Design and Analysis of a Grid-Connected Solar Power System for the Higher Institute of Marine Sciences Techniques in Sabratha, Libya

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(Abstract)

This is a study aimed at designing and analyzing a 177 kW grid-connected solar system at the Institute of Marine Science and Technology in Sabratha, Libya, using PVsyst software. The system is designed to meet the energy needs of the institute taking into account coastal environmental conditions such as high humidity and salinity. The results showed that the system produces 287.8 MWh per year, with a performance ratio of 84.5%. 385 460Wp solar panels were used spread over an area of 832 m^2, in addition to 4 inverters with a total capacity of 160 kW.

Various losses in the system, including heat losses resulting from high temperatures in summer, which negatively affected the performance of the system, were analyzed. The effect of humidity on the performance of solar panels was also studied, with relative humidity ranging from 65.8% to 75.9%. The study showed that the system is capable of reducing carbon dioxide emissions by 7606.6 tons over 30 years, contributing to achieving environmental sustainability goals.

The study confirmed Libya's solar potential due to high levels of solar radiation, especially in coastal areas such as Sabratha. She also pointed to the importance of using simulation software such as PVsyst to improve the design of solar systems and reduce costs.

Keywords: PVsyst Software, Solar Photovoltaic, Renewable Energy, performance ratio.

(الملخص)

تهدف هذه الدراسة إلى تصميم وتحليل نظام شمسي متصل بالشبكة بقدرة 177 كيلو واط في معهد علوم وتكنولوجيا البحار في صبراتة ، ليبيا ، باستخدام برنامج .PVsyst تم تصميم النظام لتلبية احتياجات المعهد من الطاقة مع مراعاة الظروف البيئية الساحلية مثل الرطوبة العالية والملوحة. أظهرت النتائج أن النظام ينتج 287.8 ميجاوات ساعة سنويا بنسبة أداء تبلغ 84.5٪. تم استخدام

385 لوحا شمسيا 460 واط موزعة على مساحة 832 مترا مربعا، بالإضافة إلى 4 محولات بسعة إجمالية تبلغ 160 كيلو واط.

تم تحليل الخسائر المختلفة في النظام، بما في ذلك فقد الحرارة الناتجة عن ارتفاع درجات الحرارة في الصيف، والتي أثرت سلبا على أداء النظام. كما تمت دراسة تأثير الرطوبة على أداء الألواح الشمسية حيث تراوحت الرطوبة النسبية من 65.8٪ إلى 75.9٪. وأظهرت الدراسة أن النظام قادر على تقليل انبعاثات ثاني أكسيد الكربون بمقدار 7606.6 طن على مدى 30 عاما، مما يساهم في تحقيق أهداف الاستدامة البيئية.

وأكدت الدراسة القدرة الشمسية في ليبيا بسبب المستويات العالية من الإشعاع الشمسي، خاصة في المناطق الساحلية مثل صبراتة. كما أشارت إلى أهمية استخدام برامج المحاكاة مثل PVsyst لتحسين تصميم أنظمة الطاقة الشمسية وتقليل التكاليف.

الكلمات المفتاحية: برنامج PVsyst، الطاقة الشمسية الكهروضوئية، الطاقة المتجددة، نسبة الاداء

1 Introduction

In light of increasing environmental challenges, volatile fossil fuel prices, and erratic public grid voltage in Libya that threatens devices, the use of solar energy is one of the sustainable alternative solutions for electricity generation, especially in remote areas and marine environments where it is difficult to provide or ensure the stability of conventional energy sources. Solar energy is an ideal choice for these sites due to the abundance of solar radiation, as well as its ability to provide independent and reliable energy solutions that reduce dependence on irregular grids. This study aims to design an independent solar energy system using PV Syst software and analyze its performance at the site of the Higher Institute of Marine Science Technologies, where the system is designed in a way that takes into account marine environments and provides energy needs sustainably, with a focus on achieving autonomy and protecting equipment from voltage fluctuations. [1][2] .

Solar energy is one of the most prominent renewable energy sources, as it contributes to meeting global energy needs in a sustainable manner, especially in light of the increasing climate and economic challenges. Standalone solar systems are able to provide clean energy in remote locations with a lack of traditional energy infrastructure, while reducing carbon emissions by up to 40% compared to fossil fuels [3].

These systems rely on efficient integration of solar panels, batteries, and charge controllers to ensure a continuous supply of power, even in unstable climatic conditions. According to recent studies, solar systems contribute to reducing energy costs by 30% in the long run, making them an economical and sustainable option [4].

Moustafa et al. (2024) presented the design of a 130 kW peak (KWp) grid-connected solar system using PVsyst software for a plant in Obour City, Egypt. The results showed an annual output of 212.7 megawatt hours (MWh) and a performance rate of 80.04%, with a reduction in the monthly bill by ~20%. Pollution losses and high temperatures have been identified as the most prominent challenges. The study emphasized the efficiency of the system and the importance of using simulation software to improve design and reduce costs.[5].

Alkahani et al. (2024) presented the design and analysis of a 400 MW grid-connected solar system in Riyadh, Saudi Arabia, using PVsyst software. The results showed that the system produces 858,548 MWh per year, with a performance ratio of 87.21%. Three types of solar panels (580W, 330W, 255W) were compared, with the panels with higher power showing higher efficiency and lower losses. The study confirmed Riyadh's great potential in the field of solar energy due to its high levels of solar radiation.[6]

Ahmad et al. (2019) presented the design and analysis of a 250 kW grid-connected solar system in Baghdad, Iraq, using PVsyst software. The results showed that the system produces 346,692 kWh per year, with a performance ratio of 75%. 1428 Sharp 175Wp solar panels were used spread over an area of 1858 square meters. Various losses in the system were analyzed, including quality losses, cable losses and inverter losses. The study confirmed Baghdad's potential in the field of solar energy due to the appropriate climatic conditions [7].

Research has also indicated that improving storage efficiency can reduce waste from not using excess energy by more than 20%, enhancing continuity of performance even during low-radiation seasons. These innovations contribute to higher energy efficiency and reduced dependence on fossil fuels, reinforcing the role of solar energy as a sustainable source that supports environmental and economic development goals[8].

With the development of design and analysis techniques using software such as PVsyst, productivity can be improved by up to 15% by adjusting the angle of inclination and selecting the right components [9].

Libya, with its privileged geographical location and high solar radiation levels of more than 2,000 kW/m² per year, is an ideal environment for the development of solar energy systems [10].

However, designing independent and efficient solar systems in coastal areas requires meeting growing energy needs while addressing environmental challenges such as high humidity and salinity [11].

2. Design and Objective

The design of PV plants required the usage of hundreds of PV panels, each capable of producing hundreds of watts. During the PV plant design operations, the designer must select the proper number, size, and type of PV modules and inverters. Furthermore, components need to set up PV plants in order to maximize energy output while also enhancing plant lifetime maintenance. A thorough grasp of the system and components is essential when constructing a 177 kW PV plant. As a result, the designer will need to understand more about site selection and solar statistics, components and specifications, solar PV efficiency, and design optimization.

3. Selection of solar locations and data for solar power plant

The station is located at the Higher Institute of Marine Science Technologies in the center of Sabratha, As shown in Figure 1.

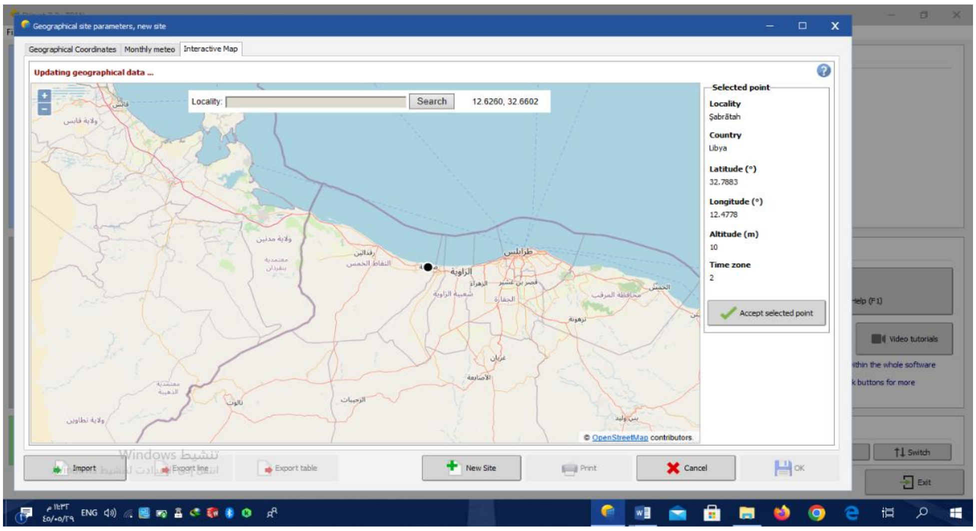

Figure 1: Location the Higher Institute of Marine Science Technologies

Information collected from the websites of the Higher Institute of Marine Science Technologies in Sabratha and can They can be found on the websites of the National

Aeronautics and Space Administration (NASA) and Libyan National Center for Standardization and Metrology.

Table 1: Weather, temperature and radiation at the site.

Site: Şabrātah (Libya)
Data source: Meteonorm 8.0 (1991-2009), Sat=100%

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	81.8	42.0	12.2	3.00	3.587	75.0
February	94.6	50.1	13.4	3.50	3.997	70.8
March	140.9	70.0	16.6	3.50	5.455	68.1
April	171.1	84.5	19.6	3.99	6.701	66.9
May	199.1	92.9	23.1	4.09	6.708	65.8
June	198.1	95.8	25.6	3.80	5.427	67.2
July	217.3	87.4	28.6	3.40	5.300	67.2
August	202.2	81.3	29.1	3.60	5.108	68.4
September	157.6	73.6	26.8	3.80	5.873	70.0
October	124.4	60.0	24.0	3.20	5.090	68.3
November	91.0	41.1	18.4	2.89	4.219	68.1
December	72.5	35.8	13.7	2.99	3.724	72.5
Year	**1750.6**	**814.5**	**20.9**	**3.5**	**5.099**	**69.0**
	Paste	Paste	Paste	Paste		

Global horizontal irradiation year-to-year variability 2.9%

Table 1 shows that the highest total horizontal radiation was recorded in July (217.3 kWh/m²/month), which indicates the abundance of solar energy during the summer. The average relative humidity ranges between 65.8% and 75.9%, which may require studying the effect of humidity on panel performance. Annual wind speed contributes to natural cooling, which improves the performance of panels in summer.

4. Selection and size of solar PV and inverter

After the technical and engineering calculations of the system, the panels and transformers must be It was selected in a precise technical way, taking into account the capacity and efficiency of the equipment.

4.1 PV Module Characteristics

The table below provides the technical details of the PV modules used in the system. These modules are the primary components for converting solar radiation into electrical energy. The performance of the modules is measured under standard test conditions (STC) and includes details about capacity, configuration, and physical dimensions.

Table 2 depicts the characteristics of the photovoltaic matrix and the inverter

Parameter	**Value**
Manufacturer	**Generic**
Model	**SPR-X21-460-COM**
Unit Nominal Power	**460 Wp**
Number of PV Modules	**385 units**
Nominal Power (STC)	**177 kWp**
Module Configuration	**55 strings × 7 modules in series**
Power at Operating Conditions (50°C)	**165 kWp**
Voltage at Maximum Power (U mpp)	**490 V**
Current at Maximum Power (I mpp)	**337 A**
Total Module Area	**832 m²**
Cell Area	**754 m²**

Table 2 depicts the characteristics of the photovoltaic matrix and the inverter. The station uses **385 PV modules**, each with a nominal power of **460 Wp**, resulting in a total capacity of **177 kWp** under standard test conditions (STC). The modules are configured into **55 strings, each containing 7 modules in series**, ensuring optimal system performance and reliability.

4.2 Inverter Characteristics

The inverters convert the direct current (DC) produced by the PV modules into alternating current (AC) suitable for the grid connection.

Table 3: Electrical Data Specification for Commercial Inverter.

Parameter	**Value**
Manufacturer	**Generic**
Model	**NXV0040**
Unit Nominal Power	**40.0 kWac**
Number of Inverters	**4 units**
Total Power	**160 kWac**
Operating Voltage	**340-800 V**
Power Ratio (DC:AC)	**1.11**

The system includes **4 inverters**, each with a nominal power of **40 kWac**, providing a total capacity of **160 kWac**. The **DC:AC power ratio** of **1.11** ensures high efficiency while minimizing energy losses during the conversion process.

Inverters are used to convert direct current (DC) to alternating current (AC) and reduce the harmonics that come from the conversion. Table 3 shows the electrical data requirements of a commercial inverter. The PV power array and inverter characteristics are the most essential considerations when choosing and developing a solar PV system. The attributes include information about the PV modules, the overall power of the array, the array's working circumstances, and the inverter. Figure 2 Provide a report that describes in full the features of both the PV module and the inverter.

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	SPR-X21-460-COM	Model	NXV0040
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	460 Wp	Unit Nom. Power	40.0 kWac
Number of PV modules	385 units	Number of inverters	4 units
Nominal (STC)	177 kWp	Total power	160 kWac
Modules	55 Strings x 7 In series	Operating voltage	340-800 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.11
Pmpp	165 kWp		
U mpp	490 V		
I mpp	337 A		

Figure 2: The PV array and inverter characteristic.

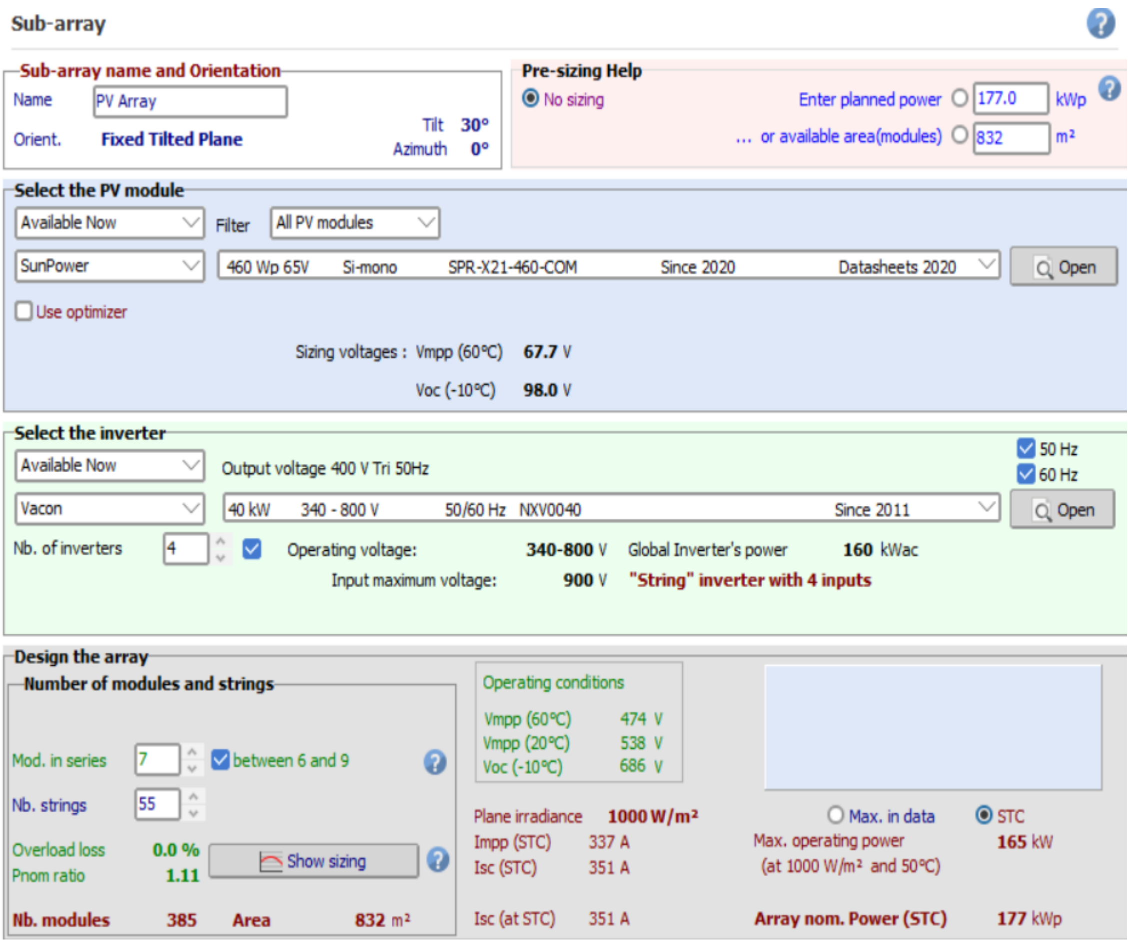

Figure 3: System Design (Solar Module, Inverter, Array Design).

5 Environmental and Energy Benefits

The solar power station is designed to meet the energy demands of the institute while minimizing its environmental footprint.

- **Annual Energy Production:** Estimated at **287.8 MWh/year**, significantly contributing to the institute's energy independence.
- **Carbon Emission Reduction:** The system is expected to reduce **7606.6 tons** of CO_2 emissions over 30 years, aligning with sustainability objectives.

5.1 Design Layout

A PV grid-connected system comprises of a solar array, inverters, a user (load), and a grid connection. The grid does not include a storage component because the generated energy is fed into the public power grid. Figure 4 illustrates the proposed model using PVsyst software. It clearly demonstrates how the system is connected and how the user receives power from t PV he power plant.

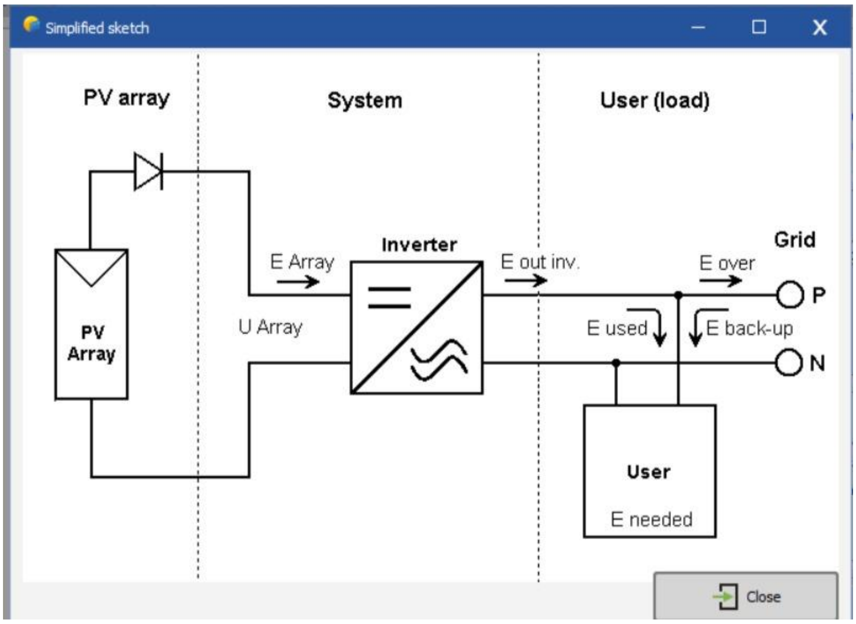

Figure 4: PVsyst Schematic Diagram of System.

5.2The Calculation of the required space

A total of 385 panels/modules were used in the design of our PV power plant. The area of each unit is 754 m2 and hence the total generating area of the plant is 832 m2 while the total area of the plant will be larger than the generating area of the plant. The distance between the panels must be calculated (these panels need a stand), and thus the total area required is estimated by dividing the total area by 0.7

6. Results and discussion

A simulation of a solar power plant designed to provide 177 KW of required power, system efficiency and system losses has been performed. The results are based on simulation software for the case and analysis of system components, a full report on which is published. The report contains several important features that describe the system.

6.1 Main Simulation Results

Table 4 presents the main balances and simulation results of the Higher Institute of Marine Science Technologies Sabratha photovoltaic facility. According to the table, the highest monthly energy output occurred in August (31.15 MWh) and the lowest level in December (17.37 MWh). The annual effective energy output of the E matrix is (287.80) kWh. However, it should be remembered that matrix E uses DC energy. After converting DC electricity into AC energy, we have an electronic network connected to the grid. Annual grid-connected power. The annual power connected to the grid is 1625 kWh / kWp / year The difference between an electronic matrix and an electronic network determines the efficiency of the inverter (0.845).

Table 4: Balances and main results.

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	ratio
January	81.8	41.98	12.22	115.1	113.3	18.92	17.99	0.882
February	94.6	50.13	13.39	121.1	119.2	19.78	18.81	0.877
March	140.9	69.98	16.62	163.7	160.7	26.22	24.96	0.861
April	171.1	84.47	19.63	178.2	174.4	28.13	26.78	0.849
May	199.1	92.90	23.11	190.1	185.6	29.64	28.18	0.837
June	198.1	95.81	25.61	182.3	177.8	28.24	26.85	0.832
July	217.3	87.35	28.61	202.7	197.9	30.94	29.43	0.820
August	202.2	81.35	29.13	204.5	200.1	31.15	29.64	0.819
September	157.6	73.57	26.78	175.6	172.1	27.16	25.86	0.831
October	124.4	60.02	24.03	154.5	152.1	24.23	23.07	0.843
November	91.0	41.11	18.42	129.4	127.2	20.74	19.74	0.862
December	72.5	35.79	13.66	106.2	104.5	17.37	16.48	0.877
Year	1750.7	814.45	20.98	1923.4	1884.9	302.52	287.80	0.845

Where; GlobHor: Horizontal global irradiation.

DiffHor: Horizontal diffuse irradiation.

T_Amb: T ambient Temperature Glob Inc: Global incident in coll.

plane GlobEff: Effective Global, correspond for IAM and shadings.

EArray: Effective energy at the output of the array.

E_Grid: Energy injected into grid.

PR: Performance Ratio.

6.2 Performance ratio

The ratio of the effective power generated at the output of the array to the power produced by an ideal PV system under the conditions is known as the performance ratio. Typically, standard test conditions (STC) are used, which have the same "global" radiation level. System and array losses in PV systems, array losses, wiring, mismatch, module quality, shading effects, PV power conversion rate, and IAM contribute to their performance ratio According to Figure 5, the overall performance of our system was 84.94. System performance was good, but there was a noticeable difference in monthly performance between the summer and winter seasons. The reason for this was high temperatures in the summer, which had a negative impact on performance. July and August had the lowest performance. During these months.

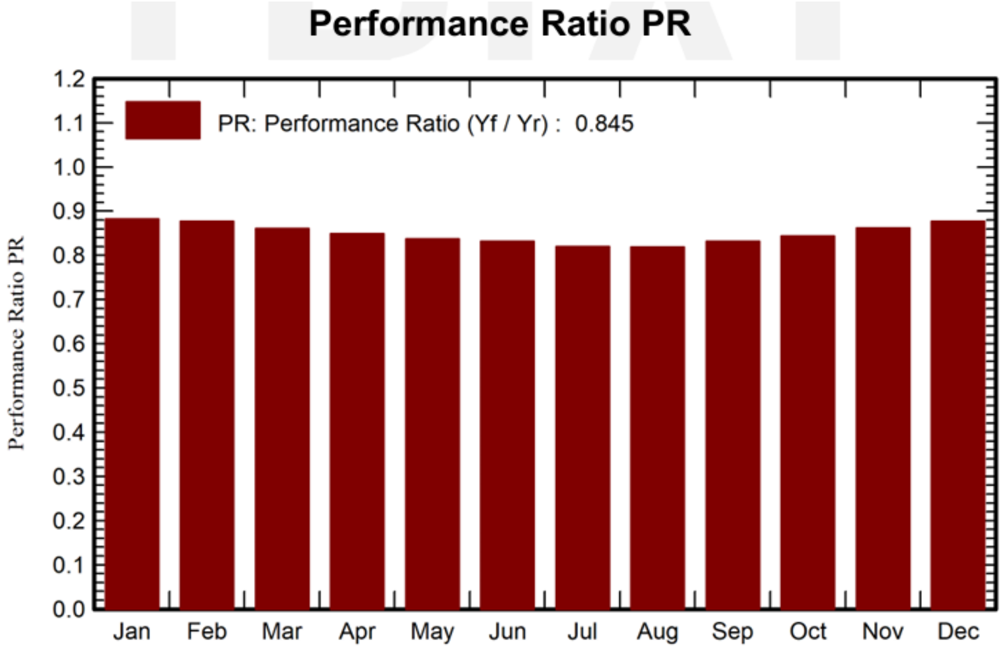

Figure 5: Performance ratio (%).

6.3 Normalized production

The subsequent the normalized production of a photovoltaic power plant is shown in Figure6. It provides the system losses, PV array collection losses, and useable energy generated by the inverter output. The monthly output and losses per kWh are displayed clearly.

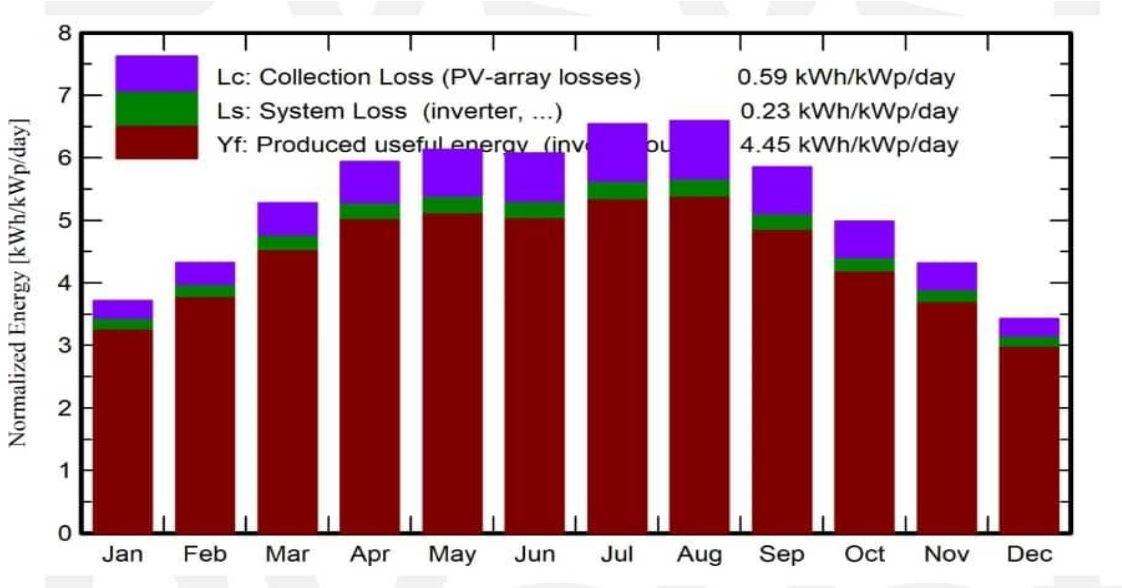

Figure 6: Normalized productions kWh/KWp/day.

Table 5: Result overview.

Parameter	**Value**
System Production	**287.8 MWh/yr**
Specific Production	**1625 kWh/kWp/yr**
Performance Ratio	**0.845**
Normalized Production	**4.45 kWh/kWp/day**
Array Losses	**0.59 kWh/kWp/day**
System Losses	**0.23 kWh/kWp/day**

7 Conclusion

The main objective of this study is to develop a plan to reduce the dependence of the the Higher Institute of Marine Science Technologies in Sabratha, Libya region on the public electricity company, while enhancing the availability of electricity, which would accelerate social and economic growth in the city of sabratha. This will be achieved by using PVSYST software to design, simulate and evaluate a 177 KW PVC plant per day. The following conclusions were drawn from this study: This project effectively demonstrates how temperature fluctuations affect the performance of solar units on an annual and daily basis. The heat has a greater impact on the efficiency of solar light. Data efficiency increases to the highest level in the morning and peaks in the afternoon before beginning to decline until sundown. As each solar unit has a different level of efficiency, it may be better to cool them to improve performance.

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