Design and Simulation Analysis of 1 MWp Grid Connected Photovoltaic System Floating over Lake Nasser by using PV SYST Software

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ABSTRACT

This study aimed at developing a standard procedure for the design of floating PV energy system at the Lake Nasser's surface for the production of solar energy. The performance of the connected solar PV system was also simulated over the design of large-scale system using PV Syst. software. The project began with a prefeasibility study of a grid-conducted solar PV system using PV Syst. software which has a broad database of meteorological data including global daily horizontal solar irradiance and also a database of various renewable energy systems components from different manufacturers. An extensive literature review of solar PV systems with a special focus on grid-connected systems was conducted after which the procedure for the design of institutional large-scale grid connected solar PV systems was developed. The technical and financial performances of the grid-connected solar PV system were simulated using the PV Syst software.

Keywords: PV Syst. Software, Lake Nasser, Floating PV, Solar Irradiance.

1. INTRODUCTION

Lake Nasser is located in one of the hottest areas in the world as shown in Fig. 1, with an average daily solar energy of about 6.72 kWh/m^2 global Horizontal Irradiance (GHI), while average Direct Normal Irradiance (DNI) reaches 7.92 kWh/day. The yearly average DNI power is between 320 to 340 W/m^2, while the yearly average GHI power is between 280-290 W/m^2. The average PV potential in the Aswan region is estimated to be 2455 kWh/yr per square meter. However, the average daily incident solar energy experiences some seasonal variation over the course of the year. The brighter period of the year lasts for 3.9 months, from April 28 to

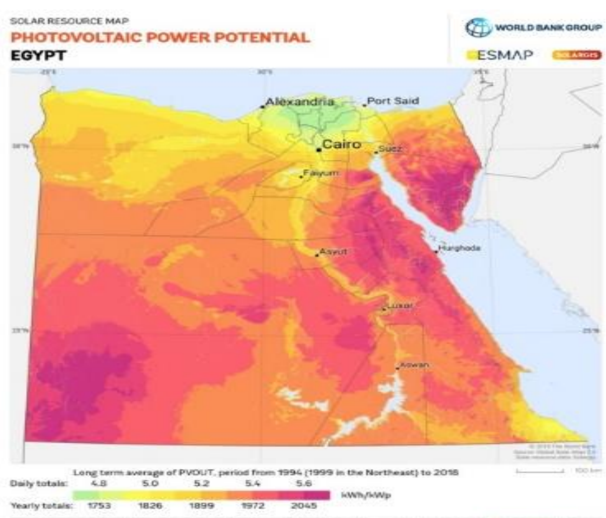


Fig. 1 Average daily GHI solar irradiation in kWh/day

August 25, with an average daily incident shortwave energy per square meter above 7.6 kWh. The brightest day of the year is June 22, with an average of 8.4 kWh. The darker period of the year, from November 9 to January 31, has an average daily incident shortwave energy per square meter below 5.3 kWh. The average monthly sun-hours are about 322 hours/month as shown in Fig.2.

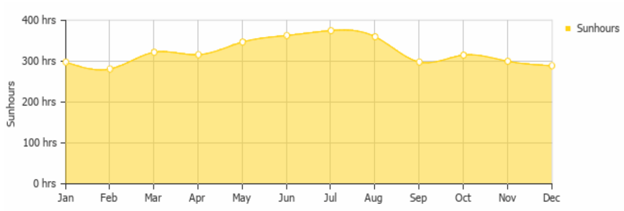


Fig.2 The average monthly sun hours

On average, July is the sunniest, while February has the lowest amount of sunshine. The average annual amount of sun hours is 3865.0 hours for 2018. The average in July and August exceed 380 sun hours. With low-cost PV technology of 21% efficiency, we expect an average daily solar electric energy of 1.41 kWh/m^2.

In inland installations, the reflections from the surrounding hot land surface contribute to the overheating of land PVs and reduces its efficiency. The temperature has a negative effect on the PV cell power. A typical solar cell Power-versus temperature is shown in Fig 10. The figure shows a PV module peak power versus voltage when its temperature varies between 25 ^oC to 65 ^oC in steps of 10 degrees at a constant 1000 Wm² solar irradiance. The

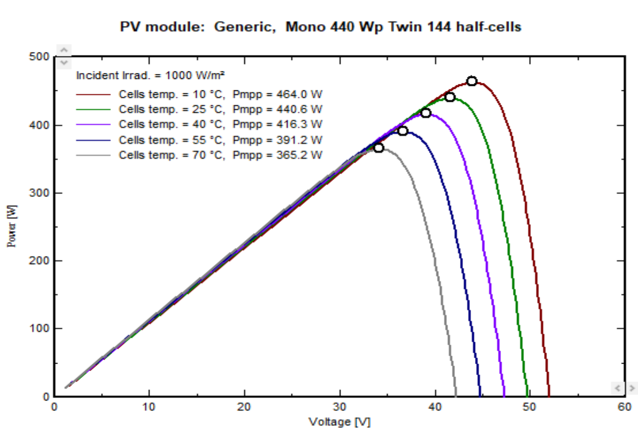


Fig.3 Temperature dependent PV module power output

figure indicates clearly the negative effect of increased panel temperature on the panel output power. In spite of the hot air temperature, especially in summer, Fig. 4 clearly depicts the mild surface water temperature of Lake Nasser compared to the air temperature. Several studies verified the higher efficiency of FPVs installations, between 10-17.5%, over inland installations due to the cooling effect of water bodies. For example, a study of the performance of 100 kW and 500 kW floating PV systems on a reservoir in South Korea have been analyzed. The result showed how both systems provided a higher power generation during the whole test period compared to an overland PV system. The study concluded that the floating PV system has a capacity factor higher from 7.6% to 13.5% than that of the ground-mounted PV system40. A modeling study41 showed that placing solar arrays on the water will increase their energy output and efficiency levels by 8% to 10%. Accordingly, based on the previous studies and the mild water temperature of Lake Nasser, we expect between 10-13 % improvements in efficiency over inland installation operating under the same air temperature.

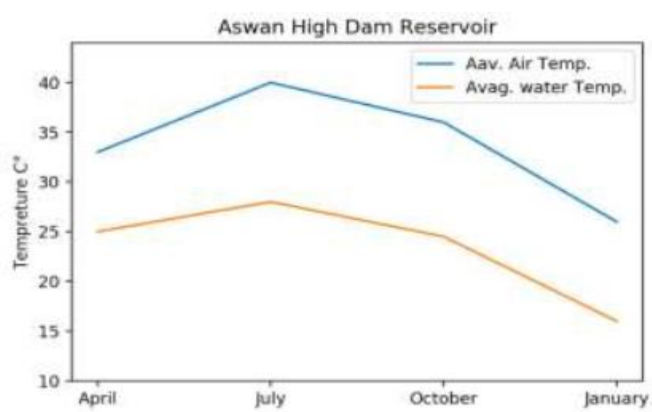


Fig. 4 Lake Nasser surface temperature compared with air temperature

Photovoltaic systems are solar energy supply systems, which convert sunlight directly to electricity. The chief component in PV systems is the solar panel which is formed by putting together several PV cells. Putting together several PV cells forms a PV module; several modules form arrays and several arrays form panels. The modular nature of PV cells makes it possible for them to be used for a wide range of power applications ranging from a few milliwatts in wrist watches and scientific calculators to several megawatts in central power stations. Solar cells are usually made of semiconductor materials such as silicon, gallium arsenide, cadmium telluride or copper indium diselenide (DGS, 2008). Solar cells come in two major forms based on the nature of the material used in their production. The two main forms are crystalline solar cells and thin film solar cells. Crystalline solar cells, so far, have the highest conversion efficiencies when it comes to photovoltaic cells and the main types are monocrystalline and polycrystalline cells (DGS, 2008). Thin film cells, although less efficient than crystalline silicon offer greater promise for large-scale power generation because of ease of mass-production and lower materials cost. The commonest example of thin film cells is the amorphous silicon cell (DGS, 2008). Photovoltaic systems can be grouped into two main groups; namely off-grid systems and grid-connected systems (DGS, 2008).

Off-Grid Systems

Off-grid PV systems, as the name implies, are systems that are not connected to the public electricity grid. These systems require an energy storage system for the energy generated because the energy generated is not usually required at the same time as it is generated (DGS, 2008). In other words, solar energy is available during the day, but the lights in a stand-alone solar lighting system are used at night so the solar energy generated during the day must be stored for use in the night. They are mostly used in areas where it is not possible to install an electricity supply from the mains utility grid, or where this is not cost-effective or desirable. They are therefore preferable for developing countries where vast areas are still frequently not supplied by an electrical grid. Off-grid systems are usually employed in the following applications; consumer applications such as watches and scientific calculators, industrial applications such as telecommunications and traffic signs and remote habitations such as solar home systems and water pumping applications. **A typical off-grid system comprises the following main components:**

• Solar PV Modules: these convert sunlight directly to electricity.

• Charge Controllers: manage the charging and discharging of the batteries in order to maximize their lifetimes and minimize operational problems

• Battery or Battery Bank: Stores the energy generated by the PV modules

• Inverter: converts the DC current generated by the solar PV modules to AC current for AC consumer load (DGS, 2008).

Grid-Connected PV Systems

Grid-connected systems are systems connected to a large independent grid usually the public electricity grid and feed power directly into the grid. These systems are usually employed in decentralized grid-connected PV applications and centralized grid-connected ATPS (2013). Decentralized grid-connected PV applications include rooftop PV generators, where the PV systems are mounted on rooftops of buildings and incorporated into the building's integrated system (DGS, 2008). In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is served by the PV system and the excess is fed into the grid; their capacities are usually in the lower range of kilowatts (DGS, 2008).

A typical grid-connected PV system comprises the following components:

• Solar PV Modules: these convert sunlight directly to electricity.

• Inverter: converts the DC current generated by the solar PV modules to AC current for the utility grid.

• Main disconnect/isolator Switch

• Utility Grid

2. ABOUT THE PROGRAMS:

There exist several software's to simulate and design the solar PV systems namely: PVSYST, PVGIS, Helioscope, Arc GIS, Google Sketch up, SolarMAT, HOMER and so on. Among the aforementioned software's, PVSYST is little bit easier to analyze and design. Helioscope is also considered to be a good option in order to design a solar PV system, but it is cloud computing based platform and commercially very expensive. Google Sketch up is mainly used to design 3D pictures of PV system installations. The advantage of PVSYST is that, it gives us the information about the power output, sankey diagram representation describing about the various losses in the system output, generates report for future investigations and user friendly environment.

3. LITERATURES REVIEWS

Anand Mohan et.al mainly focused on the development of photovoltaic power system in Himachal Pradesh area and explained about the economical aspects involved in the installation of the power plant. Also, the authors illustrated about the load analysis considering the power vitality [1].

C. P. Kandasamy et.al elucidated about the solar potential assessment using PVsyst. software for the prevailing geographical conditions in southern parts of Tamil Nadu state. The performance of 1000 kWp grid connected photovoltaic system has been considered for simulation study. The aspects like energy production and other cost parameters were discussed in the paper [2].

Nallapaneni Manoj Kumar et.al explained about the 100kWp grid connected system which is suitable for catering the needs of electrical power supply for an academic institution [3].

Paras Karki et.al focused on comparing the performance aspects of grid connected systems installed in the areas of Kathmandu and Berlin[4].

The authors in [5] focused on the aspects of design and installation of grid based PV system in Madan Mohan Malaviya University of Technology which is located in Gorakhpur, India. The authors in [6] illustrated about the importance of HOMER and SolarMAT softwares in designing the hybrid based PV systems. They also explained about design criteria of solar PV systems by representing the CO_2 emission levels.

II. ABOUT PVSYST

The PVSYST is a better simulation tool which facilitates various options like designing a grid connected PV system, standalone PV system, small scale energy production for pumping applications and only DC power production. Depending upon the requirement, the user can select a particular design area and mitigate for solution. The software also provides an opportunity to have a preliminary design for marketing and promotion of PV system installations to the consumers. The Detailed design is for solar installers and it can generate the results such that, based on the simulation results one can initiate the process of setting up a solar PV plant.

III. DESIGN METHODOLOGY

The steps involved in simulation design are illustrated in the form of flow chart below:

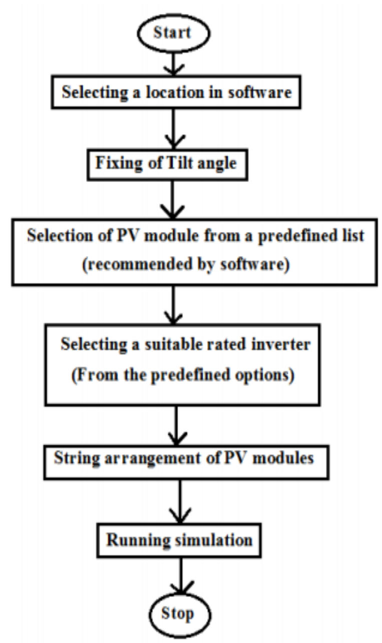


Fig. 5 Flow chart of design procedure

The various steps involved in designing the grid connected solar PV system in simulating platform are explained below in detail in a user friendly manner.

A. Specifying the geographical site parameters

Consider an area where we need to install a PV based power plant. The most important aspect is to select the geographical area and should be linked with any data source like NASA-SSE satellite data which is specified by software. The following table depicts the geographical site parameters of Vishakhapatnam region in Andhra Pradesh which is predefined by software itself. This data could be considered as reference data for any area in Andhra Pradesh. The advantage of the PVSYST is that, after selecting the region of installation, the software itself will link the latitude and longitude data which are taken from NASA-SSE satellite station automatically.

Table- I: Monthly geographical conditions

	Global horizontal irradiation kWh/m²/mth	Horizontal diffuse irradiation kWh/m²/mth	Temperature °C
January	133.6	36.0	16.5
February	147.0	36.1	17.4
March	195.9	45.6	21.4
April	205.5	53.1	26.8
May	222.9	59.8	30.5
June	225.6	55.8	32.1
July	226.0	59.2	32.7
August	213.6	56.7	32.6
September	183.6	51.0	31.9
October	160.6	46.2	28.5
November	135.3	36.0	22.7
December	125.6	34.1	18.1
Year	**2175.1**	**569.6**	**25.9**

B. Block diagram of grid connected PV system

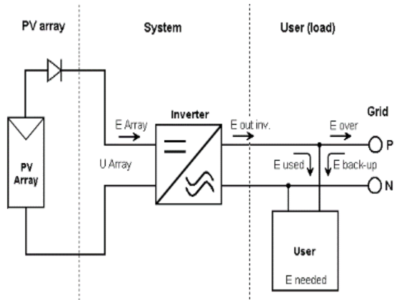


Fig. 6 Grid connected PV system schematic representation

A. Fixing of Tilt and Azimuth angle

The Tilt angle can be modified depending upon the place of installation and also to maximize the yield of solar energy. The Tilt angle is kept around **20** degrees. Azimuth angle is specified as **zero** in simulation.

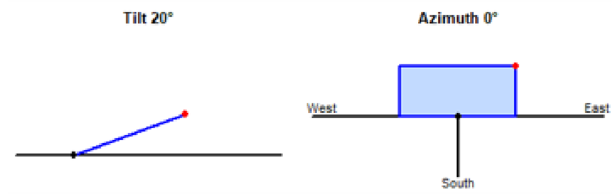
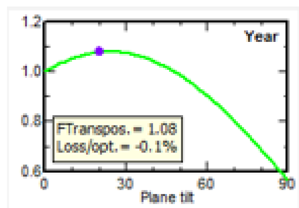


Fig. 7 Tilt and azimuth angle fixation

The performance curve of Tilt angle and plane orientation is shown below in Fig. 7 and Fig. 8 respectively.



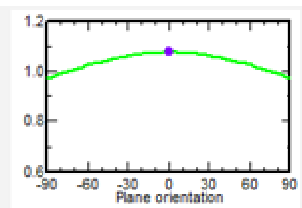


Fig. 7 **Fig. 8**

B. Selecting a suitable PV module:

Depending upon the economic viability option, ageing factor and performance criteria, a PV module could be chosen among the available list which is predefined in the software. **440Wp 35V Si-mono Twin 144 half-cells** PV model has been selected for simulation to obtain better performance output.

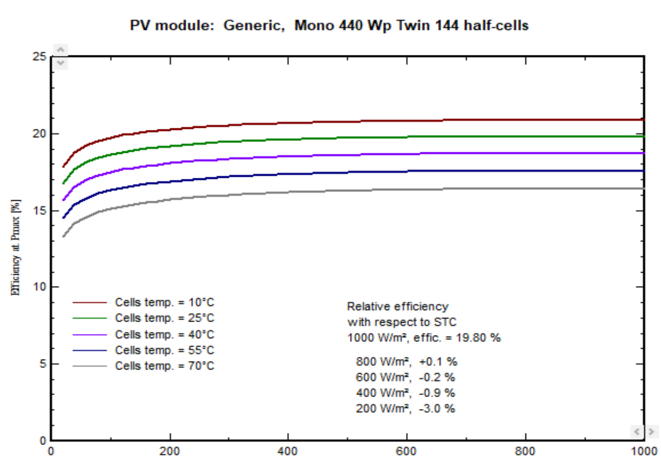


Fig. 9 Optimized Si-mono Twin Solar PV module curves

Table- II: PV model values

440Wp 35V Si-mono Twin 144 half-cells model parameters at Tref = 25 °C	
SHUNT RESISTANCE (*Rsh*)	1000 ohm
SERIES RESISTANCE (*Rs*)	0.23 ohm
NOMINAL POWER (STC)	440 Wp
SHORT CIRCUIT CURRENT (Isc)	11.1 A
OPEN CIRCUIT VOLTAGE (Voc)	49.7 V
CURRENT AT MPP (Impp)	10.7 A
VOLTAGE AT MPP (Vmpp)	41.1 V

C. Selecting a suitable Inverter:

An inverter can also be selected from the options specified by the software and the technical feasibilities of available inverters could be examined. **Solectria 545-820 V (Transfo 60 Hz) 750kW SGI 750 XTM** Inverter has been chosen for simulation purpose.

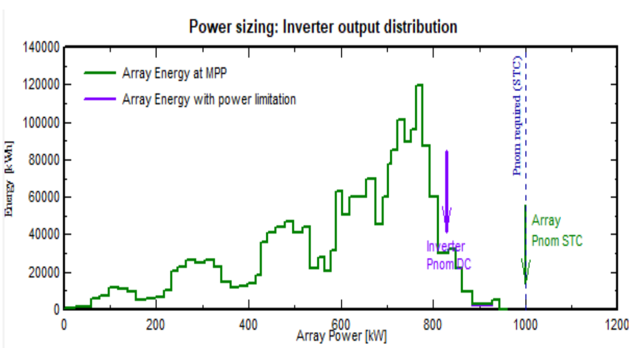


Fig. 10 Power sizing of inverter output

The array voltage sizing can also be depicted as follows:

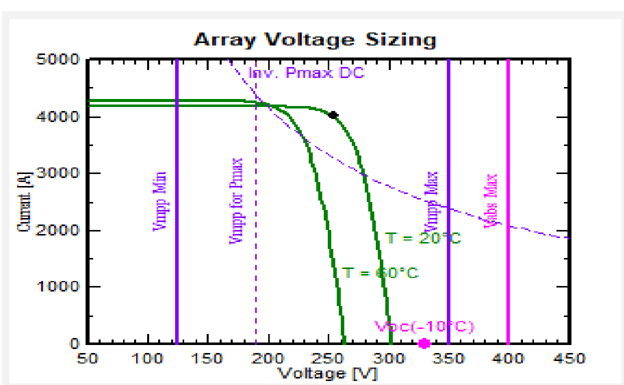


Fig. 11 PV array voltage sizing

D. Number of modules and string arrangement:

The software also suggests us about the optimal string assessment of PV modules. According to this case study, the software recommended the total no. of modules (**2274**). **6** modules in **series** and there should exist **379** strings in **parallel** for getting optimized power output.

G. Efficiency curve at Medium Voltage 615 V

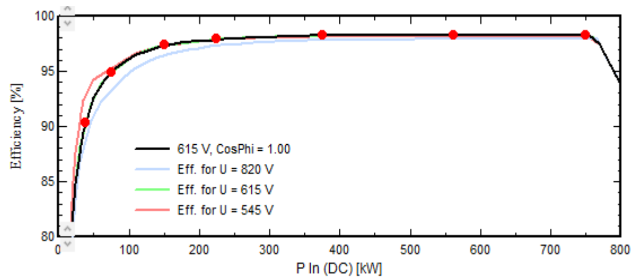


Fig. 12 Efficiency [%] versus P in [DC] [kW] Characteristic's Curve

H. Curve Parameter (Incident Irradiance)

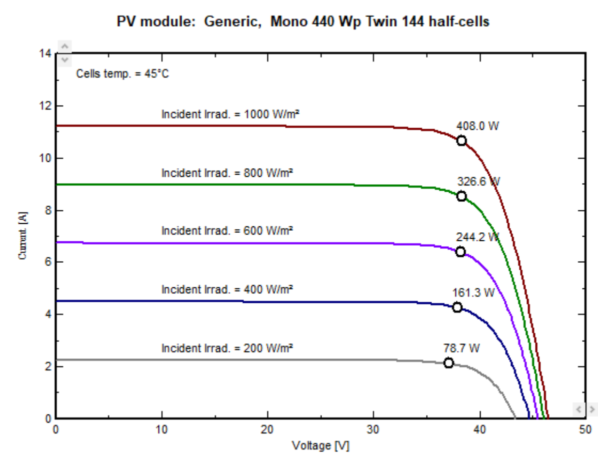


Fig. 13 Current [A] versus Voltage [V] Curve

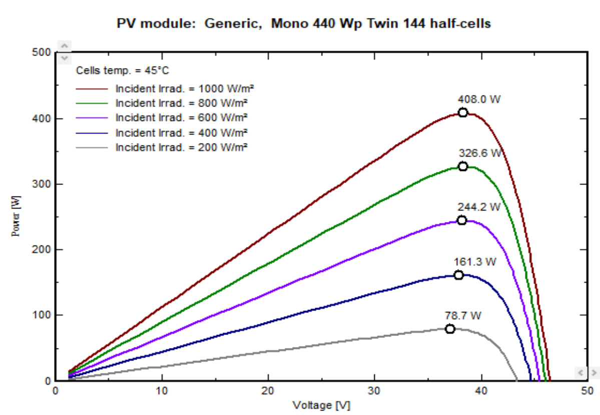


Fig. 14 Power [W] versus Voltage [V] Curve

Model Parameters:

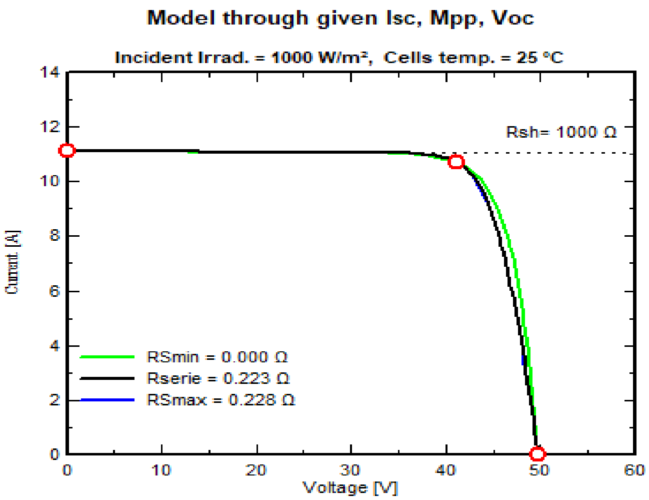


Fig. 15 I-V Characteristic's Curve

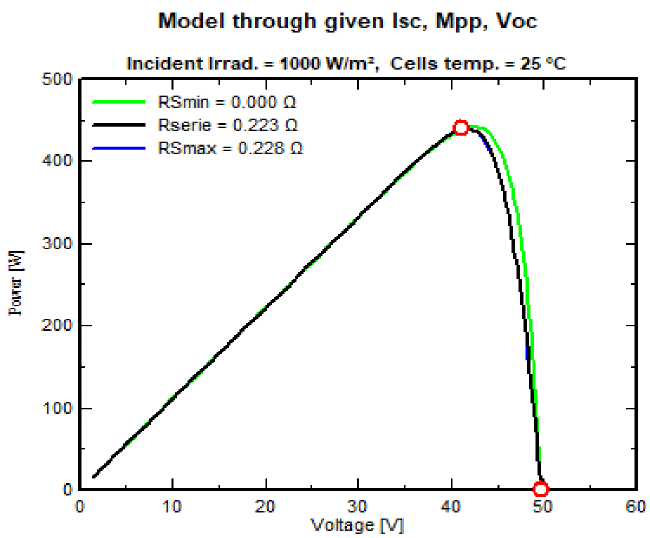


Fig. 16 P-V Characteristic's Curve

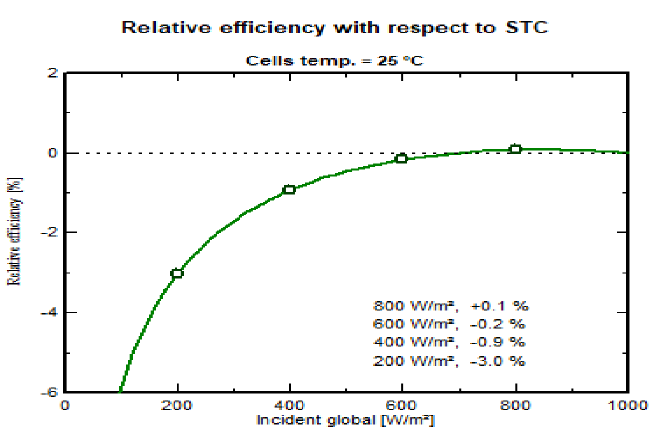


Fig. 17 Relative Efficiency [%] versus Incident Global [W/m^2] Characteristic's Curve

H. Curve Parameter (Battery cell)

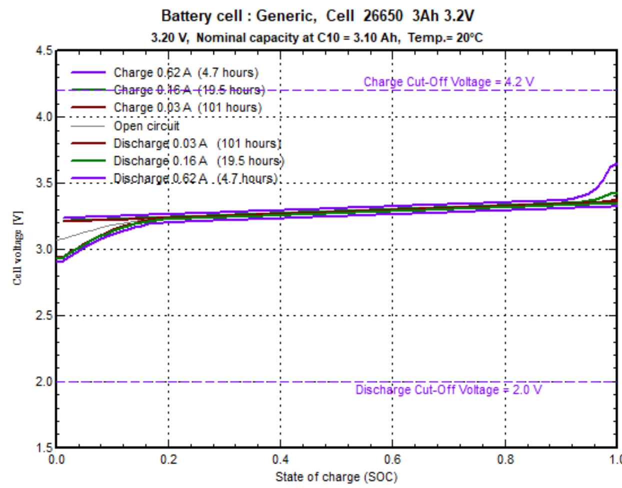


Fig. 18 Charge/Discharge versus SOC

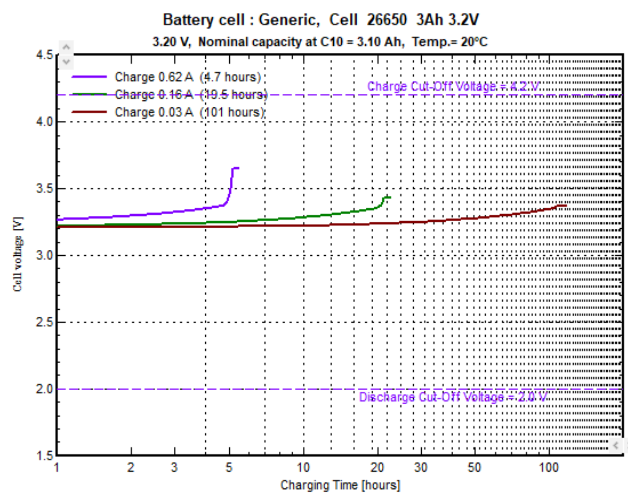


Fig. 19 Charge Voltage versus time

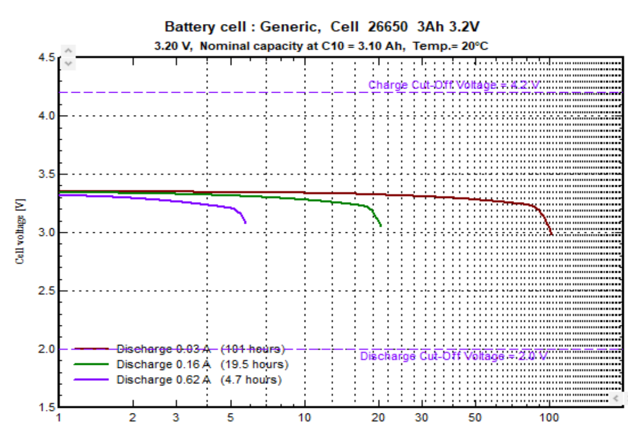


Fig. 20 Discharge Voltage versus time

IV. SIMULATION RESULTS AND DISCUSSIONS

After undergoing the design procedure mentioned above, the model should be simulated and the inferences can be analyzed for assessing the plant efficiency.

Detailed simulation has been performed and obtained various outputs which are represented below for better understanding of the plant installed. The various results such as daily input /output plots, sankey diagram representation of losses, horizon line drawing plot of location chosen, performance ratio data plot, daily energy output plot including the incident variations, array temperature distribution during running conditions, array power distribution plot, normalized productions including the loss changes, plot examining about the sun azimuth and incidence angle are presented below respectively.

A. Beam irradiance distribution

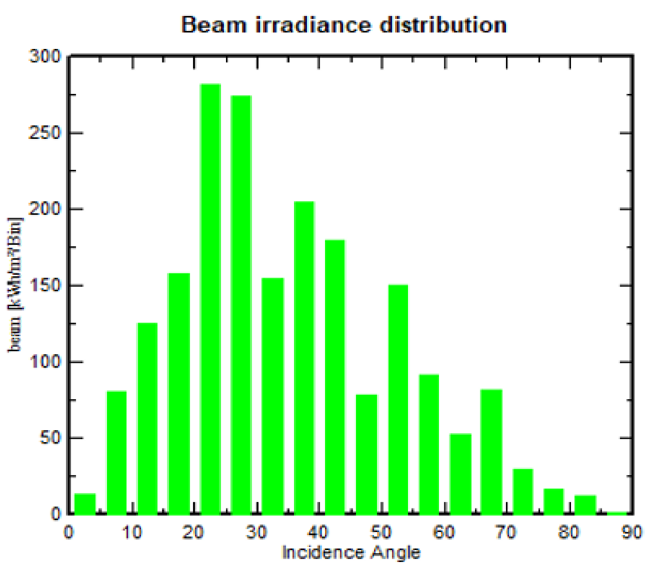


Fig. 21 Beam irradiance distribution as a function of incidence angle

B. Global irradiance distribution

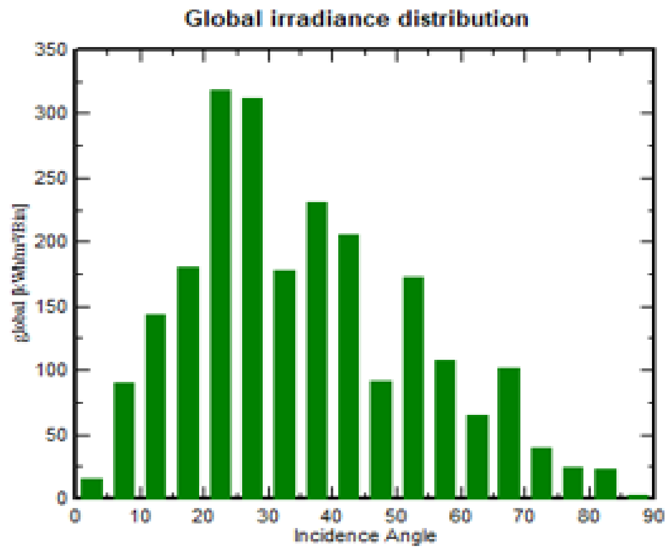


Fig. 22 Global irradiance distribution as a function of incidence angle

A. Daily input / output diagram

The following plot shows the daily variations in the input/output profiles of energy injected into the grid (kWh/day) and the global incidence on the plane (kWh/m^2. day).

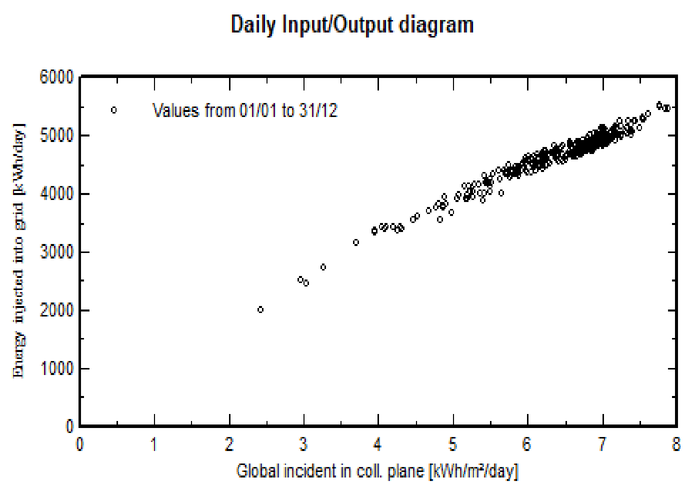


Fig. 23 Energy injected to grid versus global incident plot.

B. Sankey diagram of losses:

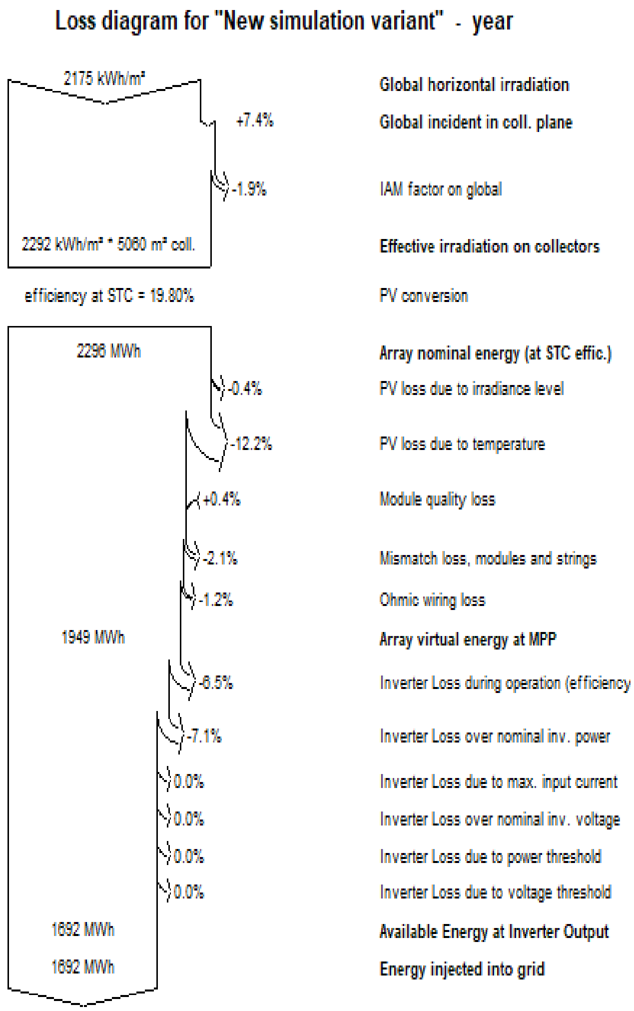


Fig. 24 Sankey diagram simulation outcome

The above diagram represents the energy input and the energy output including step by step loss analysis. Sankey diagram is a very useful tool to examine the plant efficiency. A total of **1692** MWh is the energy injected into the grid as shown in the simulated figure. Array nominal energy is estimated as **2296** MWh. So, a difference of **604** MWh is the total losses of the system.

C. Horizon line drawing:

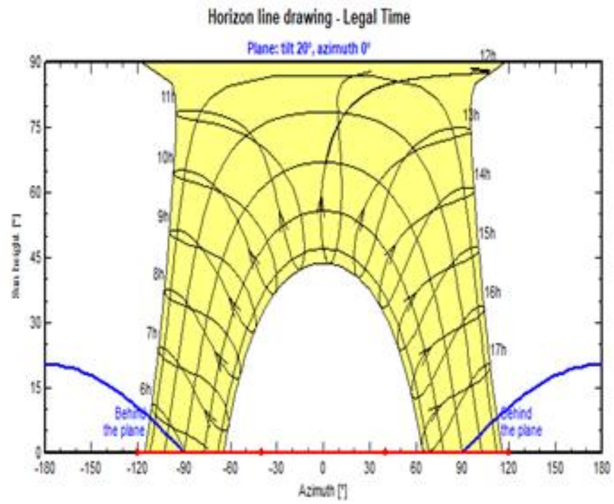


Fig. 25 Horizon (for shadings) line diagram

D. Performance ratio:

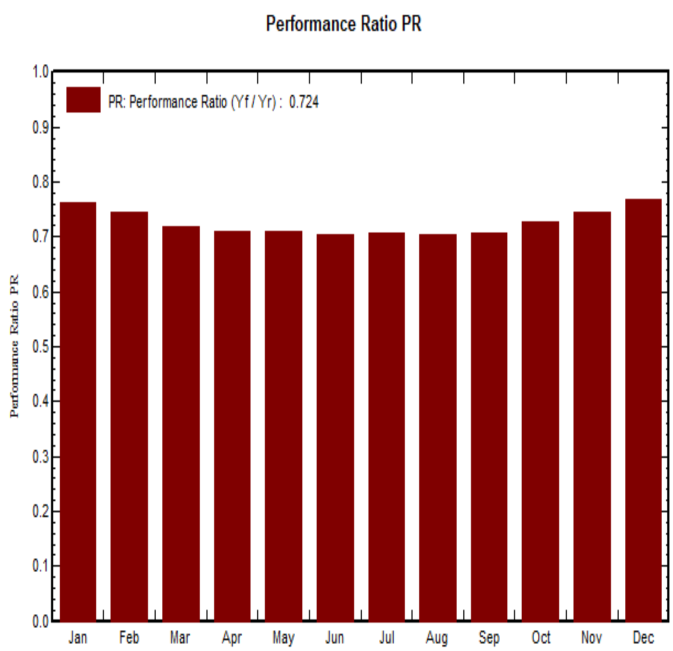


Fig. 26 Performance ratio curve analysis

E. Daily energy output plot:

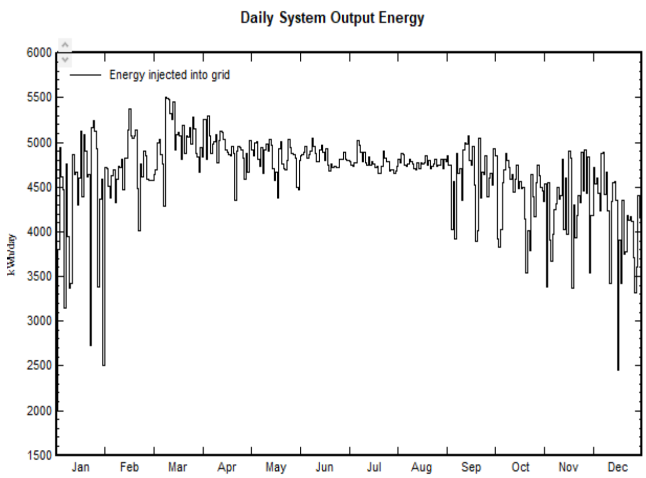


Fig. 27 Daily energy response variations

F. PV array temperature distribution:

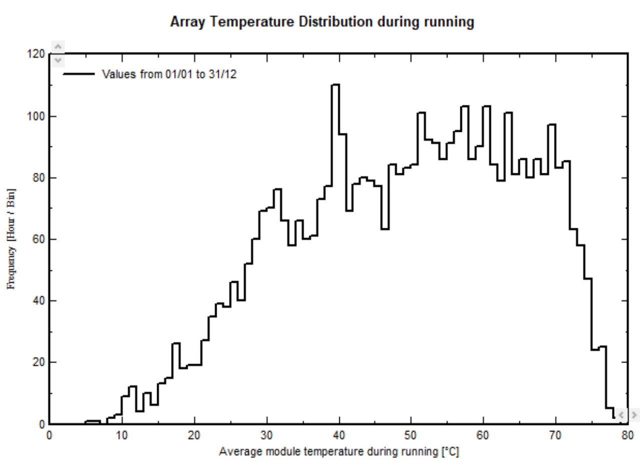


Fig. 28 Temperature distribution of array

E. PV array power distribution:

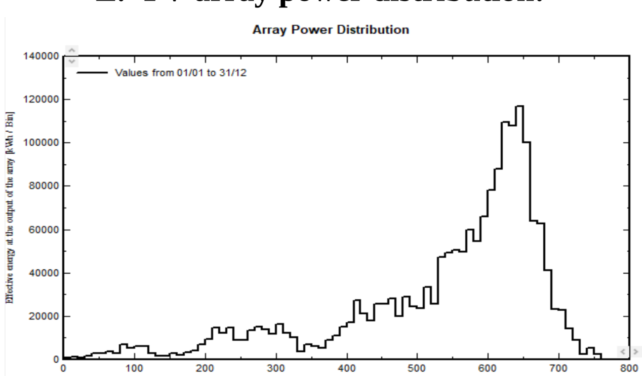


Fig. 29 power distribution of array

H. Sun incidence angle plot including its azimuth:

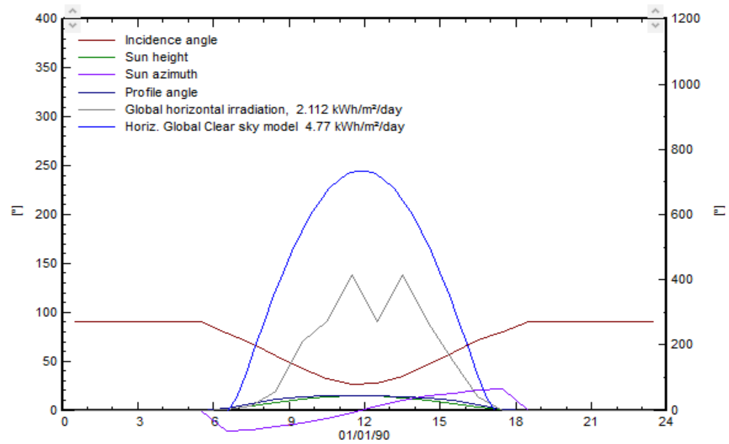


Fig. 30 Incidence plot of sun

I. Normalized power production (per installed kWp):

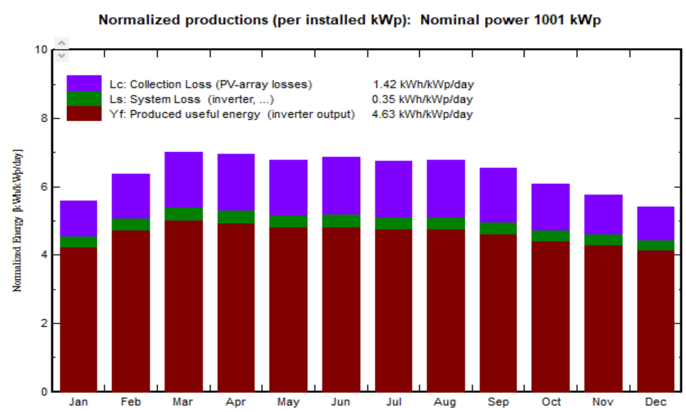


Fig. 31 Normalized power plot

V. CONCLUSION

This paper significantly emphasized on simulating a **1MWp** solar based Photovoltaic power plant and explained the design procedure to mitigate the issues related to selection of PV modules, inverter power sizing, location selection, strings arrangement etc. one can keep this paper as a reference tool to investigate the installation aspects of grid connected systems. This paper serves as a better guide for the beginners and solar practitioners, who are interested in installing a solar energy based grid connected photovoltaic system and also can estimate various losses in the system accurately with the help of PVSYST software. The major advantage of PVSYST is that, one can generate the complete installation report and examine the power output and losses in the plant.

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