Agricultural Grid Connected Photovoltaic System Design and Simulation in Egypt by using PVSYST Software

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Abstract:- Agricultural Photovoltaic Systems are a key technology to achieve sustainable development goals by reducing competition between land for food and electricity. In addition, Agricultural Photovoltaic Systems are at the heart of the link between power generation, crop production and irrigation water conservation. The main ecophysiological constraint on crop production under photovoltaics is the reduction of light. It is difficult to recommend shade tolerance for some plant varieties due to insufficient information on shading conditions for most plants. The use of shading panels (photovoltaic panels) requires more crop-specific research to determine the optimal percentage of panels and their placement that will not reduce agricultural yields. Crop yield variation versus field shading and availability to maximize the system require extensive research. This study aims to develop a standard procedure for designing an agricultural grid-connected photovoltaic power generation system for solar power generation in an agricultural area in Bahteem, Egypt. The technical and annual performance of the grid-connected PV system was simulated using PV Syst software. The paper started with a pre-feasibility study of a grid-connected photovoltaic system using PV Syst. Software with an extensive database of meteorological data, including global daily horizontal solar irradiance, and a database of various renewable energy system components from different manufacturers. In this work, a comprehensive literature review of agricultural solar photovoltaic systems is conducted, with a particular focus on grid-connected systems, followed by a design procedure for grid-connected solar photovoltaic systems. The planned photovoltaic system will generate a total of 400 KWp of electricity. This generated electricity can drive down electricity prices by exporting excess electricity to the national grid. In addition, solar power systems are fuel-efficient and have a low environmental impact.

Key-Words:- Agrivoltaics, Solar photovoltaic, Land use, Energy, agriculture.

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1 Introduction

By 2050, the world population is projected to grow to 9.6 billion. At the same time, people are looking for the basic needs of a decent life, which increases the demand for food and energy. Population increases also affect per capita land availability and land quality. Some lands that could be used to support a growing population are becoming unproductive or degraded due to a variety of reasons such as desertification, salinization, and waste disposal [1].

Desertification is the result of land degradation leading to reduced land productivity and complete abandonment of agricultural land, leading to a food crisis. Arid regions with severely degraded land threaten severe desertification. Deserts continue to increase around the world compared to agricultural land, and this is most severe in arid and semi-arid regions [2]. Modern agriculture relies heavily on electricity and energy, mainly generated from traditional fossil fuels, so solar photovoltaic technology can be an ideal backup energy source, providing sustainable clean energy with low greenhouse gas emissions [3]. The operation of applying solar photovoltaic technology to agricultural activities is called photovoltaic agriculture or agro-photovoltaic, in which the electricity generated by the solar photovoltaic system is used to meet the electricity demand of agricultural production activities such as irrigation, planting and irrigation. Over the past 20 years, many scholars have conducted economic research and experimented with this application.[4]. Given the need to increase energy and food production in the future, agricultural photovoltaic systems (AVS) have been identified as hybrid systems that combine photovoltaics and agriculture simultaneously in the same area [5]. Depending on climate and cultivar choice, combining the two production methods may improve crop yields and, in some cases, even benefit each other, as the water evaporated from the plants helps lower the operating temperature of PV modules. In some cases, however, crop yields increased as solar panels relieved some of the stress on plants from heat and UV damage.AVS has been shown to benefit plants grown under photovoltaic panels (PVP) and themselves [6]. According to Marrou, Dufour, et al. Plants in the shade of photovoltaic panels increase yield because evaporation is reduced by 10-30% when available sunlight is 50-70%. Therefore, agri-PV systems may be suitable for dry areas or periods of drought due to reduced water requirements (Marrou et al., Adeh et al.) [7]. In addition, PVP protects against solar radiation and avoids sunburn, frost and hail. Due to the high temperature, PVP is less efficient. However, in agro-PV systems, the ambient temperature is reduced due to the location of the crops, so the power generation is not reduced (Barron-Gafford et al,). Supporting a 60% increase in field productivity for these systems increases in 60% -70%. The agri-voltaic system has been proposed as a mixed system, combining photovoltaic with agriculture at the same time on the same land to capture solar energy, for both energy generation and food production while maximizing the solar efficiency on the land.More than three decades ago, in 1982, Goetzberger and Zastrow introduced the idea of AVSRecently, several commercial AVS plants and small-scale research facilities have been established around the world (Obergfell et al.)[8]. According to numerous research (Dupraz et al.; Elamri et al.; Valle et al.), APV can boost land production. As a result, it presents enormous promise as a co-productive, resource-efficient renewable energy system in areas with a high population density or a little amount of land, including hilly areas and islands (Dinesh and Pearce) [9]. Although many synergistic side effects are possible, semi-arid and arid regions are predicted to have the most potential (Marrou et al.; Ravi et al.). Here, intense solar radiation and associated water losses frequently have a negative impact on agricultural growth, [10]. In PV installations, it has been demonstrated that water consumption efficiency rises underneath the panels (HassanpourAdeh et al.); similar outcomes have been seen in APV systems.(Elamri et al.; Marrou et al.).These results become even more relevant as future climate change is expected to lead to increased demand for irrigation water (Elamri et al.; Hannah et al.), [11]. The reduction in solar radiation caused by the PV panels may directly help crops grown in arid conditions in addition to improving water productivity (Harinarayana and Vasavi) [12]. In addition to improving crop production, the use of APV increases farming's profitability by generating additional income through energy production (Dinesh and Pearce; Malu et al.); it may also enhance rural, off-grid electrification as part of decentralized energy systems (Burney et al.; Harinarayana and Vasavi) [13] As a result, APV can be a crucial part of systems for producing renewable energy in the future while also ensuring the economic feasibility of agriculture and food production (Dinesh and Pearce) [14]. Regarding the land-use conflict, the actual value of APV's integrated food and energy production system requires a clear distinction from PV systems that produce energy primarily. To do this, a significant level of crop output must be maintained. The first field tests examining the application of this technology and its effects on crop cultivation have demonstrated that combined PV and food-crop systems can utilize less land than independent production methods (Dupraz et al.; Marrou et al.) [15]. By increasing PV module density and lowering crop-available radiation, it is possible to increase electrical yield and financial profit (Duprazet al.). This underlines the importance of finding the right balance between food and energy production. The effects of APVS on plant development and performance are unavoidable, but only a few plant species have been scientifically studied to date, such as lettuce, cucumber, and durum wheat (see Marrou et al.) [16]. This suggests that further research is needed.This paper focuses on the simulation of grid-connected agricultural PV plants and explains the design process to alleviate issues related to PV module selection, inverter performance, string arrangement, etc

2 The Proposed Agricultural Photovoltaic System

The block diagram of an agricultural photovoltaic system is illustrated below in Fig.1. It consists mainly of two main components: the photovoltaic component and the crop component. The Photovoltaic component contains solar panels which are primarily in a grid-tied configuration, such that the excess electricity generated from the system is transferred.

2.1 The Agricultural Photovoltaic System Design

The design of the AVS includes the design of grid-connected photovoltaic power generation and the establishment of a co-production crop-growing system. The authors will consider the design of the agricultural system in another paper. Below, is a user-friendly explanation of the many phases needed in creating the grid-connected solar PV system in a simulation platform. The following flow chart serves as an illustration of the steps required in simulation design for the local electricity grid. The crop component includes the installation of suitable plants under photovoltaic panels. The main consequence of installing photovoltaic systems on crops is the creation of shading. This shading prevents the harmful effects of excessive sunlight and limits evaporation during periods of peak evaporative demand. The plants that will benefit the most from this system will be plants with high water demands and plants that are not water-stress tolerant.

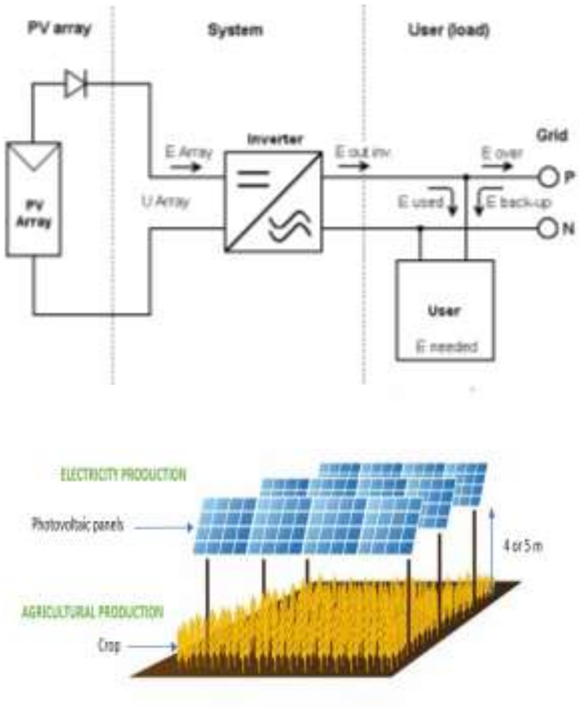


Fig. 1: The proposed agricultural photovoltaic system

2.1.1 Defining the Site's Geographic Parameters

The choice of the a location where a PV-based power plant needs to be installed is crucial, and it should be connected to any data source, such as software-specified NASA-SSE satellite data. Bahteem was chosen as the location for the system implementation. The specific geographical location of Bahteem is 30°05' north latitude, 31°17' east longitude, 34.4 meters above sea level, the annual average solar irradiance is 5.21 kWh/m2/day, and the clarity index is 0.597[17].

the geographical site specifications for the Bahteem region of Egypt are predefined by the software. For any area in Egypt , these facts could be used as references. The PVSYST has the benefit that, afterchoosing the installation location, the programme will automatically link the latitude and longitude information obtained from the NASA-SSE satellite station.

2.1.2 Fixing of Tilt and Azimuth angle

Depending on the installation location and in order to increase the amount of solar energy produced, the tilt angle can be changed. As shown in Fig.2, a 30 degree tilt angle is maintained. In simulation, azimuth angle is set at 0.

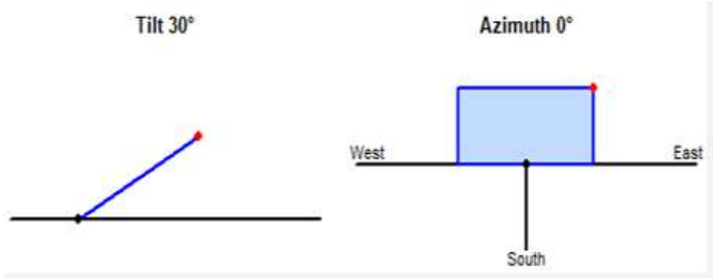


Fig. 2: Tilt and azimuth angle fixation

The performance curves for tilt angle and orientation are shown in Fig.3

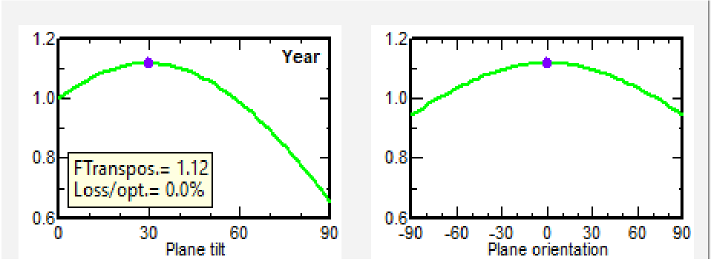


Fig. 3: The performance curve

2.1.3 Selecting the Appropriate Photovoltaic Modules

Depending on economic options, aging factors and performance criteria, PV modules can be selected from a pre-defined available list in the software. A 380Wp 29V Si-Mono bifacial PV model was selected for simulation for better output power.

The panels are monocrystalline modules 4 meters above the ground with a power generation capacity of 380 Wp. The panels are fixed at a 30° inclination angle. The tilt angle is not the theoretical optimum tilt angle equal to the latitude. This may be the result of optimization between reducing shading to increase panel rows and increasing power production.

We assume that the system is directly connected to the grid and has no load. The panels must be lifted first. The height depends on the height of the crop and also on the height of the agricultural machinery used for harvesting. The taller the panels, the stronger they must be. In fact, the structure must be able to withstand wind. Therefore, the installation system of an agricultural photovoltaic system is more expensive compared to the traditional ground photovoltaic system. To increase the radiation available to plants, transparent or translucent modules can be used. The best solution may be to install bifacial solar panels. They are translucent cells that trap radiation on their sides. The back of the panel is also a layer of silicon, rather than an opaque black film like traditional panels. This allows part of the radiation to pass through the module. They record direct and diffuse solar radiation. This improves overall efficiency.

Fig. 4 &Fig. 5 show the optimized Si-mono bifacial PV solar module curves and PV model values respectively.

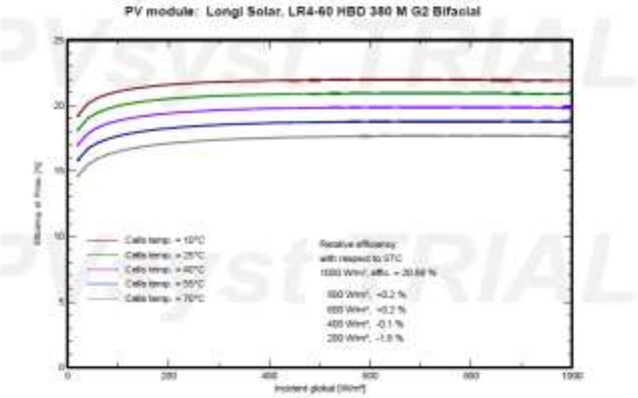


Fig. 4: Optimized Si-mono bifacial PV Solar module curves

Fig. 5: PV model values

2.1.4 Selecting a Suitable Inverter

The inverter is also a very important part of the grid-connected photovoltaic system. Inverters convert DC power from photovoltaic modules into AC power. Matching inverter specifications to PV specifications is very important for proper system operation. Inverter built-in MPPT technology for research Improves system efficiency. In addition, inverters can be selected from software-specified options and the technical feasibility of available inverters checked. 570-800 V 400 kW ABB PVI 400 inverter was selected for simulation. The power sizing of the inverter output is shown in Fig. 6.

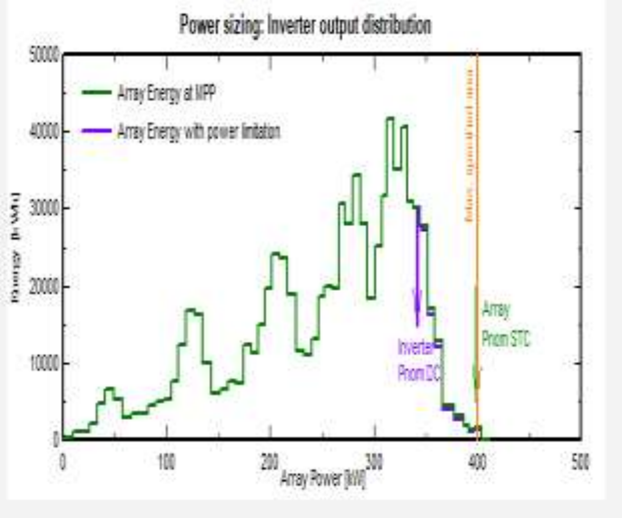


Fig. 6: Power sizing of inverter output

The output of the PV system depends upon the received solar radiation and temperature. Fig. 7 shows the voltage-current diagram of the photovoltaic module. At the 60°C temperature maximum power point voltage will be 570 V whereas at the 20°C temperature maximum point voltage will be 800V.

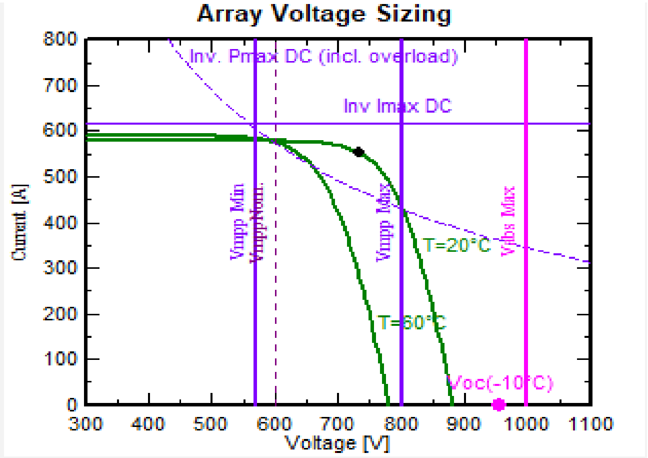


Fig. 7: PV Array Voltage-Current haracteristics

2.1.5 Number of Modules and String Arrangement

The software also provides us with recommendations for optimal string evaluation of PV modules. According to this case study, the total number of software recommendation modules is 1050. Connect 21 modules in series and 50 in parallel for optimized output power.

2.1.6 Efficiency Curve

In normal operation, the efficiency of the inverter is characterized by the power transfer function as a function of instantaneous power. This transfer is usually expressed as a function of input or output power, ie efficiency. That is, it is represented by a nonlinear curve as shown in Fig. 8, and there is a threshold input power, which can be understood as the consumption of the inverter itself.

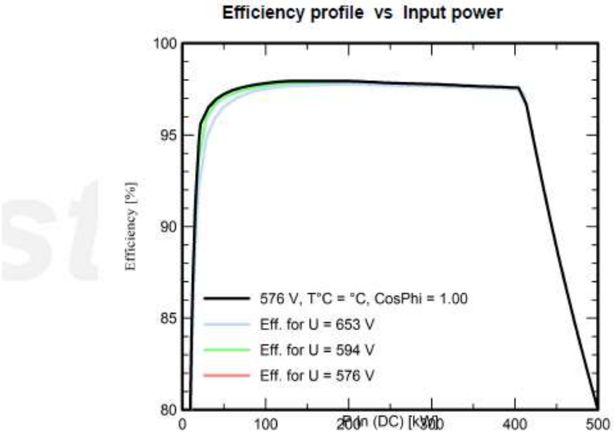
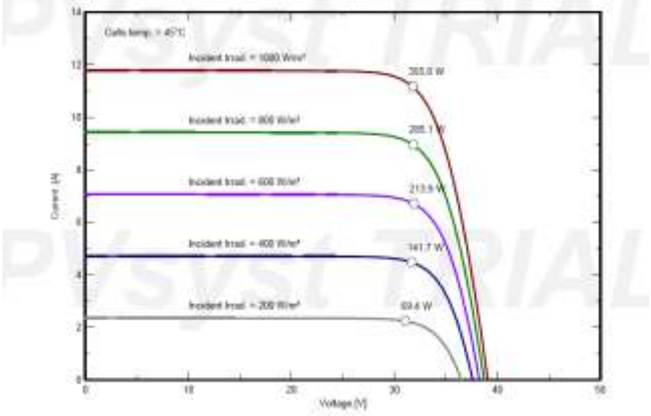


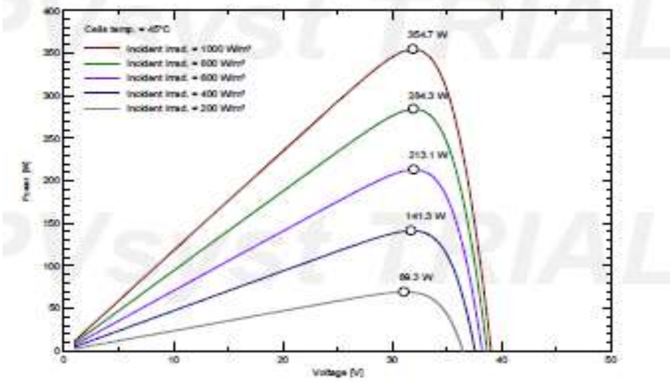
Fig. 8: Efficiency profile vs input power

2.1.7 Curve Parameter (Incident insolation)

The results of the sizing process yield a PV array characteristic at different insolation levels as shown in Fig. 9



(a) I-V characteristic



(b) P-V characteristic

Fig. 9: PV array characteristics at different insolation levels.

2.1.8 Model Parameters:

The previous topic defines the resistances involved in the one-diode model. This explains that the Low-light performance (relative efficiency) is determined by the RSerie, RShunt and RShunt(0) parameters. The Fig. 10, Fig. 11 and Fig. 12 show the model parameter at given isc, Mpp, Voc

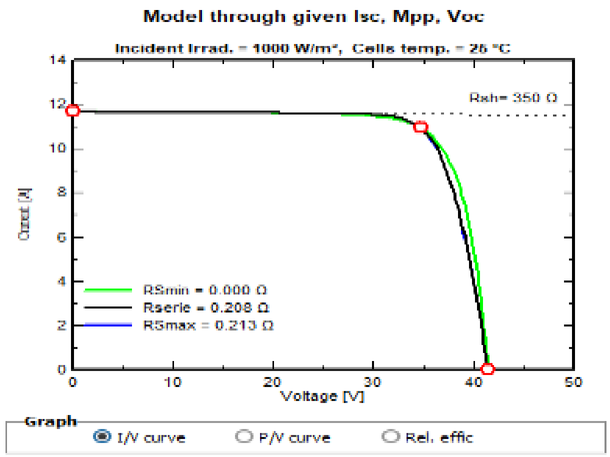


Fig. 10: I-V Characteristic's Curve

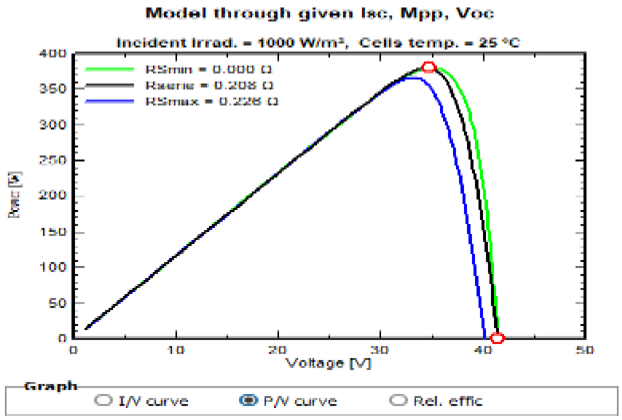


Fig. 11: P-V Characteristic's Curve

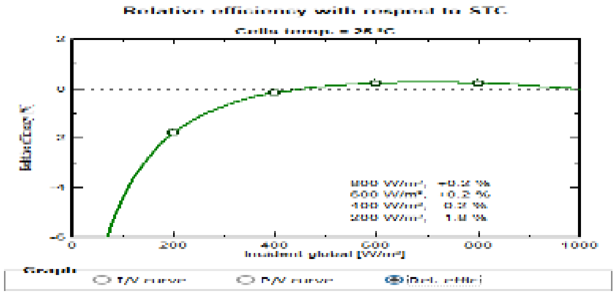


Fig. 12: Relative Efficiency [%] versus incident Global [W/m2] Characteristic's Curve.

3 Results

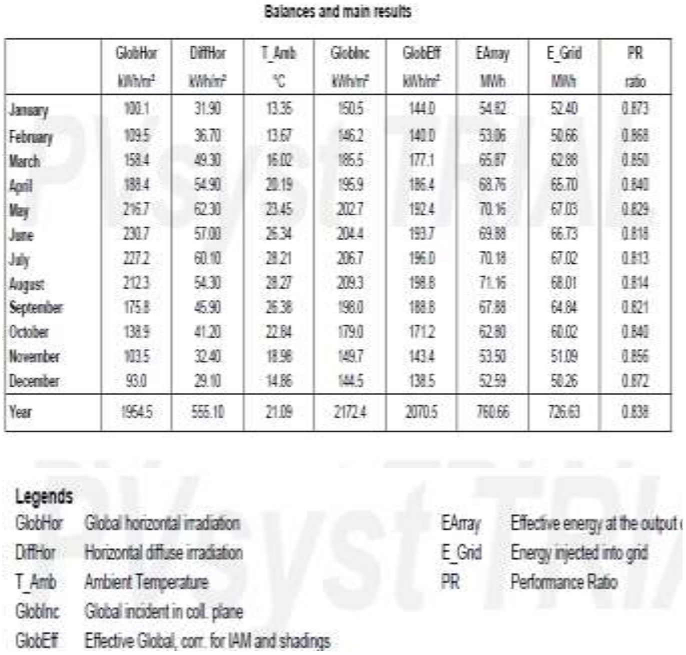
In this study, the design and analysis of an on-grid solar PV system were simulated using the PVSyst program. Numerous simulation runs and calibrations later, the most pleasing findings were discovered and examined in the results analysis section. After going through the aforementioned design process, the model should be simulated, and the conclusions can be examined to gauge plant efficiency. For a better understanding of the plant installed, a thorough simulation has been undertaken and several outputs have been generated.

Below are various results, including daily input/output plots, snaky diagram representation of losses, horizon line drawing a plot of the selected location, performance ratio data plot, daily energy output plot including incident variations, array temperature during operating conditions, array power distribution plot, normalized productions including loss changes, and plot examining about sun azimuth and incidence angle, respectively.

3.1 Balances and Main Results

The balances and key findings are shown in Table 1, together with variables including the horizontal global irradiance, ambient average temperature, the global irradiance incidence in the collector plane, and the effective global irradiance after soiling losses. Along with these elements, simulations were also performed for the DC energy produced by the mono-crystalline solar array, the energy injected into the grid after taking photovoltaic array losses into account, electrical components, and system efficiency. Each of the balances' specified factors was simulated and monthly and yearly major findings were collected. Annual values of the variables are possible as averages for temperature, efficiency, and summation for irradiance and energy. Independent of the high and configuration of photovoltaic panels, the agrivoltaic system will be able to produce an approximate quantity of 760.66 MWh year-1 of power, according to PVSyst software. The electricity would be injected into the grid, about 726.63MWh year-1. The performance ratio (PR) of the system is 83.8%. Table 1 shows values of solar energy produced and grid energy required during months and per year.

Table 1. Incident global radiation (GlobInc), solar energy (E_Solar) and grid energy (EFrGrid) calculated by PVSyst software.



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	100.1	31.90	13.36	150.5	144.0	54.82	52.40	0.873
February	109.5	36.70	13.67	146.2	140.0	53.06	50.66	0.868
March	158.4	49.30	16.02	185.5	177.1	65.87	62.88	0.850
April	188.4	54.90	20.19	195.9	186.4	68.76	65.70	0.840
May	216.7	62.30	23.45	202.7	192.4	70.16	67.03	0.829
June	230.7	57.00	26.34	204.4	193.7	69.88	66.73	0.818
July	227.2	60.10	28.21	206.7	196.0	70.18	67.02	0.813
August	212.3	54.30	28.27	209.3	198.8	71.16	68.01	0.814
September	175.8	45.90	26.38	198.0	188.8	67.88	64.84	0.821
October	138.9	41.20	22.84	179.0	171.2	62.80	60.02	0.840
November	103.5	32.40	18.98	149.7	143.4	53.50	51.09	0.856
December	93.0	29.10	14.86	144.5	138.5	52.59	50.26	0.872
Year	1954.5	555.10	21.09	2172.4	2070.5	760.66	726.63	0.838

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

3.2 Normalized Productions

Fig. 13 shows the PV power plant's normalized production. It presented system losses, significant inverter output, and PV array collection losses. The production and losses of monthly useful energy per kWh are displayed clearly. These normalized products—standardized variables for assessing the performance of PV systems—are established under the IEC rules. The collecting losses, or PV array capture losses, are 0.73 kWh/kWp/day. The solar energy generated is 4.99 kWh/kWp/day whereas the system loss is 0.23 kWh/kWp/day.

3.3 Array Loss Diagram

The array loss diagram is obtained using computer simulations, which help in the analysis of different losses that could happen when installing PV plants. The array loss diagram, which represents the different losses in the system, is shown in Fig.14. The global irradiation is 1955 kWh/m^2 on the horizontal plane. The effective irradiance of the collector, however, is 2070 kWh/ m^2. When this simulated effective irradiance strikes the surface of a photovoltaic module or array, electricity or electrical energy is generated. After PV conversion, the array's nominal energy at standard testing conditions (STC) is 828.098MWh. The PV array is 20.91% efficient at STC. The annual virtual energy supply from MPP is 761.479MWh. Thermal loss accounts for 5.7% of the losses in this stage, light-induced degradation accounts for 1.5 %, modular array mismatch accounts for 1.1%, and ohmic wiring losses account for 0.2%. The inverter power plant has 741.722MWh of available energy per year, of which 726,633MWh feeds the grid. There were two main losses in this case.2.5% inverter loss during inverter operation and 0% inverter loss over inverter rating.

3.4 Daily Input/Output Diagram

Fig. 15 displays the daily fluctuations in the energy injection into the grid's input/output profiles (kWh/day) and the worldwide incidence on the plane's incidence (kWh/m2/day).

3.5 Performance Ratio

The performance ratio (PR) primarily serves as a quality factor to evaluate the quality of a PV plant. It explains the relationship between the theoretical and practical energy outputs of the PV system. The PR shows the energy after all energy use and losses have been removed. The PR is typically about 83.8 % due to inevitable losses that occur during operation. Fig. 16 illustrates the PV plant's PR, which is the annual average PR value. The PR value varies marginally every month, as seen in Figure.

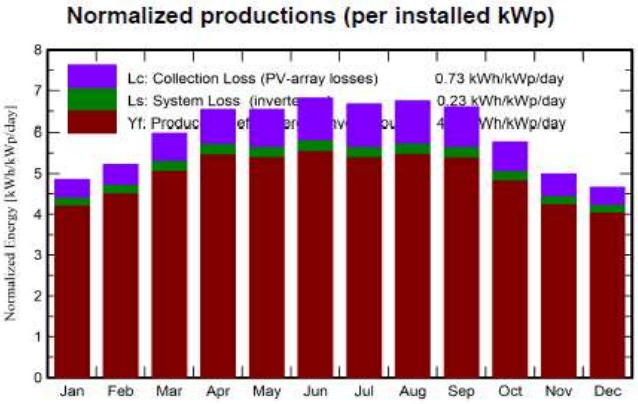


Fig. 13: PV power plant's normalized production.

Fig. 14: The array loss diagram simulation outcome

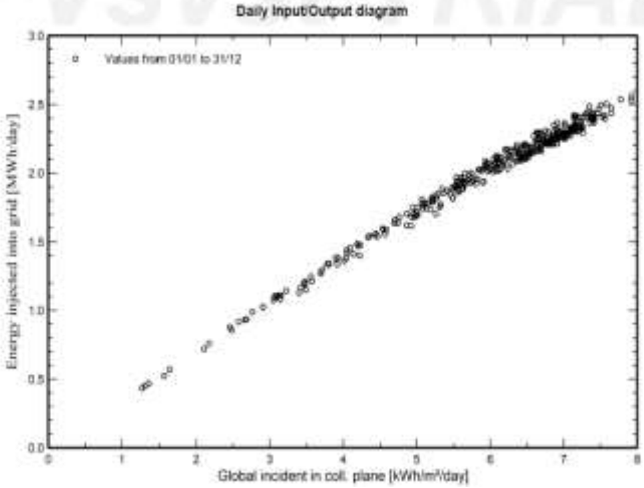


Fig. 15: Energy injected to grid versus global incident plot.

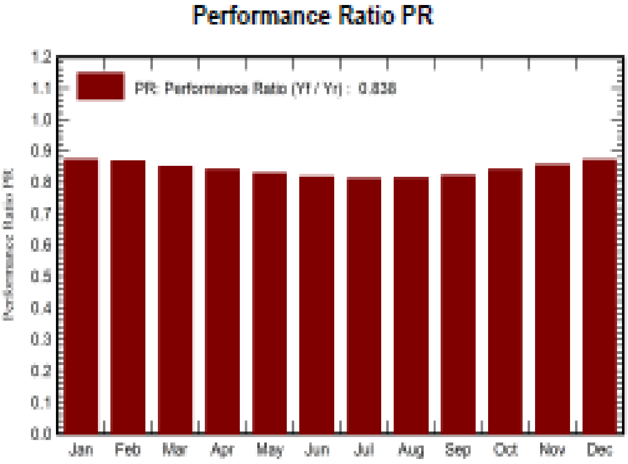
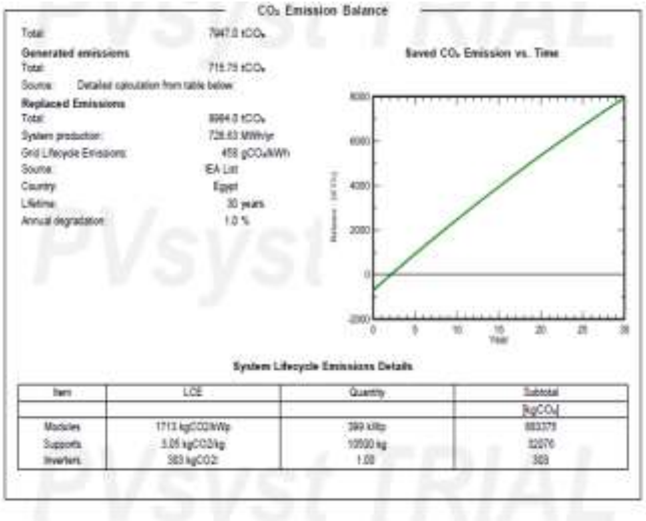


Fig. 16: Performance ratio.

3.6 CO_2 Emission Balance

Fig. 17 below shows the simulated values for the CO2 emissions balance. The Carbon Balance tool enables one to calculate the anticipated reduction in CO2 emissions from a PV system. The so-called Life Cycle Emissions (LCE), which are the CO2 emissions related to a specific component or amount of energy, serve as the foundation for this calculation. These metrics take into account a component's whole life cycle, including production, use, maintenance, disposal, etc.



Total: 7947.0 tCO₂

Generated emissions

Total: 715.79 tCO₂

Source: Detailed calculation from table below:

Replaced Emissions

Total: 8664.0 tCO₂

System production: 726.63 MWh/yr

Grid Lifecycle Emissions: 458 gCO₂/kWh

Source: IEA List

Country: Egypt

Lifetime: 30 years

Annual degradation: 1.0 %

System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[kgCO₂]
Modules	1713 kgCO2/kWp	399 kWp	683375
Supports	3.05 kgCO2/kg	10500 kg	32076
Inverters	383 kgCO2	1.00	383

Fig. 17: CO_2 Emission Balance

4 Conclusions

The paper highlights the simulation of a 400 KWp agricultural grid-connected PV system and explains the design process to alleviate issues related to PV module selection, inverter performance, location selection, string arrangement, etc.. This work provides a better guide for beginners and solar practitioners who are interested in installing solar-based grid-connected PV systems and can also use PVSYST software to accurately estimate various losses in the system. A great advantage of PVSYS is that you can create a complete installation report and check the power output and losses in the system. Simulation results for agricultural grid-connected PV systems show a system yield of 726.63 MWh/year and the performance ratio is 83.8 %. The proposed system saves fuel and has little impact on the environment.

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