IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 3 Ver. II (May. – Jun. 2016), PP 46-61
www.iosrjournals.org

Graphical and Mathematical Designing Analysis of 8 Kilo-Watt Solar Photo-Voltaic System

Nikhil Kumar Yadav [1], Dr. Dharmendra Kumar Singh [2], Amit Agrawal [3]

[1]*M.Tech (POWER SYSTEM ENGINEERING SCHOLAR)*
(Electrical and Electronics Engineering Department, Dr. C.V. Raman University, Kargi Road Kota Bilaspur, Chhattisgarh India)
[2] *Head & Associate Professor*
(Electrical and Electronics Engineering Department, Dr. C.V. Raman University, Kargi Road Kota Bilaspur, Chhattisgarh India)
[3] *Assistant Professor*
(Electrical and Electronics Engineering Department, Dr. C.V. Raman University, Kargi Road Kota Bilaspur, Chhattisgarh India)

Abstract: *This paper describes the complete mathematical parameters required for the efficient operation of Solar PV System. Solar power generation is becoming a trend now days. The cost of fossil fuels are increasing day by day, due to its limited availability, in this situation opting solar is a better option. Solar power is also considered as green power as it is pollution free. In coming 40-50 years entire power generation will be replaced by solar power generation. This paper shows latitudinal and longitudinal features of site where the solar installation is being carried out, Monthly solar irradiance data, Module connection, Inverter specification, Battery System specification, Power loss data and Desired and actual output graph. System Advisor Modeling (SAM) Software designed by N.R.E.L. is mainly used for simulation, RET plus Software is used for Solar Irradiance data collection and MATLAB is used for designing of Graphs.*

Keywords: *Inverter, Irradiance, MATLAB, Module, N.R.E.L., Photovoltaic, SAM*

I. INTRODUCTION

The 8 kilo watt solar photovoltaic system is installed at Korba Collectorate Office. The Korba is also known as power city. It is surrounded by thermal power stations from all direction. The site is situated at 22.35°N 82.68°E. The korba is 316 meter above sea level. The 8 kilo watt system has 400Ah battery and PCU (Solar Power Conditioning Unit) of 8000 VA [6]. The site location is as follows:

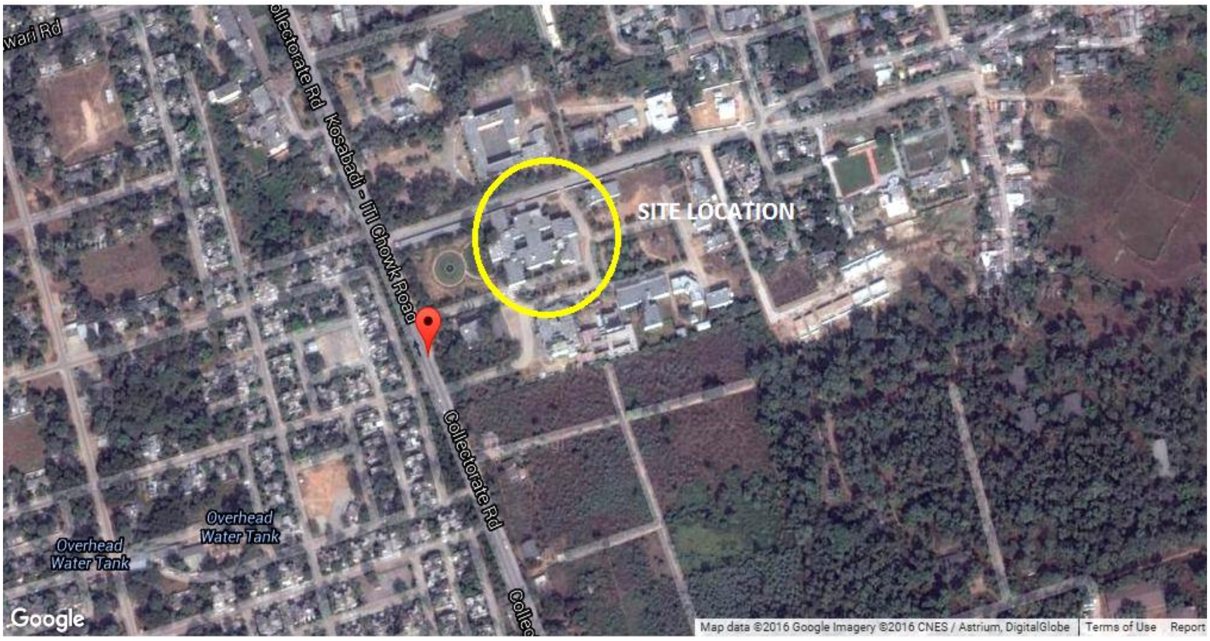


Fig. 1 Site location of 8KiloWatt Solar Photovoltaic System (Source:-Google Map)

Fig. 2 Magnified Site location of 8KiloWatt Solar Photovoltaic System (Source:-Google Map)

The available electrical utility system can be converted into solar photovoltaic system with the help of solar photovoltaic modules. Here, the system is designed such that, it generates power in availability of sunlight. In absence of sunlight, it takes power from battery, if battery gets discharged; power is taken from grid in order to maintain supply continuity. Here, to maintain power system security the system is grid connected. It offers following advantages [1]:-

- Solar Energy is pollution free.
- Photovoltaic System has no moving parts which offer low maintenance.
- Promotes power system security.
- No dependability on fossil fuels.
- If solar modules are installed over the water bodies like canals, the evaporation can be reduced which helps to save water.

With advancement in technologies, the demand of solar energy is increasing, per watt generation cost has reduced and per capita energy consumption is increasing.

II. LITERATURE REVIEW

2.1 Solar Module

A solar module is formed by the compilation of solar cells together in series or in parallel. These compilations provide higher power rating than individual solar cell. Modules have power ranging from 1.5W to 300 W are available now a days and considered as a fundamental building block of solar PV systems. Large amount of power in “Mega-Watt” range can be generated by the formation of solar arrays with no. of modules in series or parallel as per requirements [2][3].

A solar cell is a smallest fundamental unit of solar photovoltaic system. Each solar cell can generate power in mill-watt range, so, these cells are connected in series. Fixed no. of solar cells in series provides a solar module.

The module used in 8KW system is made up of 72 solar cells. The nominal voltage of solar module is 24 Volt and the maximum voltage that can be produced from solar cell is 36.5 volt. The maximum power that can be generated from this panel is 275Watt and has maximum current rating of 7.53Ampere and offers short circuit current of 8.21Ampere and open circuit voltage of 44.3 volts [6].

2.2 Parameters Of Solar Cell

The adequate performance of solar photovoltaic system can be analysed in terms of several parameters and these parameters are as follows[1][3]:-

- Short circuit current of solar panel.
- Open circuit voltage of solar panel.
- Maximum power point.
- Value of current at maximum power point.
- Value of voltage at maximum power point.

- Fill Factor
- Efficiency

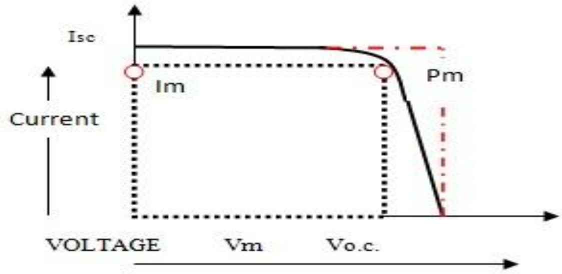


Fig. 3 PV Curve of Solar Cell

The solar modules are designed as per the Standard Test Condition which corresponds solar input of 1KW/sq.meter and operating temperature of 25◦C.

- **Short circuit current of solar panel**:-It is the maximum value of current that can be produced from solar cell and denoted by "**Isc**".The greater the value of Isc, more desirable is the cell. Sometimes the current density("**Jsc**") is mentioned in the panel instead of Isc and In that condition, the value of short circuit current can be obtained by dividing the current density by area of solar cell.
- **Open Circuit voltage of solar panel**:-It is the maximum value of voltage that can be produced from the solar cell. It is denoted by "**Vo.c.".** The greater the value of Voc, more desirable is the cell.Operating temperature and Cell technology decides V.o.c. .
- **Maximum power point of solar cell:-** It is the maximum value of power that can be produced under Standard Test Condition.It is obtained at a particular value of voltage and current and it is generally occurred at a bent of curve and denoted by "**Pm**".
- **Value of current at maximum power point:-**It is the value of current which is obtained when the solar cell operates at maximum power point. It is denoted by "**Im**" and the value of Im is always less than Isc.
- **Value of voltage at maximum power point:-** It is the value of voltage which is obtained when the solar cell operates at maximum power point. It is denoted by "**Vm**" and the value of Vm is always less than Voc.
- **Fill Factor:-**It is ratio of product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage.It is generally provided in terms of percentage or it is the ratio of area formed by Im-Vm rectangle to the area covered by Isc-Voc rectangle.Solar cell with I-V curve in the shape of square is considered better.

$$\textbf{Fill Factor} = \frac{Im\ x\ Vm}{Isc\ x\ Vsc} \quad [1]$$

2.3 External factors affecting generation of electricity fron solar cell[3][4][5]

- **Effect of conversion Efficiency :-** The conversion efficiency of solar cell is always fixed and it cannot be increased. So, greater is the conversion efficiency better is the solar cell. Cell with poor efficiency is generally not desirable.
- **Variation in amount of Input Light (Pin):-** The intensity of sunlight incident on the panel decides the power generated from the cell. The current of solar panel is directly propotional to current and the value of current increases from morning up to the afternoon and the value of current decreases from afternoon upto the evening but the the value of voltage remains almost constant from morning to evening.
- **Change in inclination of light falling on solar cell:-** The performance in terms of output power of the solar cell is maximum, when the sunrays are perpendicular to the solar cell, as there is no reflection takes place and when the sunrays are incident at some angle with Ɵ, some part of light gets reflected and that reflected radaition in W/sq.cm is –subtracted from the incident radaition in W/sq.cm.

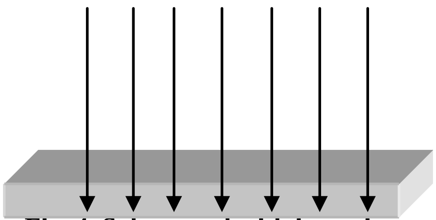


Fig. 4. Solar panel with incoming radiation at Ɵ=90°

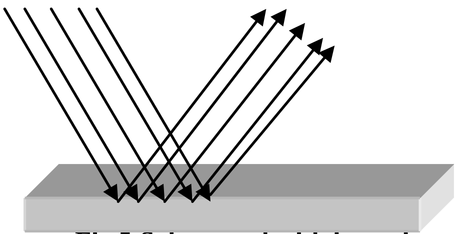


Fig.5 Solar panel with incoming radiation at ≤90°

In fig.4, the solar radiation is incident at an angle of 90°.So, Incoming light is of 1200W/sq.cm. So, In this case is taken as 1200W/sq.cm.But, in second case the Pin varies as some amount of light is reflected back from the panel.Let, 200W/sq.cm of light is reflected back, So the Pin for this case is taken as 1000w/sq.cm.

- **Affect of Temperature in solar cell :-**The solar cell is designed to operate at 25℃ as per Standard Test Condition and It is observed that, per degree increase in temperature above 25℃ provides decrease in voltage of 2.3milli volts with reduction in power by 0.45%.

  Cell Efficiency at 50C =Efficiency of cell at STC-[0.45% x at STC x Change in Temperature].So, with increase in temp. by 25, is reduced by 11.25%.

  at 50 = 14.96–[0.0045x14.96x25]=13.277 [2]

2.4Protection of solar cells through diodes[3][5]

- **Bypass Diodes**

In solar pv modules, all solar cells of similar characteristics are connected together in series.When light is incident on it, there is generation of current in individual cells which flows through the module.Suppose, some solar cells are under shaded condition(“**Condition with no sunlight”**). Under this condition, the generation of current in that particular cell will be lesser than rest of the cell or sometimes generates no current . Since the connection of solar cell is done in series, undershaded cells causes restriction in flow of current.So, this cell acts as a load . Inturn, it causes the formation of hotspots in the module. PV module glass cover breaks due to these hotspots, sometimes it also catches fire. To protect the module from this type of damage, Bypass diode is used, The polarity of this diode is opposite to that of cell and connected in parallel. Therefore, under no shading condition, the bypass diode works like open circuit(due to reverse bais condition).But, in shading condition, the diode acts as forward baised. It bypasses the current from shaded solar cell and in this way heating of shaded solar cell can be prevented.Ideally, one bypass diode is must for each cell, but as per economic consideration, a single diode is provided for string of 10-15 cells.

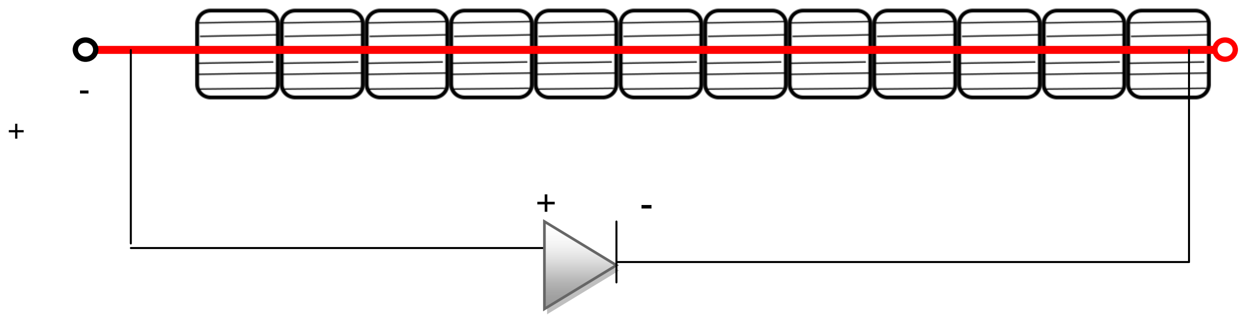


Fig.6 Series connection of 12 solar cells with 1 bypass diode

- **Blocking Diode**

In autonomous photovoltaic systems, Solar PV module are either used to fulfill load demands or used for battery charging.In day time, solar module generates electricity and supply this to battery. In off sunny days or at night, charged batteries start feeding energy to the module which causes energy loss .To overcome from this problem or to prevent supply of current from battery to module blocking diodes are used.This diode avoids battery discharging due to backflow.

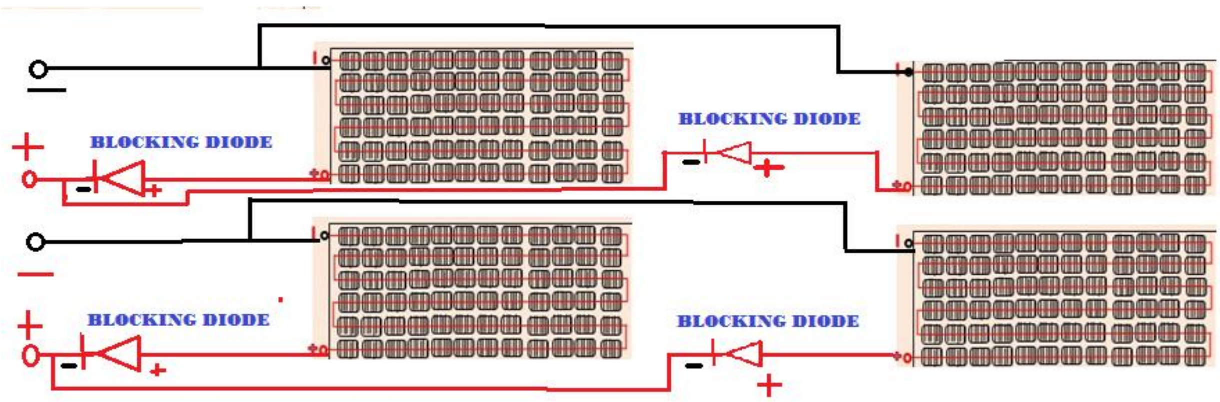


Fig.7 Blocking Diode arrangement in solar array

In the above diagram, the arrangement of blocking diode in solar arrays are represented.Each module is protected by single diode which avoids the risk of backflow of energy from battery to solar panel.

2.5 Types of solar modules

- **Monocrystalline Solar Cell** :- These types of cells offer efficiency in the range of 14.5%-24.5% .These cells are also known as single crystalline cells.Pure silicons are used for its construction because it is believed that , more pure the silicon better will be the conversion efficency. Silicon ingots are cut by 4 sides to convert this to wafers from which monocrystalline cells are made. Thats why, edge of monocrystalline are rounded instead of square. The space required by monocrystalline solar cells for generation of same elctrical ouput is less as compared to other type other type of solar cells. The multicrystalline cells are long lasting, but these panels are more expensive as compared to any other type of cells.

- **Polycrystalline Solar Cell** :-These cells are made up of multisilicon crytals, Here the melting process of silicon of silicon takes place and then this melted silicon is poured into a mold which is square in shape.so, there is no wastage of silicon in this process. It offers efficiency in the range of 12.5% - 15.5% and this cell has impure silicon and it doesn't perform adequately over higher temperature.
- **Thin film Solar Cell**: - This Solar Cell provides efficiency in the range of 7-13%. Here the series of thin film are constructed in layer over layer and these cells are flexible in nature. The heat tolerance capacity of this cell is higher, which promotes its development.

- **Amorphous silicon Solar Cell:**-These cells are used for small applications like electronic calculators and emergency lights. It involves stacking process, where multiple layers of amorphous silicon cells are created which provides efficiency upto 8%.

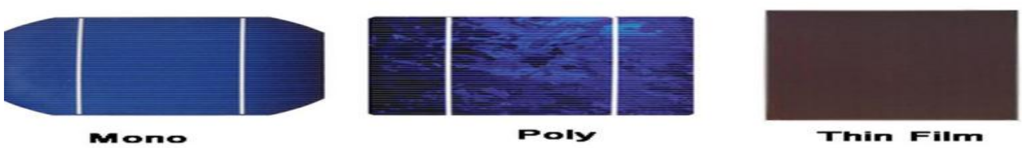


Fig.8 Various Types of solar cells

2.6 Battery[3][6]

Battery is the only device which can store electric energy in chemical form. In absence of sunlight, It supplies electrical energy to load.The batteries are mainly required in autonomous photovoltaic system and in grid connected system, no batteries are required, as in absence of sunlight grid supplies electrical energy to load.Most of the electronics like mobile, calculators, emergency lights, portable fans requires dc supply and conventional form of a.c. supply cannot be directly fed to these devices. To supply these devices, the ac is stored in batteries then supplied in dc form.A battery has two terminals, one positive(+) and other negative(-).The charged battery provides potential difference between positive and negative terminal, which causes the current to flow in the load when connected.

As per requirement, the type of battery used is selected. Rechargeable batteries are mainly used for solar photovoltaic designing process. We have used "**Tubular Gel Techology**" Rechargeable battery i.e. also known as T-Gel battery for our photovoltaic system.Solar arrays provide charge as a input to battery is nsufficient for fully battery charging. So, battery operates in Partial State of Charge. Also, solar systems are generally exposed to open atmosphere and batteries are subjected to high temperatures .In these cases the lead acetate battery doesnot work adequately due to sulphation, corossion and stratification.Instead of water top Triumph used gelled electrolyte technology in battery with cobination of tubular plates.Here, **"120 Volt 400 Ah"** battery is used for 8 KW PV system.

Fig.9 T-Gel Battery

The capacity of battery is measured in terms of Ampere Hour. It is the product of current delivered and time duration in hours.The capacity of batteries varies from few mah to thousands of Ah.As per Standard Test Condition the batteries are designed to operate at 25°C.The expression of current can be written as

$$\textbf{Current(I)}= \frac{Capacity(Ah)}{Discharge\ Duration(hour)} \qquad \textbf{[3]}$$

2.7 Inverter[3]

The variety of electrical appliances works on AC power but the photo voltaic modules generates dc power. Hence, the dc power is first converted into ac form with the help of inverter. The parameters of inverter are as follows:-

- **Input Power of Inverter**: - The input side of inverter is fed through dc source. Hence, the equation for input power is **Vdc x Idc.**

- **Output Power of Inverter**:-The output side of inverters provides the product of **Vr.m.s. x Ir.m.s.**

- **Efficiency of Inverter :-** The efficiency of inverter is given in terms of output power to the input power and can be given by :-

$$\eta_{\textbf{inverter}} = \frac{\text{Output Power}}{\text{Input Power}} \text{x}100 = \frac{\text{Vrms x I rms x PF}}{\text{Vdc x Idc}} \qquad \textbf{[4]}$$

Consider the dc power of an inverter is 700 Watt. The Output AC power is 500 Watt. What is the efficiency of inverter?

$$\eta_{\textbf{inverter}} = \frac{500}{700} \text{x}100 = 71.42\%$$

In this way the efficiency of inverter can be determined but conversion of energy into one form to another leads to losses.

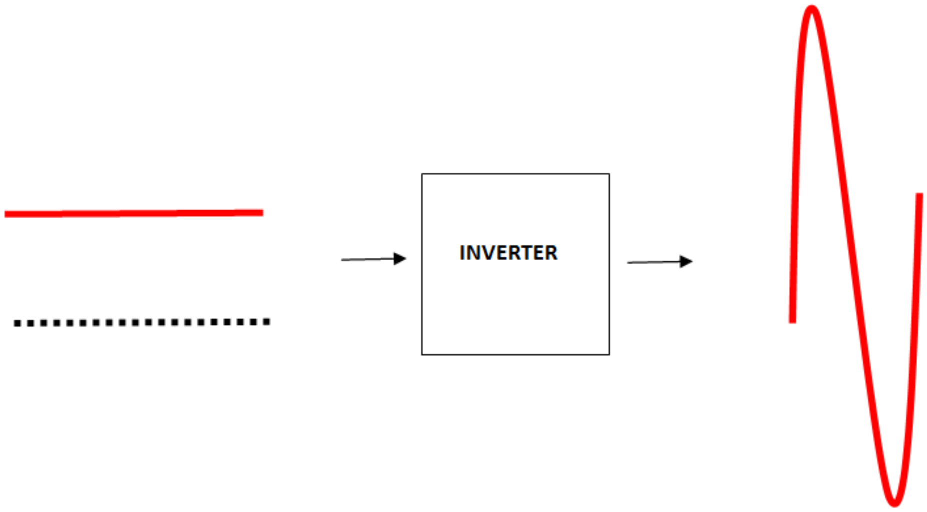


Fig. 10 DC Input Inverter AC Output

2.7 Charge Controller[3][4][6]

The flow of charge to the battery and from the battery is controlled by the charge controller, to avoid battery over charging and deep discharging .When solar module fully charges the battery, supply is breaked off by the charge controller . In the same way, if a battery goes into deep discharged mode due to its excess usage, then charge controller cuts the battery to stop the current taken from the battery.In deep discharge condition, the battery is disconnected from the circuit as battery voltage becomes too low. During charging, the voltage of terminal gets increased by charging, now charge controller connects the battery again, so that the load can extract power from the battery.

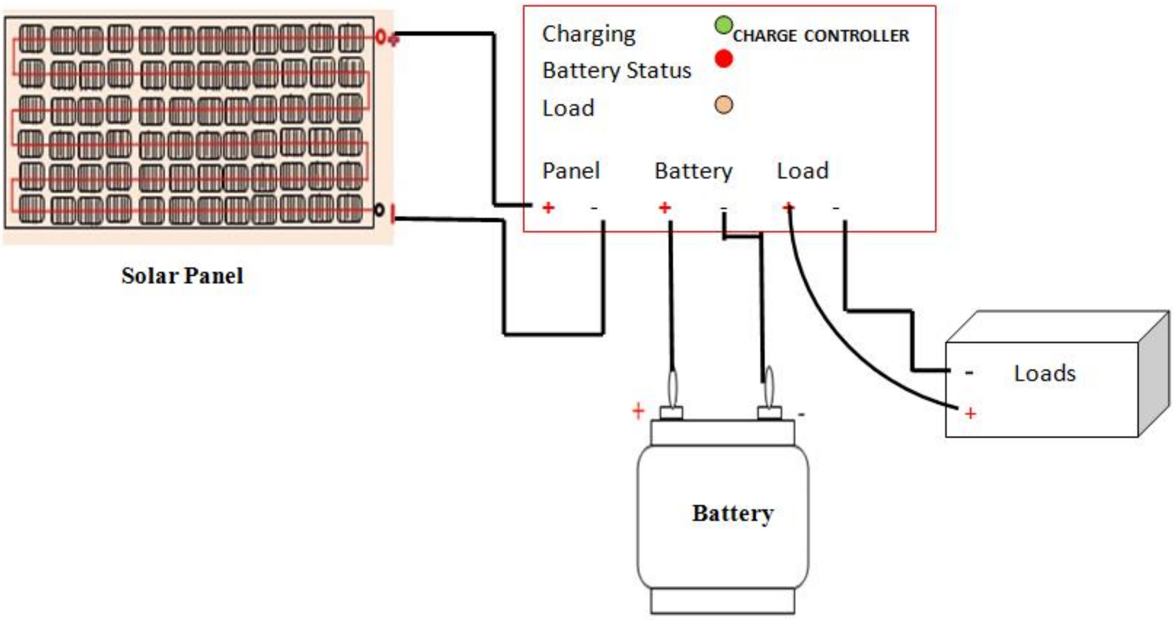


Fig. 18 Autonomous PV system with Battery Backup

Charge controllers are of two types:

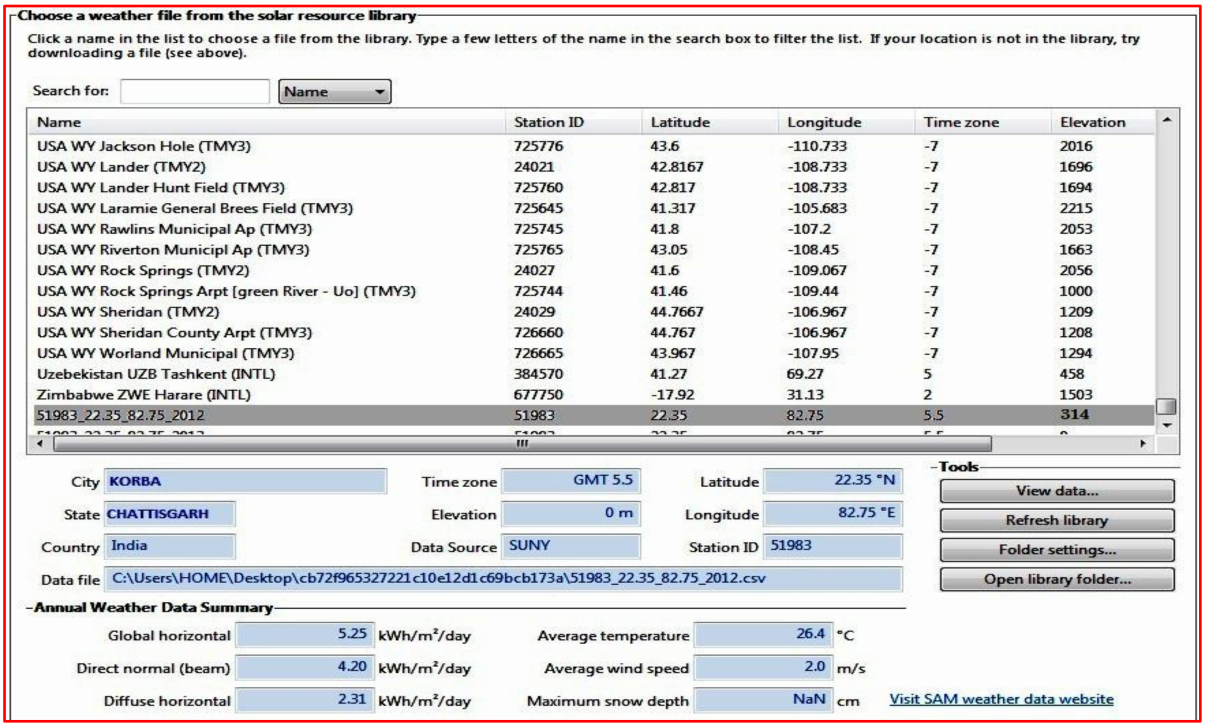
- Pulse Width Modulation Charge Controller.
- Maximum Power Point Tracking Charge Controller

In PWM charge controller the voltage across solar PV array and battery bank remains same. The voltage level across battery and array differs in MPPT charge controllers and the operation of system takes place in maximum power point of the solar panel. It also offers higher voltage level than battery bank voltage. As, the voltage is high the value of current is small. So, the conductor requirement also reduces for same flow of power. The 8KW solar PV system has 8KVA Solar Power Conditioning Unit, which is a combination of MPPT Charge Controller, Inverter and a Grid charger. It facilitates user to charge the battery with the help of solar or grid.

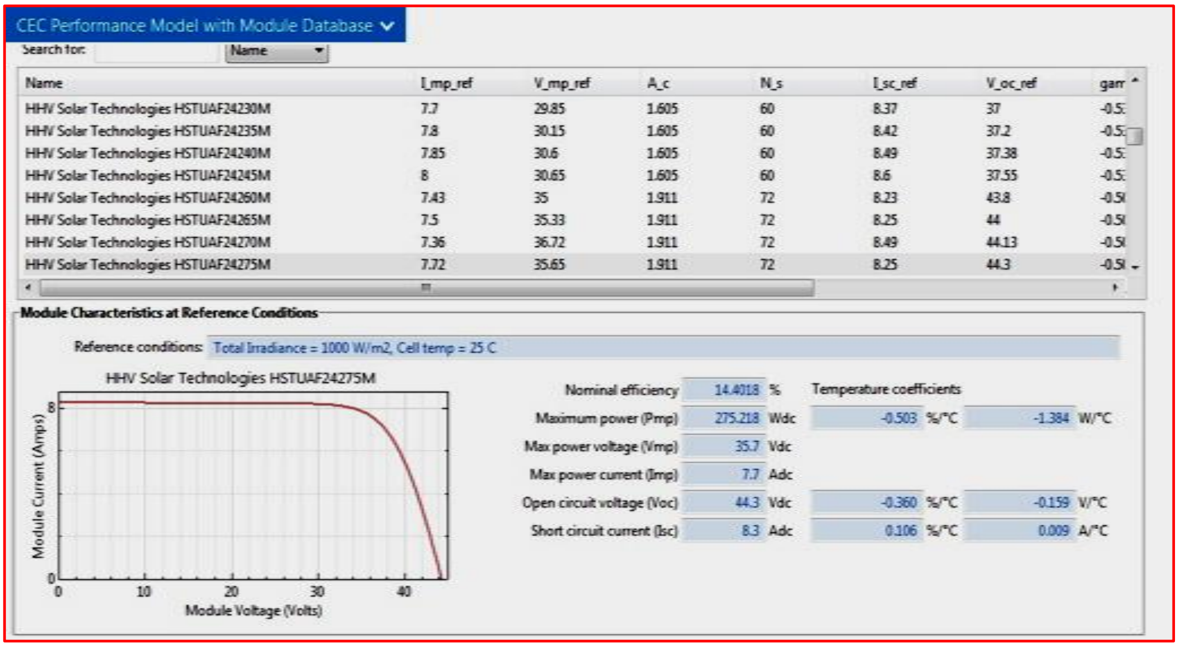
III. RESULT AND DISCUSSIONS

The System Advisor Model software is used to perform the simulation task of 8 KW solar photovoltaic system. The SAM is developed by National Renewable Energy Laboratory and 2016 version is used. It offers simulations of entire renewable energy sources and planning and detailed photovoltaic analysis is performed step by step.

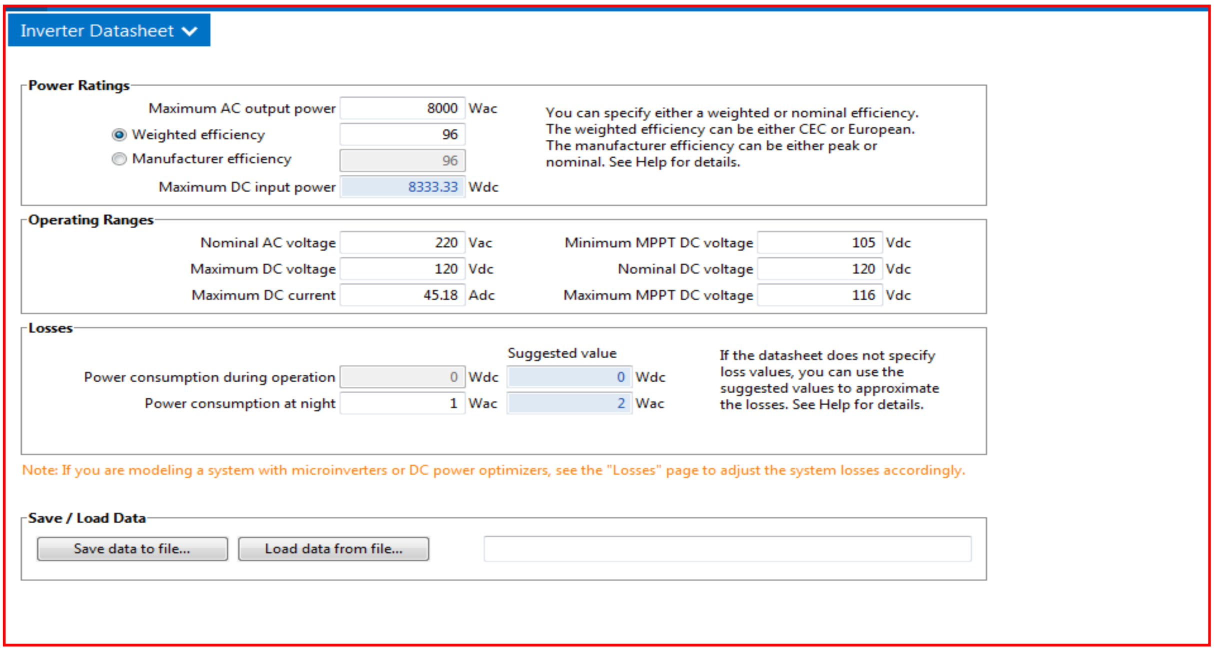
3.1 Location and Resource Data



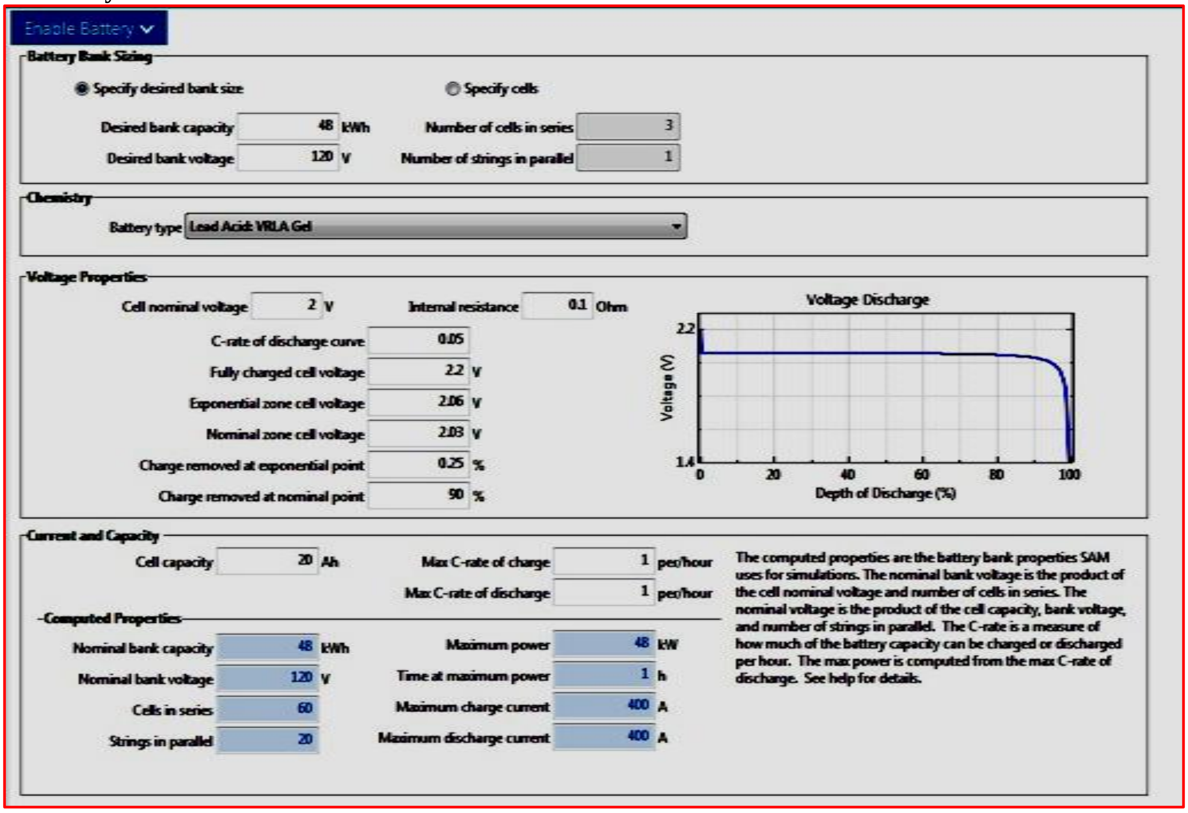
3.2 Module Data

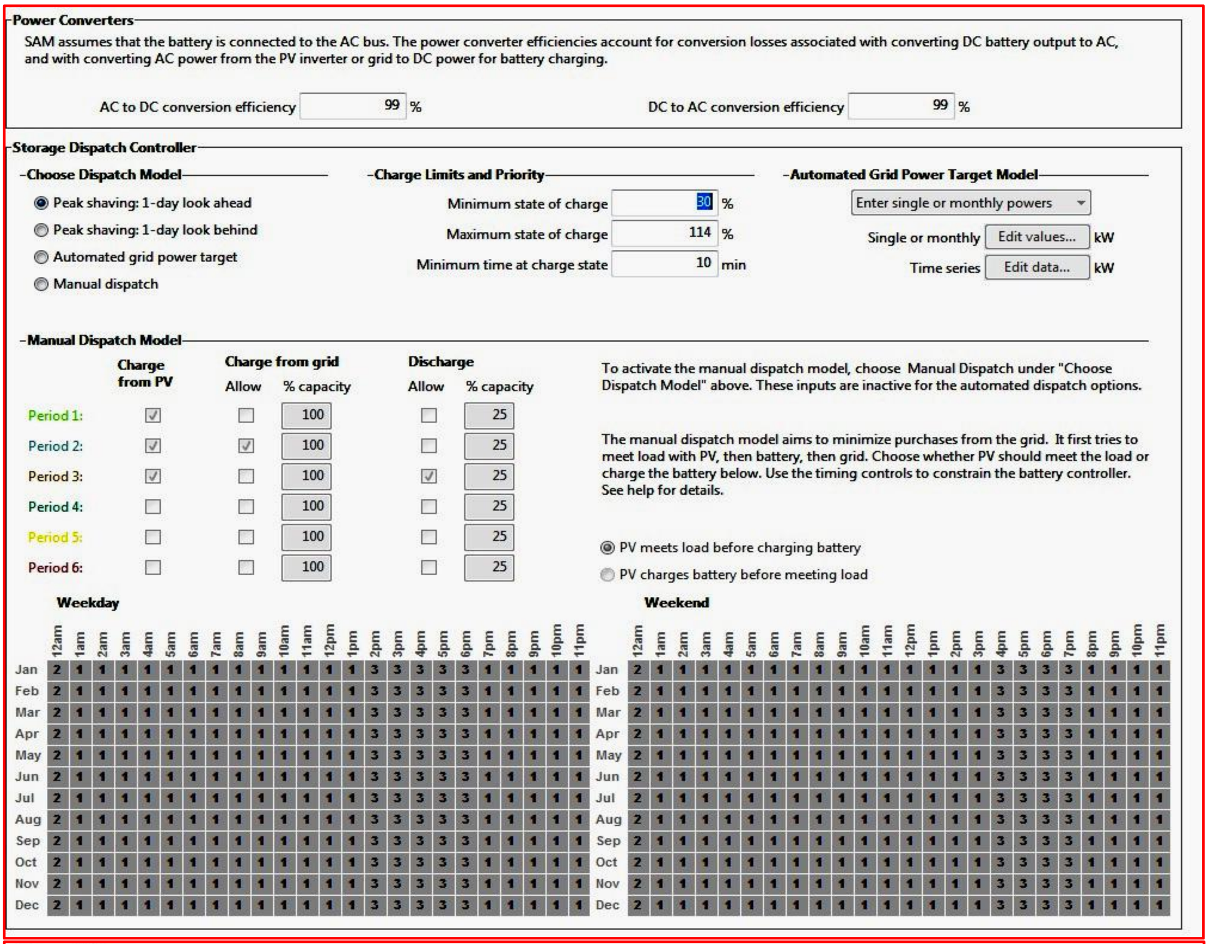


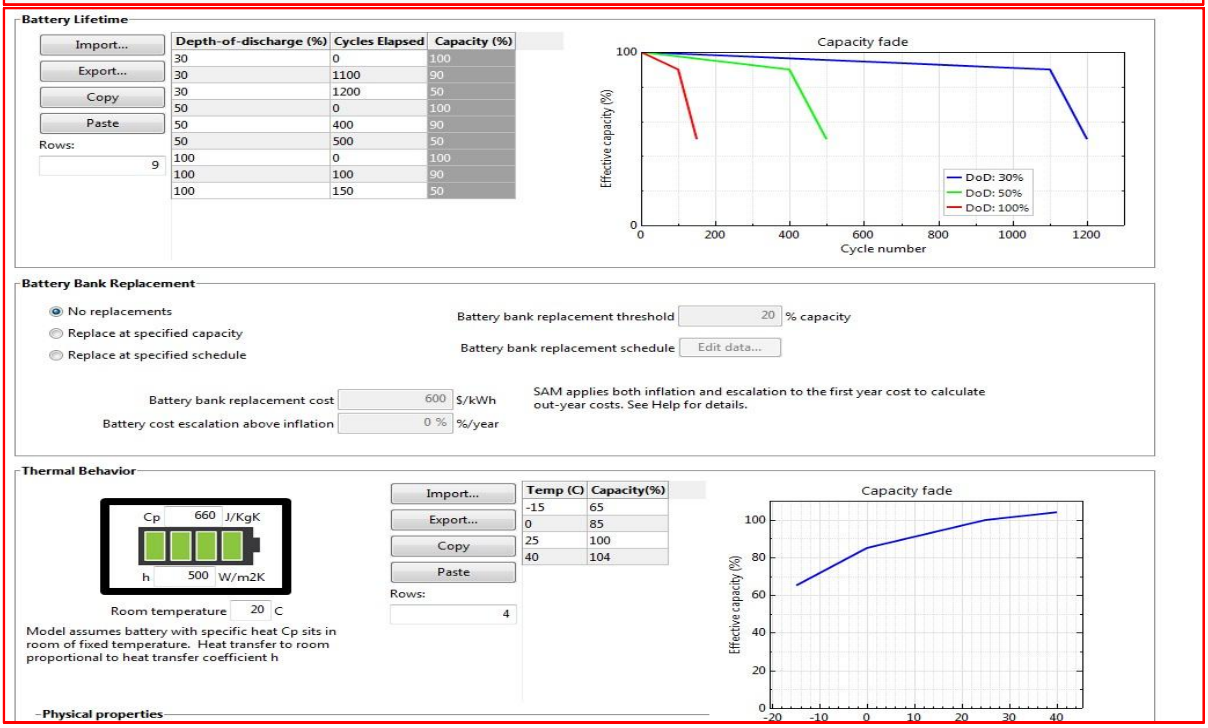
3.3 Inverter Data



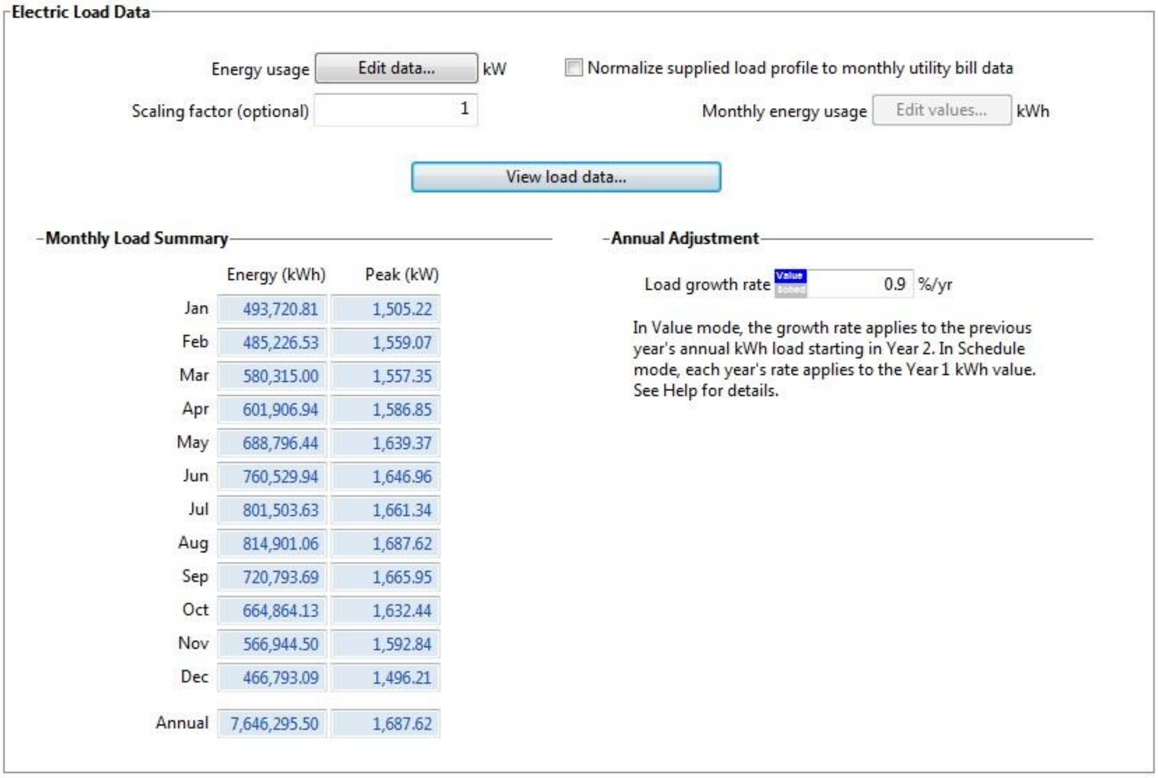
3.4 Battery Data




Power Converters
SAM assumes that the battery is connected to the AC bus. The power converter efficiencies account for conversion losses associated with converting DC battery output to AC, and with converting AC power from the PV inverter or grid to DC power for battery charging.
AC to DC conversion efficiency 99 %
DC to AC conversion efficiency 99 %
Storage Dispatch Controller
Choose Dispatch Model
Peak shaving: 1-day look ahead
Peak shaving: 1-day look behind
Automated grid power target
Manual dispatch
Charge Limits and Priority
Minimum state of charge 30 %
Maximum state of charge 114 %
Minimum time at charge state 10 min
Automated Grid Power Target Model
Enter single or monthly powers
Single or monthly Edit values... kW
Time series Edit data... kW
Manual Dispatch Model
Charge from PV
Charge from grid
Allow % capacity
Discharge
Allow % capacity
Period 1:
Period 2:
Period 3:
Period 4:
Period 5:
Period 6:
To activate the manual dispatch model, choose Manual Dispatch under "Choose Dispatch Model" above. These inputs are inactive for the automated dispatch options.
The manual dispatch model aims to minimize purchases from the grid. It first tries to meet load with PV, then battery, then grid. Choose whether PV should meet the load or charge the battery below. Use the timing controls to constrain the battery controller. See help for details.
PV meets load before charging battery
PV charges battery before meeting load
Weekday
Weekend


Battery Lifetime
Import...
Export...
Copy
Paste
Rows: 9
Depth-of-discharge (%) Cycles Elapsed Capacity (%)
30 0 100
30 1100 90
30 1200 50
50 0 100
50 400 90
50 500 50
100 0 100
100 100 90
100 150 50
Capacity fade
Effective capacity (%)
Cycle number
DoD: 30%
DoD: 50%
DoD: 100%
Battery Bank Replacement
No replacements
Replace at specified capacity
Replace at specified schedule
Battery bank replacement threshold 20 % capacity
Battery bank replacement schedule Edit data...
Battery bank replacement cost 600 $/kWh
Battery cost escalation above inflation 0 % %/year
SAM applies both inflation and escalation to the first year cost to calculate out-year costs. See Help for details.
Thermal Behavior
Cp 660 J/KgK
h 500 W/m2K
Room temperature 20 C
Model assumes battery with specific heat Cp sits in room of fixed temperature. Heat transfer to room proportional to heat transfer coefficient h
Import...
Export...
Copy
Paste
Rows: 4
Temp (C) Capacity(%)
-15 65
0 85
25 100
40 104
Capacity fade
Effective capacity (%)
Physical properties

3.5 Load Data


Electric Load Data

Energy usage [Edit data...] kW

Normalize supplied load profile to monthly utility bill data

Scaling factor (optional) 1

Monthly energy usage [Edit values...] kWh

View load data...

Monthly Load Summary

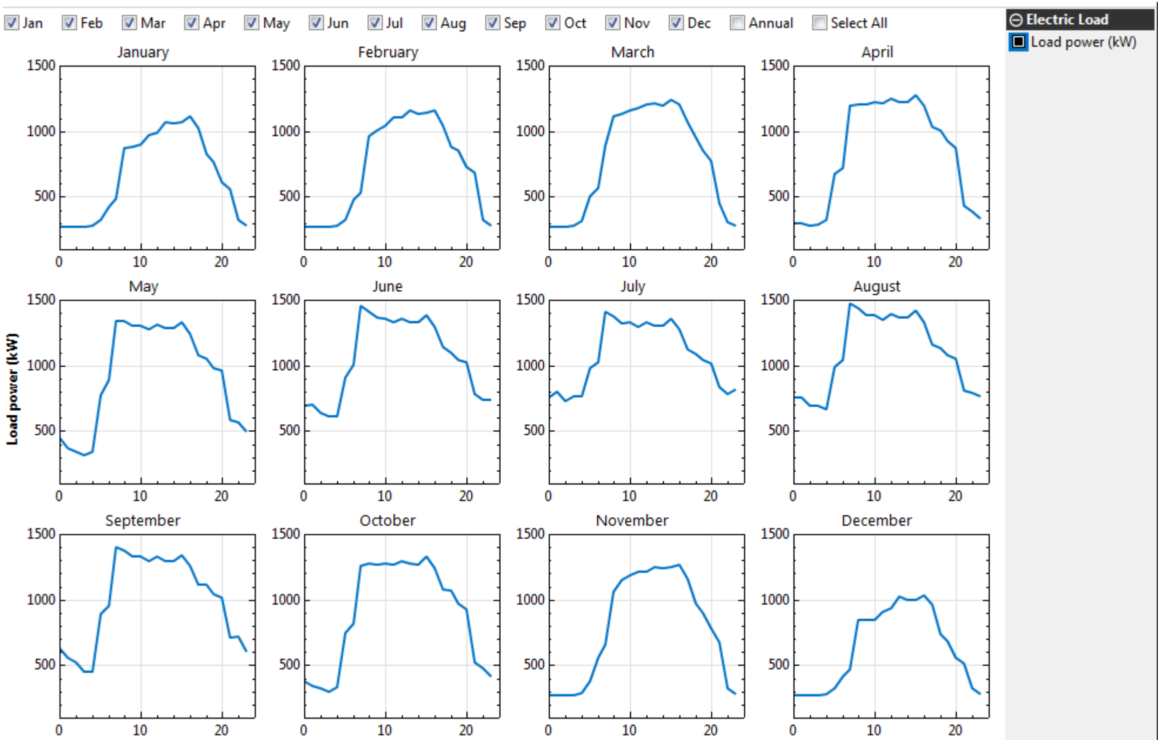
	Energy (kWh)	Peak (kW)
Jan	493,720.81	1,505.22
Feb	485,226.53	1,559.07
Mar	580,315.00	1,557.35
Apr	601,906.94	1,586.85
May	688,796.44	1,639.37
Jun	760,529.94	1,646.96
Jul	801,503.63	1,661.34
Aug	814,901.06	1,687.62
Sep	720,793.69	1,665.95
Oct	664,864.13	1,632.44
Nov	566,944.50	1,592.84
Dec	466,793.09	1,496.21
Annual	7,646,295.50	1,687.62

Annual Adjustment

Load growth rate 0.9 %/yr

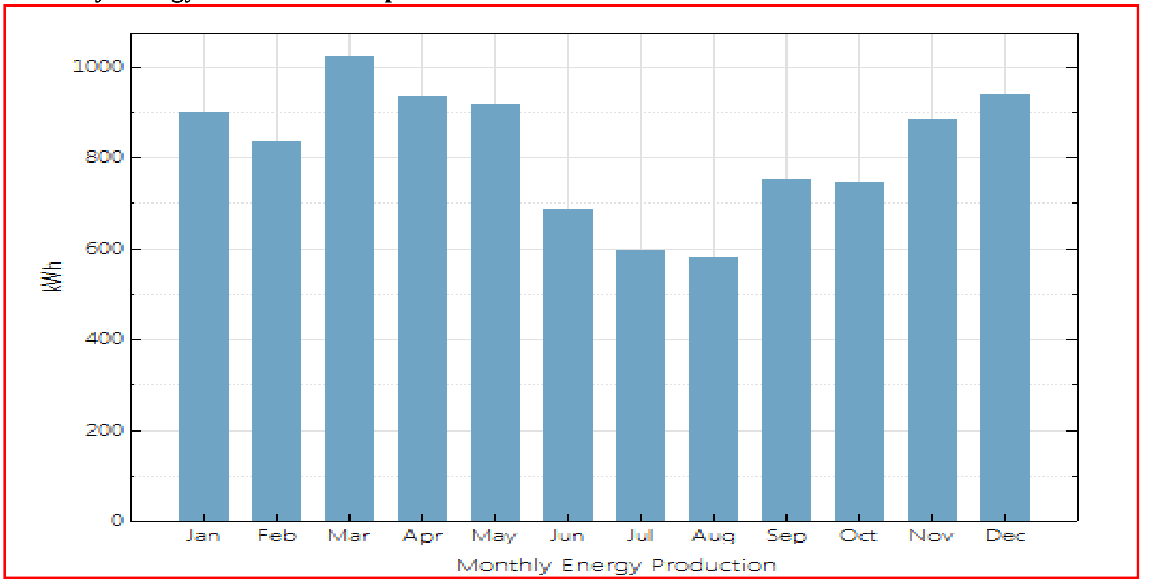
In Value mode, the growth rate applies to the previous year's annual kWh load starting in Year 2. In Schedule mode, each year's rate applies to the Year 1 kWh value. See Help for details.

3.6 Load Curves

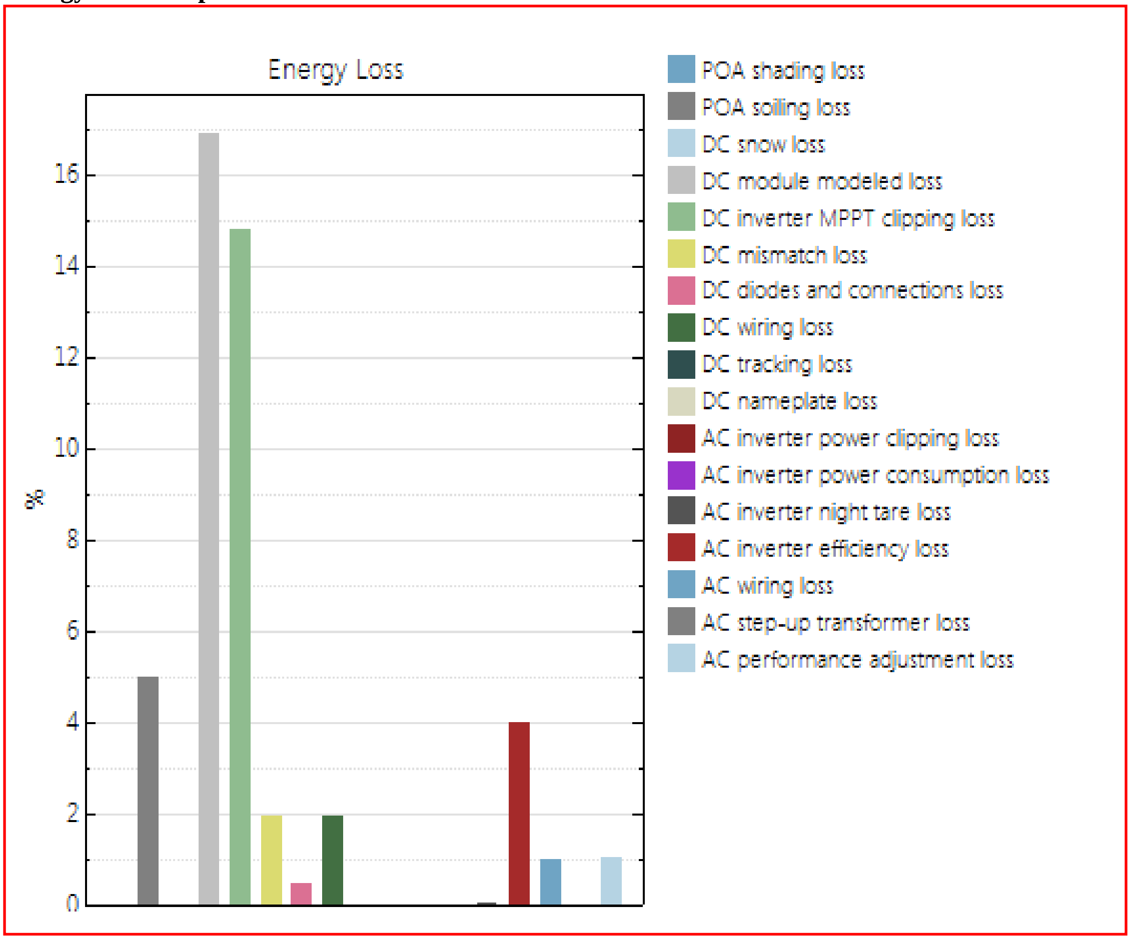


IV. SIMULATION RESULTS

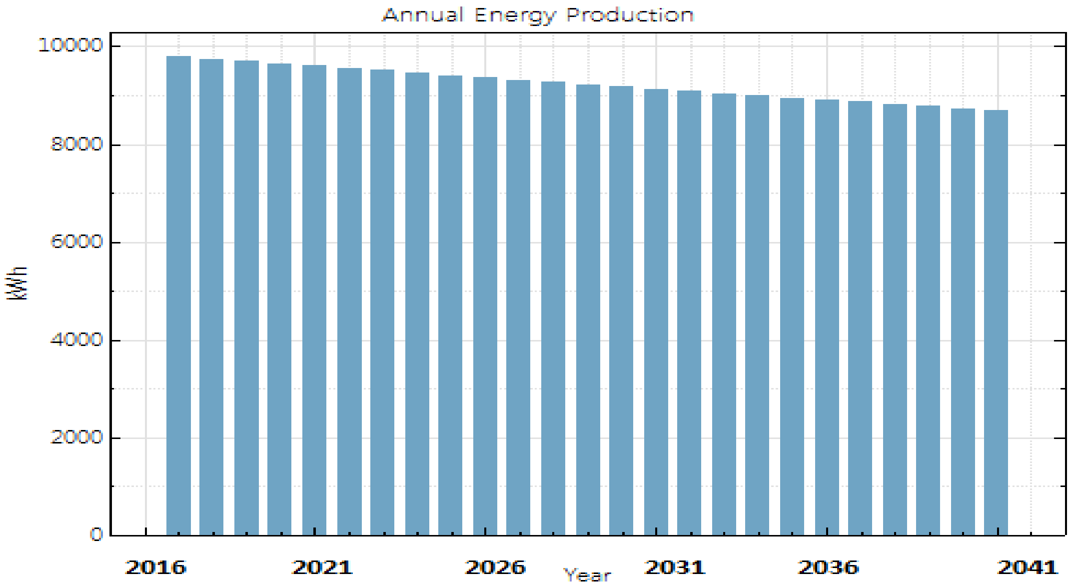
4.1 Monthly Energy Production Graph



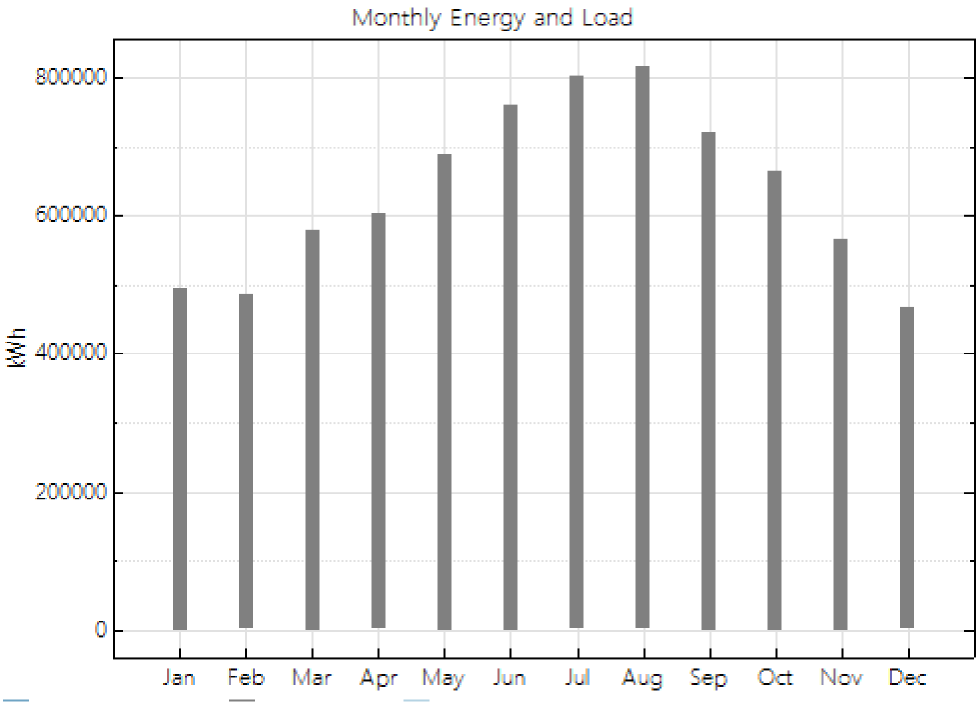
4.2 Energy Loss Graph



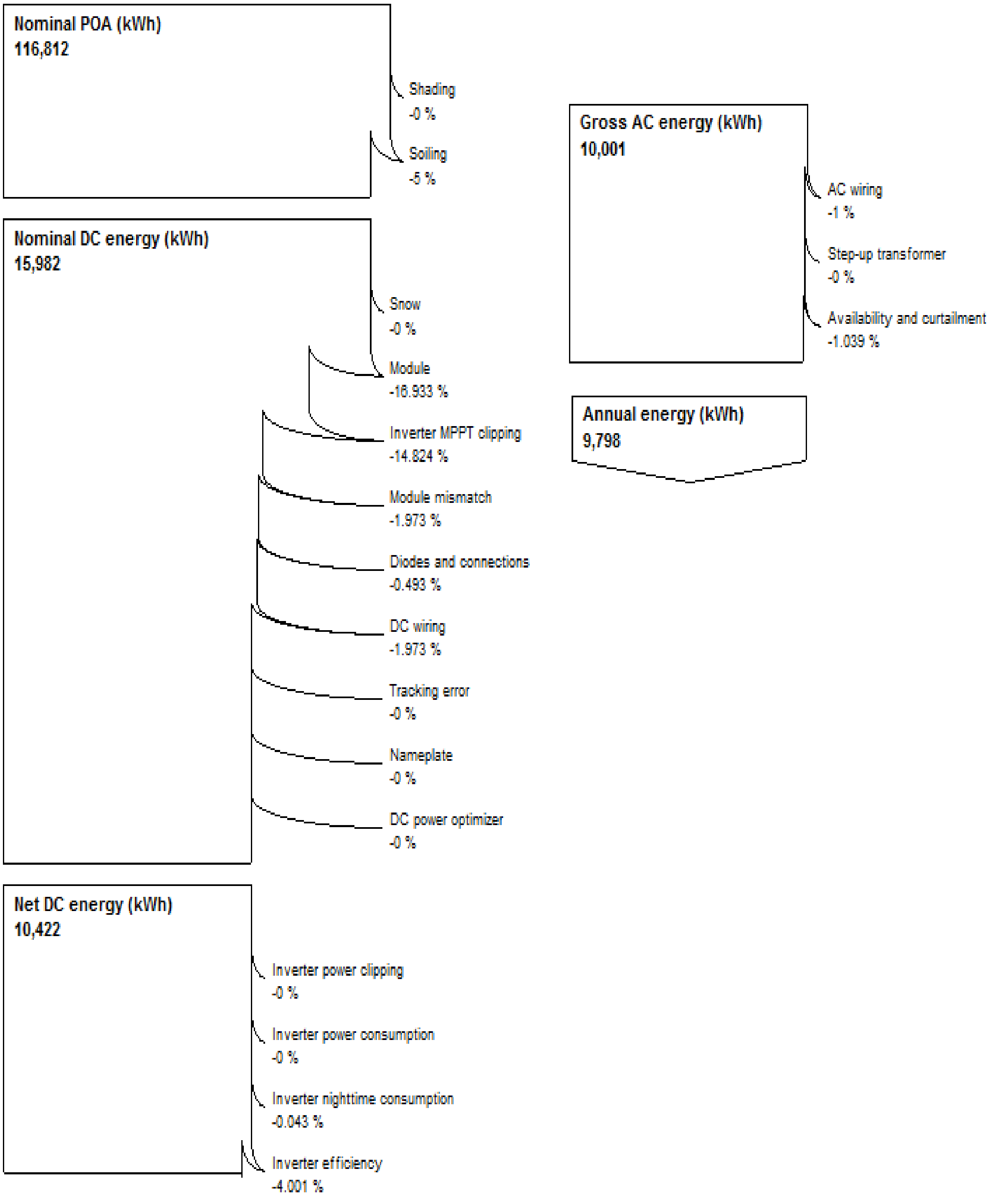
4.3 Annual Energy Production Graph



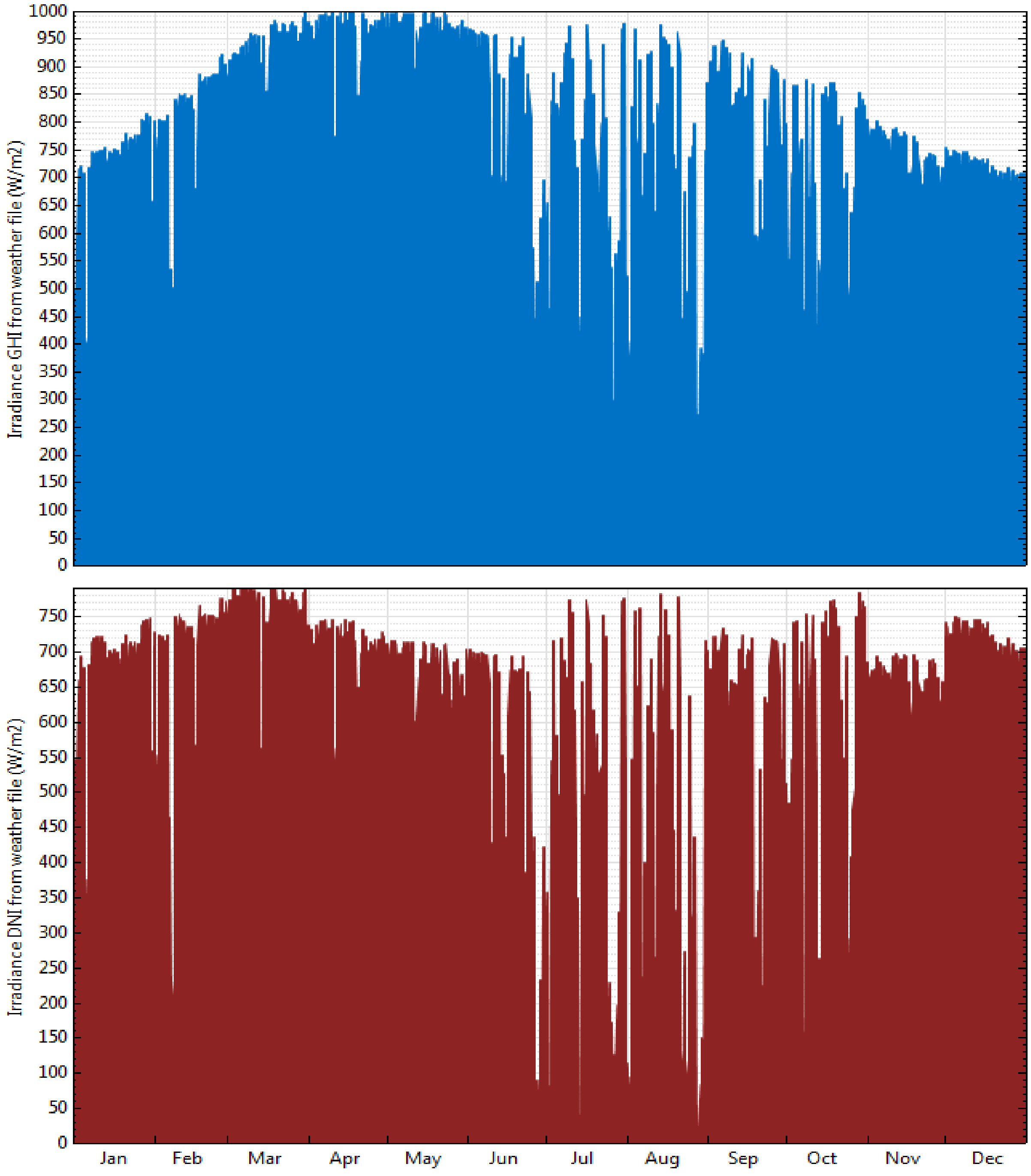
4.4 Monthly Energy and Load Graph



4.5 Losses Data



4.6 Irradiance Report in W/Sq.Meter from Weather File



V. CONCLUSION

The loads are variable in nature, so to be in a safer side, the system is designed for 8246 Watts. The 400 Ah batteries is sufficient to supply load for 8-9 hours when an average sunlight is available for 5-6 hours a day. The solar power conditioning unit provides battery charging either through solar or grid. The load curves, Irradiance data and losses curve are enough to define complete system characteristics. The system is only grid connected and one way i.e. grid is only used for battery charging and grid is not supplied through this system. Finally, Solar is the future of energy and If the wireless power transmission techniques are developed in future. Then energy from sun will be available all the time as modules are installed at orbits.

References

Journal Papers:

[1]. *Grid-Connected Photo Voltaic System Design for Koya Software Engineering Department in Iraq by Ari A. Abdurrahman published at International Journal of Engineering Trends and Technology (IJETT) – Volume 10 Number 2 - Apr 2014*

Books:

[2]. *Non Conventional Energy Sources by G.D. Rai*
[3]. *"Solar PV Manual" by Chetan Singh Solanki*.

Websites:

[4]. *www.ccs.neu.edu/home/feneric/solar.html, Eric W Brown, "An Introduction to Solar Energy"(accessed in April, 2016).*
[5]. *www.mnre.gov.in/file-manger/annual-report/20142015/EN/Chapter%204/Chapter_4.html (accessed in April, 2016).*
[6]. *www.creda.in CREDA (Chhattisgarh Renewable Energy Development Agency) is a only agency which performs renewable energy installation and maintenance tasks as per MNRE.*