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Performance analysis of PVSyst based grid connected photovoltaic systems in Pakistan compared to SAARC countries

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ABSTRACT

Electricity demand increasing day by day with the passage of time, fossil fuels and traditional electricity sources are becoming obsolete. The possibility of dealing with a power deficit and importing oil and gas for electricity generation exists for developing nations like Pakistan. One of the most accessible and affordable sources of renewable energy in the world is solar power generating. Photovoltaic (PV) cell performance is influenced by the environment and the technology used to capture the available energy. The Islamabad region of Pakistan is blessed with an average of 300 days of sunshine a year due to its location in the solar band at 33.7215°N latitude and 73.0433°E longitude. The current study compares and contrasts how Pakistan and South Asian Association for Regional Cooperation (SAARC) countries generate electricity using solar systems. Choosing one geographical place from all SAARC nations, PVSyst software is used to develop and estimate the performance study for solar model cell Panasonic 320W_p, 48V and 1.5 kW Inverter Fronius for a 9.6 kW_p load. Energy supplied into the grid is studied together with various losses that occur in the system, with the choice of PV arrays and other factors remaining the same for comparison study of all SAARC countries. The approach to minimize losses through the utilization of an adjustable tilt angle has been implemented. This study will be useful in estimating and planning the solar energy output in all SAARC nations for the same photovoltaic system, and it will be simple to trade all PV system components in the region.

1. Introduction

Fossil fuels that are imported into SAARC nations in dollars from China and the Middle East [1]. Conventional power generation sources mostly use furnace oil, gas, coal that are depleting with the passage of time and cause of greenhouse effect and price hike of electricity due to the power generation through conventional sources compel countries to install renewable based power generation plants and solar power generation is one of the cheapest options and have good potential throughout the world [2-6]. In SAARC nations, renewable energy sources including sun, wind, hydro, Magneto hydro dynamic (MHD) and all other renewable resources are frequently accessible and in plentiful supply [7,8]. High fossil fuel prices have a direct impact on everyday living in SAARC countries. energy from renewable sources, particularly solar power generation with improved technology to capture the most energy for the longest time. Given that solar irradiation is inconsistent and unavailable at night, grid-tied solar technology is one of the most dependable ways to meet user load requirements. It supplies electricity to consumers throughout the day and uses a grid-tie mechanism to export excess energy to the grid [9,10]. Solar cell power generation is direct dependent on the sun irradiance on collector plane and inverse in relation with the temperature, high temperature decreases the efficiency of solar cell [11,12]. As a result, distributed power generation through solar or wind reduces line losses and the energy issue in remote parts of SAARC countries [13,14]. Both Berlin and Kathmandu in Nepal employ 60 kW_P systems with 250 W_P Sanyo solar modules to generate electricity, however Kathmandu has more output to supply the grid. Using PVSyst software, this simulation's architecture employs a fixed inclined plane without varying the tilt angle over the course of the summer or winter [15-18]. Up to 2023, a variety of solar modules will be available, however each solar cell will have a varied efficiency owing to its open circuit voltage, cell efficiency, and short circuit current, all of which will affect the overall efficiency of the PV system [19]. Solar cells may be constructed using a number of software tools, including SCAPS-1D or LTSPICE-IV, and their I-V characteristic curves can be measured, resulting in a PV system with a higher efficiency [20,21]. PVSyst is a popular software for PV size and irradiation calculations; however, other programs such as SAM and Homer are also utilized in similar capacities. To determine whether a PV system is feasible at the suggested locations, performance ratios are calculated [22-25]. In this study, a grid-tie system comparison of all photovoltaic power generation is made for all SAARC nations. Using PVSyst simulation software, an identical proposed solar system is utilized for several SAARC locations to examine various losses and energy production in order to achieve an optimum and efficient system with lowest losses. The suggested solar system design and input parameters are shown in Section 2, the results and analysis of the photovoltaic model simulation are described in Section 3, the conclusion is shown in Section 4, and references are given in Section 5.

2. Proposed Grid Connected Photovoltaic Model

The design and estimation of a 10 KW_p PV cell and the irradiation of the sun vary by country, but the sun is not available at night. In SAARC nations, the most effective irradiance is assessed when designing PV systems to capture the sun's greatest power. Losses are also computed using the PV system's solar cell specifications. For the current study, the inverter type and other variables are the same throughout all SAARC nations' geographical locations for grid connected system. The PVSyst simulation results demonstrate the performance and losses of a grid-connected solar photovoltaic system. Losses that resulted from a variety of sources were investigated, and the overall performance ratio (PR) of a photovoltaic system for a certain geographic area is used to track its effectiveness.

2.1 Design of A Grid Connected PV System

Grid-connected photovoltaic systems can be of two major types: those with batteries and those without. Typically, systems with batteries suffer larger losses due to energy storage and many losses during the conversion of Direct Current (DC) to Alternating Current (AC) or AC to DC. Basic model of proposed system is shown in Fig. 1 given below.

Fig. 1. Grid Connected PV System

2.2 Design of PV Array

On the collector plane of the cell, photon energy packets are typically received to represent solar energy. The basic idea behind photovoltaic technology is to transform solar radiation into usable electrical energy. Solar cells are composed of semiconductor materials that form PN junctions when sunlight strikes the solar cell's collector, causing electricity to flow from the cell. Solar modules are simply solar cells linked in series, and a number of solar modules are connected in series to create solar arrays, which may be planned to use the PVsyst application, to fulfill the consumer's load requirements. The number of cells in a module and the number of modules connected in series through strings to build an array of photovoltaic systems that meet customer demand determine how much usable output the solar system can provide. The modules in series employed in the current study is 3-5 and the number of strings 6–11 depend on the radiation levels in the SAARC nations designated geographic locations. For an array, a total of 30 modules are utilized. The output of a photovoltaic system is primarily influenced by the number of solar cell modules, type of solar cell, total module area, and DC to AC power conversion through inverter. All data of current research is provided in Table 1.

Table 1.

Design of Array using PV module and Inverter selections for SAARC countries

PV system characteristics	Proposed system input values for all SAARC countries
No. of Modules	30
Area of Module	$50m^2$
Nominal PV Power	9.6 kW_p
Nominal AC Power	9.0 kWAC
P_{mpp} at operation condition (50°C)	8.91kW_p
Solar Module	Panasonic VBHN-320-SJ47 320W_p 48V
Inverter	Fronius USA -Galvo 1.5-1/240
No. of Inverters	6
Nominal Power Ratio	1.067

2.3 Comparison of Grid Connected PV System

Among all SAARC nations, India generates the most solar energy, whilst the other site chosen for this study is experiencing a severe energy shortage despite having a large solar potential due to the course of the sun. The performance analysis of a 9.6kW_p similar grid connected photovoltaic system was conducted in cities from SAARC countries using PVSyst simulation. Using inverter and cell modules as well as sizing of PV array are designed in PVSyst. Through performance analysis, this simulator is utilized to display results for all of the supplied data. The input geographical parameters for every SAARC country are displayed in Table 2 for identical photovoltaic system. Fig. 2 displays the circuit design of proposed photovoltaic system for SAARC nations so that the performance of every site can be compared. Table 1 lists the primary input parameters for the proposed photovoltaic system.

2.4 Tilt Angle of Location

The global horizontal plane has 0% loss with regard to optimal conditions when choosing the tilt angle, while the collector plane receives the greatest amount of radiation. As seen in Fig. 4, the tilt angle of 30° for Islamabad is chosen based on the sun path, while the azimuth angle is set at 0° to get the most optimal solar irradiation on the collection plane, which is 1752 kWh/m^2/year. As shown in Table 02, the appropriate tilt angle is chosen for each site within the SAARC nations while minimizing losses and optimizing global irradiation on the collector plane of the suggested PV system. In contrast, a maximum tilt angle of 32° is chosen for Kathmandu and Thimphu, while 10° is chosen for Malé.

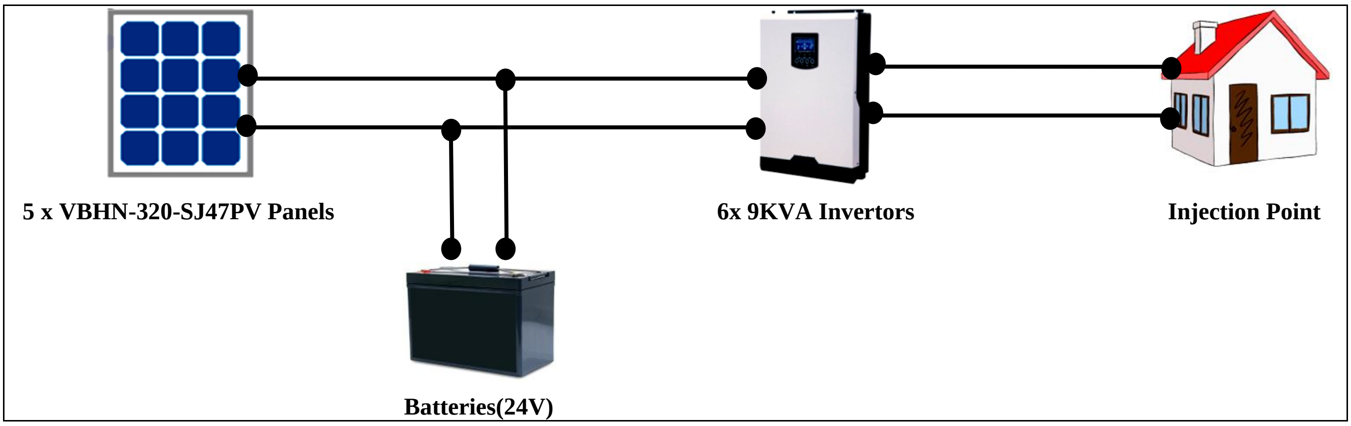


Fig. 2. Circuit Diagram For 9.6kW_p Photovoltaic System

Table 2.

Geographical location data of 9.6kW_p site in SAARC countries

Parameters	Afghanistan (Kabul)	Bangladesh (Dhaka)	Bhutan (Thimphu)	India (Ahmedabad)	Maldives (Malé)	Nepal (Kathmandu)	Pakistan (Islamabad)	Sri-Lanka (Colombo)
Latitude	34.53°N	23.71°N	27.47°N	23.07°N	4.18°N	27.70°N	33.72°N	7.18°N
Longitude	69.17°E	90.41°E	89.64°E	72.63°E	73.51°E	85.32°E	73.04°E	79.89°E
Altitude	1809m	22m	2284m	55m	2m	1289m	585m	8m

Tilted Angle	32°	13°	32°	28°	10°	32°	30°	17°
Albedo	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Time Zone	UTC+4.5	UTC+6	UTC+6	UTC+6	UTC+5	UTC+5.8	UTC+5	UTC+6
Azimuth	0°	0° 0°	0°	0°	0°	0°	0°	

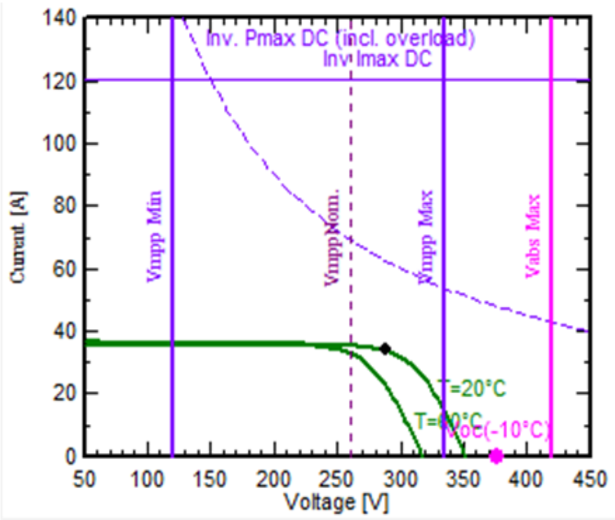
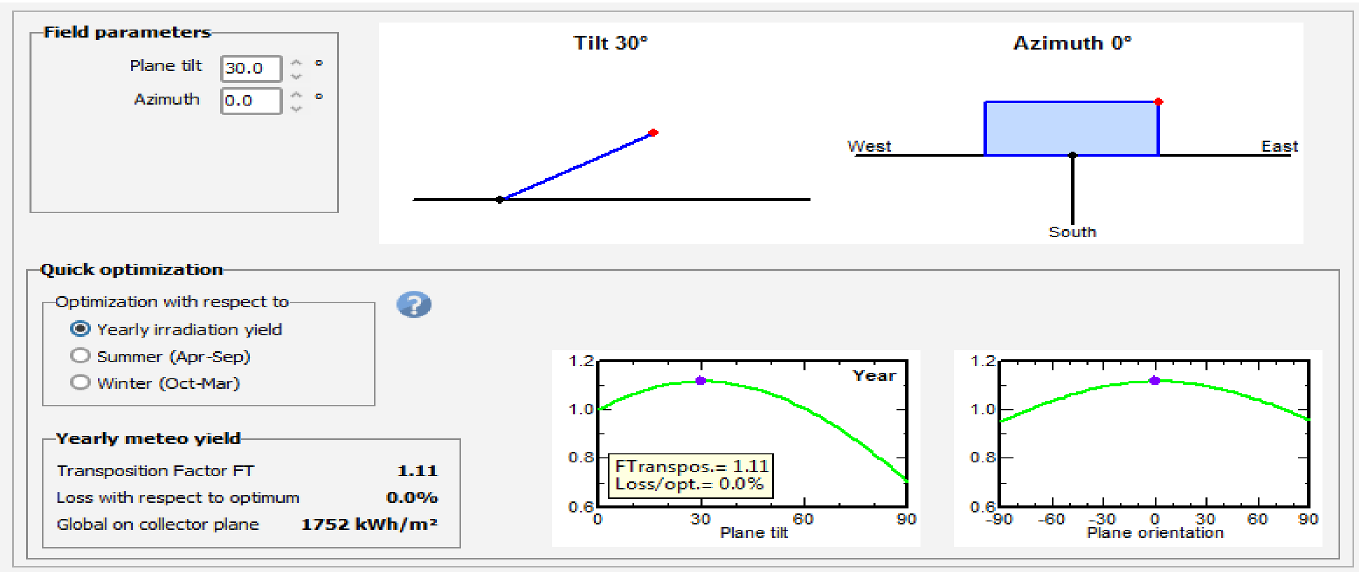


Fig. 3. Photovoltaic Module Characteristics

3. Result and discussion

PVSyst simulation software was used to validate the planned identical system for locations in south Asian nations that have different solar irradiation and solar inclination, while keeping the solar cell, inverter, and all other system characteristics constant. For a specific geographic location and energy output through a 9.6kW$_p$ grid-connected photovoltaic system, statistics of various irradiations, such as global and diffused on horizontal collector plane of solar cells per year, are provided in above Table 3. Global horizontal irradiation is at its highest in Kabul (Afghanistan) and Malé (Maldives), 2027.9 and 2037.9 respectively, and at its lowest in Dhaka (Bangladesh), and Islamabad (Pakistan), 1538.8 and 1573.2 respectively. That's why Kabul (Afghanistan) produces the most energy overall (19910 kWh), with 18913 kWh of the additional energy being exported to the grid. Dhaka has the lowest effective irradiance for collector planes (Glob-eff) while Kabul has the highest effective irradiance that is useful irradiance for the energy production of an array. Ambient temperature also has a significant impact on the "Panasonic" solar cell model, which performs well in places with low temperatures like Thimphu, Bhutan, and Kabul, Afghanistan, and exports excess energy to the grid with performance ratios of 0.886 and 0.849, respectively.

Fig. 4. Tilt Angle 30° and Azimuth angle 0° Selection for Islamabad (Pakistan) In Optimum Condition Using PVSyst



Simulator

Table 3.

Comparison of SAARC countries Simulated Result of 9.6 kW$_p$ Grid Tie PV system.

Sr. No	PV Site	GlobHor kWh/m^2/y	DiffHor kWh/m^2/y	T_Amb °C	Globinc kWh/m^2/y	Globeff kWh/m^2/y	E-Array kWh/y	E-Grid kWh/y	PR Ratio
1.	Afghanistan (Kabul)	2027.9	526.06	14.60	2320.7	2274.2	19910	18913	0.849

2	Bangladesh (Dhaka)	1538.8	933.3	25.20	1610.2	1570.2	13827	12917	0.836
3	Bhutan (Thimphu)	1807.3	716.75	3.15	2046.7	2005.0	18354	17414	0.886
4	India (Ahmedabad)	1830.7	862.2	27.61	1993.8	1955.9	16691	15811	0.826
5	Maldives (Malé)	2037.9	881.15	28.81	2048.8	2002.2	17151	16246	0.826
6	Nepal (Kathmandu)	1693.7	748.38	19.08	1889.7	1851.4	16243	15378	0.848
7	Pakistan (Islamabad)	1573.2	804.39	22.08	1732.7	1697.5	14729	13912	0.836
8	Sri-Lanka (Colombo)	1914.1	933.00	27.37	1914.0	1870.3	16123	15266	0.831

3.1 Overall Losses Diagram

Total losses initially computed total energy production, and surplus energy injected into the grid via a grid tie system. Due to the greatest and lowest performance ratios (PR), the loss diagram for Afghanistan (Kabul) and India (Ahmedabad) is shown in Fig. 5 and Fig. 6 given below, respectively. Other losses are important, but these two losses have a substantial impact on performance ratio for a particular geographic site. The two losses that are relevant are the inverter loss during operation (efficiency) and the photovoltaic losses caused by temperature effect. As a result, temperature and light exposure have a direct impact on photovoltaic cells, while the effectiveness of inverters in converting DC power to AC power is crucial for performance evaluation. Current research shows that, the temperature-related PV loss varies depending on the location and the amount of solar radiation received on horizontal collector plane. It is 6.78% for Kabul, 7.07% for Dhaka, 6.50% for Kathmandu, 2.30 for Thimphu, 8.80% for Malé, 8.22% for Colombo, 9.16% for Ahmedabad, and 7.5% for Islamabad, while inverter efficiency varies slightly for proposed locations and stays between 4.95% and 6.51%.

Furthermore, all SAARC locations' efficiency at standard temperature conditions is 19.14%, while the total surface area of all proposed sites' 9.6kW$_p$ photovoltaic systems is 50m^2. In Fig. 6 and Fig. 5 total energy available at inverter output is 15811 kWh/year and 18913 kWh/year for Ahmedabad and Kabul respectively. After deducting all losses, the total amount of energy generated at other locations such as Bangladesh (Dhaka), Bhutan (Thimphu), Maldives (Malé), Nepal (Kathmandu), Pakistan (Islamabad), and Sri Lanka (Colombo) had been 12917 kWh/year, 17414 kWh/year, 16246 kWh/year, 15378 kWh/year, 13912 kWh/year, and 15266 kWh/year, respectively. All of the aforementioned information also demonstrates that Kabul has the most potential of any SAARC location for the proposed solar power facility, whereas Dhaka has the lowest potential. Table 3 displays all of this information.

3.2 Incident Energy on Collector Lane

Having chosen several sites in south Asia of SAARC countries in order to acquire the optimal location for solar power generation during the validation of our proposed PV system using the PVSyst simulator. The software's results indicate that while reference incident energy is typically 5.463 kWh/m^2/day for geographical location Ahmadabad (India), it is greatest in the month of March and minimum in the months of July and August owing to high temperatures, which also raise collection plane temperature, as shown in Fig. 7.

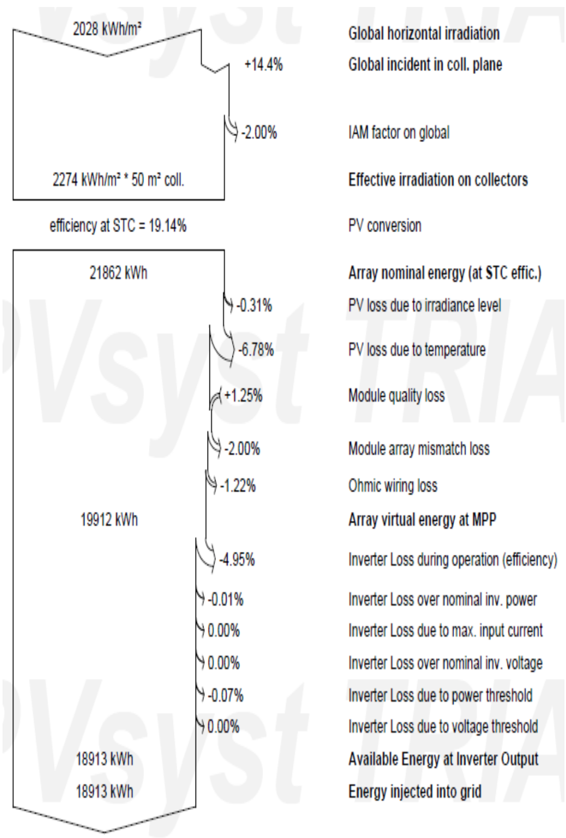


Fig. 5. Loss Diagram of PV System Geographic Location Afghanistan (Kabul)

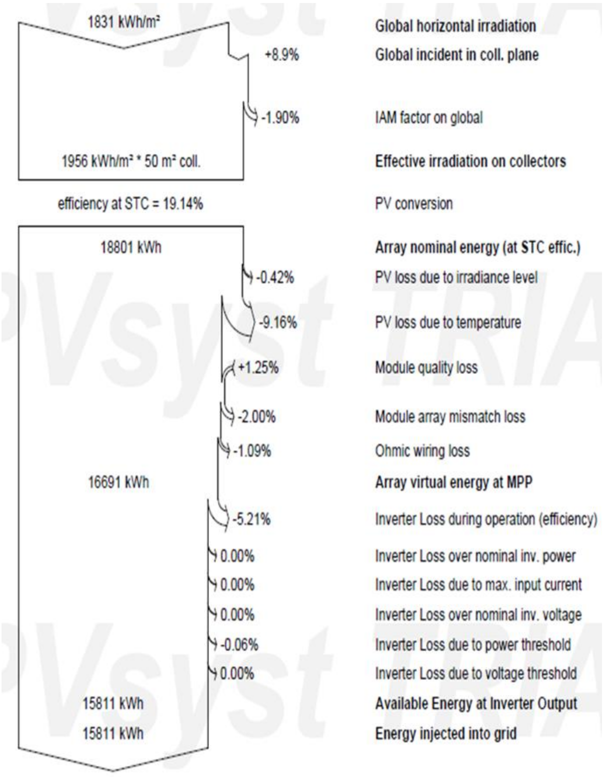


Fig. 6. Loss Diagram of PV System Geographic Location India (Ahmedabad)

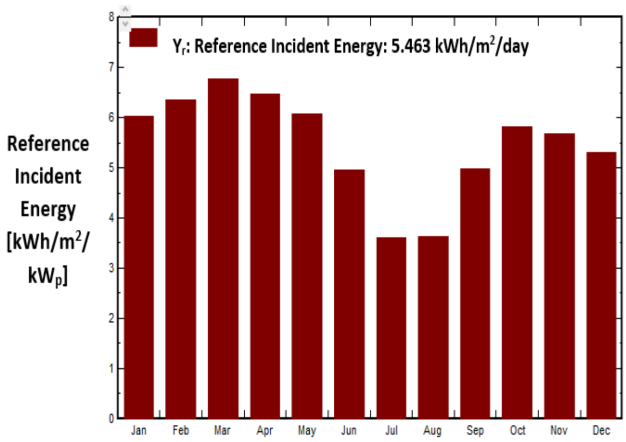


Fig. 7. Incident Energy on Collector Plane Of Ahmadabad (India)

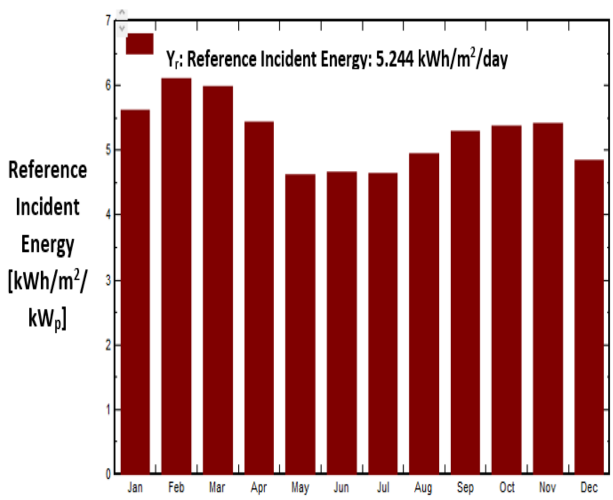


Fig. 8. Incident Energy on Collector Plane Of Colombo (Sri-Lanka)

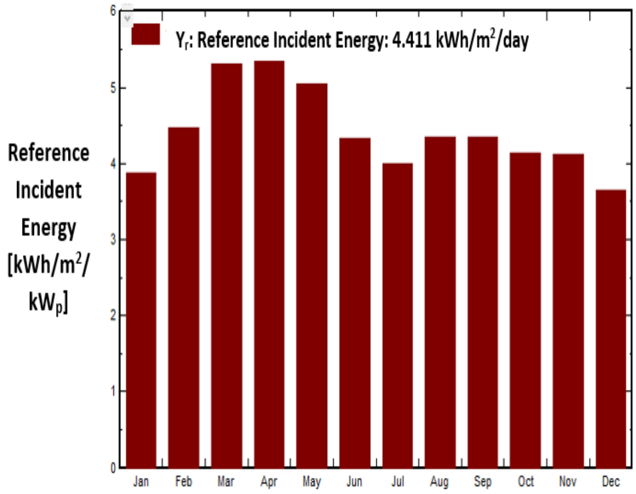


Fig. 9. Incident Energy on Collector Plane of Dhaka (Bangladesh)

As illustrated in Fig. 9, it readily goes up to 6.358 kWh/m^2/day for Kabul, whereas reference incident energy for Dhaka is normally 4.411 kWh/m^2/day. And Fig. 10. While Dhaka, Bangladesh, has less sun irradiation for power generation on collector planes, Kabul is the perfect site for a solar power plant. Other places, like Sri Lanka, Nepal, the Maldives, and Pakistan, have significant sun potential for photovoltaic systems to produce electricity. Sri Lanka's reference incident energy for Colombo is generally 5.244 kWh/m^2/day, which represents the average across all chosen SAARC nations.

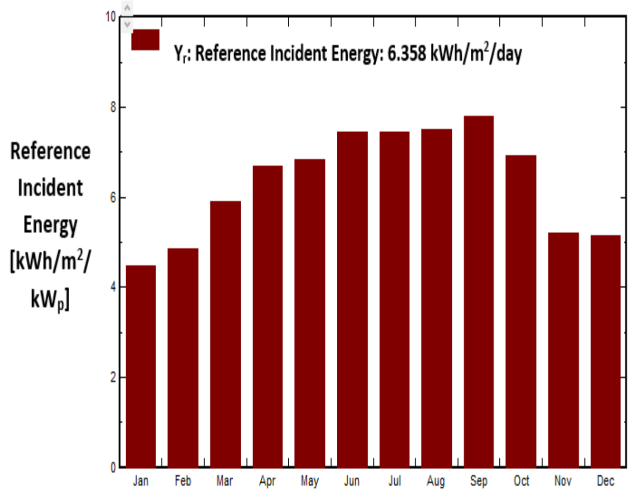


Fig. 10. Incident Energy on Collector Plane Of Kabul (Afghanistan)

3.3 Performance Ratio (PR)

The overall PR of a photovoltaic power plant depends on a variety of variables, including the type of photovoltaic cell used and its technology, the impact of different semiconductor materials on the efficiency with which solar energy can be converted into usable energy, the effectiveness of the inverter, the tilt angle of the solar cell, and all other input parameters that were previously covered in detail.

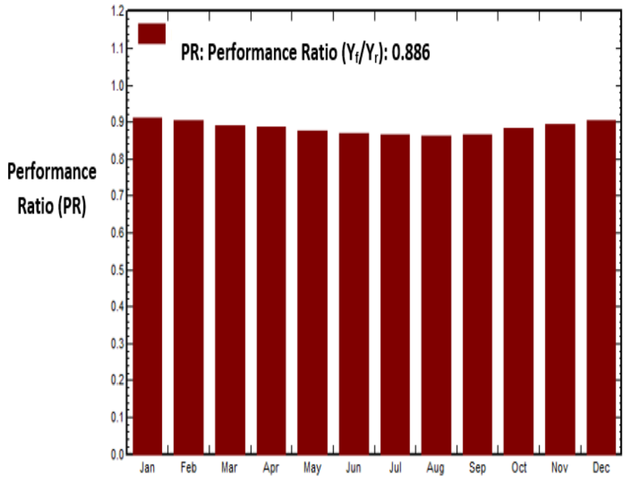


Fig. 11. PR of Timphu (Bhutan)

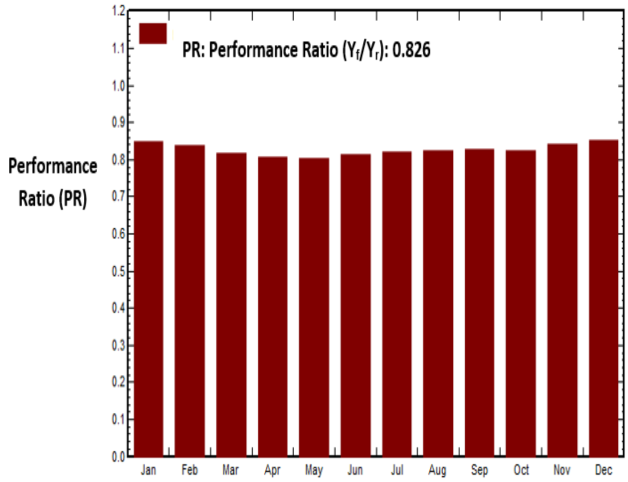


Fig. 12. PR of Ahmadabad (India)

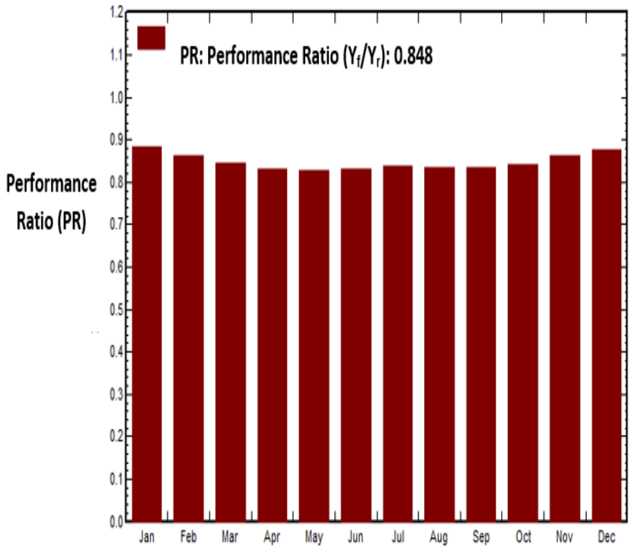


Fig. 13. PR of Khatmandu (Nepal)

Fig. 11, Fig. 12, Fig. 13, and Fig. 14 show the PR graphs for Timphu (Bhutan), Ahmadabad (India), Khatmandu (Nepal), and Islamabad (Pakistan), respectively. Timphu has the best overall PR of all the sites chosen for the suggested PV system, with a PR of 0.886, the other sites are Ahmadabad, Khatmandu, and Islamabad, with PRs of 0.826, 0.848, and 0.836, respectively.

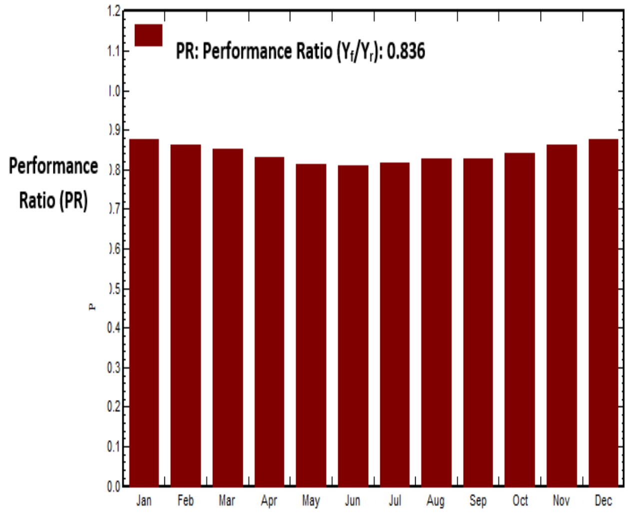


Fig. 14. PR of Islamabad (Pakistan)

3.4 Normalized Power Production (NPP) of PV system

NPP factor in various months of the year describes collection losses through PV conversion of irradiation into DC by solar cells and system losses that due to inverter and other DC to AC conversion losses, with the remaining useful energy being energy after subtracting solar cell and inverter losses. Fig. 15, Fig. 16, and Fig. 17 illustrate various NPP factors for Thimphu, Malé, and Islamabad, respectively.

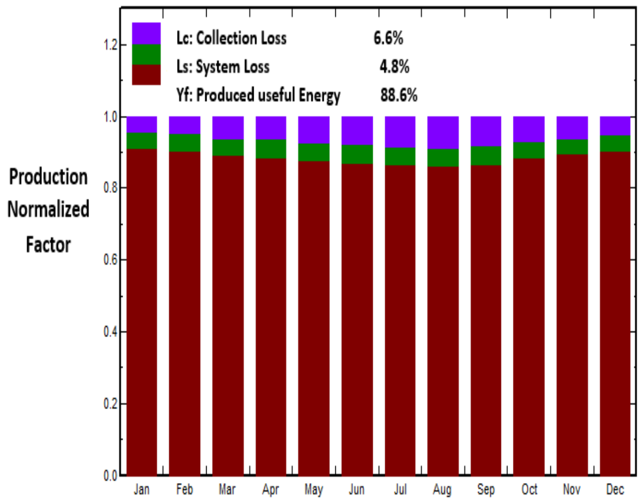


Fig. 15. Thimphu NPP

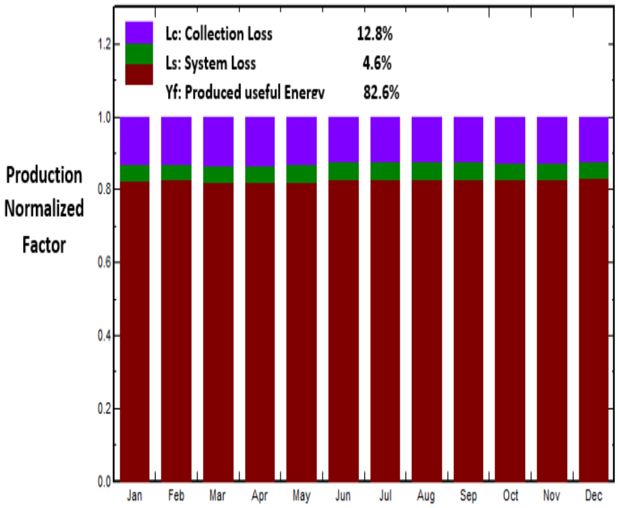


Fig. 16. Malé NPP

Losses from the photovoltaic collection are expressed as LC, inverter losses are shown as Ls, and useable energy generated by the proposed system is shown as Yf. LC losses for Thimphu. Malé, and Islamabad are 6.6%,12.8%, 11.5% are respectively. While system losses Ls are 4.8%, 4.6%, and 4.9% respectively for above said geographic locations, there is a slight variation in system losses because all locations use the same identical inverter model and solar cell, but collections losses are different due to the solar path and various irradiations and are crucial for useful energy contribution. As temperature changes in the environment, the performance of the solar cell effect, because temperature directly affect most of the parameters of solar cell. Hence it is a major factor to control to improve the output results of the solar cell. The reason for the high normalized power production in the months of November, December, January, and February in Fig. 17 for Islamabad, Pakistan, is that the temperature of the solar cells and the solar irradiation on the collector plane have a significant impact on normalized power production. This is because too high of a temperature in the month of June, July and August in Fig. 15 and Fig. 17 also reduces the efficiency of the solar cells and NPP overall. Eq. (01) shows that the efficiency of solar cell is the ratio of NPP and the$P_{in}$is the input of irradiance of sun on collector plane of proposed solar cell. Where P_{max} is the output of solar cell depends on important factors like Fill Factor (FF), Open circuit voltage (V_{oc}), and I_{sc} and short circuit current of the proposed solar cell as shown in Eq. (02). Where in Eq. (04) (V_{oc}) also temperature dependent and in Eq. (01) P_{in} is the solar irradiance on solar cell for proposed location if P_{in} increases then η decreases and effect also increases on NPP.

$$\eta = \frac{P_{max}}{P_{in}} \tag{01}$$

$$P_{max} = \mathrm{FF}.V_{oc}.I_{sc} \tag{02}$$

$$\eta = \frac{\mathrm{FF}.V_{oc}.I_{sc}}{P_{in}} \tag{03}$$

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_{sc}}{I_o}\right) \tag{04}$$

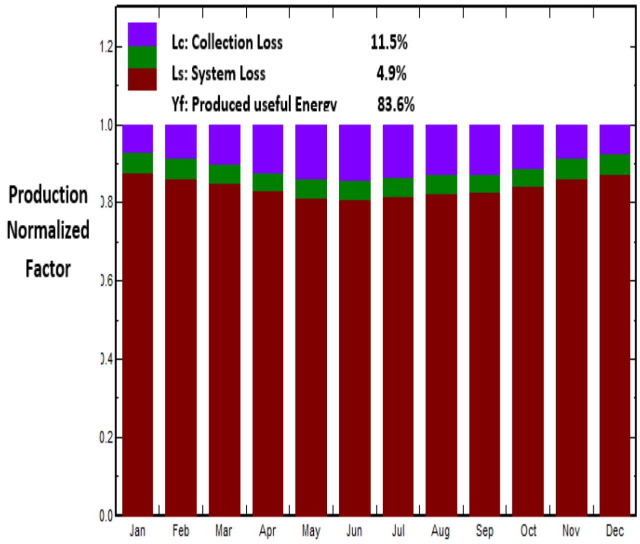


Fig. 17. Islamabad NPP

3.5 Daily Input /Output Diagram

Energy injected into grid depends on the solar irradiation on collector plane so by increasing the value of globally incident irradiation on collector plane (kWh/m^2) on x-axis also increases energy generation through proposed PV system. Daily input of solar irradiation on collector plane of solar cell throughout the year and variations come in the energy generation and energy injected into grid also varies on y-axis depending on the sun irradiations. Daily input and output are illustrated in Fig. 18, Fig. 19, and Fig. 20 for Thimphu, Dhaka, and Colombo, respectively, along with the daily energy injected into the grid (kWh/day) on y-axis and total solar radiation on the collection plane on x-axis. Among the eight SAARC countries, Dhaka has the lowest daily energy input and production, while Thimphu has the greatest. The maximum daily energy supply to the grid via the grid connection system is for Thimphu, Colombo, Khatmandu, Kabul, and Male.

In Fig. 18 that describe the daily energy input output diagram of Thimphu (Bhutan), it's clear from the figure mostly dots are concentrated above the 55 kWh/day energy injected into grid per day. Overall view of this figure shows that maximum energy injection into grid per day is above 55 kWh/day and below 70 kWh/day, and proposed PV system can inject 55 kWh/day for maximum days throughout the year.

Fig. 19 shows the input radiations of sun throughout the year and output in the form of energy generation and injection into the grid tie system in kWh/day. Mostly doted concentration is above 30 kWh/day and below 50 kWh/day, it means PV system in Dhaka (Bangladesh) can inject only 30 kWh daily. In Fig. 20 mostly doted concentration is above 40 kWh/day and below 60 kWh/day throughout the year, this PV system in Colombo can inject power above 40 kWh daily throughout the year.

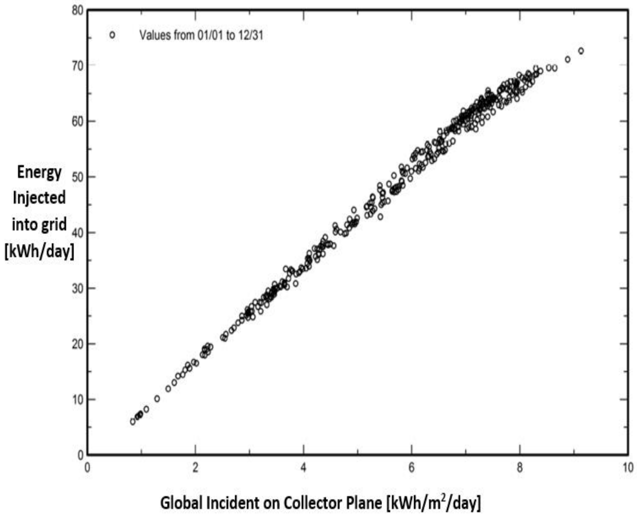


Fig. 18. Daily Input Output Diagram Thimphu (Bhutan)

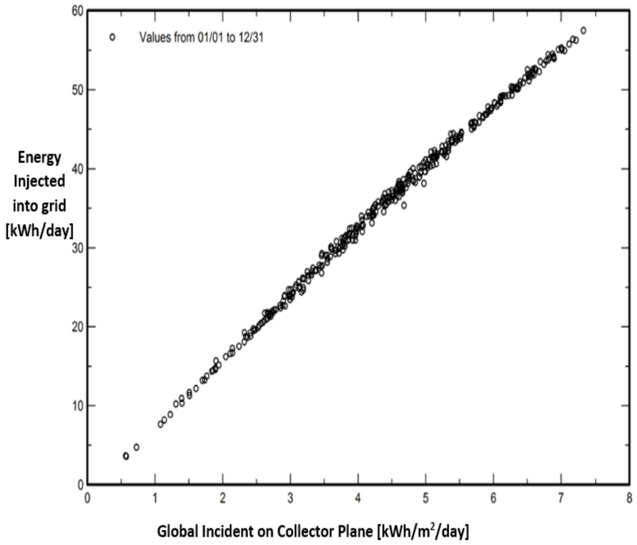


Fig. 19. Daily Input Output Diagram Dhaka

4. Conclusion

Current research given the comparison of grid connected photovoltaic system for SAARC countries using PVSyst software and meteorologist data. From the performance analysis of given identical solar PV grid-tied systems at all proposed sites, energy injected to the grid of Kabul is 83.5% greater than Ahmedabad as depicted in Fig. 5 and Fig. 6. Another significant factor contributing to Kabul's solar system's maximum potential is the city's favourable global irradiation, which is 2027.9 kWh/m2/year, with little PV loss owing to temperature and a lower ambient temperature 14.60°C.

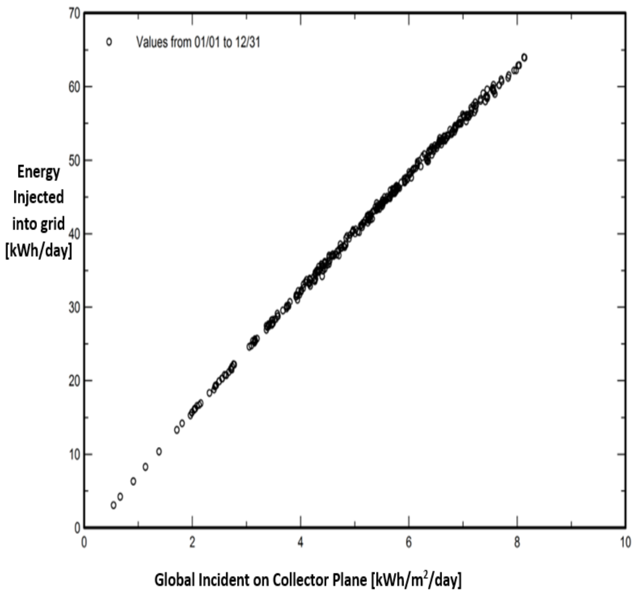


Fig. 20. Daily Input Output Diagram Colombo

Malé has the greatest global irradiation of any of the suggested sites at 2037.9 kWh/m2/year, but its performance is affected by the surrounding temperature of 28.81°C, which results in a loss of 16246 kWh/year in total energy output. Bhutan's capital, Thimphu, has a worldwide irradiation of 1807.3 kWh/m2/year, which is far lower than Kabul's, but its ambient temperature of just 3.15°C boosts its total PR to a maximum of 88.6%, and 17414 kWh/year of energy are added to the grid. Malé, the capital of the Maldives, and Ahmedabad, the largest city in India, both have the lowest overall PR 82.6%. Islamabad, the capital of Pakistan, and Dhaka, the capital of Bangladesh, have overall PR's of 83.6% and 13912 and 12917 kWh/year of energy available at inverter output, respectively. A solar power plant may be designed using the results of this study with minimal losses, a high-performance ratio, and optimum PV cell and inverter choices in an appropriate geographic location. A grid design for all SAARC countries may share power amongst all, resolving the issue of energy scarcity and lowering high electricity costs as a result of this future planning. Additionally, cooperation in the energy sector is boosting the energy shortfall in border regions and city centres of all SAARC countries.

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