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Research article

A Comparative Analysis of Various Simulation Software for grid-connected Residential Building: A Case Study at Jeddah, Saudi Arabia

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Abstract

Saudi Arabia receives significant energy daily from solar radiation, making it one of the best places to use solar energy to meet its energy needs. Grid connected Photovoltaic (PV) systems provide the electrical energy available from the solar radiation into the grid. Different simulation tools are currently available used to assess the performance of solar PV systems. The present study was conducted to design and evaluate the performance of 15 kW grid-connected solar PV system under climatic conditions of in Jeddah, Saudi Arabia. Two simulation models, Helioscope and PVsyst were used in the analysis and the results were then compared. The annual energy production, specific production, energy injected into grid, and annual performance ratio (PR) are evaluated by the software's around a whole year at the same climatic conditions. Results showed that the maximum annual solar irradiation in May was 2212 kWh/m^2. The PR based on PVsyst simulation (78.04 %) was higher than that of the Helioscope simulation (74.8%) by about 4.15%. The maximum energy production in May was about 6.1 kWh. The energy production from the PVsyst and Helioscope is 28.98 and 25.9 MWh/year with 289.8 and 259.13 MWh/year energy injected into the grid, respectively.

1. INTRODUCTION

Energy and environment applications are one of the important topics nowadays due to the population growth, enhancing human well-being, and increasing technology. Electrical energy is mainly produced from burning fossil fuels. This causes greenhouse gases, pollutes the environment, and depletes fossil fuel around the world with time. To reduce these impacts, it is necessary to take rigorous actions and increase the dependency on renewable energy sources.[1]

The building sector in Saudi Arabia consumes about 75% of the total energy produced.[2] So many initiatives have been initiated to promote renewable energy utilization to generate the required electrical energy. Saudi government initiated the King Abdullah City for Atomic and Renewable Energy (KACARE), and Saudi energy efficiency center.[3]

Incorporating renewable energy means reducing the consumption of traditional fossil fuels, hence protecting the environment. The Saudi Arabia enjoys with a large amount of yearly solar energy and long daily sunny hours. Hence, solar energy is considered a good source to produce the required electricity in this region. Among solar energy applications, Photovoltaic (PV) technology is considered one of the most viable fields for power generation.[4] Solar PV system was previously utilized fundamentally in space programs and remote locations. Recently, this technology has grown significantly and become the main producer of electricity in urban areas with potential to compete on equal terms with traditional energy sources.

In large areas where large amounts of solar energy are available, grid-connected solar PV systems have shown benefits and are gaining acceptance.[5] The required energy using grid-connected PV systems are implemented to supply the energy produced from solar energy to the electrical grid to serve a specific grid-connected customer, or in a centralized form. These systems are crucial for the fulfillment of sustainable development goals, minimize environmental pollution, and hold global warming.[6] According to Ortega-Arriaga, P., et al.,[7] the yearly increase rate trend of the grid-connected PV systems is rising continuously and has become the main market of solar energy. Customers can now gain advantages from selling surplus energy generated from PV system to the main grid.[8] Regarding the design of grid-connected PV systems, various studies suggested that the power of the power electronic devices should be less than the supplied power from the PV array.[9-13] This is because the output power from PV modules in most cases is less than that of the inverter. Li et al.[14] conducted a theoretical study on performance evaluation of grid-connected PV systems using seven types of PV modules at the same location. They concluded that performance of grid-connected

solar PV system depends on the metrological conditions and module types. Different studies are conducted also on the techno-economic off-grid solar PV systems.[15]

Several software and simulation tools are available nowadays can be easily used in evaluating and analyzing the performance of solar PV systems.[16] These models can be used to design new buildings, evaluate the potential energy, energy efficiency, and cost analysis. The simulation tools vary in complexity, as well as the required inputs required to generate the output results. With the widespread utilization of the solar PV systems, there is also a requirement to improve and develop these tools to optimize, compare, and evaluate the economic potential of the different solar configurations.[17,18]

In this work, two simulation tools namely Helioscope and PVsyst are utilized to design, evaluate, and compare the performance of grid-connected solar PV system for a residential building. Helioscope software was developed by Folsom Labs USA and used mainly in designing and evaluating the performance of PV systems.[19] The software consists of an advanced energy simulation tool, which is utilized to simulate each element from the PV system.[20] In addition, permits the user to assist the output energy that accounts for losses due to the weather. Helioscope produce system layout characterizing the quantity of energy production, losses, and efficiency. The model output includes weather conditions, annual production, Performance Ratio (PR), and other parameters. The model can be utilized for the pre-evaluating and advanced evaluation of PV systems. Guittet and Freeman[21] performed a validation study of the helioscope modeling tool performance against measured data and many different software's. Different solar PV systems are investigated. They concluded that the predictions of helioscope software are comparable with the measured data (error between -7.0% and 4.3%) and with the other software's.

PVsyst is introduced by Andre Mermoud and Michel Villoz.[22] This model is used principally in designing, simulating, and analyzing PV systems including grid-connected PV system, stand-alone system, etc. The system also includes weather conditions and PV systems components databases. The input data includes location, the used power, available area, PV type, inverter, battery, wires, etc.[23] The model generates a full report containing graphs and tables. The results contain the output energy, the PR, and loss diagram presenting the energy outputs based on the solar intensity of the entering location.[24]

Several studies evaluated the performance of solar PV systems using PVsyst software. Vidal et al.[25] designed and assisted the performance of 8.2 kW grid-connected solar PV system using PVsyst software at different climatic conditions. The month of January has the maximum energy output to inject energy into the main with 953.4 kWh while the minimum energy in June with 128.5 kWh. Gurupira and Rix[26] conducted a comparison study to evaluate the accuracy of the software tools including PVsyst, System Advisor Model (SAM), and PVLib. Annegren et. al[27] conducted a study to design PV system powered an office in Sweden using PVsyst model. The main objective of the study is to evaluate and optimize an existing PV system and assist the costs. Marrero et al.[28] conduct a measured and simulation analysis with the PVsyst and TRNSYS software's to evaluate the performance of grid-connected PV power plants. They concluded that both PVsyst and TRNSYS are used as perfect tools to evaluate the annual production of PV system with about 2% error. The results depend mainly on meteorological stations and software. Moustafa et al.[29] conducted a simulation analysis on 1 MWp grid-connected PV system using PVsyst software.

Comparative studies also have been carried out to evaluate the results from the different simulation tools to decide which software's are the most accurate in simulating PV system.[30-33] However, these researchers do not fully cover all existing simulation software's. Goel et al.[34] conducted a simulation analysis to compare the performance of 11.2 kW grid-connected rooftop solar PV system in India. The simulation was performed using PVsyst and HelioScope software. They showed that the results of annual energy generated by PVSyst and HelioScope software is 9.2% and 14.75% higher than the measured data (15.33 MWh). Talat Özden[35] performed a performance comparison on solar PV system with five PV module types using three software tools around a year at location of Ankara. The software tools are PVsol, PVsyst, and HelioScope. They concluded that the accurate estimation of the used tools is feasible and Helioscope provides better performance than others. Najibhamisu et. al[36] conduct a performance comparison between the results obtained from a 1 MW grid-connected PV plant with different simulation tools in the north India. Ten simulation tools are used SAM, PVsyst, HOMER, PVsOL, RETScreen, Solarius PV, HelioScope, Solar Pro, SOLARGIS, and PV F-Chart. The simulation results are compared with measured data from the power plant to verify the most effective tools. They showed that Homer, SAM, RETScreen and PVsyst tools are the most appropriate and effective tools to perform the analysis. All tested tools have different limitations for solving certain problems.

The working conditions and energy, exergy, and conversion efficiency of collectors are influenced by a variety of factors. The amount of solar irradiation is one of the most crucial factors. It directly influences both the strength of the solar irradiation and the effectiveness of the thermal collector. In general calculations, average solar radiation and system efficiency are employed. It is obvious that this approach cannot forecast reliable results, nevertheless. For precise solar energy calculations, the monthly distribution of the sun's radiation should be calculated.

At various areas in KSA, the literature studies for the feasibility study of the application of renewable resources using software are presented. Software for a climate consultant was made available for residential construction in Al Jubail City.[37] The authors demonstrated how green roofs could lower energy use and urban heat transmission for buildings. Another study to determine the ideal scale of a grid-connected renewable energy system was looked at in[38] at various sites in the KSA region. The research using HOMER software came to the conclusion that the output of PV depends on both economic inputs and renewable re-

sources like wind speed and solar GHI. Using PVsyst software, the author of[38] constructed a suitable PV system and looked at the possibility of reducing electricity costs and CO2 emissions at Al Juaimah, Dammam, Saudi Arabia. The system performances of the PV array generation are 1649.9 MWh/year, energy injection into the grid is 1616.9 MWh/year, performance ratio is 82.3%, payback period is 6.9 years, and CO_2 reduction is 29878.2 t, according to the paper's analysis using PVsyst software.

As per the author's knowledge, most of the aforementioned papers did not provide a comparison of different simulation software for grid-connected PV systems for residential buildings. The current research conducted to design and analyze the performance of 15kW grid-connected solar PV system for a residential installation in Jeddah (latitude 29.21 north and longitude 39.7 east), Saudi Arabia. The novelty of this procedure is the ability to provide different solutions and optimization for real case study at KSA. It also compares different common software in terms of performance, response, and accuracy. As a case study for a significant Saudi Arabian commercial metropolis, Jeddah has been chosen due to its available data, high population, ease of develop the system. Two simulation software's Helioscope and PVsyst used in the analysis. The reason for choosing these programs is that they are used commonly by designers, funding agencies, and investors. Due to their capability to perform multiple analyses which makes it easier and faster to assist various solar PV system configurations. Both programs use the same conceptual model for horizon profiles, which are a series of azimuth and elevation points that identify mountains or distant shading objects. The results from the software include annual system energy production, specific production, energy injected into grid, and PR are compared at the same weather conditions. To the best of the author knowledge, there is no similar studies conducted for a grid-connected solar PV system located in Jeddah, Saudi Arabia. This comparative analysis would generate an optimal design for a residential located in Jeddah, Saudi Arabia.

2. MATERIAL AND METHODOLOGY

In this study, 15kW grid-connected solar PV system as an average system size for a residential installation in Jeddah city, Saudi Arabia was designed and analysis. The city of Jeddah is located on the west coast of the KSA (latitude 29.21 north and longitude 39.7 east).

The system is composed of 30 PV modules, one inverter with a capacity of 15kW, two strings with 29m, and user loads as shown in Fig. 1. The distance between each module is 0.5 meter. The energy production from the system was simulated using Helioscope and PVsyst software. The results from each model are compared.

The project location and layout of is modeled by Helioscope and PVsyst is illustrated in Fig. 2.

The PV module efficiency can be given by

$$\eta_{pv} = \frac{P_{DC}}{G_t \times A_m} \times 100 \quad (1)$$



Figure 1. The 15kW grid-connected solar PV system in Jeddah, Saudi Arabia.



Figure 2. Site location in Jeddah, Saudi Arabia.

Where P_{DC} is the direct-current power from the PV, Gt is total solar irradiance in Wm^{-2}, A_m is PV module area, m^2 , and η_{pv} is the efficiency of PV system.

The instantaneous inverter efficiency given by

$$\eta_{\text{inv}} = \frac{P_{AC}}{P_{DC}} \times 100 \quad (2)$$

Where P_{AC} is the alternative-current power from the PV, P_{DC} is the direct-current power from the PV, and η_{inv} is the efficiency of PV inverter.

The instantaneous efficiency of PV system is given by

$$\eta_{\text{sys}} = \eta_{\text{PV}} \times \eta_{\text{inv}} \quad (3)$$

Where η_{inv} is the efficiency of PV inverter, η_{PV} is the efficiency of PV array, and η_{sys} is the efficiency of the entire system.

The performance ratio PR represents the overall efficiency of the PV system compared to the ideal efficiency. It is expressed as the ratio of the final (actual) and reference yield (theoretically)[39]:

$$PR = \frac{Y_f}{Y_r} \times 100 \quad (4)$$

Where Y_f is the field yield and Y_r is the reference yield.

The system loss Ls ($hday^{-1}$) is associated with the energy loss on the AC side, such as the discontinuous operation of the inverter, AC transformer and wiring [36]:

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

Where Y_a is the array yield.

3. SIMULATION RESULTS AND DISCUSSIONS

In this section, performance of the 15kW grid-connected solar PV system for a residential installation in Jeddah, Saudi Arabia is simulated. The Helioscope and PVsyst software tools are used to design and simulate the system over

a whole year field data weather of Jeddah. The simulated results from both simulation tools are analyzed and compared at the same weather condition. Both software tools generate a simulation report, thus calculating the average monthly power generation, losses that the system may present, and calculating the annual PR.

3.1. SOLAR PV SYSTEM DESIGN

The main variables of the proposed system depend mainly on the geometry of Jeddah and affected the total irradiance are the latitude angle (21.67° N) and the azimuth angle (164°). The tilt angle is 10° for the beam irradiance changing by the hour. To compare the results from the used simulation tools, the simulation was performed with the same component specifications of solar panels, inverters, azimuth, and inclination angles. The 15-kW grid-connected solar PV system has an installation scheme of 30 PV modules, one inverter with capacity of 15kW, two strings with 29m, one cluster control, and a combiner box. The nominal power of each PV module is 500 Wp (2 strings × 15 in series) with 584V nominal voltage and 23A nominal current. The distance between each module is 0.5 meter.

3.2. SOLAR RADIATION

Table 1 shows the average monthly global horizontal irradiation (GlobHor), horizontal diffuse irradiation (DiffHor), global incident in coll. plane (GlobInc), effective global (GlobEff), and ambient temperature (Tamb). In addition, the average yearly sum of these parameters is shown.

The month of July boasts the highest average temperature, with a recorded maximum of 31.58 °C as shown in Table 1. The average maximum temperature is 38.8 °C and low of 27.2 °C during July. The month of January is characterized by the lowest temperatures, which have an average reading of 24.1 °C .

As shown, the maximum global horizontal irradiation on the horizontal plane, global incident energy, and the effective global irradiation are in May with 244.9, 240.2, and 224.6 kWhm^{-2}, respectively. While the minimum global horizontal irradiation and global incident are in January with 142.6 and 160kWhm^{-2} respectively. In addition, the average yearly global horizontal irradiation is 2380.2 kWhm^{-2}. The GlobHor which is the collection of direct and diffuse solar radiation, is high at the summer season. In addition, the total yearly solar radiation is almost 2380 kWh/m^2 which represents suitable energy to be used at the selected location.

3.3. SYSTEM LOSSES

Figs. 3 (a) and (b) show the system losses results from Helioscope and PVsyst software of the 15kW grid-connected solar PV system respectively. The total losses by Helioscope software were affected by 28.3% with the losses by the temperature being the highest with 7.5% as shown in Fig. 3 (a).

The sum of total losses by PVsyst software is about 24.63% with a greater loss by temperatures of 11.55% as shown in Fig. 3 (b). Using the results from PVsyst software,

	GlobHor kWh/m²	DiffHor kWh/m²	GlobInc kWh/m²	GlobEff kWh/m²	T_Amb °C
January	142.6	50.88	160.8	144.9	24.01
February	165.2	46.53	181.7	166.2	24.51
March	211.0	58.44	221.9	205.0	25.43
April	221.4	67.14	223.1	207.6	25.98
May	244.9	71.88	240.2	224.6	29.00
June	235.2	75.23	227.9	213.0	30.43
July	236.8	75.32	230.9	216.1	31.58
August	219.2	77.86	218.8	204.8	31.55
September	202.4	67.90	209.4	194.3	30.33
October	192.7	57.59	208.6	191.0	30.19
November	160.3	45.26	181.2	163.6	26.23
December	148.3	44.40	171.0	153.4	26.12
Year	2380.2	738.43	2475.5	2284.6	27.97

Table 1. Horizontal irradiation and air temperature.

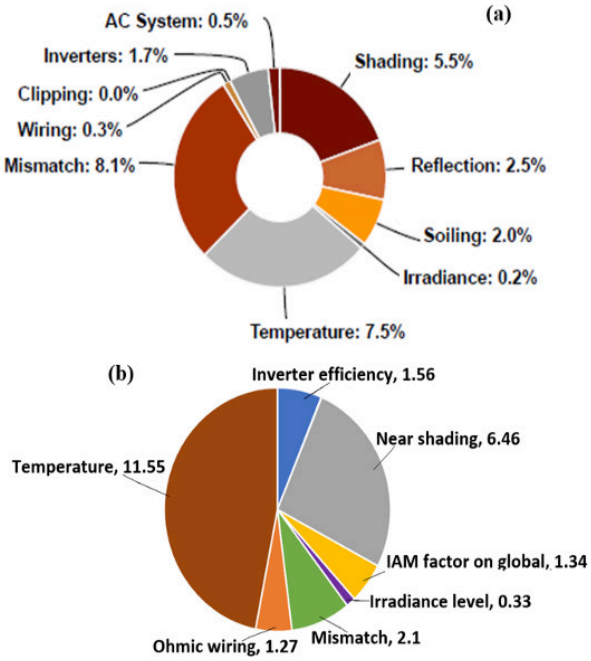

Figure 3. Variation of monthly energy production by Helioscope software.

horizontal global irradiation, and the effective irradiation on collector results in loss of energy of about 0.33% due to the solar irradiance. Using the PV conversion of solar irradiation, the rated power of the array in the standard conditions is 34.30 MWh and the efficiency of the PV panel is 20.94%.

Figure 4 shows the annual system energy production is 28.98 MWh/year. It is observed that the different losses occurring of 11.55% due to the temperature, 6.46% due to the irradiance level and 1.27% loss of ohmic. The energy available on the annual basis from the inverter output is 28.98 MWh which are fed to the main grid. Concerning losses related to the investor, during its operation, this corresponds to 1.56%.

Since the highest solar radiation occurs during the summer season as shown in Table 1, the energy consumption is also high at summer season. We could conclude that solar system may provide the required load demand for the desired application.

Table 2. Comparison between the results carried out by the Helioscope and PVsyst simulation software's.

Parameters	Global horizontal irradiation (kWh/m^2)	Annual energy production (MWh)/year	Specific production (kWh/)/y	Hours
PVsyst V7	2380	28.98	1932	-
Helioscope	2212.2	25.91	1729.2	4564

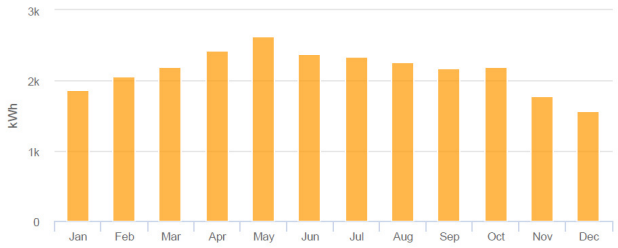

Figure 4. Variation of monthly energy production by PVsyst software.

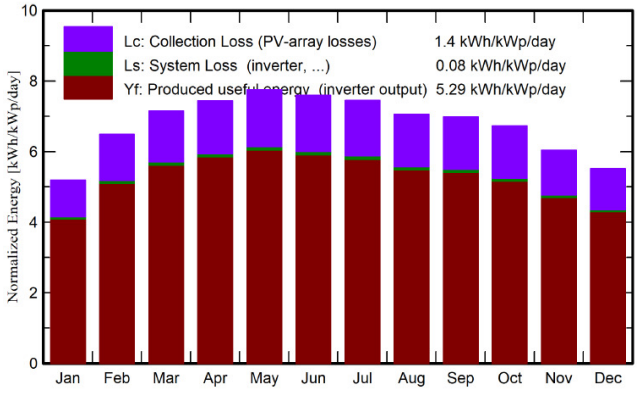

Figure 5. System losses by a) Helioscope and b) PVsyst software tools for the 15kW grid-connected system.

3.4. SYSTEM PERFORMANCE

The Performance of the PV system is depicted by the simulation energy production and annual PR.

3.4.1. PV ENERGY GENERATION

Figs. 4 and 5 shows graphically the monthly variation of energy production by 15kW grid-connected solar PV system using Helioscope and PVsyst software models, respectively. As shown, the maximum energy production is in May with 2.6 kWh by the Helioscope model and 6.1 kWh by the PVsyst model. The minimum energy production obtained during January with about 1.6 kWh by the Helioscope model and 4 kWh by the PVsyst model. This is due to the maximum global horizontal irradiation and ambient temperatures based on the location obtained in May and the minimum in January as shown previously in Table 1. The generated power, according to temperature increasing, are decreased slightly even with constant solar irradiance.

Fig. 5: System losses by a) Helioscope and b) PVsyst software tools for the 15kW grid-connected system.

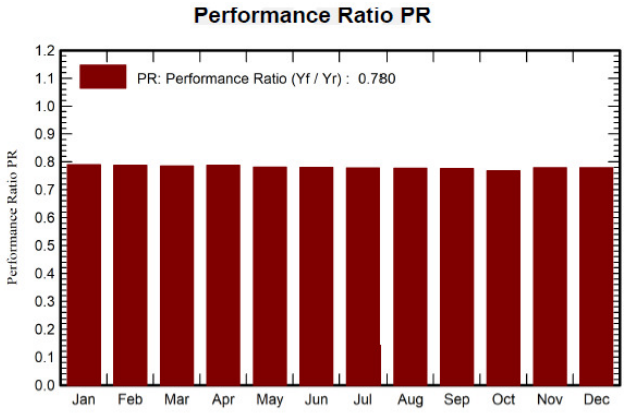

Figure 6. Performance ratio (%) from PVsyst simulation.

Table 2 presents a comparison between the simulated results carried out by the Helioscope and PVsyst simulation software's. Comparing the results from the two simulation models, they do not differ much. The annual global horizontal irradiation estimate from PVsyst is 2380 $kWhm^{-2}$. Helioscope annual Global horizontal irradiation result 2212.2 $kWhm^{-2}$ as shown previously from Table 2.

The total annual energy production from the PVsyst is 28.98 MWh/year while the total annual production from Helioscope is 25.9 MWh per year with energy injected into the grid is 289.8 MWh per year. The difference is that PVsyst takes 1% lower losses in the system, and this can answer why the annual generation of PVsyst is higher by 3.1MWh than that of Helioscope model.

3.4.2. PERFORMANCE RATIO (PR)

The performance ratio (PR) shows the ratio of available energy to export to the main grid after determining energy losses (thermal losses, absorption losses) and operating energy consumption. Fig. 6 represents simulation results of average performance ratio (PR) from the Helioscope simulation. As shown, there is a small variation in PR value monthly. The approximate value of PR found in both software's corresponds to ≈87%. The annual performance ratio of the 15 kW PV electrical energy generation obtained from PVsyst simulation is 78.04 % and 74.8 % from Helioscope simulation. The PR based on PV-Syst simulation is higher than that of the Helioscope simulation by 4.15%. The difference is that PVsyst takes 1% lower losses in the system, and this can answer why the PR based on PV-Syst is higher than that of Helioscope model.

4. CONCLUSION

This research has estimated the performance of a 15-kW grid-connected PV system for residential building in Jeddah, Saudi Arabia Two simulation models, Helioscope and PVsyst were utilized in the analysis and results are compared. The following conclusions are obtained from the research:

- The annual global horizontal irradiation is 2212.2 kWh/m^2.
- The maximum energy production was in May with 2.6 kWh by the Helioscope model and 6.1 kWh by the PVsyst model.
- The total annual energy production from the PVsyst is 28.98 MWh/year with energy injected into the grid is 289.8 MWh/year.
- The total annual production from the Helioscope is 25.9 MWh/year with energy injected into the grid is 259.13 MWh/year.
- The approximate value of PR found in both software's corresponds to ≈87%.
- The annual performance ratio 78.04 % and 74.8 % for the PVsyst and Helioscope simulations respectively.
- The PR of the PV-syst simulation tools is higher than that of the Helioscope by 4.15%.

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