Evaluation of the performance of a 98.4 kWp grid-tied PV system and analysis of the proposed design with different simulation tools

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***Abstract*— Photovoltaic solar systems are being widely used around the world to generate electricity. In Albania, since the adoption of the law on promoting the use of energy from renewable energies (law no. 7/2017), the increase of interest for the production of electricity from PV systems has begun. PV power systems in grid-tied mode are economically viable because their payback period is relatively short (4-7 years). This fact has led to an increase in the number of installations recently in our country, consequently increasing production capacity, mainly in industrial and residential facilities. For this reason, determining and evaluating the performance of a grid-tied PV system becomes a necessity. This study presents an evaluation of the performance of the 98.4 kWp PV installation on rooftop in an industrial building in Tirana, and is proposed some design configurations for better energetic performances of PV system. The data was obtained from monitoring of the PV systems starting from January to December 2021. The PV system is characterized with different performance parameters including: Reference yield, final yield, capacity utilization factor (CUF) and performance ratio (PR). Three simulation software, System Advisor model (SAM), PVsyst, and RETScreen software are used to simulate the proposed configurations design, and a comparison of performance among simulations is made.**

***Keywords*— PV System, Simulation Software, SAM, PVsyst, RETScreen, Array Yield, Final Yield, Performance Ratio, Capacity Utilization Factor**

I. Introduction

Simulation tools play a crucial role in the design, optimization, and evaluation of photovoltaic (PV) systems. These tools use mathematical models to simulate the behavior of PV systems under different conditions, allowing engineers and designers to make informed decisions about system sizing, layout, and performance.

There are several simulation tools available for PV systems, each with its own strengths and weaknesses. Some of the most commonly used tools include PVsyst, SAM, PVSol, RETScreen and Homer. Each of these tools has a unique set of features and capabilities that make it suitable for different applications. When evaluating different simulation tools for PV systems, there are several factors to consider. First, the accuracy of the tool is critical, as it directly impacts the reliability of the system design. The tool should be able to accurately predict the performance of the system under different weather conditions, shading, and other variables.

Considering climatic conditions and solar potential in Albania the PV solar energy will become one of the major future sources of electricity generation. At the end of 2018, 10 MW of solar PV was connected to the grid. Some major projects about 340 MW have passed the approval phase and is expected to increase the TIPC. Albania's technical potential for the deployment of solar PV is estimated at 2 378 MW, with production of 3 706 GWh annually [1]. Since the adoption of the law on promoting the use of energy from renewable energies (law no. 7/2017), the increase of interest for the production of electricity from PV systems has begun. The law stipulates that a consumer of electricity can also be self-producer of electricity. PV power systems in on grid mode are economically viable because their payback period is relatively short (4-7 years) [2] [3]. This fact has led to an increase in the number of installations recently in our country, consequently increasing production capacity, mainly in industrial facilities, and residential facilities. Properly design and installation of such systems will also increase the energy performance of these systems.

The main purpose of this study is to evaluate the performance of the 98.4 kWp PV installation on rooftop in an industrial building in Tirana, and is proposed some design configurations for better energetic performances of PV system. The data was obtained from monitoring of the PV systems starting from January 2021 to December 2021. The PV system is characterized with different performance parameters including: Reference yield, final yield, capacity utilization factor and performance ratio. Three simulation software, System Advisor model SAM, PVsyst, and RETScreen are used to simulate the best configurations of the proposed design, and a comparison of performance of simulation design with different simulation software is made. The main contribution of this study is in two aspects: first the evaluation of the performance of the real PV system installed on the terrace of an industrial building, and second two configurations design are proposed and then tested with three simulation tools.

II. Materials and Methods

A. *Description of installed PV system*

The PV power system is installed on the rooftop of an industrial building in Tirana city, Albania. The PV power system is a grid tied typology according to the block scheme diagram shown in figure 1, the energy generated from the power system is mainly for self-consumption. The PV power system consists of 240 monocrystalline solar modules, each one has capacity of 410 Wp, and together comprises a total installed capacity of 98.4 kWp. The tilt angle of PV panel is 5o and 80^o towards the south. As shown in Figure 1, the PV modules are arranged in 3 parallel strings with 5x16 modules in each string and connected to 3 inverter 27 kW each one, feeding directly for self-consumption or into the grid. Electrical data for PV modules are given in table 1.

TABLE I. Table 1. Electrical data of PV modules

PV module	Specifications
Nominal power	410 W
Efficiency	19.9 %
Rated Voltage (Vmpp)	44.5 V
Rated current (Impp)	9.21 A
Open-circuit voltage (Voc)	53.9 V
Short-circuit current (Isc)	9.89 A
Maximum system voltage	1500 V

B. *Performance evaluation parameters of PV plant*

In order to estimate the performance of the grid tied solar PV power system several parameters in daily, monthly and yearly basis were defined:

Array Yield Y_a [kWh/kWp]

The energy output delivered by the PV system divided by the rated power of PV system gives the array yield.

Final yield (Y_F) [kWh/kWp]

Final Yield is defined as the ratio of the overall AC energy by the rated power of PV installation. Final Yield is a parameter dependent on solar radiation. It provides a relative measure of generated energy by PV system and allows comparing PV systems at different size. [4]

Reference Yield $Y_{r,m}$

The Reference Yield is defined as the ratio of the global solar radiation on tilted surface by the PV's reference irradiance which is Go=1 kW/m2.

Based on the above parameters we can also define: Performance ratio and capacity utilization factor

Performance Ratio PR

All loses in all components of the PV systems determine the PR value of the PV system. Month-to-month variations in solar radiation and ambient temperature influence the performance parameters of the PV system [5] [6]. If the system is properly designed, soil, dust and temperature of the solar panels are three factors that determine if a PV system has a high performance. The temperature of the panel as a factor that affects the performance of the PV system, in addition to the air ambient temperature, also depends on the way the panel is mounted, whether it allows air to circulate naturally below the panel or not [7]. The PR can be defined as the final yield divided by the reference yield [8]. Table 2 shows the equation of array yield, final yield, reference yield, and performance ratio and capacity utilization factor in daily monthly and yearly basis.

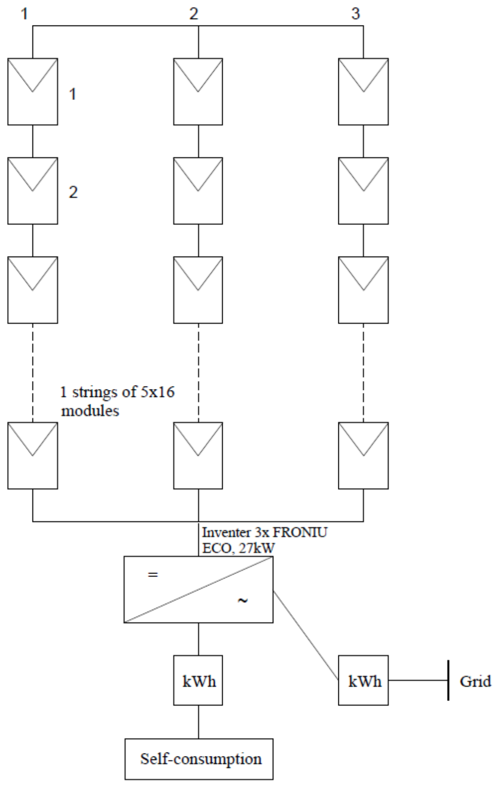

Figure 1. Block scheme diagram of PV system

TABLE II. PERFORMANCE PARAMETERS FOR SOLAR PV INSTALLATION

	Daily	Monthly	Yearly
Array Yield	$Y_{a,d} = \frac{E_{DC,d}}{P_{PV,rated}}$	$Y_{a,m} = \frac{1}{n}\sum_{d=1}^{n} Y_{a,d}$	$Y_{a,y} = \frac{1}{12}\sum_{m=1}^{12} Y_{a,m}$
Final Yield	$Y_{f,d} = \frac{E_{AC,d}}{P_{PV,rated}}$	$Y_{f,m} = \frac{1}{n}\sum_{d=1}^{n} Y_{f,d}$	$Y_{f,y} = \frac{1}{12}\sum_{m=1}^{12} Y_{f,m}$
Reference Yield	$Y_{r,d} = \frac{H_{t,d}}{G_o}$	$Y_{r,m} = \frac{1}{n}\sum_{d=1}^{n} Y_{r,d}$	$Y_{r,y} = \frac{1}{12}\sum_{m=1}^{12} Y_{r,m}$
Performance Ratio PR	$PR_d = \frac{Y_{f,d}}{Y_{r,d}}$	$PR_m = \frac{Y_{f,m}}{Y_{r,m}}$	$PR_y = \frac{Y_{f,y}}{Y_{r,y}}$
Capacity Utilization Factor CUF	$CUF_d = \frac{E_{AC,d}}{P_{PV,rated} * 24}$	$CUF_m = \frac{1}{n}\sum_{d=1}^{n} \frac{E_{AC,d}}{P_{PV,rated*24}}$	$CUF_y = \frac{1}{12}\sum_{m=1}^{12} CUF_m$

The capacity factor (CUF)

The CUF can also be thought of as a measure that indicates how long the power plant has been producing energy at rated power. CUF can be defined as the AC energy produced by the PV system during a specific period divided by the AC energy that can be generated if the system operated with its nominal power during that same period [9] [10] [11].

III. RESULTS AND DISCUSSION

A. *Performance evaluation of the PV system*

Figure 2 shows the energy generated by the actual design of PV system for year 2021. The PV system has produced 130.69 MWh. From the figure 2 it is clear that the maximum production is in the summer months, which reaches the maximum value in June with a maximum value of energy produced of 17.94 MWh, and the winter months are also the months with the minimum energy production, where the minimum value reaches December with 4.03 MWh.

The energy generated from the PV system and simulations software is shown in figure 4. Yearly generated energy from simulation tools is 132.22 MWh, 135.053 MWh and 133.78 MWh for SAM, PVsyst and RETScreen respectively. From the above values, it is clear that closer value to the energy produced by the real system is the value obtained from the SAM simulation. Figure 3 show the monthly average of final yield and reference yield for the real PV system. The monthly average daily of final yield and reference yield varied between 1.37 kWh/kWp in December, 5.88 kWh/kWp in July, 1.95 kWh/kWp in December, and 6.79 kWh/kWp in July respectively.

Figure 5 shows the monthly variations of PR and CUF for PV system. From figure 5 it is clear that monthly PR for real system vary from 63.53 % in November to 94.2 % in March, as for CUF is vary from 5.7 % in December to 25.3 % in June. The yearly average value of CUF is 15.11 % or 55 days in a year the PV system is generating energy at full power output. The PR and CUF is calculated using equation (4) and (5) respectively. It is a general result that the PR value decreases with increasing temperature. From figure 5 it can be seen that the lowest value of PR is in July, since the ambient temperature is also maximum. The opposite happens with CUF values, for summer months CUF gets maximum values. The comparison of the monthly PR value of real PV system and simulation tools is shown in figure 6. From the figure 6 it can be seen that the best trend line that follow the monthly PR value for real system is from SAM simulation. The simulations in SAM, PVsyst and RETScreen software are made for the same configurations with real situation of PV system. Figure 7 show the monthly variations of CUF for real PV system and for simulation for SAM, PVsyst, and RETScreen. The value of monthly variations of CUF with RETScreen simulation of PV system is more closely with real PV system. Also, to make a comparison between real PV system and softwares simulation and to validate the correlation between them we perform a multiple regression analysis. The regression analysis shows that the R2 value is higher for RETScreen software, R^2 = 0.993. The R^2 value for SAM and PVsyst software is 0.989 and 0.978 respectively.

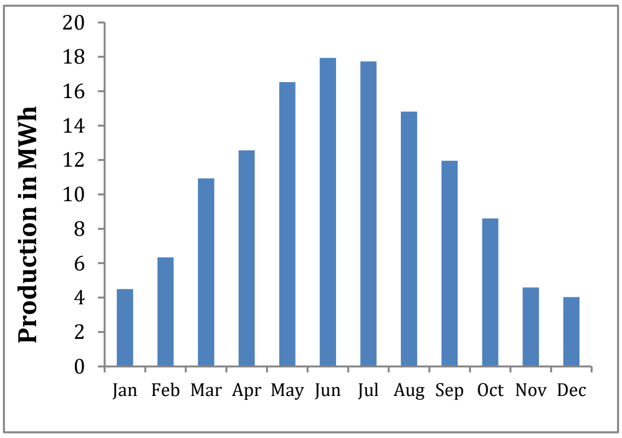

Figure 2.Energy production of PV system

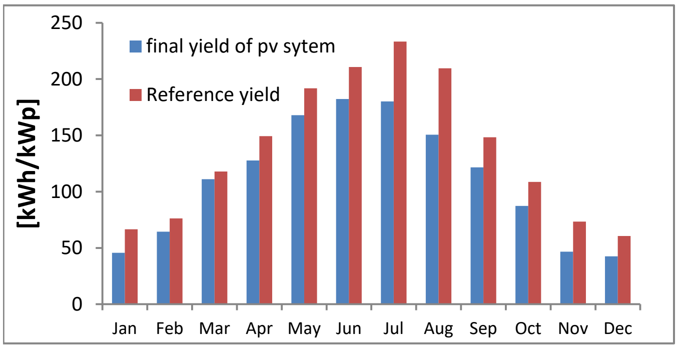

Figure 3. Monthly average of Final Yield and Reference Yield of the PV system

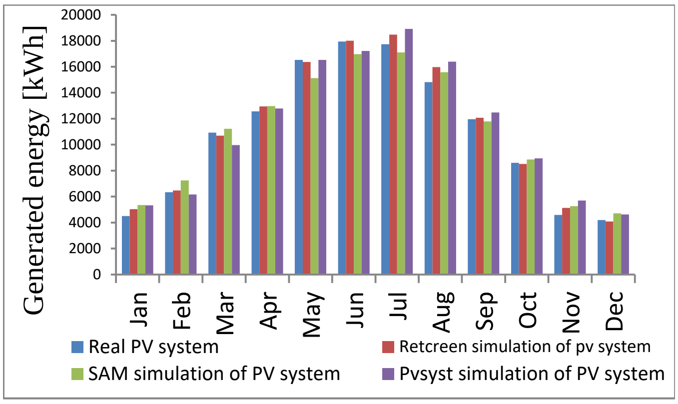

Figure 4. Generated energy of real PV system and simulations of PV system

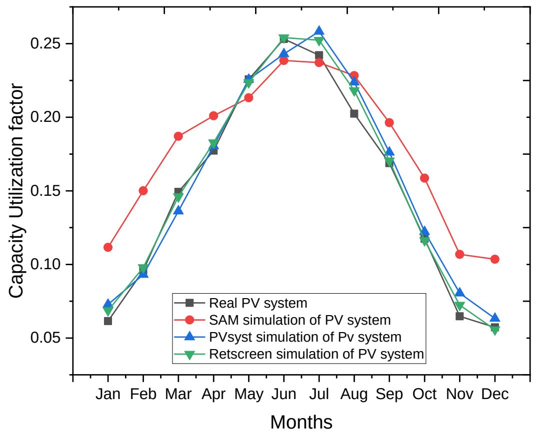

Figure 7. Monthly variations of CUF for real system and software simulations

TABLE III. YEARLY AVERAGE VALUE OF PR, CUF VALUE AND ENERGY PRODUCED FOR REAL PV SYSTEM AND FOR PROPOSED DESIGNS

	Real PV system	Design 1			Design 2		
		SAM	RETScreen	PVsyst	SAM	RETScreen	PVsyst
PR [%]	79.3	85.93	83.53	86.72	86.16	83.33	86.59
CUF	15.13	17.7	17.52	18.33	17.96	17.62	18.51
Energy	130.069	153.295	151.251	158.370	154.957	152.054	159.834

B. *Simulation results of proposed designs*

In this section an introduction of the main features of 3 simulation softwares developed not only for PV systems design, and a comparative analysis of the main performance parameters of the PV system proposed designs are discussed.

System Advisor Model (SAM)

The SAM softwares is developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories, USA. The main databases that SAM uses is NREL and National Solar Radiation Database (NSRDB). To simulate a PV system configuration and make performance prediction, SAM uses input data like module type inverter specification, system design, losses etc [12].

PhotoVoltaic Systems (PVsyst)

It is a software for design all components of a PV system. It covers grid-connected, stand alone, pumping and DC - grid PV systems typology. The software includes meteorological data and database for components of PV system. Preliminary Design, Project Design, Databases and Tools, are the main features of the PVyst software. To perform a simulation, need input data like panel orientation, components of the system, PV modules in series and parallel, inverter model etc. Also, the software package offers economic evaluation of PV systems [13].

Renewable Energy Technologies Screen (RETScreen)

RETScreen platform is a software which helps professionals and decision-makers to identify and assess the viability of energy technologies for all scale application. In order to assist the users, the model integrated a number of technology databases also including a global database of climatic conditions obtained from ground-based stations and satellite data. This software can perform feasibility and performance analysis including energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis [14].

The performance of a PV system depends on several factors, some of which have a stochastic character such as the climatic conditions of the site, while others factors such as the tilt angle of the solar panels and their orientation, are determined at the design stage of the PV power system. For this reason, the proper design of these systems is of particular importance to increase the energetic performance of the system. To increase the energy performance of the PV system, we have proposed 2 different system design configurations. Design 1: tilt angle of the solar panels 25 degrees, and oriented to the south. Design 2: tilt angle of the solar panels 30 degrees, and oriented to the south. Three simulation software RETScreen, PVsyst and SAM are used to simulate and test the performance of the proposed design configurations.

Performance ratio (PR) and capacity utilization factor (CUF) are evaluated for actual design configuration and proposed design configuration of PV system.

Figure 8 shows the monthly PR values from software simulations for design 1. The average annual PR values are 85.9%, 86.7% and 83.53% for SAM, PVsyst and RETScreen respectively. Figure 9 shows the monthly PR values from software simulations for design 2. The average annual PR values are 86.16 %, 86.59 % and 83.3% for SAM, PVsyst and RETScreen respectively. Figure 10 presents the monthly CUF values from the software simulations for the proposed design 1. CUF value with SAM simulation software varies from 10.3% in December to 23.8% in June; With PVsyst software the value of CUF varies from 11.3 % in December to 25.65 % in July; CUF value with RETScreen simulation software varies from 8.7 % in December to 24.46 % in July. Figure 11 presents the monthly CUF values from the software simulations for the proposed design 2. From the simulation with SAM software the value of CUF varies from 10.94% in December to 23.41% in June; With PVsyst software the value of CUF varies from 12.06 % in December to 25.2 % in July; With RETScreen software the value of CUF varies from 9.19 % in December to 24.23 % in July. The yearly average value of PR, CUF value and energy produced for real PV system and for proposed designs are given in table 3.

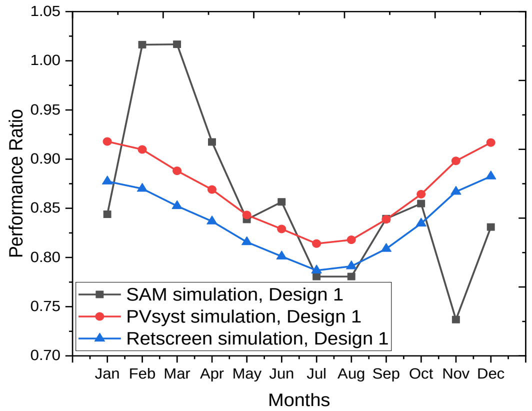

Figure 8. Monthly variations of PR for the proposed design, Desing 1

Our calculation shows that increasing the tilt angle of the solar PV panels will automatically increase the area that the panels will occupy on the terrace [15]. If the solar PV panels are to be installed with a tilt angle of 25o towards the south, Design 1, the area occupied by the PV system would increase by 71 % referred to actual design, and the energy that the PV system would produce, is 17. 85 % higher than what the actual design system produces (SAM simulation), 16.28 % higher than what the actual design system produces (RETScreen simulation), and 21.75 % higher than what the actual design system produces (PVsyst simulation). Whereas if the solar PV panels will be installed at a tilt angle of 30o towards the south, Design 2, the area occupied by the PV panels would increase by 86%, and the energy that the PV system would produce, is 19.13 % higher than what the actual design system produces (SAM simulation), 16.9 % higher than what the actual design system produces (RETScreen simulation), and 22.8 % higher than what the actual design system produces (PVsyst simulation). It is clear that in both situations the cost of installing the PV system would increase.

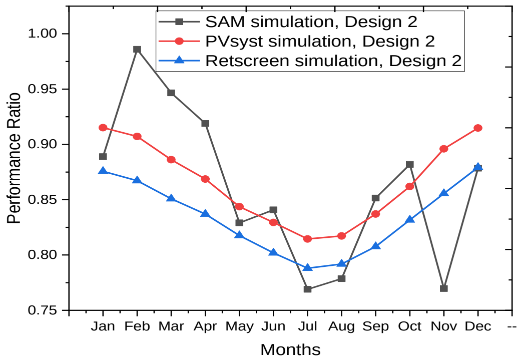

Figure 9. Monthly variations of PR for the proposed design, Desing 2

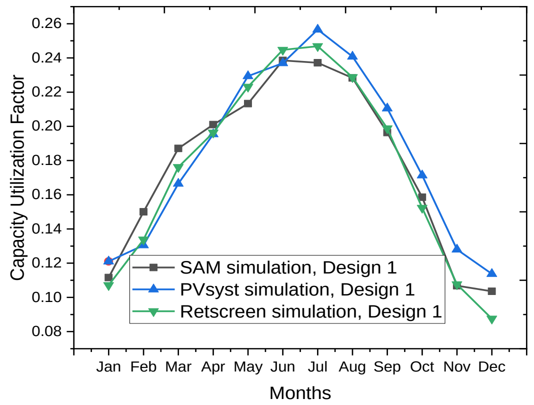

Figure 10. Monthly variation of CUF for proposed desing, Desing 1

In design 1 the monthly average daily of final yield varied between 2.48 kWh/kWp in December to 5.72 kWh/kWp in June for SAM simulation, between 2.72 kWh/kWp in December to 6.15 kWh/kWp in July for PVsyst simulation and between 2.10 kWh/kWp in December to 5.92 kWh/kWp in July for RETScreen simulation. In design 2 the monthly average daily of final yield varied between 2.62 kWh/kWp in December to 5.62 kWh/kWp in June for SAM simulation, between 2.89 kWh/kWp in December to 6.04 kWh/kWp in July for PVsyst simulation and between 2.20 kWh/kWp in December to 5.81 kWh/kWp in July for RETScreen simulation.

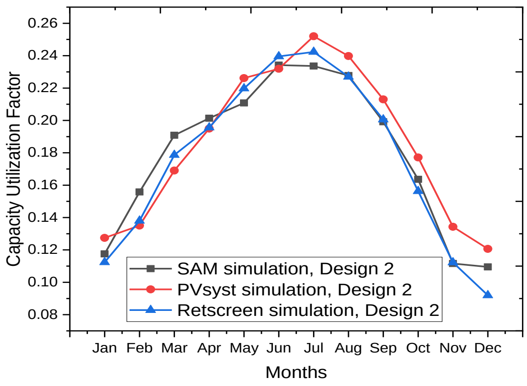

Figure 11. Monthly variation of CUF for proposed desing, Desing 2

IV. Conclusions

In this study a 98.4 kWp grid -tied PV system in an industrial building in Tirana has been monitored for a one-year period and three simulations software is used to re-design the PV system in terms of increasing the energetic performance. The simulations were performed for 2 proposed designs. As a conclusion we can say:

- The annual electricity generated by the PV system is 130.69 MWh.
- The annual electricity generated by the PV system from simulations with SAM, RETScreen and PVsyst is 132.22 MWh, 133.78 MWh and 135.05 MWh respectively.
- PR and CUF values of real PV system are 79.3 % and 15.13 % respectively.
- Of the three-simulation software, the simulation results closest to the values of the real PV system are from RETScreen software.
- In Design 1 the annual electricity generated by the PV system, simulated with SAM, RETScreen and PVsyst are 153.29 MWh, 151.25 MWh and 158.37 MWh respectively.
- In Design 2 the annual electricity generated by the PV system, simulated with SAM, RETScreen and PVsyst are 154.95 MWh, 152.05 MWh and 159.83 MWh respectively.
- The biggest PR and CUF values for proposed Design 1 are for PVsyst software and are 86.72 % and 18.33 % respectively.
- The biggest PR and CUF values for proposed Design 2 are for PVsyst software and are 86.59 % and 18.15 % respectively.

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