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Solar Potential Assessment of 600 MW Grid-Connected Photovoltaic System for Remote Area in South Punjab

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Abstract

Electricity is a need for our daily existence; nevertheless, the power crisis is becoming worse every day, and line voltage drops at distribution companies' end points destroy everyday equipment. The majority of the power used now comes from hydroelectric or conventional thermal power plants in Pakistan. Growing environmental concerns about greenhouse gas emissions and other issues are pushing for the use of renewable energy technology, including solar cells, in the generation of power. Current research proposed a novel idea for the solution to the energy shortage and reducing the peak price of electricity bills by proposing the design of a 600 MW grid-connected photovoltaic system and its performance ratio for the proposed location in Fort Munro, South Punjab, Pakistan. The proposed location is a tourist attraction place in South Punjab and a hilly area for a picnic point that improves the economic growth of the localities by providing clean, green, and cheap electricity. The design of the PV system is on the 'PVSyst Software'. The novelty of the current study is about critical problems specific to Pakistan like high electricity bills and power quality issues like voltage sag and swell in remote areas. Blackout and brownout problems for the specific location are daily problems. Current research uses the PVSyst program to simulate and assess the performance of a grid-connected Photovoltaic (PV) system. Overall annual performance of the proposed Photovoltaic Power Plant (PPP) and all losses including solar cell irradiation, cell conversion efficiency, PV array, and inverter losses are calculated. Based on the findings, the feasibility of designing a 600 MW solar PPP is examined by contrasting the solar energy output of a remote location in Fort Munro's southern area in Punjab. The proposed site in South Punjab has an annual Performance Ratio (PR) of 87.2%. The PR is at its highest point of the year in January at 92.1% and at its lowest level in May at 84.5%. This study will assist in the establishment of a grid-connected PPP system to improve low voltage in distant areas and meet Pakistan's need for clean, and green energy.

Index Terms: *Grid Connected Photovoltaic System, Photovoltaic Power Plant, PVSyst Software, Solar Cell/Electricity, and Southern Punjab.*

I. INTRODUCTION

The components of a photovoltaic (PV) system include a battery, power conditioning components, and a PV array. The photovoltaic cell generates electricity in the form of Direct Current (DC) and through grid-connected or standalone systems so that this clean and green energy is consumed by the user [1]. When using Alternating Current (AC) loads, the system needs an inverter to change the DC power source into AC power. PV systems come in two varieties: free-standing and grid-connected. Grid-tie PV systems minimize inverter and PV array losses by feeding electricity in the form of Alternating Current or AC power through net metering and hybrid systems [2]. Grid does not need to use fossil fuels, which are harmful to the environment, in order to consume this natural, green energy. When compared to conventional power generation resources, the Photovoltaic Power Plant (PPP) can be installed anywhere with no expensive infrastructure requirements and almost no operating costs [3]. It also helps distribution companies meet their electricity needs in remote areas where low voltage is typically a persistent complaint [4]. The choice of photovoltaic cells, tilt angle, inverter conversion, and output are only a few of the components that affect the grid tie system's overall Performance Ratio (PR). Standalone PPP directly feeds the load and does not require any local utility grid in the night time i.e., the required load is fulfilled through the battery storage system [5]. Battery storage or buck-boost converter systems are also important because of solar irradiation variation on the surface of solar cells [6]. System design estimation and feasibility are crucial in situations where the installed planned system's load requirement exceeds it, or when excess power is generated and the load requirement is zero or minimal [7]. In these cases, the excess power can be stored in the battery system for the night or sent back to the grid through a grid-tie system, providing endless load capacity [8]. The goal of this stand-alone photovoltaic power generation is to electrify the dwelling [9]. For the study and sizing of both grid-connected and standalone solar systems, a large range of instruments are available. Simpler tools are used by system designers and installers to determine the PV system's size [10]. For optimization, scientists and engineers are usually the ones who employ more complex simulation tools. Three categories of software tools exist for solar systems; simulation, sizing, and pre-feasibility study. A specific PC software program for PV systems is called PVsyst [11]. The University of Geneva created this software. It includes pre-feasibility, sizing, and simulation support for grid-connected or free-standing PPP systems in rural or urban locations [12]. Geographical location and its data are crucial for the design and optimization of PPPs. A large site can be chosen for the installation of solar cells, and solar irradiation is more significant for the chosen location. The availability of solar cells in Pakistan is also more significant for precise and on-time results using PVSyst software [13]. Analyses of finances can also be done. It was shown that installing PPP is both economically practical and viable in any nation, especially those where solar power is available for the highest number of days during the year [14]. This reduces the cost of CO_2 emissions and the energy resources required to create conventional power [15]. The ratio of the reference yield (Yr) to the final PV system yield (Yf) is known as the PR [16]. The proposed site for a 600 MW grid-connected solar PPP in the 'Fort Mounro' southern part of Punjab, Pakistan is explored by analyzing the energy output, PR, efficiency, and losses. The proposed site of Multan Electric Power Company (MEPCO) power distribution is far from the center and experiences low voltage throughout the day in peak demand hours. Power generation through solar cells will address all these issues that not only provide basic needs to the localities but also boost the national economy. The novelty of work is also important in designing a 600 MW photovoltaic power plant by addressing solar irradiation, and its data for the specified location is collected from the meteorology department of Pakistan. Irradiation throughout the years in different seasons like summer and winter is different, and according to this tilt and azimuth angle are assessed for an optimized angle to convert the maximum collected irradiation into useful energy. Geographical location is selected to boost the voltage and get rid of voltage loss for many days that not only affect the daily life routines but also affect the national economy. Selection of location also plays a vital role because this hilly area has good potential for electricity throughout the year i.e., the maximum irradiation compared to the whole Punjab and KPK regions. Different loss calculations like irradiation conversion losses, temperature losses, cell losses, PV array losses, and conversion of DC into AC inverter losses are also proposed in this work.

II. GEOGRAPHICAL LOCATION OF PPP

The Khar Village in Fort Munro is the proposed location, its latitude is 29.939018 and its longitude is 69.981553 as depicted in Figure 1. The geographic parameters like direct global horizontal irradiation on collector plane of solar cell, diffuse horizontal irradiation, temperature, wind velocity are important parameters for the choice of geographical location. All parameters for each month of the suggested location are shown in Table I and should be taken into account.

Figure 1: Geographical Location Detail

Table I: Geographical Parameters of the PV Grid Tie System

Month	Direct Irradiation (kWh/m²/ month)	Diffuse Irradiation (kWh/m²/month)	Temperature (°C)	Global Incident (kWh/m²/month)	Global Effective (kWh/m²/month)	Wind Velocity (m/sec)	Relative Humidity (%)
January	114.5	30.56	4.67	178.4	176.4	0.79	84.1
February	127.4	37.31	8.52	173.8	171.6	1.01	79.2
March	168.1	59.55	14.39	195.5	192.0	1.00	67.6
April	188.3	65.73	20.62	192.1	188.2	1.09	49.4
May	207.3	83.06	24.68	189.8	185.1	1.11	46.6
June	204.0	86.55	24.46	178.8	174.4	1.01	63.9
July	202.6	96.52	23.85	181.9	177.7	0.80	77.9
August	193.0	86.12	22.75	186.9	183.0	0.60	83.0
September	184.3	50.44	20.88	204.7	201.0	0.71	81.9
October	158.8	45.51	17.48	205.1	202.4	0.49	72.5
November	126.4	30.77	11.36	192.7	190.3	0.50	71.3
December	109.2	28.73	6.77	177.3	175.3	0.59	79.3
Yearly	1984.1	700.85	16.74	2257.1	2217.3	0.8	71.4

The average annual temperature recorded for the PPP is 16.74°C. The minimum temperature recorded in the month of January is 4.67°C and the maximum in the month of May is 24.68°C. The projected PPP's average annual global horizontal direct and diffuse irradiance is measured at 1984.1 kWh/m^2 and 700.85 kWh/m^2, respectively. In the same way that the greatest ambient temperature is recorded in May and the minimum temperature is recorded in December. The maximum direct global horizontal irradiation on the surface plane of the Jinkosolar cell is recorded at 207.3 kWh/m^2 in May and 109.2 kWh/m^2 in December. The distribution company typically experiences its peak load throughout the summer months of May through September.

III. GRID-CONNECTED PPP

The 600 MW grid-connected solar PPP for the proposed location in south Punjab consists of a PV array, Inverter, and grid-connected system. The suggested model of the grid-connected photovoltaic system concept is depicted in Figure 2. Grid-connected PPP systems employ 76 'Sungrow' inverters with a maximum capacity of 6874 kW of a single unit. Each Jinkosolar cell has 410 Wp, 36 V, silicon mono type.1463410 number of Jinkosolar modules are needed for a 600 MW solar PV facility. Installing a grid-connected plant requires 2944404 m^2 of space. The solar panel's orientation and inclination for the proposed location are depicted in Figure 3. To achieve maximum solar irradiation, the tilt angle of a photovoltaic array is maintained at 34°, and the azimuth angle for the proposed site is 0° where loss optimization is 0.0%.

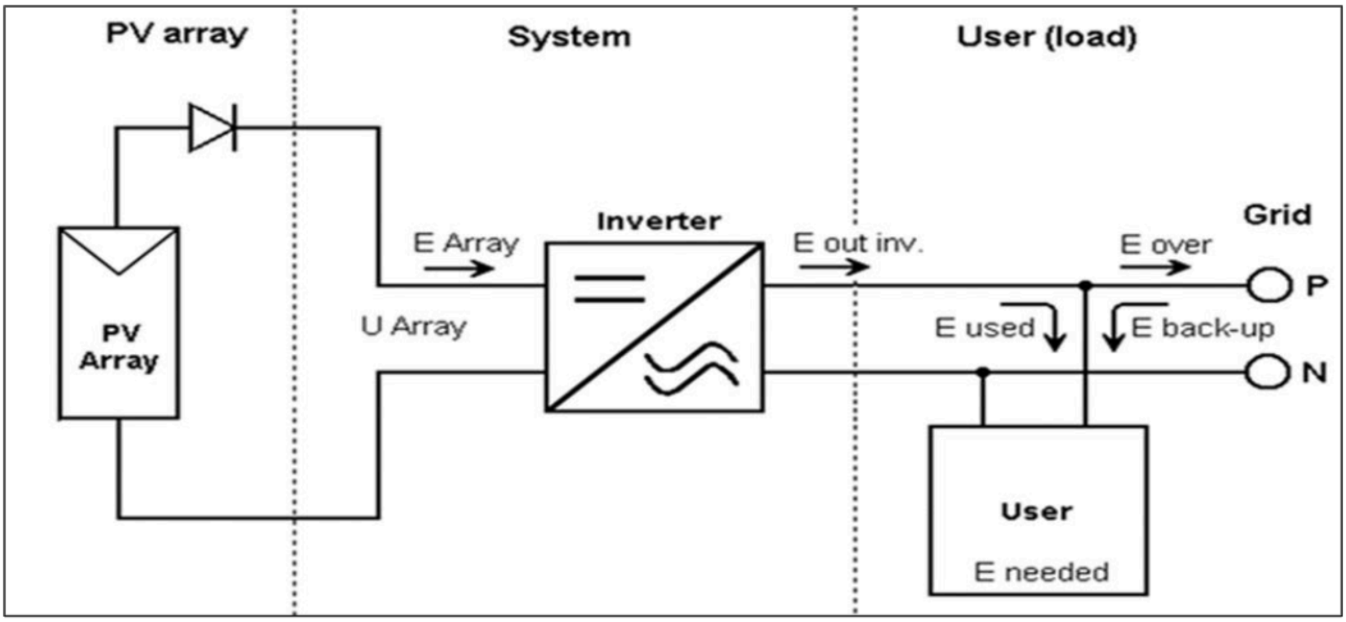

Figure 2: Proposed Photovoltaic Power Plant

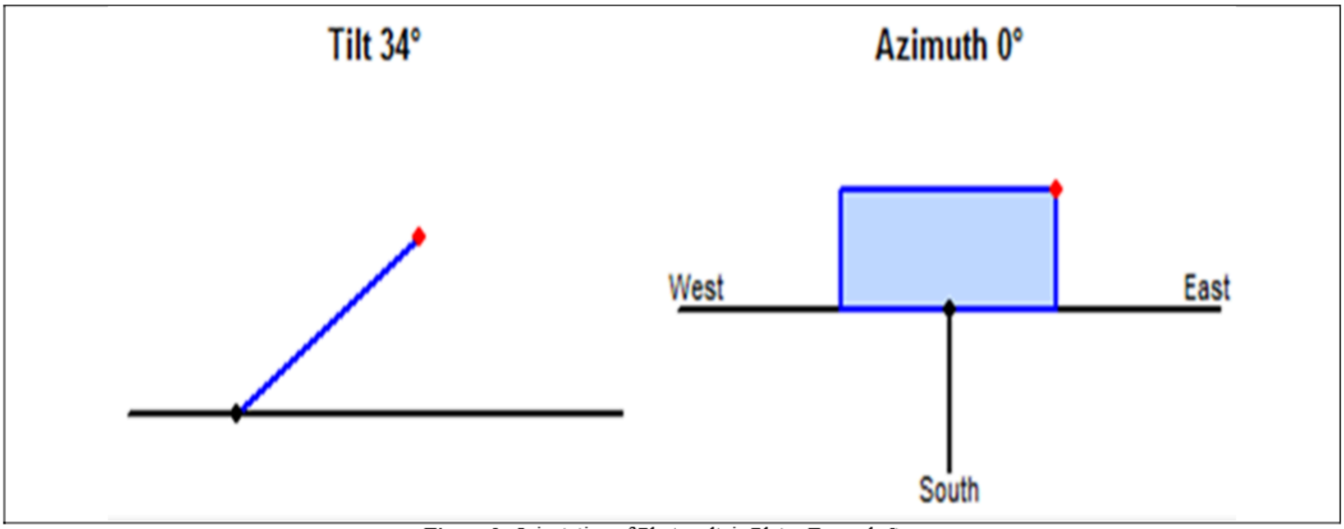

Figure 3: Orientation of Photovoltaic Plates Towards Sun

IV. PERFORMANCE ANALYSIS

Effective energy at the output of the array of solar cells, energy injected into the grid, and average monthly and annual PR are depicted in Table II. It shows the average monthly energy added to the grid, expressed in MWh. 106545 MWh was the greatest energy that was added to the system in October, which is the ideal month to receive a high number of irradiations on the collector plane of solar cells with normal ambient temperature. The bare minimum of energy added to the system in June was 91010 MWh due to high-temperature losses in this particular month. In all, 1180427 MWh of energy are added to the system annually.

Table II: PR and Injected Energy into Grid

Month	Global horizontal direct Irradiation (kWh/m2/day)	Global horizontal diffuse Irradiation (kWh/m2/day)	Effective energy at the output of the array (MWh)	Energy injected into the grid (MWh)	Performance Ratio (%)
January	3.69	0.99	99603	98528	0.921
February	4.55	1.33	94811	93758	0.899
March	5.42	1.92	104050	102926	0.877
April	6.28	2.19	99208	98050	0.851
May	6.69	2.68	97307	96191	0.845
June	6.80	2.89	92061	91010	0.848
July	6.54	3.11	94167	93089	0.853
August	6.23	2.78	96824	95711	0.854
September	6.14	1.68	105462	104277	0.849
October	5.12	1.47	107718	106545	0.866
November	4.21	1.03	104273	103186	0.893
December	3.52	0.93	98226	97156	0.914
Yearly	5.44	1.92	1193710	1180427	0.872

Table I and Table II display climatic and incident energy statistics for the proposed PPP system. The average yearly global horizontal irradiation is 5.44 kWh/m^2/day for direct radiation, and 1.92 kWh/m^2/day for diffuse radiation, respectively can be observed. The optimal direct global horizontal irradiation for the PPP system is 6.80 kWh/m^2/day, which is reported as the maximum in June, and 3.52 kWh/m^2/day, which is recorded as the minimum in December. The average yearly direct global irradiation is 1984.1 kWh/m^2/month, with May having the highest value at 207.3 kWh/m^2/month and December having the lowest amount at 109.2 kWh/m^2/month. The PR of the incident energy for every month of the year is depicted in Figure 4.

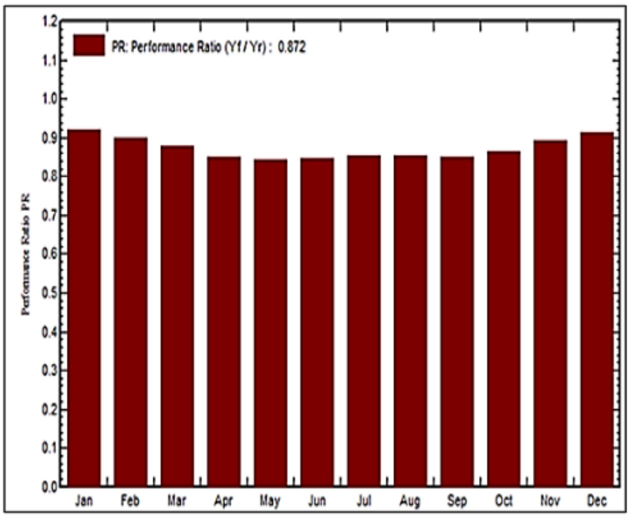

Figure 4: Performance Ratio of PPP

The PR on average annually is recorded as 0.872. On the collection plane, the total global incident energy is maximum in the month of September almost touching the 7 kWh/m^2/day. The complete monthly average incident energy is recorded as 6.184 kWh/m^2/day which is shown in Figure 5. Incident energy in the collecting plane is recorded minimum in the month of December that is 5.6 kWh/m^2/day which is the global incident energy.

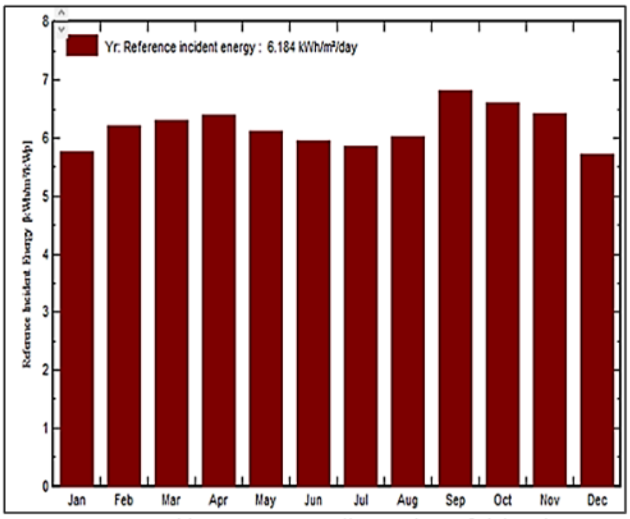

Figure 5: Incident Energy on Collector Plane of Jinkosolar

V. NORMALIZED POWER PRODUCTION

Normalized power data with respect to daily power generation through the proposed PPP is depicted in Figure 6.

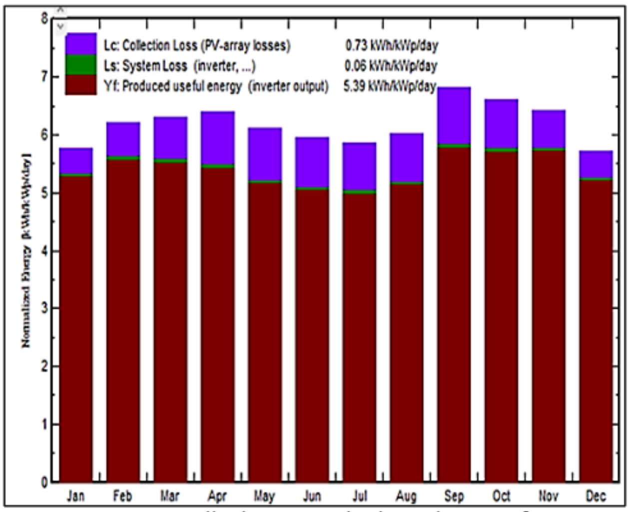

Figure 6: Normalized Power Production and Losses of PPP

Here Lc shows collection losses of photovoltaic array that is recorded 0.73 kWh/kWp/day and Ls shows system losses of PPP is recorded 0.06 kWh/kWp/day, whereas Yf denoted useful energy of inverter on inverter output is 5.39 kWh/kWp/day. The daily irradiation is maximum converted into useful average energy annually. The per day production of normalized power is recorded as 5.39 kWh/kWp.

VI. LOSS DIAGRAM OF PPP

The overall system loss diagram for the proposed PPP is shown in Figure 7. The average annual output of 1984.1 kWh/m^2 is the horizontal global irradiation on the collector plane of photovoltaic cell that is converted into 2217 kWh/m^2 and the effective irradiation for 2944404 m^2 of the available collector plane of Jinkosolar cell is observed. Here PV conversion efficiency is 20.50% for Jinkosolar cells at standard temperature and pressure. Thus, there are 1338100 MWh of nominal energy available at the PV array however, some energy is wasted because of variations in temperature, irradiance, and the quality of the solar cell modules, this energy is also computed as losses for the PPP system. The largest amount of solar energy that can be converted from DC to AC with an inverter is 1194000 MWh. There is 1180427 MWh of energy available at the inverter output after all the inverter losses. Thus, 1180427 MWh of energy is injected into the system. The overall power conversion efficiency of the JinkoSolar cell is recorded for the proposed PPP around 20.50%. The performance ratio overall recorded 87.2% for the available irradiance of the proposed PPP including both JinkoSolar cell and inverter losses.

Hourly based average annual energy generation through PPP is depicted in Table III.

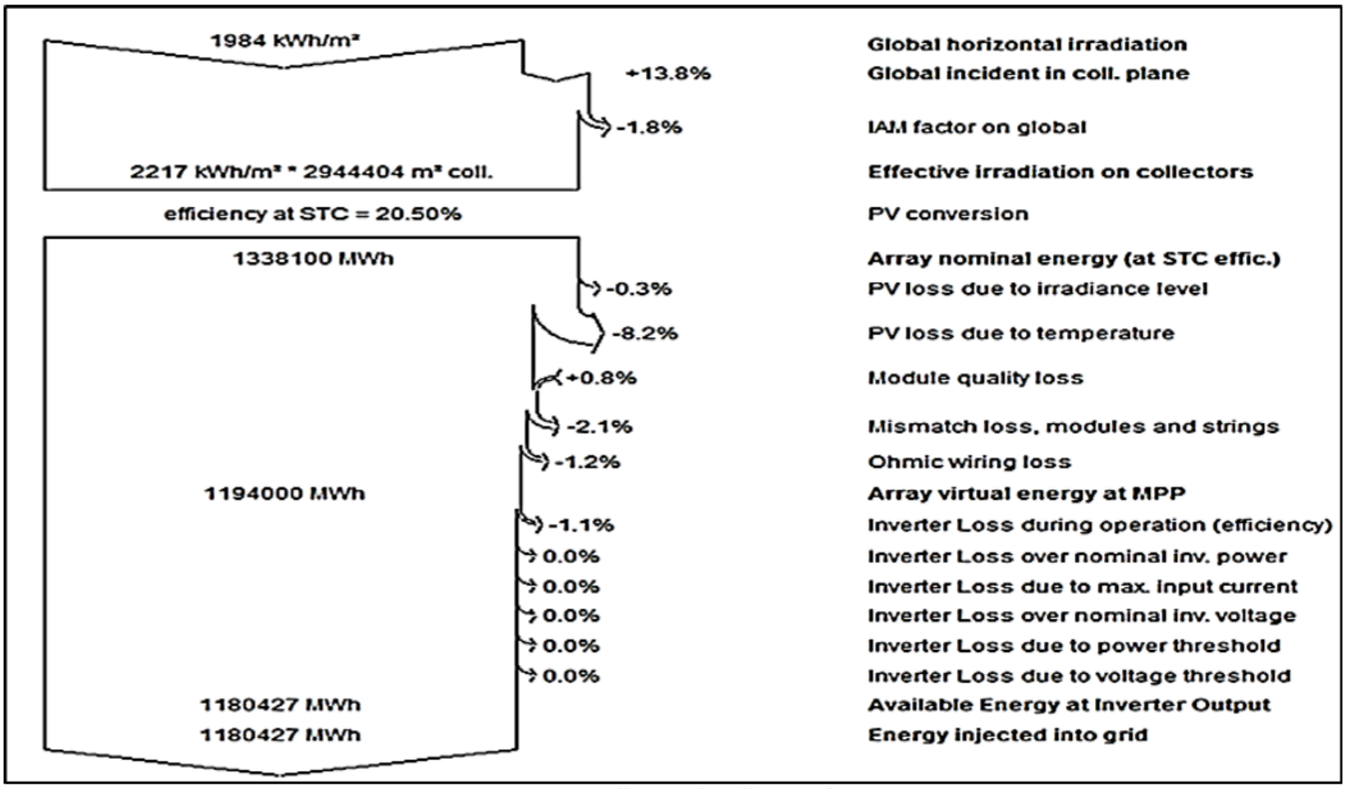

Figure 7: Overall system loss diagram of PPP

Table III: Average Annual Hourly Based Energy Injected into Grid

Month	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM
Jan	0	1	6020	10428	13093	13902	14125	13586	12193	9631	5535	14	0
Feb	0	585	5313	9081	11729	13149	13736	12957	11374	8969	5606	1257	0
Mar	1	2389	6639	9947	12359	13421	14025	13452	12219	9776	6325	2374	0
Apr	408	3020	6546	9531	11829	13167	13361	12451	11102	8952	5529	2093	62
May	950	3641	7144	9955	12127	12539	12678	11481	10062	7906	5290	2041	376
Jun	1016	3267	6506	9408	11140	11966	11843	11230	9702	7533	4711	2051	636
Jul	951	2991	6073	9151	11575	12126	11890	11494	10096	8165	5383	2465	729
Aug	668	2920	6241	9513	11832	12980	13156	11896	10585	8154	5282	2178	306
Sep	169	3646	7876	11139	13282	14018	14056	13105	11271	8793	5330	1593	0
Oct	6	3910	8294	11627	13741	14954	14890	13729	11882	8795	4502	217	0
Nov	0	3017	7727	11166	13458	14555	14741	13731	11874	8714	4203	0	0
Dec	0	69	6675	10735	13000	14349	14441	13557	11693	8434	4203	0	0
Yearly	4169	29456	81056	121681	149164	161127	162942	152668	134053	103822	61897	16283	2109

The PPP's power generation is used to plan the load management of both shiftable and non-shiftable loads. Unnecessary load shifting occurs during peak power generating hours. The maximum electricity generated during the day at 12 PM is 162942 MWh. Throughout the year, extra load can be shifted to the highest power generation hours of 9:00 AM to 3:00 PM. The minimum power generation hours are 6:00 PM and 6:00 AM. Data depicted in Table III is crucial for the availability of power through PPP and this clean and green energy fulfills the load requirement of remote area. According to the result depicted in Table IV the proposed location has the advantage of improved PR (%) and less losses in solar cells and the conversion system overall.

Table IV: The Suggested Approach is Compared to Several Investigations Conducted in Pakistan's South Punjab

S. No.	Solar PV System	PR (%)	Conversion Losses in Inverter
1.	Photovoltaic system in IUB Bahawalpur	83.5	0.8%
2.	QA Solar Photovoltaic Plant	79	2%
3.	Current Research in DG Khan, Fort Munro	87.2	0.6%

VII. CONCLUSION

Current research is the design of a 600 MW grid-connected PV system for a remote location in Pakistan. PVSyst software is used to develop an efficient photovoltaic system for a grid-connected environment. While applying no shading effect for the design of the proposed PPP considered; maximum irradiation received on the solar plate by adjusting the tilt angle at 34° and azimuth angle at 0°. The overall efficiency recorded for the PPP is 87.2% which is the maximum in the month of January which is 92.1% and the minimum in the month of May 84.5%, when high temperature is recorded throughout the year. Overall location in South Punjab offers a more favorable economic environment for the installation of PPP. The average annual performance ratio is calculated for different seasons that show systems efficiency ranging from a minimum of 84.5% to a maximum of 92.1%, as this study can be used for future research work for the geographical locations similar to the proposed location for the design of PV plants and solar installations. The tilt angles of modules also help to maximize the efficiency of the system.

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Authors Contributions

All the authors equally contributed to this research work.

Conflict of Interest

The authors declare no conflict of interest and confirm that this work is original and not plagiarized from any other source.

Data Availability Statement

The testing data is available in this paper.

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