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Solar Energy Capacity Assessment and Performance Evaluation of Designed Grid-Connected Photovoltaic Systems †

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Abstract: One of the most common sustainable energy resources that contributes a significant portion of the energy produced from renewable resources is solar photovoltaic. The research presented in this paper examines the behaviour of a 150.7 kWp grid-connected PV energy generation system to either feed electrical loads of site (a public university, GCU Faisalabad) or to feed into the utility grid when the generation from the PV system is more than the demand from the on-site load. PVSyst software is used in the system simulation together with Meteonorm produced and measured climatic information sets (solar irradiance, ambient temperature and wind speed). The analysis of the simulated energy yields includes determining the optimal energy generation photovoltaic array, the energy that is fed into the utility network, normalised energy generation per installed kWp and performance ratio. The computed annual worldwide incident energy on the collector without optical adjustments is 1764.0 kWh/m^2, and the annual effective global irradiance after optical losses is 1654.7 kWh/m^2. With this irradiation, the solar (PV) array produced 218.12 MWh of DC energy annually, whereas 211.70 MWh of AC energy was injected into the national grid. The collection of the designed PV system is 0.87 kilowatt-hour/kWp/day, system losses is 0.120 kilowatt-hour /kWp/day and produced useful energy 3.85 kilowatt-hour /kWp/day. The measured average yearly performance ratio (PR) is 79.64%. In the month of January, the highest PR value of 85.4% was achieved.

Keywords: Photovoltaic system; Performance ratio; Energy generation; Grid connected; PVSyst software

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1. Introduction

Energy systems have transformed from conventional to renewable due to the depletion of fossil fuels and problems with carbon (CO2) emissions [1, 2]. Additionally, there is a growing emphasis on the production of renewable energy as a result of the need for economic stability and energy security [3]. Solar energy is attractive and sustainable when compared to other renewable energy resources [4]. Solar Photovoltaic energy is regarded as a safe, attractive, and clean way to generate electricity [5, 6]. Due to its simple and easy installation, low maintenance requirements, reliability, and absence of fuel costs, the solar PV system has a promising future and is becoming more popular [7, 8]. The electrical output of the PV system can be supplied into the utility grid in accordance with pre-established reliability and quality standards and without affecting the regular operation of electric network. An inverter is used to connect the photovoltaic array to the system, which converts the DC output of the PV modules into an AC output matched to the frequency and voltage of the utility network [9, 10].

A performance evaluation for the photovoltaic system is used to determine the PV energy generation potential. The performance of solar (PV) modules installed outside around the world has been the focus of various studies [11]. A technical and economic assessment of a limited group of residential systems in Palestine was presented in [12], showing results demonstrating that a 5 kW PV system could be payback in less than five years. For a rooftop grid connected photovoltaic system in Serbia [13], Norway [14] and Eastern India [15], respectively, the same approach was taken into consideration. In [16], the PVSyst tool was used to analyse the three grid connected PV system technologies—monocrystalline, poly-crystalline, and amorphous. Research show that monocrystalline technology performs better than poly-crystalline technology while amorphous technology performs the poorest. Under various Pakistani climates, annual energy behaviour indices for various PV technology types have been investigated [17, 18].

Tech-economic and environmental features of photovoltaic system have been taken into account for city in the Indonesia [19], highlighting the benefits and limitations of these installations. The enormous potential for adequate solar power generation was demonstrated by a comparison between simulated and measured performance of the on-grid photovoltaic system in the South Africa [20]. In the power quality investigations for a photovoltaic grid-connected system in Egypt, both sunny and overcast scenarios were taken into account [21], and it was found that low solar irradiation has a significant impact. However, there is a deficiency of publicly available information regarding the operation and energy output of small grid-tied PV systems working in the southern South America [22]. An evaluation and performance analysis of a 28 kWp grid-connected PV system in the Saharan climate was presented in [23].

Advanced computer-based modelling studies are necessary to forecast the behaviour of a Photovoltaic system, its operating characteristics under different climatic conditions, the different combinations of system components, and alternative installation methods [24, 25]. In this study, PVSyst [26], a popular computational tool, is utilised to model the system. The primary contribution of this research work is the measurement of the annual electrical energy (MWh) yield and related performance ratio (PR) of a solar (PV) system installed in Public Sector University in Punjab Province, Pakistan.

2. Materials and Methods

The PV arrays, inverter, and energy utility metre are the main components of PV system. The solar module racking system was used to install the PV array described in this research on the roof with a "pitch" distance of 3 meter at the GCU Faisalabad. There were 274 monocrystalline (LR5-72 HPH 550M) PV modules in the system. With the technical specifications presented in Table 1, each photovoltaic module has a power rating of 550 Wp. The 274 PV modules were divided into 15 parallel strings. With first inverter, all 5 stings have 18 series-connected PV modules and with second and third inverters, two strings have 19 and three strings have 18 series connected PV modules. All strings were oriented south with an azimuth angle of 180° and a tilt angle of 20° as shown in Figure 1. Table 2 provides a technical overview of the PV system.

Table 1. Characteristics of the PV module at STC.

Parameters	Specification
Type	Monocrystalline-Si
Maximum module power (P_{MAX})	550 W
Open circuit voltage (V_{OC})	49.80 V
Volatge at Maximum power (V_{MP})	41.95 V
Current at Maximum power current (I_{MP})	13.12 A
Short circuit current (I_{SC})	13.98 A
PV module efficiency	21.5%

Table 2. Provides a technical overview of the PV system.

System information	Specification
Nominal power (Pnom) of photovoltaic system	150.70 Wp
Number of PV modules	274
Number of inverters	3
Inverters loading ratio	1.092
Total number of PV strings	15
Titl angle	15°
Azimuth angle	180°

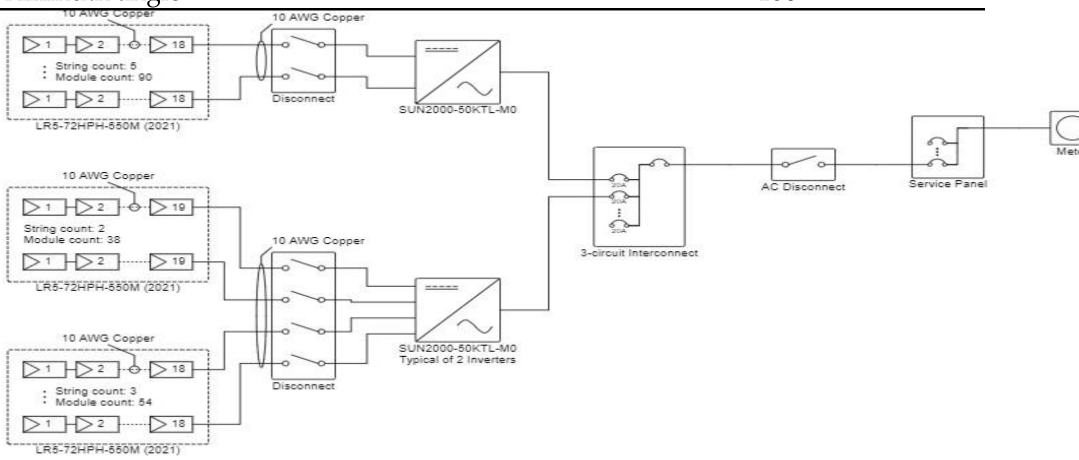

Figure 1. SLD of 150.7 kW grid connected PV system.

For the purpose of converting DC voltages to AC voltages, on-grid Huawei inverter (SUN2000-50KTL-M0) inverter with 200 V ~ 1,000 V MPPT operational voltage range was selected. The electrical grid metre and breaker panel were used to connect the inverter to the utility grid, which had an 1100 V maximum input voltage. The inverter needed to modify its operating point in order to operate at its highest efficiency level because the array current and voltage were depending on the prevailing weather conditions. Table 3 presents technical specification of inverter.

Table 3. Technical specification of inverter.

Parameters	Specification
Inverter model	SUN2000-50KTL-M0
Inverter maximum efficiency	98.7%
Maximum input voltage	1100.0 V
MPPT voltage range	200 V - 1000 V
Max. short circuit current per MPPT	30 A
Max. AC active power (cosφ=1)	55,000 W
Rated output voltage	220 V / 380 V, 230 V / 400 V
Rated AC grid frequency	50 Hz / 60 Hz
Adjustable power factor range	0.8 LG ... 0.8 LD

3. Results

3.1. Annual Calculated Parameters

The findings of the simulation were used to derive the three key annual data. The first parameter was the total amount of energy generated by PV system, which is equivalent to 211.7 MWh/year. The second computed parameter was specific productions per installed kilowatt, which is equivalent to 1405 kWh/kWp/year, and the third computed parameter represent the average performance ratio (PR) of the system for year, which is 79.64%.

3.2. Simulation Results from PVSyst

Table 4 shows the ambient temperature, the global horizontal and diffuse irradiance, the effective global irradiance after accounting for soiling and shading losses. The annual global horizontal and diffuse irradiance is 1635.9 kWh/m^2 and 895.1 kWh/m^2 respectively. The computed annual worldwide incident energy on the collector without optical adjustments is 1764.0 kWh/m^2, and the annual effective global irradiance after optical losses is 1654.7 kWh/m^2. With this irradiation, the solar (PV) array produced 218.12 MWh of DC energy annually, whereas 211.70 MWh of AC energy was injected into the national grid. The annual global inverter losses are 3745.7 kWh and inverter losses during operation are 3671.1 kWh.

Table 4. Results for 150.7 kWp photovoltaic system.

	GlobHor	DiffHor	Amb. Temp	GlobInc	GlobEff	DC Energy at PV Array	Energy injected to Grid
	kWh/m^2	kWh/m^2	°C	kWh/m^2	kWh/m^2	MWh	MWh
January	84.1	40.9	12.54	103.9	96.3	13.56	13.37
February	102.5	50.8	16.51	119.7	112.4	15.40	15.19
March	142.8	69.9	22.38	157.7	148.6	19.62	17.70
April	161.6	86.2	27.19	167.8	157.9	20.40	20.11
May	184.4	98.3	32.91	184.4	173.7	21.93	21.60
June	178.5	102.7	32.89	176.1	165.9	21.01	20.70
July	163.1	108.3	31.57	161.3	151.1	19.68	19.40
August	157.5	100.1	30.85	160.2	150.3	19.54	19.26
September	149.4	73.6	29.29	161.3	151.8	19.61	19.33
October	128.8	70.8	26.19	146.1	137.5	18.27	16.81
November	99.5	50.7	19.45	120.8	112.7	15.51	15.30
December	83.5	42.7	14.51	104.6	96.5	13.58	12.91
Year	1635.9	895.1	24.73	1764.0	1654.7	218.12	211.70

3.3. Normalised Energy Production

The normalised production is the standard parameter for evaluating the performance of the photovoltaic system and is defined by the IEC norm. A comparison of the behaviour of photovoltaic designs built in similar climatic conditions can be made using this data. Figure 2 shows the results of the simulation analysis used to determine the system and collection losses as well as the useful produced energy per installed kilowatt/day. The collection of the designed PV system is 0.87 kilowatt-hour/kWp/day, system losses is 0.120 kilowatt-hour /kWp/day and produced useful energy 3.85 kilowatt-hour /kWp/day.

3.4. Performance Ratio of PV system

The simulated analysis produced an average yearly PR value for the 150.70 kWp PV system of 79.64 %. Figure 3 depicts a slight monthly change in the PR value on a monthly basis. In the month of January, the highest PR value of 85.4% was achieved. Additionally, it should be noted that all PR values were high during the winter. This appears to show that the simulated PV system behaves somewhat in accordance with ideal behaviour. This may be primarily caused in practical working situations by northwest cold winds cooling the module's surface, lowering the ambient temperature and preventing the module surface from rising above a certain temperature. The temperature corrected performance ratio also shown in Figure 3.

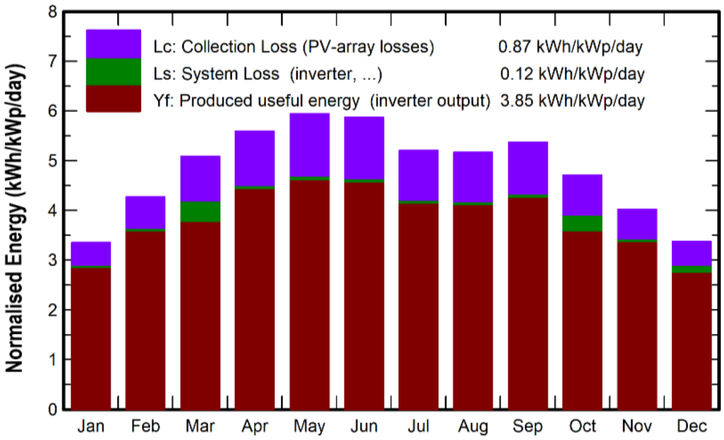

Figure 2. Normalised energy production.

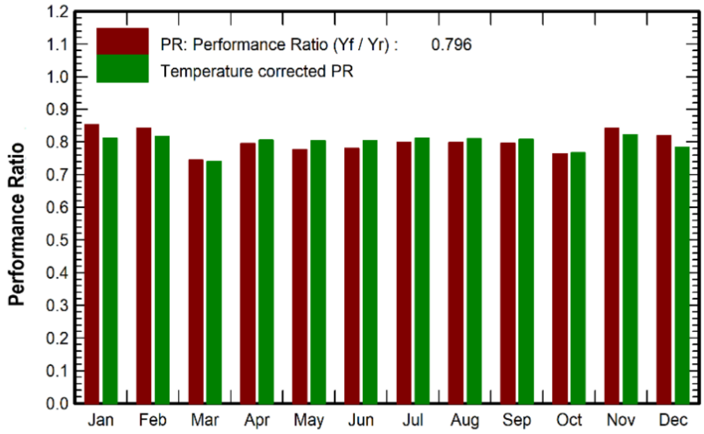

Figure 3. Performance ratio and temperature corrected performance ratio of PV system.

The output power distribution of the photovoltaic system and the array voltage distribution of the photovoltaic system with respect to frequency are shown in Figure 4. The array voltage is within the MPPT voltage range of the inverter. As you can see from the graph, most of the time, the voltage is between 620 volts and 670 volts.

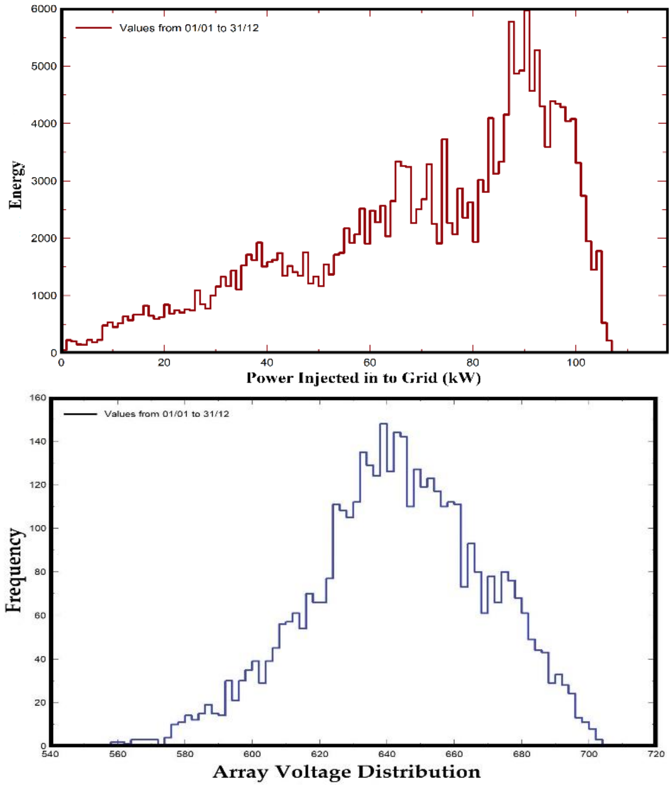

Figure 4. (a) Output power distribution of the photovoltaic system **(b)** Array voltage distribution with respect to frequency.

4. Conclusion

The PVSyst programme is used to simulate a 150.70 kWp photovoltaic (PV) system connected to the utility grid installed in GCU Faisalabad. There were 274 monocrystalline (LR5-72 HPH 550M) PV modules in the system and divided into 15 parallel strings. The computed annual worldwide incident energy on the collector without optical adjustments is 1764.0 kWh/m^2, and the annual effective global irradiance after optical losses is 1654.7

kWh/m². With this irradiation, the solar (PV) array produced 218.12 MWh of DC energy annually, whereas 211.70 MWh of AC energy was injected into the national grid. The collection of the designed PV system is 0.87 kilowatt-hour/kWp/day, system losses is 0.120 kilowatt-hour/kWp/day and produced useful energy 3.85 kilowatt-hour /kWp/day. The measured average yearly performance ratio (PR) is 79.64%. In the month of January, the highest PR value of 85.4% was achieved. The annual global inverter losses are 3745.7 kWh and inverter losses during operation are 3671.1 kWh. In order to promote the use of photovoltaic energy in Pakistan, this paper presents the energy production potential of a small-scale grid-connected photovoltaic system in the Punjab region of Pakistan. The data will be used to enlighten decision-makers, communities, and governmental organisations about this potential.

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Conflicts of Interest: The authors declare no conflict of interest.

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