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RESEARCH ARTICLE

PERFORMANCE EVALUATION OF A 67.2 KWP SI-POLY PHOTOVOLTAIC SYSTEM CONNECTED TO THE GRID USING PVSYST TOOL

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Abstract

This paper presents the simulated performance evaluation of a 67.2 kWp grid-connected Si-poly photovoltaic system. This study was carried out to assess the feasibility of installing a photovoltaic system to supply the electrical loads at the Alioune DIOP University of Bambey, Senegal, a public institution. Indeed, the UADB is facing load shedding problems caused by its exorbitant energy consumption. The study system comprises 240 Si-poly modules. Each module has a rated output of 280 Wp. All photovoltaic modules are connected in 12 strings, each string consisting of 20 modules in series. Three solar inverters, each rated at 20 kW, are used for interconnection with the grid via a public meter. For the case study, PVsyst 7.4 is used for simulation. PVsyst 7.4 is a PC software package for the design, dimensioning and data analysis of complete photovoltaic systems. Meteonorm 8.1 meteorological data sets on solar radiation, ambient temperature, wind speed and humidity from the PVsyst database were used for this analysis. In this study, the parameters evaluated were the photovoltaic array's effective energy production, the energy injected into the grid, the performance rate and the normalized energy production per kWp installed. The 67.2 kWp photovoltaic system generates 111.287 MWh/year of DC energy, of which 108.980 MWh/year of AC energy is fed into the grid. The system's annual performance rate is around 81.5%, and the loss diagram over the whole year is also computed.

Introduction:-

Need for reducing GHG emissions and the significant rise in the price of conventional energy fuels have given most countries the opportunity to develop new energy policies. These policies have been designed to promote renewable energy sources in the power sector [1]. Solar energy is currently attracting worldwide attention and playing a key role in the provision of clean, sustainable energy [2]. Further, to promote the use of solar energy on a national scale, the Energy Sector Development Policy Letter (ESDPL) was launched by the Government of Senegal, as part of the implementation of the ECOWAS Renewable Energy Policy (EREP). The ESDPL was signed in February 2008, setting the share of renewable energies in the national energy balance at 15% by 2020 [3]. By 2022, Senegal has already installed 245 MW of solar power [4]. Senegal aims to supply its entire population with energy by 2025, while reducing its dependence on imported fossil fuels. To achieve this goal, the Senegalese government, through the National Agency for Renewable Energy (NARE), has promoted the use of solar energy by offering subsidies to

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homeowners who set up solar power plants. However, there are a number of technical obstacles that need to be taken into account.

It's well known that the solar energy available at a given location is not the same throughout the year, and varies from place to place. Seasonal variations also influence the amount of solar radiation reaching the earth's surface, which has a direct impact on the amount of energy available [5]. This has a direct impact on the amount of energy a solar PV plant can produce [6]. In addition, the types of components used in the solar power plant can have a major influence on the plant's producibility. But the installation method adopted also influences energy production. In addition, for a power plant to operate normally and over the long term, all the above factors need to be taken into account by studying them effectively point by point. For this, it is advisable to have prerequisites on a solar power plant and its operating characteristics under different climates, different component combinations and different installation methods. Given that it's quite difficult to acquire this knowledge in every case, it makes sense to carry out in-depth practical studies or to use computer simulation study facilities. In recent years, researchers have shown that computer simulation studies are more advanced and useful tools for analyzing the operating and performance characteristics of power plants under different climates and capacities. These study methods are even used to evaluate the performance of hybrid renewable energy systems [7, 8]. We conduct a literature review of previous work on the performance and pre-feasibility analysis of a solar power plant, using PVsyst software.

OyaKilci and Murat Koklu (2019) presented the importance of fixed and vriable angle in solar power plants analysis using PVsyst. The authors designed two different systems with fixed and seasonal angular variations. The first study is done with a fixed constant angle of 25°, and the second study with detected angular variations of 10° to 30° in winter and summer. The electricity output of both systems, the specific data and the performance value are calculated. The results of their study showed that the seasonal system performed better, producing 32.2 MWh more per year than the fixed system [9].

B. S. Emmanuel and M. Paul O. (2021) presented the design, simulation and performance evaluation of 30 kwp solar PV grid-connected power system using PVsyst. In their study, the authors employed three-stage methodologies for system performance analysis which are: the specification of the study environment and meteorological data for the system's location in the PVsyst environment, the selection of appropriate data and parameters such as solar module tilt angle, the available component layout area, the module type and inverter type, and finally iterative variants of the simulated design and performance analysis. The results of this simulation study revealed that the system can deliver an energy output of 46.63 MWh/year, with an average performance ratio of 82.67%, and a saving of around 433.6 tons of CO2 emissions annually compared to the emission of a fossil fuel system with the same energy output [10].

A performance evaluation study of three grid-connected solar PV plants, with capacities of 100 kWp, 300 kWp and 2 MWp, in a semi-arid region with a hot, dry climate was carried out by SumitVerma and al. (2021) [11]. This study showed the comparative performance between PV system simulation results with PVsyst and measured plant performance data. The aim of this study was to examine the energy production and performance ratio of the three types of solar power plant in order to identify the reasons for the difference in production between simulation and reality. The actual performance ratios for the three plants of 100 kWp, 300 kWp and 2 MWp are 79.34%, 72.64% and 74.3%, respectively. The simulated performance ratios for the 100 kWp, 300 kWp and 2 MWp plants are 83.72%, 76.85% and 80.9%, respectively. In this study, PV modules perform well in semi-arid regions, with best performance observed during the months of March, April and May. According to the authors, this performance can be improved if awareness is raised of component efficiency, proper tilt angle and choice of site.

A 3 kWp grid-connected solar photovoltaic system is designed, simulated and analyzed by Md. Samiul Islam and al. (2022) in Tetulia, Panchagrah, Bangladesh [12]. The aim of this study was to carry out a feasibility analysis and simulation of a rooftop solar photovoltaic system for a residential consumption of 8.1 kWh/day using PVsystsoftware. The annual performance of the system was shown in terms of energy production on an annual basis, with the highest energy (214.9 kWh) from the rooftop photovoltaic system being sent to the grid in March, while the lowest energy (99.3 kWh) is delivered in July. The importance of this research is that it enables users to set up their own PV systems that meet reliability criteria.

An optimal design of a stand-alone PV system was developed by Y. M. Irwan and al. (2015) using the PVsyst simulation tool to predict performance [13]. The annual performance of the system was shown in terms of energy production on an annual basis from the PV grid, i.e. 841.31 kWh, and energy supplied to the load, i.e. 735.84 kWh.

KanchanMatiyali and Alaknanda Ashok (2016) carried out a performance study of a 400 kWp grid-connected solar photovoltaic power plant to be installed in Dhalipur using the PVsyst simulation tool [14]. It was found that the proposed system is entirely feasible. The simulated system showed a performance ratio of 78.1%, with a final yield ranging from 3.14 kWh/kWp/day to 5.65 kWh/kWp/day.

For our case study, we chose the well-known and widely used PVsyst simulation software to study the performance of a 67.2 kWp Si-poly photovoltaic system connected to the grid to supply a university.

Description of the proposed grid-connectedsolar PV power plant:-

The proposed PV system consists of 280 Wp Si-poly solar modules with 12 strings of 20 modules in series each, three inverters, a power conditioning unit and grid-connected equipment. This installed power makes UADB self-sufficient in energy, and the choice of such configuration results in a nominal power ratio of 1.01 and overload loss of 0.0%. The solar PV plant will be installed on a 400 m2 site at the Alioune DIOP University of Bambey. The layout of the storage batteries is not designed for electricity storage. Fig. 1 shows the proposed model for the grid-connected PV plant.

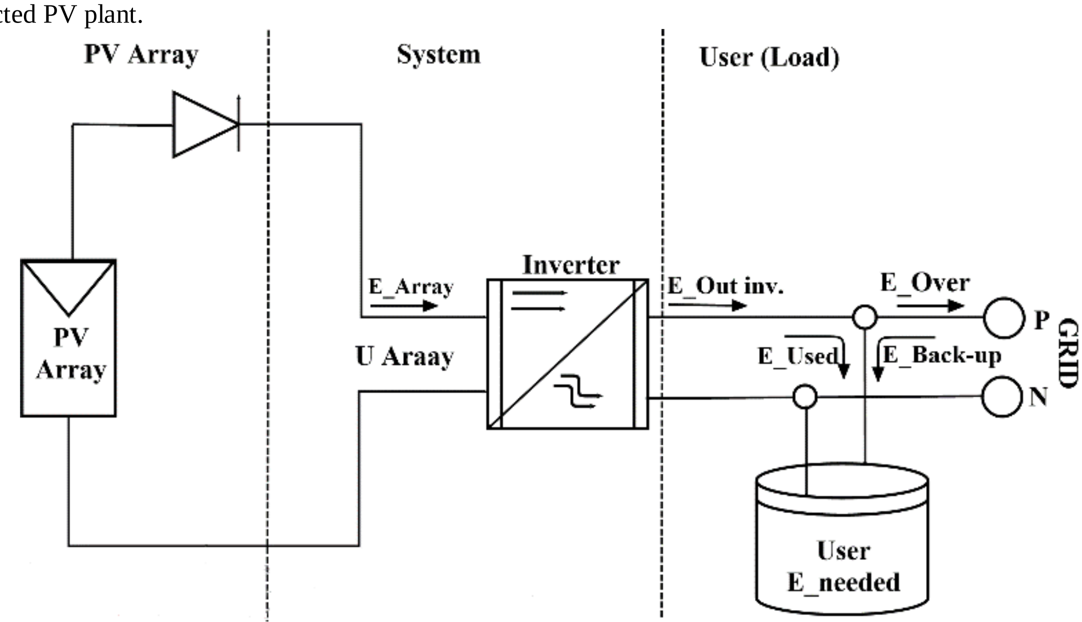

Figure 1:- Proposed Grid Connected Solar PV plant.

Description of grid connected Si-poly photovoltaic system:-

This section describes a grid-connectedphotovoltaic system, as shown in Figure 1. The main components used to configure this system are the PV module array, the system of inverters, fuse box and electricitymeter, and the gridlines. PV modules generate direct current (DC) and voltage from the sun's rays. Invertersact as DC/AC converters. Theyconvert direct current and voltage intoalternatingcurrent and voltage (AC). At the inverter output, these AC currents and voltages are fedinto the grid via an energymeterfollowed by a fuse box. In this type of PV system, the inverterdoeseverythingitcan to be in phase with the grid, as itconstantlyproduces an alternating output. The connection to the gridcanbe made from the output terminals of an inverterwith the connection of a circuit breaker in the fuse box and theelectricitymeter [15]. Table 1give the specifications of the proposedgrid and Table 2give the specifications of solar module and inverter. Figure 2 shows the system specificationgeneratedusingPVsyst software.

Table 1: Datasheet of gridspecificationat operating condition (50°c)

Frequency of system	50 Hz
Phases	3ϕ
Voltage_ mpp	568 V
Current_ mpp	106 A
Power_ mpp	60.3 kWp

Table 2:- Datasheets of solar module and inverter.

Components	Specifications	Parameters
PV module	Model	Neosun NS-280P-60
	PV module capacity	280 Wp
	V_{oc}	38.5 V
	V_{max}	31.60 V
	I_{sc}	9.29 A
	I_{max}	8.86 A
	Number of cells	60
Inverter	Model	SUN2000-20KTL-M2 220Vac
	Maximum input Power	20 kW_{dC}
	Minimum MPP input voltage	160 V
	Maximum MPP input voltage	950 V
	Absolute max PV voltage	1080 V
	Maximum output Power	20 kWac
	Efficiency	98.42%

Current-Voltage versus irradiance and cells temperature:-

Bambey is located in a high-sunshine, high-temperature environment, and as the power of a PV module varies according to the amount of solar radiation, module temperature and load demand, it is necessary to plot the evolution of IV characteristics as a function of variations in temperature and sunshine. Figure 3 shows that increasing irradiation at a constant temperature (average cell temperature = 45 ºC), results in an increase in PV module output. Figure 4 illustrates the decrease in output power with increasing temperature at constant solar irradiation (solar incidence = 1000 W/m^2).

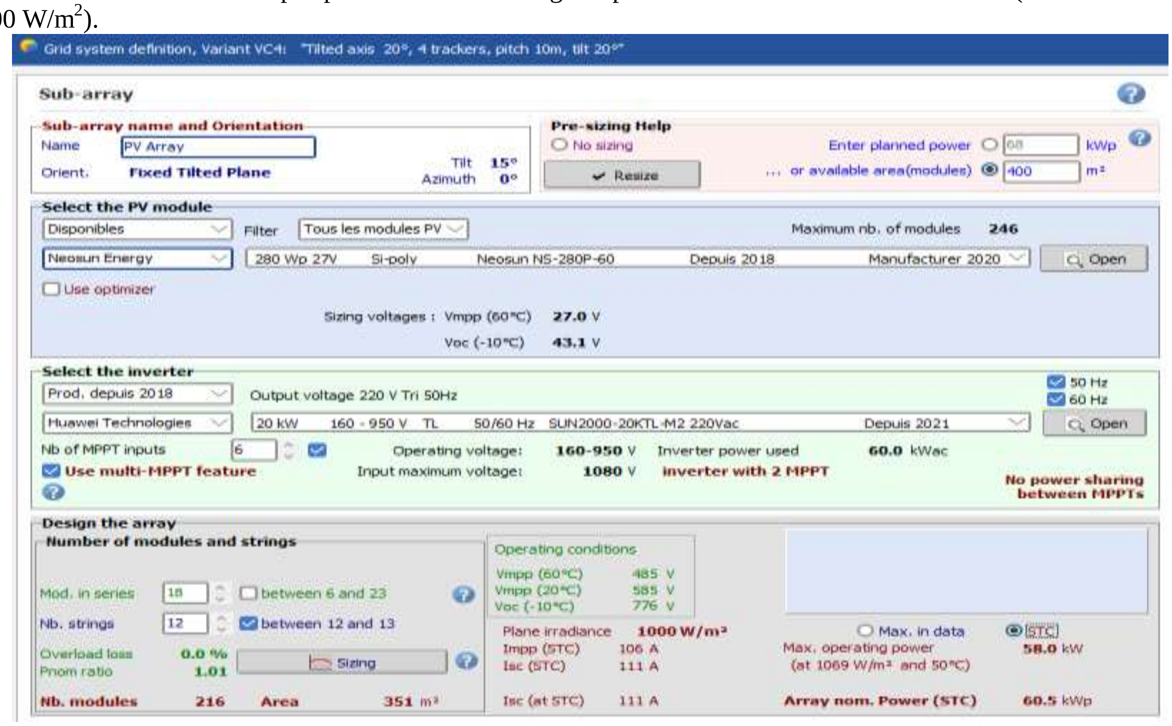

Figure 2:- System specification generated using PVsyst software

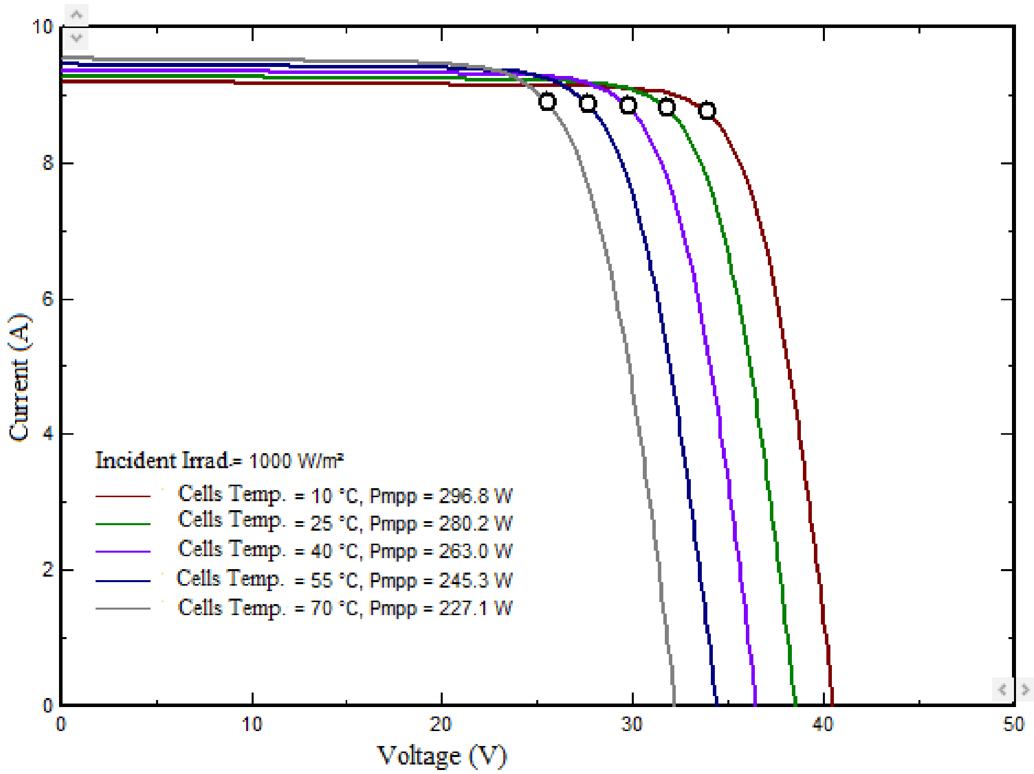

Figure 3:- I-V versus Irradiance.

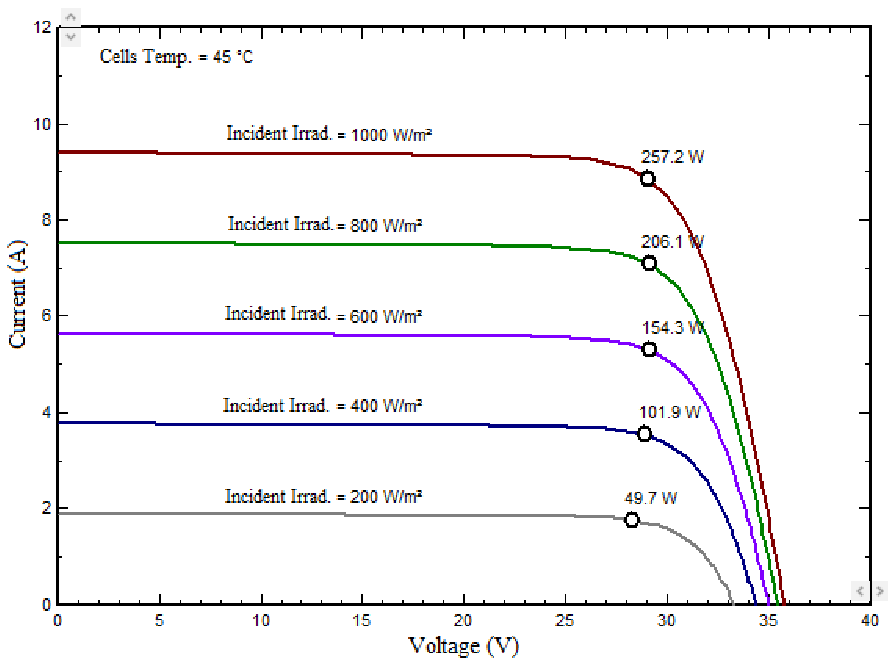

Figure 4:- I-V versus Temperature.

PV field layout:-

The figure 5 shows the tilt and the orientation angles of the solar panels for our own site, located at ADUB, Senegal. The tilt angle (relative to the horizontal) of the PV array is that of the site's latitude, in order to obtain the greatest possible amount of solar radiation [16]. The optimum tilt angle for the site is 15°, the optimum orientation facing due south, with an azimuth of 0°.

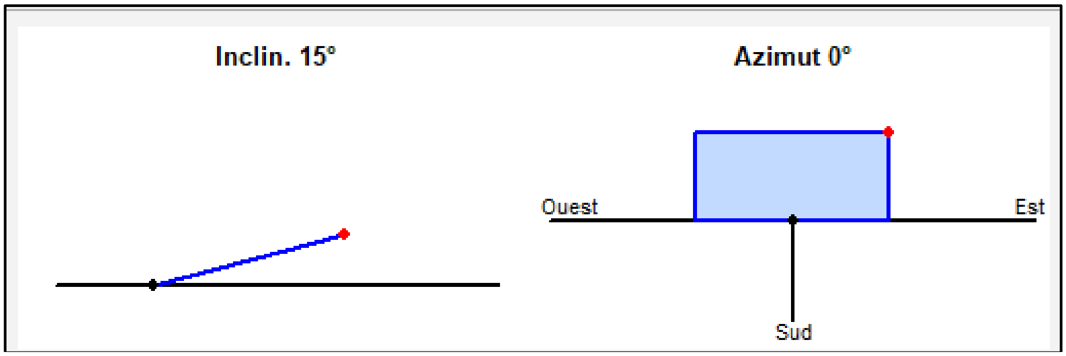

Figure 5:- Tilt and orientation.

Photovoltaic system parameters for performance analysis:-

Performance parameters for analyzing the performance of grid-connectedphotovoltaicsystems have been developed by the International Energy Agency (IEA) [17, 18, 19, 20]. The parameters used are the referenceyield, the array yield, the final system yield, the array capture losses, the system losses, the performance ratios, the capacityutilization factor, the invertereffi救iciency, the system efficiency, the energyinjectedinto the grid, etc. These parameters enable a completepre-feasibility analysis of a grid-connected PV system. These parameters enable a completepre-feasibility analysis of a grid-connected PV system.

Reference yield:-

It isrepresented by the notation Y_r and corresponds to the ratio between horizontal irradiance on an H_t plane (kWh/m^2) and referenceirradianceat STC G_{STC} (1kW/m^2). This parameterrepresents the equivalentnumber of hoursatreferenceirradiance. $Y_r$isnumericallyexpressedwith the units as kWh/m^2/day [21, 22].

$$Y_r = H_t / G_{STC} \quad (1)$$

Array yield:-

It isrepresented by Y_a notation and isdefined as the ratio between the DC energygenerated by the photovoltaic array and the rated power of the photovoltaic array. This parameterrepresents the amount of DC energyproduced by the photovoltaicgenerator. It isestimated in hours per day/month/year [21, 22].

$$Y_a = E_{DC}\ (kWh) / P_{pv,rated} (kW_p) \quad (2)$$

Final system yield:-

It isrepresented by the notationY_f. It isdefined as the ratio between the AC energy production of the photovoltaic system (inverter output) and the peak power, i.e. per kW$_p$installedat STC photovoltaicfield. This parameterrepresents the amount of energyinjectedinto the grid on an annual, monthly or daily basis [21, 22].

$$Y_f = E_{AC}\ (kWh) / P_{pv,rated} (kW_p) \quad (3)$$

Array capture losses:-

It isrepresented by the notation L_C and defined as the differencebetween the referenceyield (Y_r) and the array yield (Y_a). This parameterrepresents a loss thatmainlyoccursat the PV fieldlevel due to variations in externalclimatic conditions such as increased PV celltemperature, partial shading, dust accumulation on the PV panel, maximum power point errors and gridimbalance [17, 18, 21, 22].

$$L_C = Y_r - Y_a \quad (4)$$

System Losses:-

It isrepresented by L_S notation and defined as the differencebetween the array yield (Y_a) and the final system yield (Y_f). This parameterrepresents a loss thatoccursat the inverter system and otherelectrical components used for gridintegration [17, 18, 21, 22].

$$L_S = Y_a - Y_f \quad (5)$$

Performance ratios:-

It ischaracterized by *PR* notation and defined as the ratio between the actualenergyfedinto the grid and the rated power of the photovoltaic array. It is a determining factor in the performance analysis of these types of PV systems, as itisrepresented by the ratio between the referenceyield and the final yield. The performance ratio (*PR*) makesit possible to compare the energyproduced by solar power plants installed in differentregions. It is a dimensionlessparameter and isavailable as one of the criteria in IEC 61724 [17, 18, 21, 22].

$$PR = Y_f/Y_r = E_{AC}\,(kWh) \times G_{STC}\,(kW/m^2)\,/H_t(kWh/m^2) \times P_{pv,rated}\,(kW_p) = \eta_{syst}/\eta_{syst,STC} \quad (6)$$

Where $\eta_{syst} = E_{AC}\,(kWh)\,/H_t(kWh/m^2) \times A\,(m^2)$ and $\eta_{syst,STC} = P_{pv,rated}(kW_p)\,/\,G_{STC}\,(kW/m^2) \times A\,(m^2)$

Result and Discussion:-

In this section, the simulation results of the proposed PV system are analyzed. As a reminder, the parameters studied are mainly the energyproduced, the energyinjected, the performance ratio and the arrowlosses. The resultsobtained have been analyzed to assess the performance of the Si-poly photovoltaic system.

The total amount of energyproduced by the 67.2 kWp Si-poly photovoltaic system over an annualperiod, referred to as the energyproduced, is 111.287 MWh/year, and the specific production on annual basis per installedkWpis 1656.06 kWh/kWp/year. This corresponds to an averageannualyield (*PR*) of 81.5%.

Balances and main results:-

Balances and main resultsshown in Table 3includes the variables like global irradiance on horizontal plane, ambientaveragetemperature, global irradiance on collector plane withoutanyoptical corrections, effective global irradianceconsideringsoilinglosses and shadinglosses.

In this site, the annual global irradiation on the horizontal plane is 1963.4 kWh/m² and the global incident energy on an annual basis on the collectorwithoutoptical corrections and the effective global irradiation afteropticallosses are 1989.1 kWh/m² and 1934.4 kWh/m², respectively. Withthis effective irradiation, the annualenergyproduced on the DC side by the PV array and the annualenergyproduced on the AC side and fedinto the grid are 111.287 MWh and 108.980 MWhrespectively.

Table 3:- Balances and main results of a 67.2 kWp si-poly photovoltaic systems.

Month	GlobHor kWh/m^2	T_{Amb} °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh
Jan	135.4	24.48	149.7	145.7	8.578	8.404
Feb	141.4	25.92	150.4	146.6	8.494	8.321
Mar	183.4	28.97	188.3	183.8	10.398	10.178
Apr	187.7	29.73	184.5	179.7	10.151	9.936
May	190.8	30.91	181.3	176.1	9.990	9.780
Jun	180.0	30.76	169.1	164.0	9.395	9.201
Jul	187.4	30.18	176.1	170.7	9.829	9.626
Aug	176.9	28.97	171.6	166.5	9.670	9.474
Sept	158.0	28.13	158.9	154.4	8.939	8.754
Oct	156.6	29.76	164.3	160.0	9.161	8.969
Nov	136.5	27.90	150.0	146.1	8.431	8.255
Dec	129.2	25.49	144.8	140.9	8.252	8.084
Year	1963.4	28.45	1989.1	1934.4	111.29	108.98

Normalized productions:-

Normalized productions such as collection losses, system losses and produced useful energy per installedkW_p/day were evaluated from the simulation study, see in Fig. 6. These normalized productions are defined by the *IEC* norms [23] and are standardized variables for assessing the PV system performance. L_c is the collection lossesor the PV array capture losses i.e. 0.91 kWh/kW_p/day. L_s is the system loss i.e. 0.09 kWh/kW_p/day and the $L_f$is theproduced useful energy i.e. 4.44 kWh/kW_p/day.

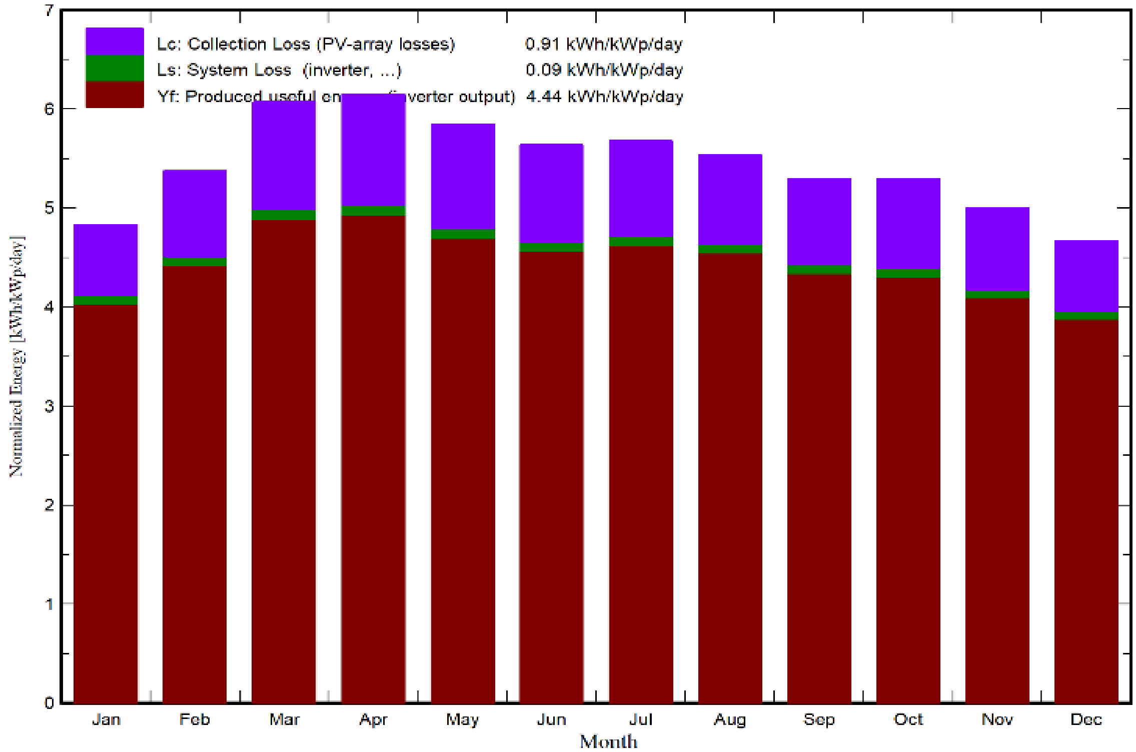

Figure 6:- Normalizedenergy productions per installedkWp.

Energy injected to grid:-

Energyproduced by PV array cannotbe the same as energyinjectedinto the grid. Energyfrom the PV array is DC which has to beconverted to into AC energy in order to feed the grid. Duringthissomeamount of energyislostin terms of AC wiring loss.

The designed 67.2 kW_p Si-poly photovoltaic plant injects 108980 kWh of energyintogrid on yearly basis. Monthly and dailysum of specificelectricityinjectedintogrid are 1621.756 $kWh/kW_p$and 53.17 kWh/kW respectively.

The PV plant generated and injected more energy to the grid in the month of March i.e. 10178 kWh. The lowestamount of AC energythatisinjectedintogridis 8084 kWh whichis in the month of December. The detailed information about the AC energythatisinjectedinto the gridistabulated in Table 4.

Table 4:- Energy injected to grid and performance ratio (note: kwp is 67.2).

Month	E_Grid kWh	Esm_GridkWh/kWp	Esd_Grid kWh/kWp	PR (%)
Jan	8,404	125.060	4.034	83.5
Feb	8,321	123.824	4.270	82.3
Mar	10,178	151.458	4.886	80.4
Apr	9,936	147.857	4.929	80.1
May	9,780	145.536	4.695	80.3
Jun	9,201	136.920	4.564	81.0
Jul	9,626	143.244	4.621	81.3
Aug	9,474	140.982	4.548	82.2
Sept	8,754	130.268	4.342	82.0
Oct	8,969	133.467	4.305	81.2
Nov	8,255	122.842	4.095	81.9
Dec	8,084	120.298	3.881	83.1
Year	108,980	1,621.756	53.17	81.5

Performance ratio:-

The performance ratio (*PR*) for the simulated 67.2 kW_p Si-poly photovoltaic system is 81.5 %, whichis the annualaverage PR value. The figure 7 shows the variation in PR value on a monthly basis. A small variation in the PR value wasnotedfrommonth to month, and the monthly values have been tabulated in Table IV.

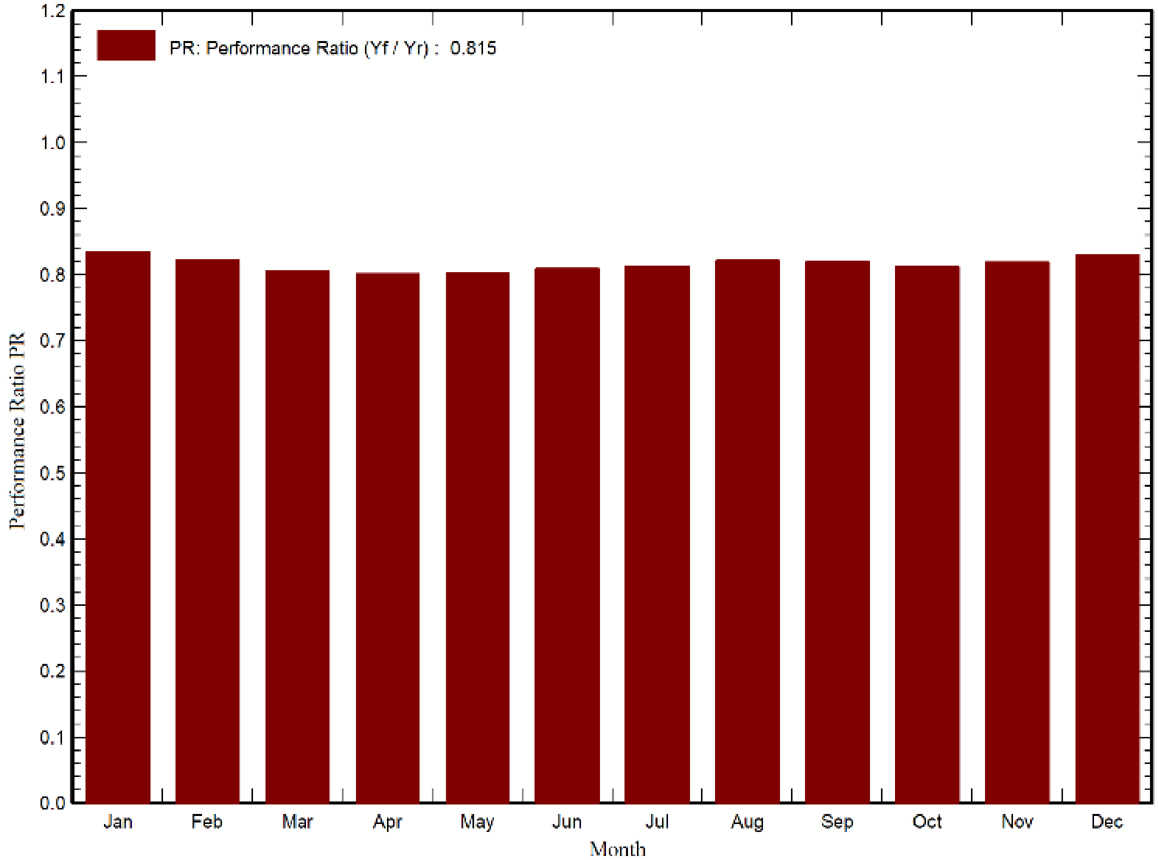

Figure 7:- Performance ratio (%).

Arrow loss diagram:-

Arrow loss diagramisobtainedfrom the simulatedstudies, which help in analyzing the variouslossesthat are tobeencounteredwhileinstalling PV plant or constraints to beconsidered. The figure 8 shows the arrowdiagram loss representing the variouslosses in the system. The global irradiance on horizontal plane is 1963 kWh/sq. m. But the effective irradiance on collectoris 1934 kWh/sq. m. This result in the loss of energy i.e. 1.5 % due to irradiancelevel. Whenthis effective irradiancefalls on the surface of a photovoltaic module or array, electricity or electricalenergyisproduced. After the PV conversion, array nominal energyat standard testing conditions (STC) is 130.076 MWh. The yield of the photovoltaicgeneratorunder standard test conditions isaround 16%. Annual array virtualenergyat MPP is 111.287 MWh. The variouslosses are: 12.87 % due to temperature, 0.48 % due to irradiancelevel, 1.0 % due to module array mismatch and 1.08 % is the ohmicwritinglosses. Availableenergy on annual basis atthe inverter output facilityis 108.980 MWh and the sameisinjected to grid. Heretwolosseswere possible, one isinverter loss duringinverteroperation i.e. 2.0 % andinverter loss over nominal inverter power is 0.0 %.

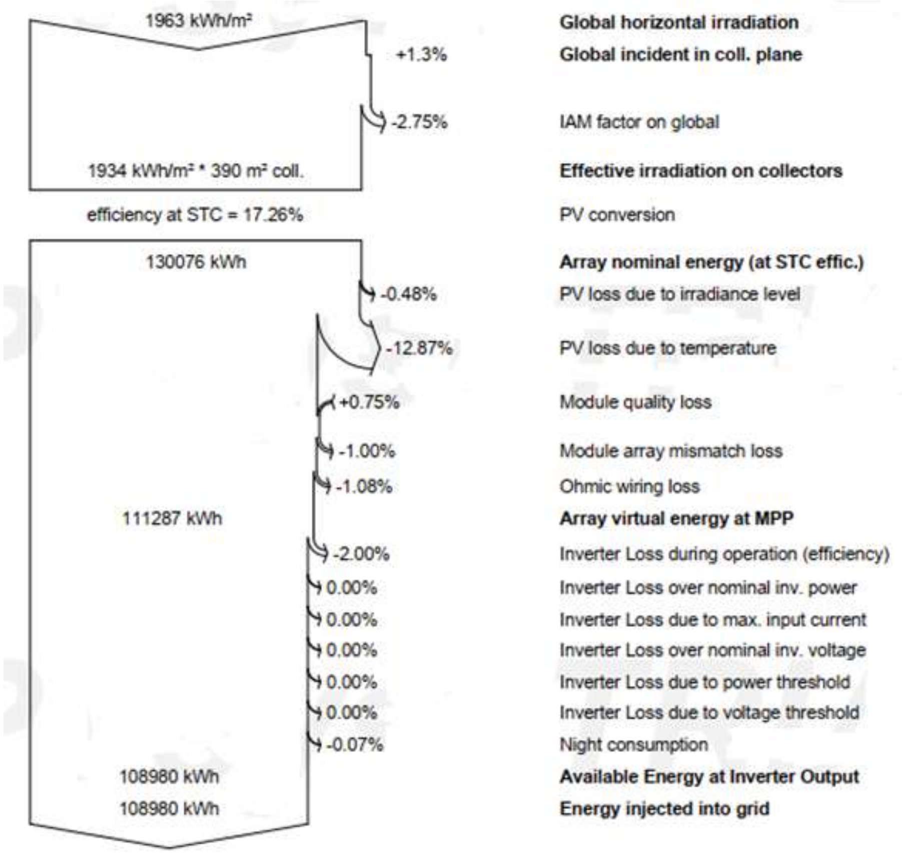

Figure 8:- Arrow loss diagram for the planned gird tied 67.2 kWp Si-poly photovoltaic system.

Conclusion:-

The simulated performance of a 67.2 kWpgridconnected Si-poly photovoltaic system isstudiedusing the PVsyst simulation tool. The followingremarks have been drawnfromthisstudy:

On an annual basis, 108.980 MWh/yearis the energyinjectedinto the gridwith a specific production on an annual basis per installedkWp of 1621.756 kWh/kWp/year. The maximum energyinjectedinto the gridis in the month of March i.e. 10178 kWh, and the minimum energyis in the month of December i.e. 8084 kWh. The average performance ratio (*PR*) of the Si-poly photovoltaic system is 81.5% in the simulatedstudy for the planned location. The resultsallow us to concludethat the plannedphotovoltaic system willbringoperationalbenefits to installers or owners.

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