Design and comparative analysis of grid-connected BIPV system with monocrystalline silicon and polycrystalline silicon in Kandahar climate

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Abstract

Building integrated photovoltaic (BIPV) system is a new and modern technique for solar energy production in Kandahar. Due to its location, Kandahar has abundant sources of solar energy. People use both monocrystalline and polycrystalline silicon solar PV modules for the grid-connected solar PV system, and they don't know that which technology performs better for BIPV system. This paper analysis the parameters, described by IEC61724 "Photovoltaic System Performance Monitoring Guidelines for Measurement, Data Exchange and Analysis" to evaluate which technology shows better performance for the BIPV system. The monocrystalline silicon BIPV system has a 3.1% higher array yield than the polycrystalline silicon BIPV system. The final yield is 0.2% somewhat higher for monocrystalline silicon than polycrystalline silicon. Monocrystalline silicon has 0.2% and 4.5% greater yearly yield factor and capacity factors than polycrystalline silicon respectively. Monocrystalline silicon shows 0.3% better performance than polycrystalline silicon. With 1.7% reduction and 0.4% addition in collection losses and useful energy produced respectively, monocrystalline silicon solar PV system shows good performance than polycrystalline silicon solar PV system. But system losses are the same for both technologies. The monocrystalline silicon BIPV system injects 0.2% more energy to the grid than the polycrystalline silicon BIPV system.

Keywords: Photovoltaic technologies, Performance analysis, Solar energy, Solar irradiance, Performance ratio

1. Introduction

The worldwide renewable energy revolution has been sparked by rising energy prices and climate change, moving us towards self-sustaining energy resources and technology to exploit them [1]. Solar energy, which is plentiful, environmentally friendly and can be used for domestic use, is one of the main renewable energy sources. Solar energy is converted into electric potential by a photovoltaic system. As opposed to other renewable energies, photovoltaic (PV) has many distinctive advantages. Solar cells can be attached to buildings without occupying the ground, for example. Since the regular peak of PV power almost overlaps the peak of electricity demand in the commercial and industrial sectors, it can save transmission and dispatch costs by distributed applications, which is particularly interesting. The modularity of PV systems allows for step-by-step implementation and versatile building [2].

The photovoltaic modules or panels are made of semiconductors that allow the direct conversion of sunlight into electricity. For a very long period of time, these modules will provide you with a safe, efficient, maintenance-free and environmentally friendly source of electricity. An effective solar PV system implementation requires awareness of its operational efficiency under different climatic conditions [3]. Several papers and studies have been conducted globally to determine the viability and efficiency of various SPV power plants, and it can be concluded that the PV power plant is a viable and feasible alternative to meet current and potential power requirements [4].

It is possible to distinguish photovoltaic (PV) systems into standalone and grid-tied systems. The latter is when the PV panel supplies the utility grid, in case it has met the local load already. Selling the excess energy produced from the user to the utility is useful over time, for a lower amount than vice versa, which can contribute to a reduction in the payback period. These devices must be carefully installed and maintained, as they must comply with the manufacturer's safety and quality requirements and application standards [5]. Ameur et al.[6] evaluated and compared several indices assessing the efficiency of various grid-connected photovoltaic technologies, namely amorphous silicon (a-Si), polycrystalline silicon (pc-Si), and mono-crystalline silicon (mc-Si), each generating approximately 2 KWp, and established a forecast for future prospects. Standard selection criteria are normally adopted by BIPV project developers before the project is implemented. In addition, this also helps the developer in evaluating the efficacy of the specific option.

The practical viability of BIPV application in the construction projects depends on many factors such as location and advances in BIPV Technology in the surrounding areas. Another critical criterion is the building's architectural style. In determining the outline of the project based on 3D drawing, this criterion is most important. The cost of the project will assess the real economic feasibility and appropriateness of the entire project in the country's current economic scenario [7]. Although PV modules are sold under STC conditions based on the power rating, the energy they generate under real operating conditions is important for return-on-investment. Therefore, their characteristics with regard to temperature, broadband irradiance, spectral irradiance and angle of incidence are determined when assessing the suitability of different modules or module technologies for investment decisions (AOI) are important [8].

Architectural design requirements clash with optimizing photovoltaic energy output when photovoltaic modules are incorporated in a house. As a result, BIPV arrays mostly do not face south and are often vertically installed. A larger portion of the overall sunlight striking the array is diffuse or at high incidence angles under these conditions A large amount of total annual energy is provided at low light levels at northern latitudes. In order to obtain winter sunlight that passes through a greater air mass due to the low level of the winter sun in the sky, vertical arrays are better oriented. High Air Mass alters both the spectral characteristics of sunlight and decreases the intensity of a PV module light incident. Due to greater cloud cover, winter light is often diffuse at northern latitudes. Diffuse light has numerous spectral features and has a lower intensity than direct irradiance [9].

2. Methodology for performance analysis of the PV system

The performance parameters are developed by the International Energy Agency (IEA) for analyzing the performance of solar PV grid interconnected systems. Many performance parameters are used to define the overall system performance concerning the energy production, solar resource and overall effect of system losses. The various parameters are the performance ratio, final PV system yield and reference yield.

2.1. Array yield

It is equal to the time which the PV plant has to operate with nominal solar generator power Po to produce array DC energy Ea. Its units are kWh/d∗kWp [10].

YA = EA/P0 (1)

where Array energy output per day EA = Idc∗Vdc∗t (kWh),

Idc = DC current (A)

Vdc = DC voltage (V)

P0 = Nominal Power at STC..

2.2. Reference yield

The reference yield is the cumulative in-plane irradiance H divided by the PV's reference irradiance G. It reflects the energy obtainable under ideal conditions. If G equals 1 kW/m2, then Yr is the number of peak sun hours or the solar radiation in units of kWh/m2. The Yr defines the solar radiation resource for the PV system. It is a function of the location, orientation of the PV array, and month-to-month and year-to-year whether variability [7–13].

Its units are h/d.

YR = Ht/Go (2)

where,

Ht = Total Horizontal irradiance on array plane (Wh/m2),

Go = Global irradiance at STC (W/m2).

2.3. Final yield

The final yield is defined as the ratio of net daily, monthly or annual AC energy output to the rated power of the installed PV array of the complete PV system supplied by the array. The daily final yield is given by [14].

YR = HT/HR (kWh / kWp) (3)

2.4. Performance ratio

The final yield divided by the reference yield is the output ratio. Compared to the output of the plant, the performance ratio can be defined as a comparison of the plant output by taking into account irradiation, panel temperature, grid availability, aperture area size, rated power output, temperature correction values [10].

$$PR = YF/YR \tag{4}$$

3. Description of the grid-connected solar BIPV system

A grid-connected BIPV system consists of solar panels, inverters, a power conditioning unit and grid connection equipment. It has an effective utilization of power that is generated from solar energy as there is no energy storage. When conditions are right, the grid-connected BIPV system supplies the excess power, beyond consumption by the connected load to the utility grid. But, in stand-alone systems batteries are used to store energy, or else energy has to be directly connected to load.

3.1. The geographical location of the site

The BIPV solar photovoltaic system is located at a longitude of 65.72 E, latitude 31.62 N, and an altitude of 1021 m. The considered building is located in Deh-e Khw ājah, Kandahar, Afghanistan as it is located at a geographically good location where it can absorb more solar radiation for the entire year as power generated by solar plant completely depends up on its sun's insolation.

3.2. The BIPV System Configuration

The total rating of the BIPV System is 10 KW which occupied nearly 65 m^2 of building front view. This system covers the front view of the building facing south and is grid-connected. All system is one block and consists 40 modules, with 2 strings in each string, 20 modules in series. The design is performed with 2 options, first, with monocrystalline silicon solar PV and then with polycrystalline silicon solar PV. (See Fig. 1). The plant is installed in such a way that it is cost-effective, more reliable, and more energy output. During nights when there is no power generation due to lack of solar radiation, the power is taken back from the grid for internal power requirements. The power is utilized for lighting, and control room appliances.

3.3. Tilt angle

The tilt angle of the PV array is usually kept as equal to the latitude of the corresponding location to get maximum solar radiation. But in this system it is not practical practice to keep the system on tilt equal to latitude due to the vertical structure of the front view of the building. So, due to this limitation, the tilt angle for this system is kept 90° and azimuth 0° south-facing.

3.4. Solar PV Modules

Solar PV modules used in this study are of two types. Table 1 shows the description of both monocrystalline silicon solar PV system and polycrystalline silicon solar PV system.

a **b**

Fig. 1. Grid-connected BIPV system with (a) monocrystalline silicon and (b) polycrystalline silicon

Table 1: Description of mono and poly crystalline silicon solar system

Specifications	**Mono - Si**	**Poly-Si**
Model	AD250M6. Bb	AD250P6 − Ab
Power	250 W	250 W
Short Circuit Current	8.65 A	8.71 A
Open Circuit Voltage	37.9 V	37.88 V
Current at Maximum PowerPoint	8.11 A	8.15 A
Voltage at Maximum Power Point	30.82 V	30.67 V
Efficiency	15. 41 %	15. 4 %
Temperature Coefficient	0.06 %/℃	0.06 %/℃
Length	1636 mm	1636 mm
Width	992 mm	992 mm
Cell Area	237.4 cm^2	243.4 cm^2

4. Result and discussion

4.1. Performance of Mono-Crystalline Silicon Building Integrated Solar PV System

Table 2 shows the global horizontal irradiation, horizontal diffuse irradiation, ambient temperature, global incident in solar PV plane, effective global irradiation. for IAM and shadings, effective energy at the output of the array, energy injected into grid and performance ratio for monocrystalline silicon. The DC energy generated varies from a maximum value of 1.534 MWh with array yield 5.113 h/d in month of November to a minimum value of 0.482 MWh with array yield of 1.6 h/d in month of June and with an average array yield 3.33 h/d. Reference and final yields are 3.91 KWh/m2/KW/m2 and 3.247 h/d respectively. Panel generation factor ranges from a minimum value of 3.25 h/d in month of December to a maximum value 7.88 h/d in month of June, and the average value is 5.63 h/d. While the yearly yield factor and capacity factors measured for this system are 1185 h/year and 0.1352.

The performance ratio for building integrated monocrystalline silicon solar system ranges from a minimum 73.2% in month of June to a maximum 89.3% in month of January and the yearly average performance ratio is 82.9% (see Fig. 2). The decrease in performance ratio in June is due to temperature losses. The temperature reaches to very hot 39.1°C in this month [15]. Inverter and system efficiencies for this system are 97.53% and 15.02% respectively. Fig. 3 shows collection losses, system losses and useful energy produced 0.59 KWh/KW/day, 0.08 KWh/KW/day and 3.25

KWh/KW/day respectively.

Table 2: New simulation variant balances and main results for monocrystalline silicon solar PV system

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	104.9	34.62	6.39	152.2	148.4	1.386	1.359	0.893
February	114.0	37.70	10.78	126.5	121.9	1.134	1.109	0.877
March	159.6	56.41	16.72	124.1	116.5	1.070	1.044	0.841
April	191.9	61.24	22.65	97.1	87.9	0.796	0.774	0.797
May	223.3	67.04	28.22	72.8	63.8	0.567	0.546	0.749
June	236.5	65.63	28.02	62.9	54.2	0.482	0.461	0.732
July	226.9	75.67	26.75	69.3	60.4	0.542	0.521	0.752
August	215.6	69.00	26.27	92.2	82.0	0.734	0.712	0.773
September	195.4	41.02	24.20	128.1	118.0	1.047	1.021	0.797
October	163.5	33.08	20.97	166.4	159.1	1.402	1.374	0.826
November	123.1	27.61	14.11	176.7	171.7	1.534	1.505	0.852
December	101.0	27.79	8.61	162.1	158.5	1.455	1.425	0.879
Year	2055.5	596.81	19.52	1430.4	1342.6	12.150	11.851	0.829

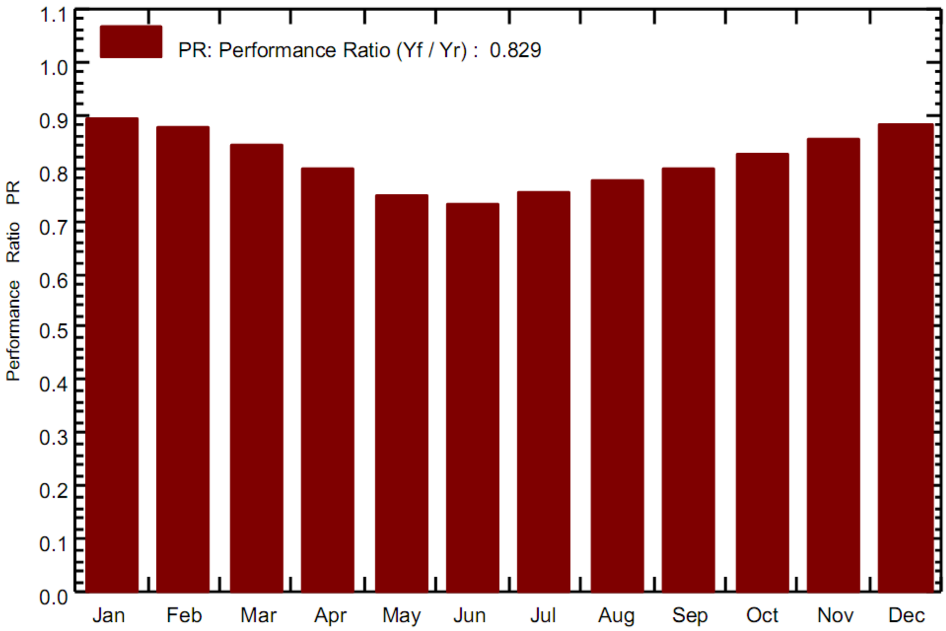

Fig. 2. Performance Ratio PR of monocrystalline silicon solar PV system

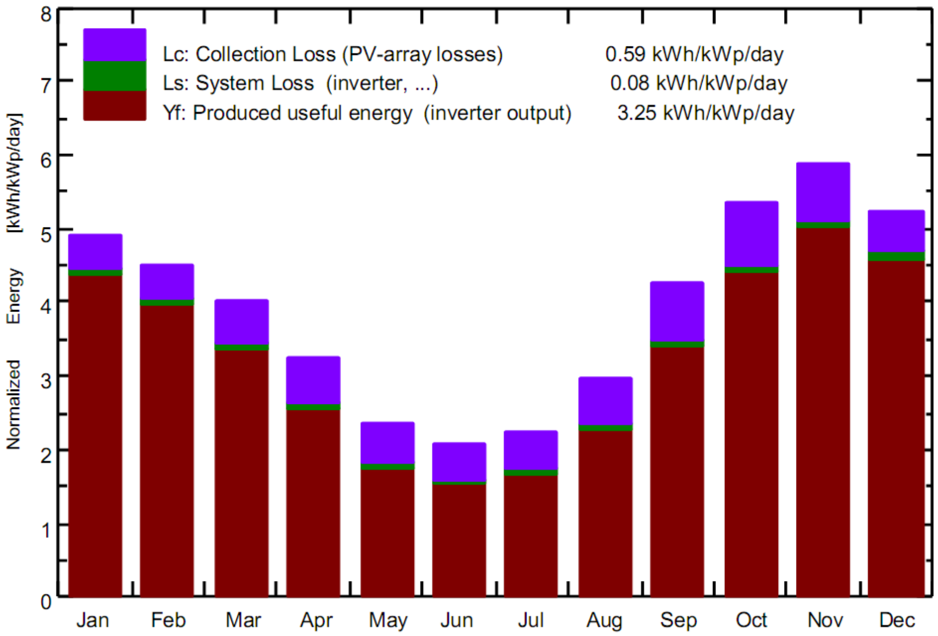

Fig. 3. Normalized productions (per installed kWp): Nominal power 10.00 kWp for monocrystalline silicon solar PV system

4.2. Performance of Poly Crystalline Silicon Building Integrated Solar PV System

Table 3 shows the global horizontal irradiation, horizontal diffuse irradiation, ambient temperature, global incident in solar PV plane, effective global irradiation. for IAM and shadings, effective energy at the output of the array, energy injected into grid and performance ratio for polycrystalline silicon solar PV system. The DC energy generated by polycrystalline silicon solar PV system varies from a maximum value of 1.533 MWh with array yield 5.11 h/d in month of November to a minimum value of 0.481 MWh a little different from that monocrystalline silicon solar PV system with array yield 1.603 h/d in month of June, and with an average array yield 3.32 h/d. Reference and final yields are 3.91 KWh/m2/KW/m2 and 3.242 h/d respectively. Panel generation factor ranges from a minimum value of 3.25 h/d in month of December to a maximum value of 7.88 h/d in month of June, and the average value is 5.63 h/d.. While the yearly yield factor and capacity factors measured for this system are 1183 h/year and 0.135.

The performance ratio for building-integrated polycrystalline silicon solar system ranges from a minimum of 73% in month of June to a maximum 89.2%, a little less than mono crystalline technology, in month of January and the yearly average performance ratio is 82.7% (see Fig. 4). Inverter and system efficiencies for this system are 97.54% and 15.03% respectively. Fig. 5 shows collection losses, system losses and useful energy produced 0.6 KWh/KW/day, 0.08 KWh/KW/day, and 3.24 KWh/KW/day respectively

4.3. Comparison of Performance of Mono and Poly Crystalline Silicon BIPV System

Performance analysis of both mono and poly crystalline silicon shows that there is difference in performance between these two technologies. The array yield for mono and polycrystalline silicon is 3.3 and 3.2 h/d respectively, which shows that the monocrystalline silicon solar PV system has 3.1% greater array yield than polycrystalline silicon solar PV system. Reference and final yields are 3.91 KWh/m2/KW/m2 and 3.247 h/d for monocrystalline silicon and 3.91 KWh/m2/KW/m2 and 3.242 h/d for polycrystalline silicon respectively, that illustrates, there is no difference in reference yield but the final yield is 0.2% greater for monocrystalline silicon than polycrystalline silicon. Samsuri &

Ahmed [16] studied to evaluate the performance of two PV technologies (C-Si and CIS) for building integrated photovoltaic based on tropical climate condition and showed that the final yield of CIS was as low as 2.98 hours/day in July to the highest value of 4.31 hour/day in March. The final yield for the c-Si power plant ranged from 2.92 hours/day in July to 4.14 hours/day in March.

Meanwhile, the yearly yield factor and capacity factor calculate are 1185 h/year, and 0.135 for monocrystalline silicon, and 1183 h/year and 0.129 for polycrystalline silicon respectively, which shows monocrystalline silicon has 0.2% and 4.5% greater yearly yield factor and capacity factor than polycrystalline silicon respectively. Panel generation factor ranges from a minimum value of 3.25 h/d in month of December to a maximum value of 7.88 h/d in month of June for monocrystalline silicon and ranges from a minimum value of 5.63 h/d in month of December to a maximum value 7.88 h/d in month of June for polycrystalline silicon, which seems that there is no difference in panel generation factor.

Another important parameter for performance analysis is the performance ratio which is 82.9% for monocrystalline silicon and 82.7% for polycrystalline silicon respectively. This shows that monocrystalline silicon performs better with a value of 0.3% than polycrystalline silicon. Vikrant Sharma et al. [17] predicted annual energy yield and performance ratio values to 4.89%, 4.94%, 1.16% and 4.34%, 4.93%, 1.88% for p-Si, HIT and a-Si arrays respectively, and David A. et al. [18] studied the performance ratio varies from 48.84% (CIS) to 71.26% (for p-Si). Renu and Goel [14] evaluated performance analysis of 11.2 kWp rooftop grid-connected PV system in Eastern India and showed that PV module efficiency, inverter efficiency and performance ratio were found to be 13.42%, 89.83% and 0.78 respectively. Akash Kumar et al. [19] conducted research on simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology and find that the PR of the PV systems varies from 70% to 88% and their energy yields range from 2.67 kWh/kWp to 3.36 kWh/kWp.

Collection losses, system losses, and useful energy produced are 0.59 KWh/KW/day, 0.08 KWh/KW/day, and 3.25 KWh/KW/day for monocrystalline silicon, and 0.6 KWh/KW/day, 0.08 KWh/KW/day, and 3.24 KWh/KW/day for polycrystalline silicon respectively, with 1.7% decrease and 0.4% increase in collection losses and useful energy produced respectively, monocrystalline silicon solar PV system is efficient than polycrystalline silicon solar PV system, but system losses remains the same for both technologies. The yearly AC energy injected to the grid is 11.85 MWh and 11.83 MWh for mono and polycrystalline silicon respectively, which shows that the monocrystalline silicon BIPV system injects 0.2% greater energy to the grid than polycrystalline silicon BIPV system. Arechkik Ameur et al. [6] evaluated the Performance evaluation of different photovoltaic technologies in the region of Ifrane, Morocco, and showed that the total accumulative energy output for mc-Si is only 1.24% greater than the pc-Si and largely higher than the a-Si by 14.61%.

Table 3: New simulation variant balances and main results for polycrystalline silicon solar PV system

	GlobHor kWh/m²	**DiffHor** kWh/m²	**T_Amb** °C	**GlobInc** kWh/m²	**GlobEff** kWh/m²	**EArray** MWh	**E_Grid** MWh	**PR** ratio
January	104.9	34.62	6.39	152.2	148.4	1.385	1.358	0.892
February	114.0	37.70	10.78	126.5	121.9	1.132	1.108	0.876
March	159.6	56.41	16.72	124.1	116.5	1.068	1.043	0.840
April	191.9	61.24	22.65	97.1	87.9	0.794	0.772	0.795
May	223.3	67.04	28.22	72.8	63.8	0.565	0.544	0.747
June	236.5	65.63	28.02	62.9	54.2	0.481	0.459	0.730
July	226.9	75.67	26.75	69.3	60.4	0.541	0.520	0.750
August	215.6	69.00	26.27	92.2	82.0	0.733	0.711	0.771
September	195.4	41.02	24.20	128.1	118.0	1.045	1.019	0.796
October	163.5	33.08	20.97	166.4	159.1	1.401	1.372	0.825
November	123.1	27.61	14.11	176.7	171.7	1.533	1.503	0.851
December	101.0	27.79	8.61	162.1	158.5	1.454	1.424	0.878
Year	2055.5	596.81	19.52	1430.4	1342.6	12.131	11.833	0.827

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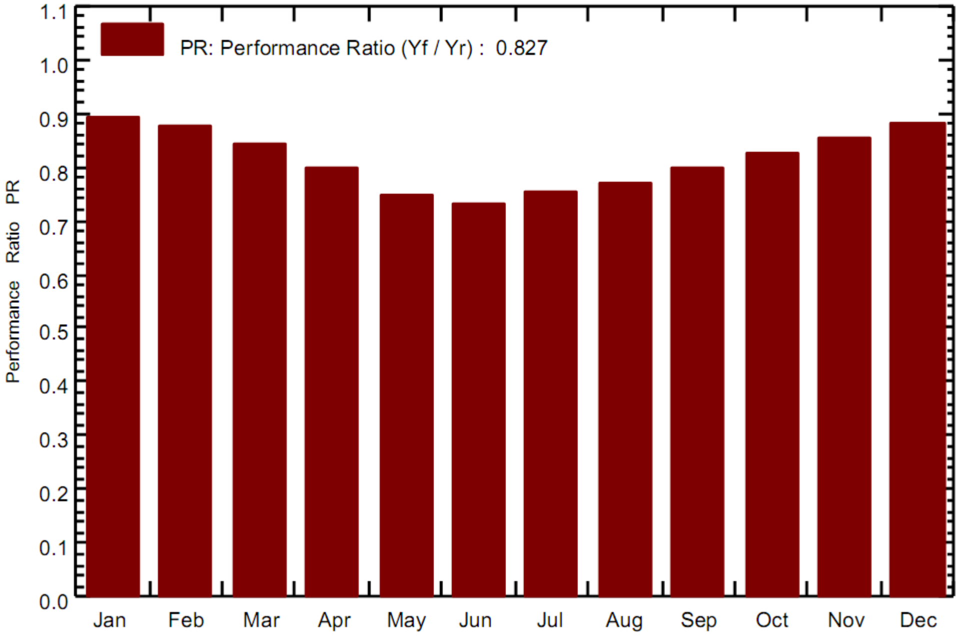

Fig. 4. Performance Ratio PR of polycrystalline silicon solar PV system

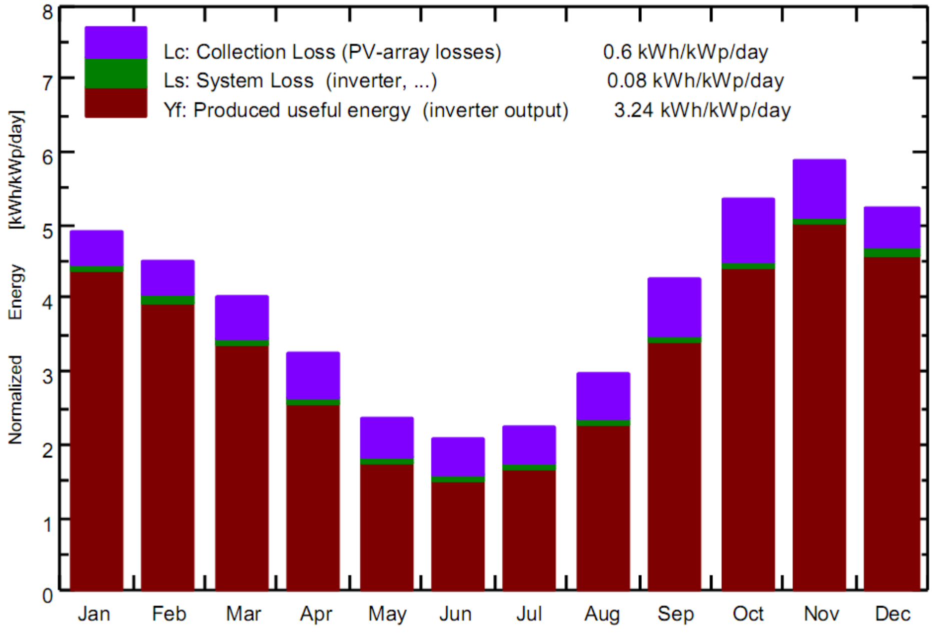

Fig. 5. Normalized productions (per installed kWp): Nominal power 10.00 kWp for polycrystalline silicon solar PV system

5. Conclusion

The performance analysis shows that the monocrystalline silicon BIPV system has a 3.1% more array yield than the polycrystalline silicon BIPV system. final yield is 0.2% greater for monocrystalline silicon than polycrystalline silicon. Monocrystalline silicon has 0.2% and 4.5% greater yearly yield factor and capacity factors than polycrystalline silicon respectively. Monocrystalline silicon shows better performance with a value of 0.3% than polycrystalline silicon. With a 1.7% decrease and a 0.4% increase in collection losses and useful energy produced respectively, monocrystalline silicon solar PV system shows better performance than polycrystalline silicon solar PV system. But system losses are the same for both technologies. The panel generation factor is the same for both of them with an average value of 5.63. The monocrystalline silicon BIPV system injects 0.2% greater energy to the grid than the polycrystalline silicon BIPV system. Finally, the performance analysis shows that the monocrystalline silicon BIPV system is efficient than polycrystalline silicon BIPV system.

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