7,482	90
DC primary load	799	10
Total	8,282	100

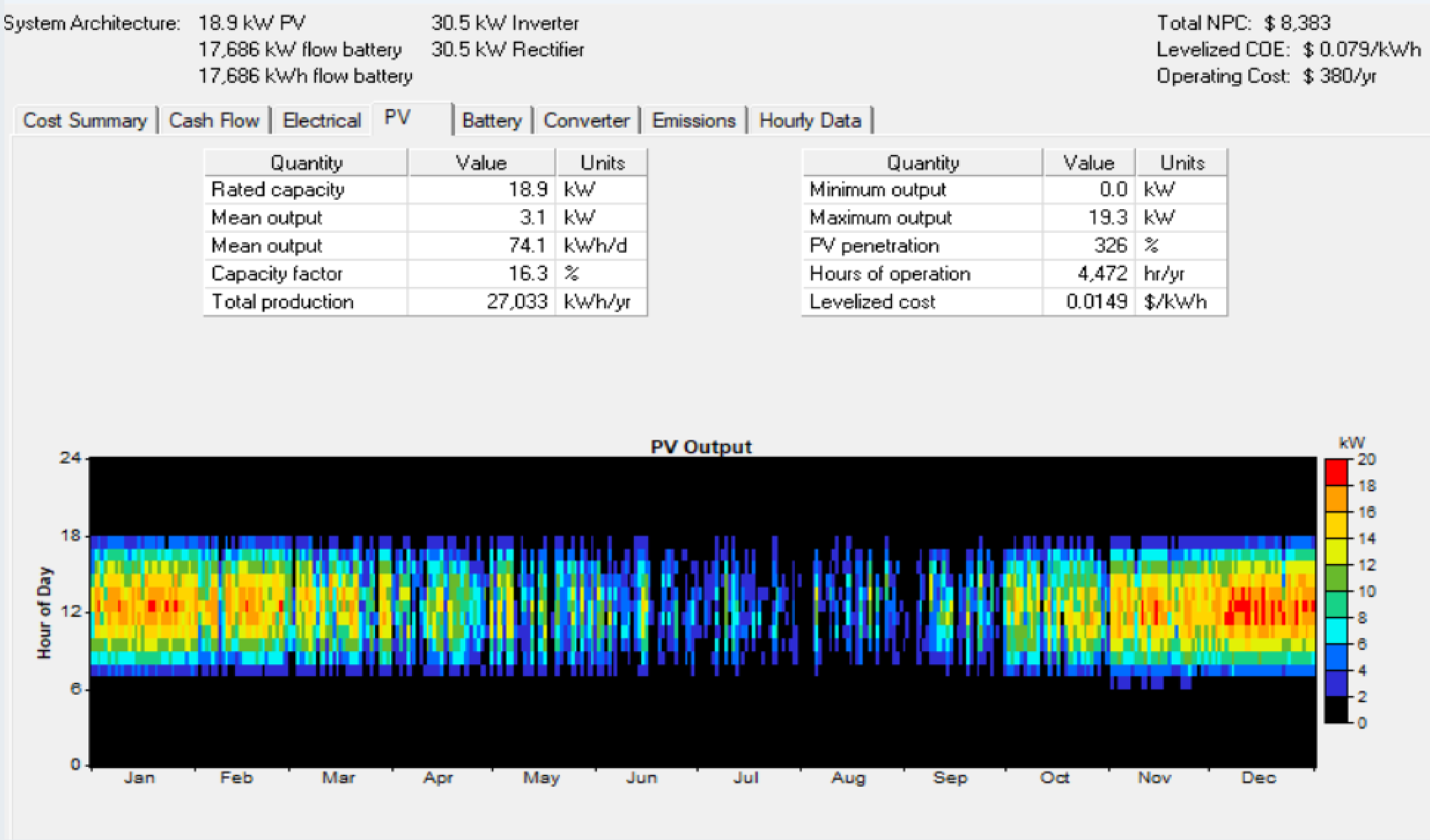
Quantity	kWh/yr	%
Excess electricity	17,112	63.3
Unmet electric load	0.0000158	0.0
Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	1.00

Figure 12. Monthly Average Electricity Production

HOS Cont……

- The PV output data is presented in Fig.13



System Architecture: 18.9 kW PV, 17,686 kW flow battery, 17,686 kWh flow battery, 30.5 kW Inverter, 30.5 kW Rectifier

Total NPC: $ 8,383
Levelized COE: $ 0.079/kWh
Operating Cost: $ 380/yr

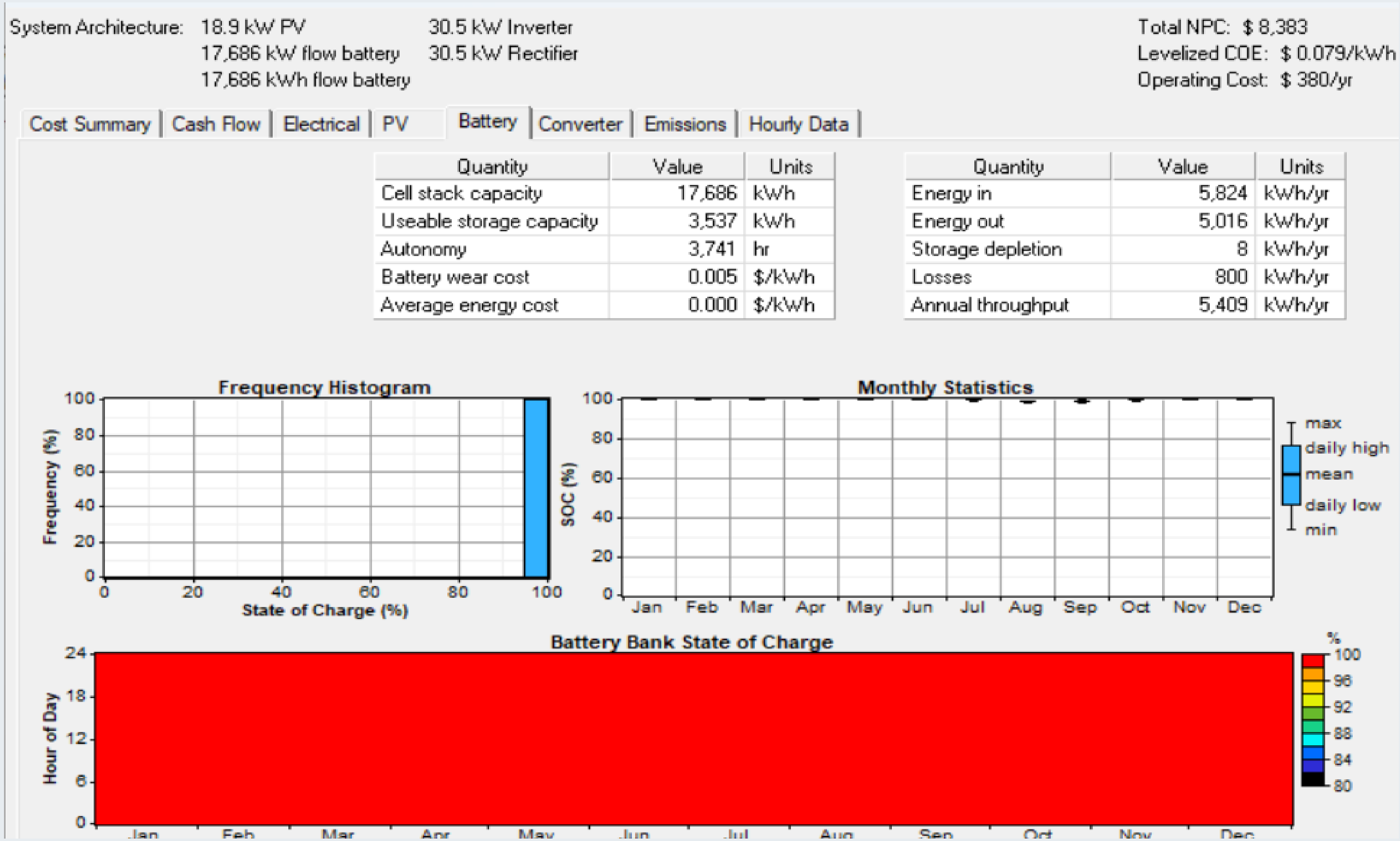
Quantity	Value	Units
Rated capacity	18.9	kW
Mean output	3.1	kW
Mean output	74.1	kWh/d
Capacity factor	16.3	%
Total production	27,033	kWh/yr

Quantity	Value	Units
Minimum output	0.0	kW
Maximum output	19.3	kW
PV penetration	326	%
Hours of operation	4,472	hr/yr
Levelized cost	0.0149	$/kWh

Figure 13. PV output power

HOS Cont……

- The battery status during operating condition is presented in Fig.14



System Architecture: 18.9 kW PV 30.5 kW Inverter
17,686 kW flow battery 30.5 kW Rectifier
17,686 kWh flow battery

Total NPC: $ 8,383
Levelized COE: $ 0.079/kWh
Operating Cost: $ 380/yr

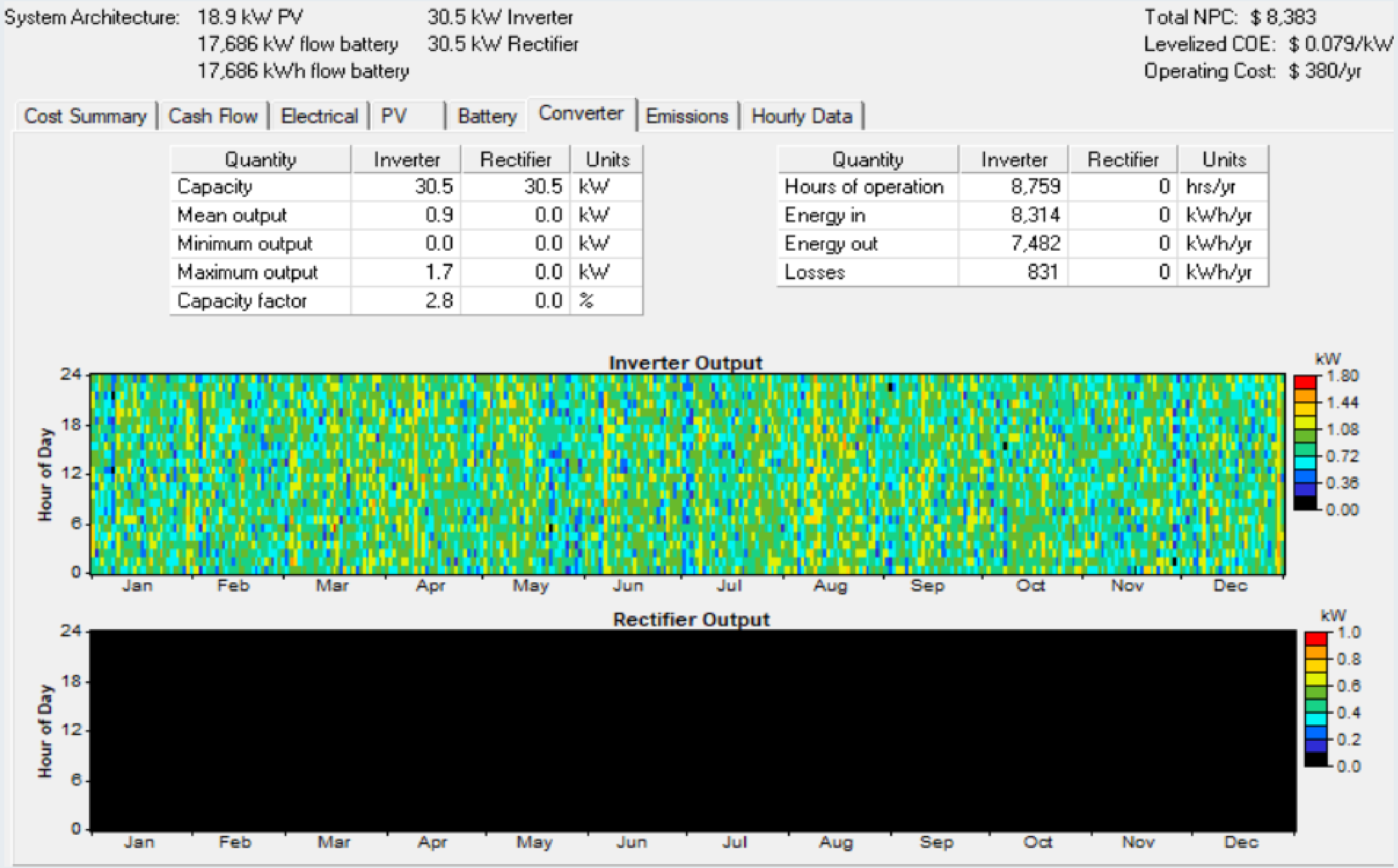
Quantity	Value	Units
Cell stack capacity	17,686	kWh
Useable storage capacity	3,537	kWh
Autonomy	3,741	hr
Battery wear cost	0.005	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	5,824	kWh/yr
Energy out	5,016	kWh/yr
Storage depletion	8	kWh/yr
Losses	800	kWh/yr
Annual throughput	5,409	kWh/yr

Figure 14. Battery status during operating condition

HOS Cont……

- The converter status during operating condition is presented in Fig.15



System Architecture: 18.9 kW PV 30.5 kW Inverter
17,686 kW flow battery 30.5 kW Rectifier
17,686 kWh flow battery

Total NPC: $ 8,383
Levelized COE: $ 0.079/kW
Operating Cost: $ 380/yr

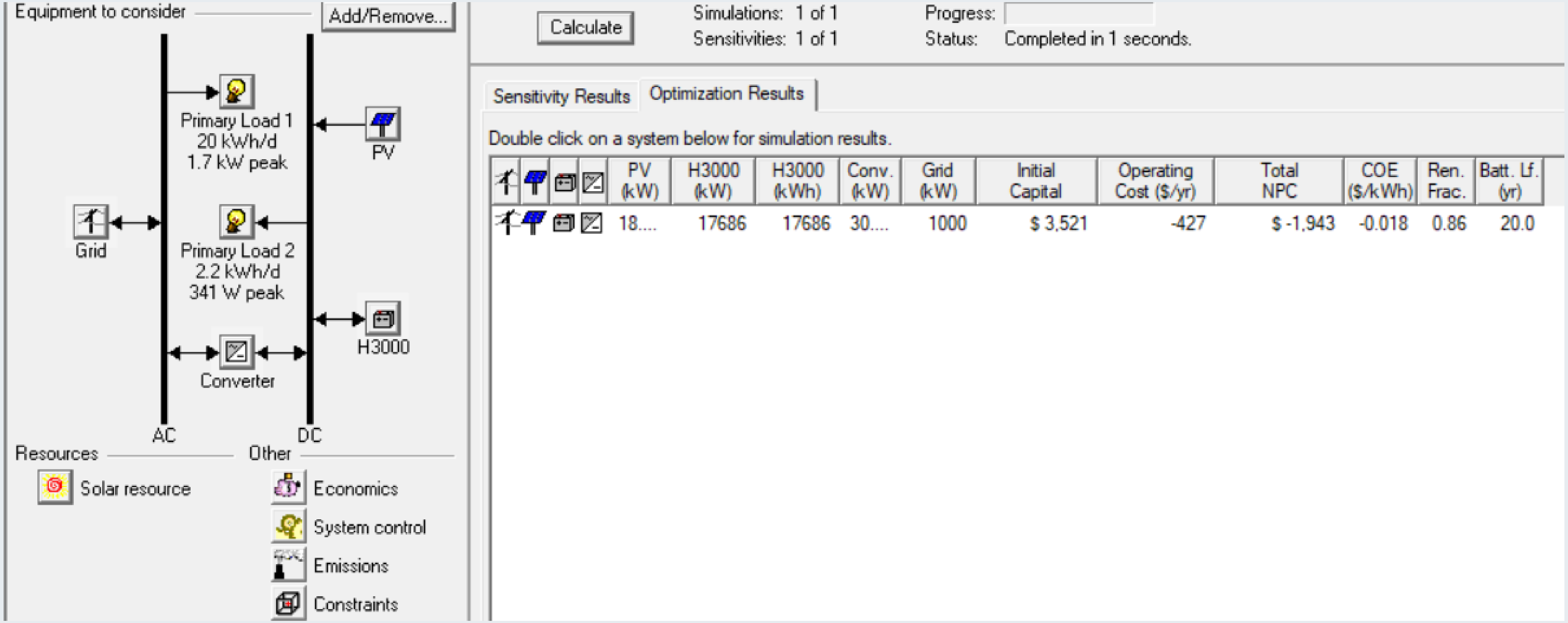
Quantity	Inverter	Rectifier	Units
Capacity	30.5	30.5	kW
Mean output	0.9	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	1.7	0.0	kW
Capacity factor	2.8	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,759	0	hrs/yr
Energy in	8,314	0	kWh/yr
Energy out	7,482	0	kWh/yr
Losses	831	0	kWh/yr

Figure 15 Converter status during Operating condition

C. Homer solution for Grid connected system(HSGS)

- The model of Grid-connected PV system for selected system is presented in Fig.16



Simulations: 1 of 1
Sensitivities: 1 of 1
Progress:
Status: Completed in 1 seconds.

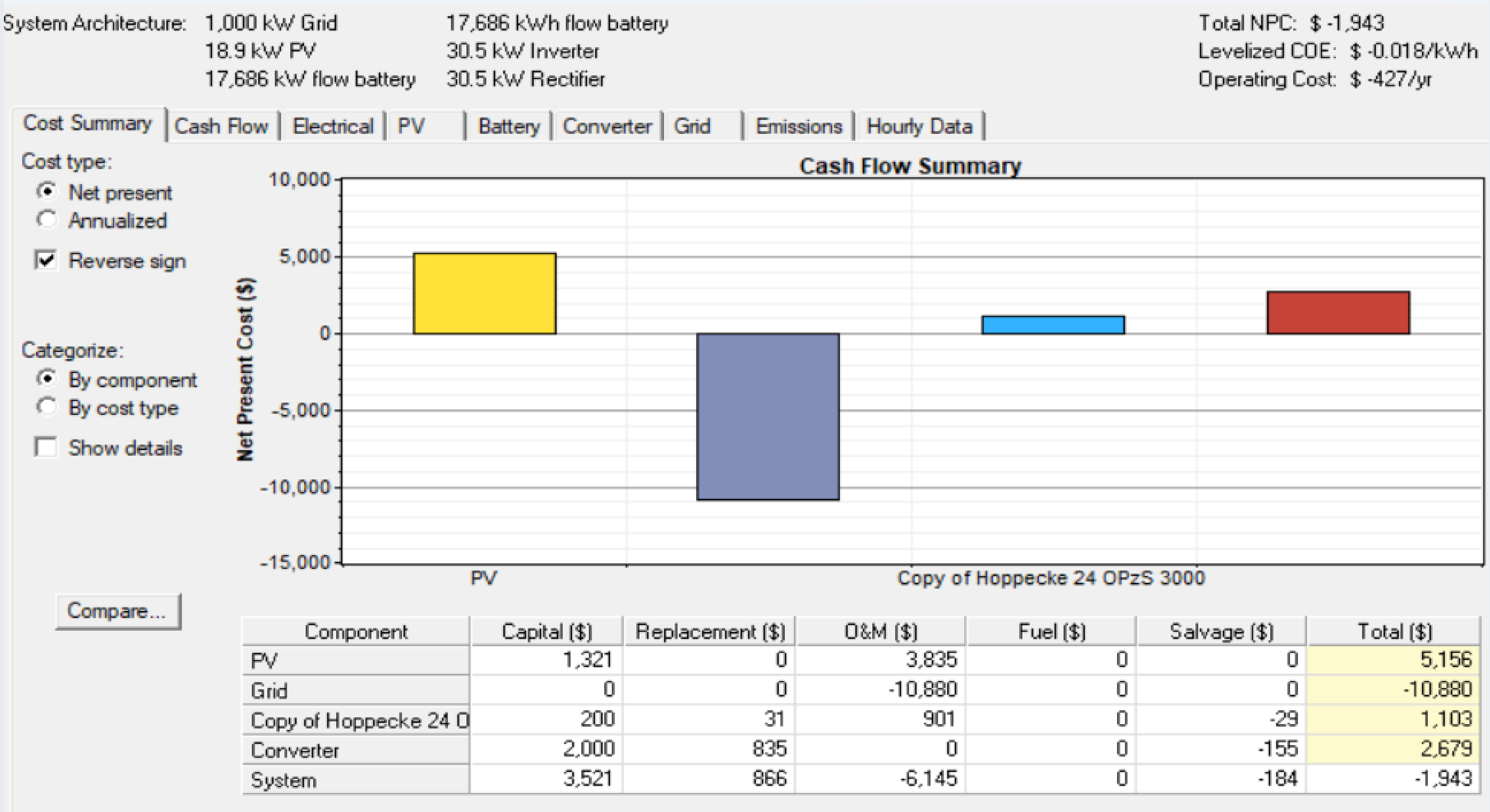
Double click on a system below for simulation results.

PV (kW)	H3000 (kW)	H3000 (kWh)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Batt. Lf. (yr)
18....	17686	17686	30....	1000	$ 3,521	-427	$ -1,943	-0.018	0.86	20.0

Figure 16. grid connected PV system model

HSGS Cont…..

- The cost of Grid-connected PV system for the same energy requirement is system is presented in Fig.17



System Architecture: 1,000 kW Grid
18.9 kW PV
17,686 kW flow battery
17,686 kWh flow battery
30.5 kW Inverter
30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

Cost type:
● Net present
○ Annualized
☑ Reverse sign

Categorize:
● By component
○ By cost type
☐ Show details

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,321	0	3,835	0	0	5,156
Grid	0	0	-10,880	0	0	-10,880
Copy of Hoppecke 24 O	200	31	901	0	-29	1,103
Converter	2,000	835	0	0	-155	2,679
System	3,521	866	-6,145	0	-184	-1,943

Figure 17 cost summary of Grid connected PV system

HSGS Cont.….

The cash flow based on the system life span is presented in Fig.18

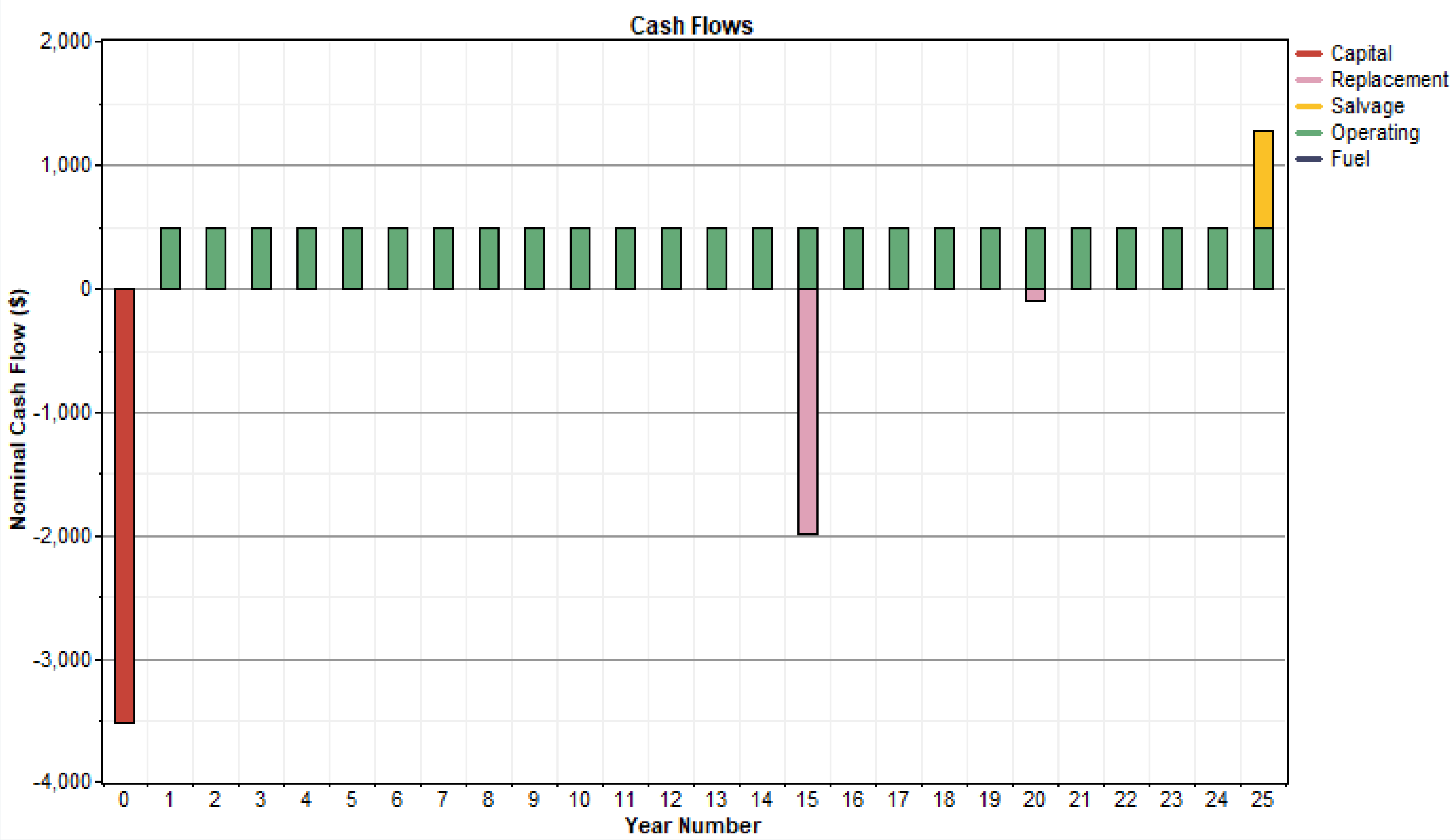
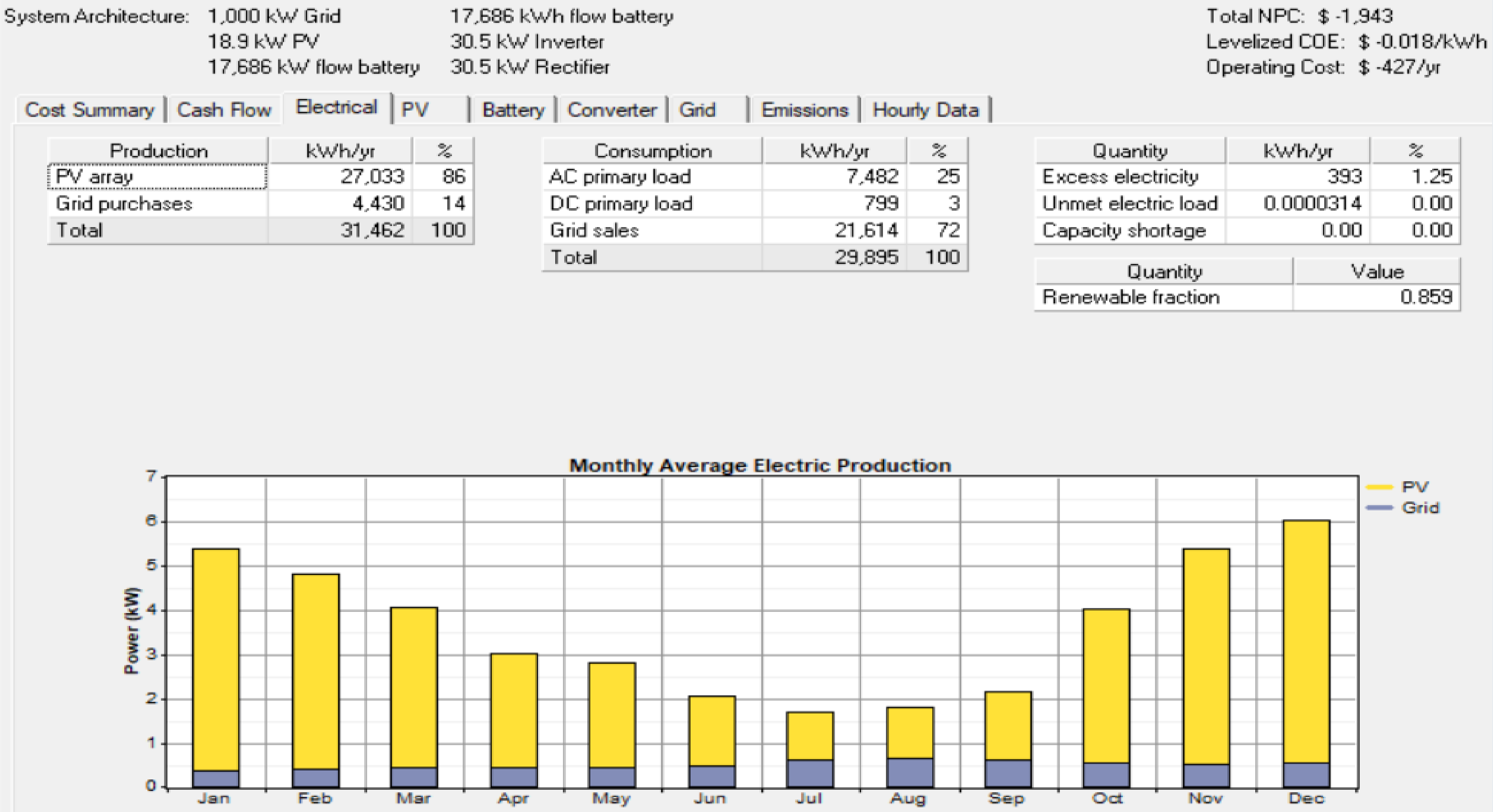


Figure 18 cash flow summary of Grid-connected PV system

HSGS Cont…..

- The monthly average energy production is presented in Fig.19



System Architecture: 1,000 kW Grid
18.9 kW PV
17,686 kW flow battery
17,686 kWh flow battery
30.5 kW Inverter
30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

Production	kWh/yr	%
PV array	27,033	86
Grid purchases	4,430	14
Total	31,462	100

Consumption	kWh/yr	%
AC primary load	7,482	25
DC primary load	799	3
Grid sales	21,614	72
Total	29,895	100

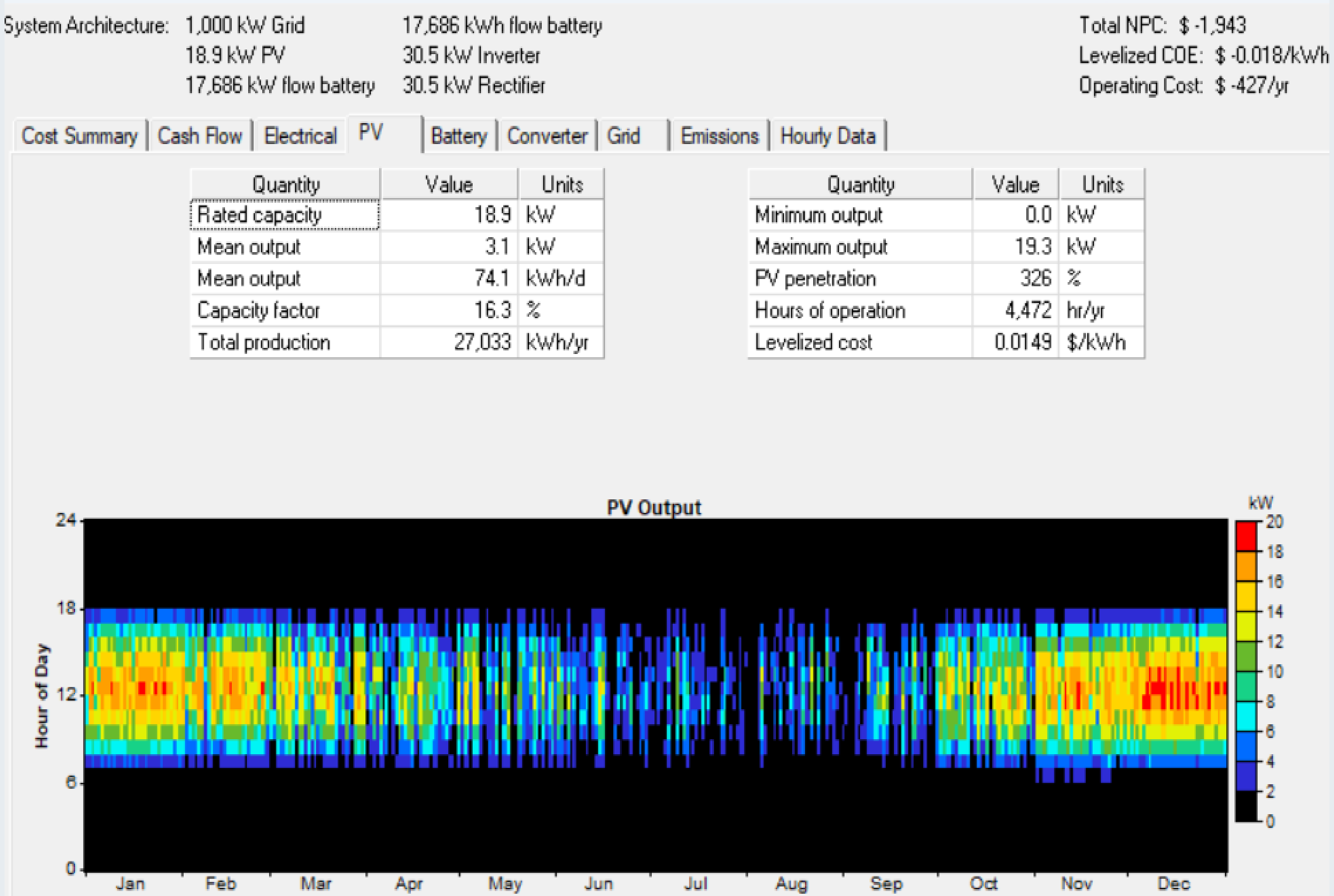
Quantity	kWh/yr	%
Excess electricity	393	1.25
Unmet electric load	0.0000314	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.859

Figure 19 Monthly average electricity production of PV vs Grid

HSGS Cont…..

- The PV output operation is given in Fig.20



System Architecture: 1,000 kW Grid
18.9 kW PV
17,686 kW flow battery
17,686 kWh flow battery
30.5 kW Inverter
30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

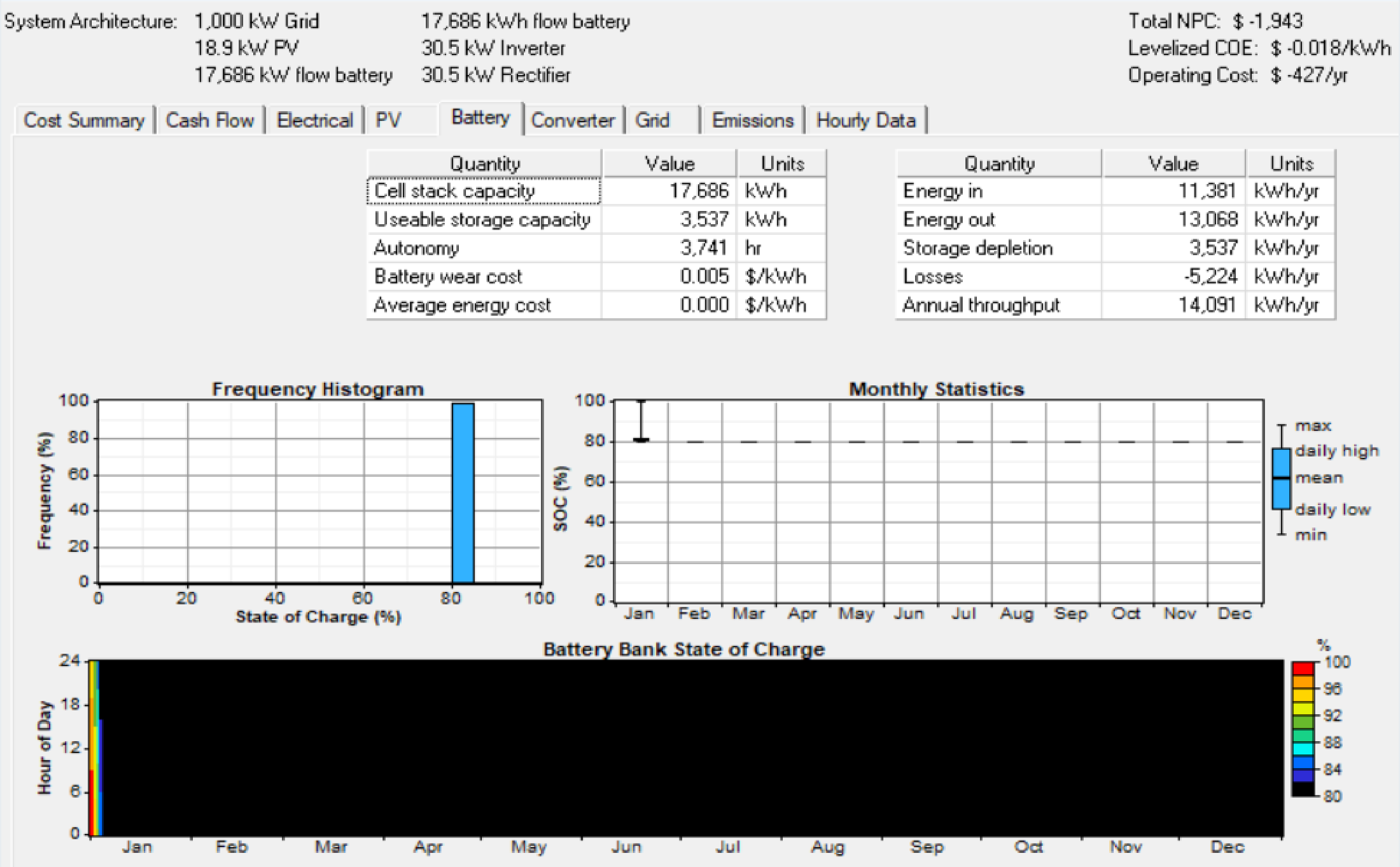
Quantity	Value	Units
Rated capacity	18.9	kW
Mean output	3.1	kW
Mean output	74.1	kWh/d
Capacity factor	16.3	%
Total production	27,033	kWh/yr

Quantity	Value	Units
Minimum output	0.0	kW
Maximum output	19.3	kW
PV penetration	326	%
Hours of operation	4,472	hr/yr
Levelized cost	0.0149	$/kWh

Figure 20 PV output operation data

HSGS Cont.….

- The operation of Grid connected PV system battery is given in Fig.21



System Architecture: 1,000 kW Grid 17,686 kWh flow battery
18.9 kW PV 30.5 kW Inverter
17,686 kW flow battery 30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

Quantity	Value	Units
Cell stack capacity	17,686	kWh
Useable storage capacity	3,537	kWh
Autonomy	3,741	hr
Battery wear cost	0.005	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	11,381	kWh/yr
Energy out	13,068	kWh/yr
Storage depletion	3,537	kWh/yr
Losses	-5,224	kWh/yr
Annual throughput	14,091	kWh/yr

Figure 21 the operation of Grid connected PV system batter

HSGS Cont…..

- The operation of Grid connected PV system converter is given by:

System Architecture: 1,000 kW Grid
18.9 kW PV
17,686 kW flow battery
17,686 kWh flow battery
30.5 kW Inverter
30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

Quantity	Inverter	Rectifier	Units
Capacity	30.5	30.5	kW
Mean output	2.9	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	30.5	0.3	kW
Capacity factor	9.4	0.1	%

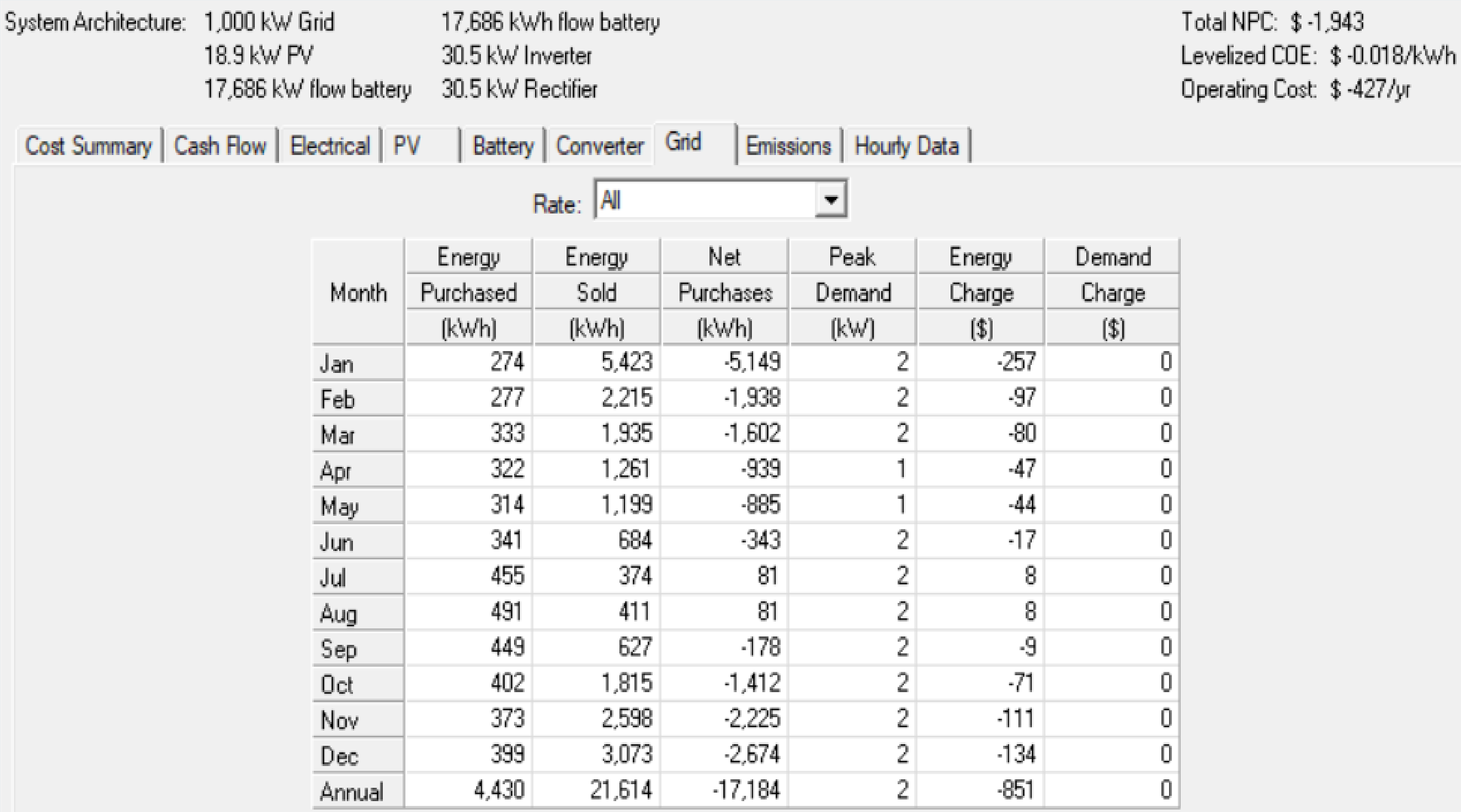
Quantity	Inverter	Rectifier	Units
Hours of operation	4,531	2,200	hrs/yr
Energy in	27,917	459	kWh/yr
Energy out	25,126	390	kWh/yr
Losses	2,792	69	kWh/yr

Figure 22. The operation of Grid connected PV system converter

HSGS

Cont.….

- Energy flow data between grid and PV is given in Fig.23



System Architecture: 1,000 kW Grid | 17,686 kWh flow battery
18.9 kW PV | 30.5 kW Inverter
17,686 kW flow battery | 30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

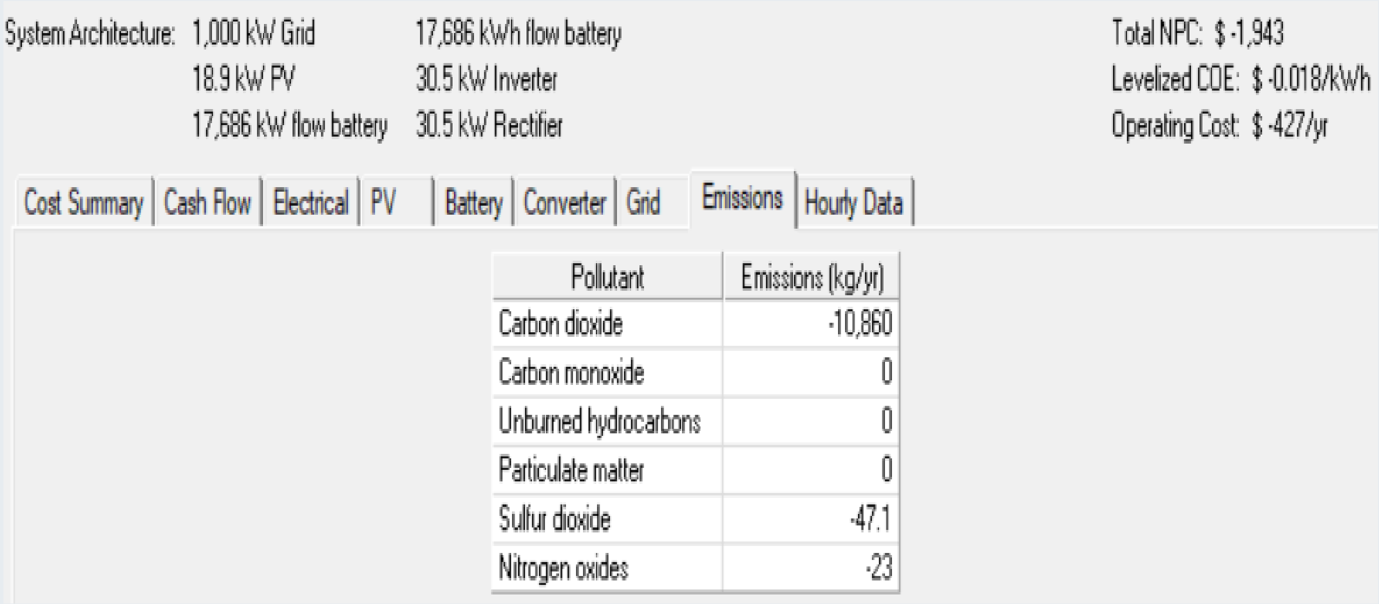
Rate: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	274	5,423	-5,149	2	-257	0
Feb	277	2,215	-1,938	2	-97	0
Mar	333	1,935	-1,602	2	-80	0
Apr	322	1,261	-939	1	-47	0
May	314	1,199	-885	1	-44	0
Jun	341	684	-343	2	-17	0
Jul	455	374	81	2	8	0
Aug	491	411	81	2	8	0
Sep	449	627	-178	2	-9	0
Oct	402	1,815	-1,412	2	-71	0
Nov	373	2,598	-2,225	2	-111	0
Dec	399	3,073	-2,674	2	-134	0
Annual	4,430	21,614	-17,184	2	-851	0

Figure 23. Energy flow data between grid and PV

HSGS Cont…..

- The environmental effect of grid-connected PV system is given in Fig.24



System Architecture: 1,000 kW Grid
18.9 kW PV
17,686 kW flow battery
17,686 kWh flow battery
30.5 kW Inverter
30.5 kW Rectifier

Total NPC: $ -1,943
Levelized COE: $ -0.018/kWh
Operating Cost: $ -427/yr

Pollutant	Emissions (kg/yr)
Carbon dioxide	-10,860
Carbon monoxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	-47.1
Nitrogen oxides	-23

Figure 24 : Emission reduction data

HSGS Cont.….

- **Summary of Homer optimization**: This interesting project presents a comparative study of the stand-alone and grid connected PV systems, one connected to the local grid (on-grid) and the other is standalone (off-grid), without taking the influence of sensitive variables into consideration.
- The simulation results reveal that the local grid is most cost-effective than off-grid design for the similar load.
- It also gives the optimal solution for off-grid and grid connected system, where the homer optimization solution provides better optimal solution compared to the hand based solution.
- Besides this, the importance of connected RE to grid in terms of carbon emission reduction, bidirectional flow of energy and energy billing reduction are clearly indicated in Grid-connected systems.

Summary

- This lecture note comprises the designing methods of off-grid and grid connected system.
- The software application on designing and optimization of PV system is discussed.
- Different software application on RE system, specifically the Homer optimization software is discussed.
- The project design of Off-grid and Grid connected PV system using hand-calculation and Homer optimization is also discussed
- The importance of charge controller/battery in off-grid and grid connected system is also observed from the design project

References

[1]. A.,Mustafa Yaseen; A., Mohammed Hasan and h., Maher Alwan. ‘’Estimation of loads for off-grid solar photovoltaic systems’’. International Journal of Power Electronics and Drive Systems (IJPEDS). V.13(2). 2022.

[2].H., Meg; Q., Tom; R., Kristen and etl. ‘’Requirements and Guidelines for Installation of Off-Grid Solar Systems for Public Facilities’’. https://www.lightingglobal.org/wp-content/uploads/2021/05/QualityAssurance-OffGridSolar-PublicFacilities-Nov2020.pdf

[3]. NREL. Getting Started Guide for HOMER Version 2.1. National Renewable Energy Laboratory. 2005. www.nrel.gov

Thank you !

Appendix A: Typical Power Consumption Demands of Various Appliances

Typical Power Consumption Demands	Wattage/appliance's	Daily use (hours)	Daily Energy Use (watt hours)
Appliance	Watts		
Coffee Pot	200	0.25	
Coffee Maker	800	0.25	
Toaster	800-1500	0.25	
Blender	300	0.15	
Microwave	600-1500	0.3	
Hot Plate	1200	0.3	
Washing Machine Automatic	500	0.25	
Washing Machine Manual	300	0.25	
Vacuum Cleaner Upright	200-700	0.25	
Vacuum Cleaner Hand	100	0.25	
Sewing Machine	100	0.25	
Iron	1000	0.25	
Clothes Dryer Electric	400	0.25	
Clothes Dryer Gas heated	300-400	0.25	
Water Pump	250-500	0.25	
Ceiling Fan	10-50	0.25	

Appendix A Cont.…

Table Fan	**10-25**	**0.25**	
Electric Blanket	200	0.25	
Blow Dryer	1000	0.25	
Shaver	15	0.15	
Computer Laptop	20-50	5	
Computer PC	80-150	5	
Computer Printer	100	0.25	
Typewriter	80-200	0.3	
TV 25" Color	150	4	
TV 19" Color	70	4	
1TV 2" B&W	20	4	
VCR	40	0.2	
Clock Radio	1	0.3	
Satellite Dish	30	2	
CB Radio	5	0.3	
Electric Clock	3	24	
Lights: 100W Incandescent	100	4	
Lights: 25W Compact Fluorescent	28	4	
Lights: 50W DC Incandescent	50	4	

Appendix A Cont….

Lights: 40W DC Halogen	**40**	**4**	
Lights: 20W Compact Fluorescent	22	4	
Compact Fluorescent Incandescent: 40-watt equivalent	11	4	
Compact Fluorescent Incandescent: 60-watt equivalent	16	4	
Compact Fluorescent Incandescent: 75-watt equivalent	20	4	
Compact Fluorescent Incandescent: 100-watt equivalent	30	4	
1/4" Drill	250	4	
1/2" Drill	750	4	
1" Drill	1000	0.5	
9" Disc Sander	1200	0.5	
3" Belt Sander	1000	0.5	
12" Chain Saw	1100	0.5	
14" Band Saw	1100	0.5	
7-1/4" Circular Saw	900	0.5	
8-1/4" Circular Saw	1400	0.5	
Refrigerator/Freezer 20cf 1.8Kwh per day	540	15	
Refrigerator/Freezer 16cf 1.6Kwh per day	475	13	
Sun frost 16cf DC	112	7	
Sun frost 12cf DC	70	7	
Freezer 14cf	440	15	
Freezer 14cf	350	14	
Sun frost Freezer 19cf	112	10	