

## **Estimation and Sizing of 1.00 KW<sub>p</sub> AC Grid-connected Photovoltaic System**

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**Abstract:** Energy availability is a prerequisite for any growing country, including Pakistan, to maintain economic progress. This article presents a solar-based energy solution alternative for the densely populated geographic location of Sindh province, in Pakistan, along with the performance analysis and calculation of a cost-effective photovoltaic energy option. The energy source that is growing the fastest in the globe is solar electricity. 2000 MW of solar electricity will be installed in Pakistan through January 31, 2025; just 150 MW had been installed three years earlier for Sindh province in Pakistan. Geographic and climatic studies indicate that Pakistan has enormous potential for photovoltaic (PV), direct and indirect solar irradiation of 5.6–6.7 kWh/m<sup>2</sup>/Day on photovoltaic plane surface. Geographical data, climatic data, and energy demand consumption are collected for the proposed location. Performance ratios and losses have also been examined using the simulation program PVSyst. The simulated system only needed a small amount of roof space and battery storage to meet the maximum demand, leaving plenty of flexibility for future system expansion to keep up with growing energy needs. This process is affected by several factors such as solar radiation, geographic coordinates, and load requirements. The size and design of the PV system are determined based on watt-hour consumption estimates. Overall losses and estimation of the performance analysis of the grid-connected photovoltaic system are recorded in current research. The simulation results of the proposed model included performance ratio, energy generated that was injected into the grid, photovoltaic power generation, and conversion losses, all are calculated. Analysis of

performance ratios revealed that January and December yielded the best PR of 80.8%, while May yielded the lowest PR of 70.5%. The reduced power capacity of the system is caused by many sorts of losses. This research will help with the development and scaling of grid-connected photovoltaic systems for various locations worldwide by employing the same technique.

**Keywords:** Solar System, Power Generation, Grid-connected Photovoltaic System (GCPS), Optimized Photovoltaic System (OPS), PVSyst,

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## **1. Introduction**

Electrical energy is essential to the nation's economic stability and general progress in lifestyle. The availability of enough, affordable energy is essential for ending poverty, promoting human welfare, and improving living conditions everywhere.

[1,2]. Conventional energy sources, such as coal, oil, and gas, were the primary sources of energy in the past and were essential to increasing humankind's quality of life and energy supply. Since the dawn of time, modern energy sources have been essential to humankind. Green Clean Energy sources derived from resources are called renewable energy sources found in nature, such as the sun, wind, and water. Compared to other energy sources, they are more ecologically friendly. It is possible to produce power with nearly zero emissions of harmful gases and pollutants by using a variety of sustainable energy sources [3]. Residential and agriculture sectors will be the main consumers of power [4]. Pakistan is now experiencing a severe energy deficit, with most people unable to obtain enough electricity to satisfy their basic daily needs. In contrast to industrialized nations like the United Kingdom, which consumed 39.40 MWh and 36.60 MWh in the same year, the main energy consumption per person in (2022) and (2023) was 6.70 MWh and 6.60 MWh, respectively [5]. Pakistan is largely reliant on imports of oil as its major energy source. The sharp rise in crude oil prices in recent years has sparked concerns about costly energy. The situation is much worse because there has been a power outage since (2007) [6]. NEPRA Energy Report (2020) [7] states that under current policy and planning, the scenario of electricity shortages will continue until (2030). Pakistan's location in the sun path presents a unique potential for solar power generation, as it lessens the need to import oil and coal to meet the energy needs in Pakistan from Saudi Arabia, Dubai, and other Asian countries through hot water ports. Pakistan harvesting all available clean and green energy sources to

satisfy its energy demands. The country's 5.5–6.5 kWh/m<sup>2</sup>/day photovoltaic energy potential is sufficient to meet a community's energy needs. The only national resource that is unaffected by social, political, or legal disputes is this one [8-10]. A photovoltaic (PV) system is one that directly converts sunshine into electricity. PV devices have an easy-to-understand design and require relatively little upkeep. One important advantage of solar photovoltaic systems is their ability to be used as stand-alone or grid-connected systems. Microwatts or megawatts are the two sizes of PV systems [11]. All solar cells available in the market in Pakistan have power conversion efficiencies that average around 16%, photovoltaic systems focus on simulation work, and the efficiency of many semiconductor connection layers and cells reaches up to 48% [12]. Around ten years ago, the cost of a PV panel was \$20 per W; by (2022), it was less than \$2 per W. In the global market, photovoltaic solar cells have increased as a result of price decreases throughout the last 10 years. Currently, silicon-based panels have a market share of about 80% [13]. Globally, the capacity of solar photovoltaic systems has increased significantly in the last two years. 2013 saw a gain in worldwide capacity of around 39 GW, bringing it to approximately 139 GW [14]. As per the recently released policy scenario by the IEA, the percentage of solar energy in power generation is expected to increase from 1.4% to 4.8% of global electricity supply by (2040), or 1000 TWh [15]. Using a variety of techniques and designs, several researchers have created grid-connected photovoltaic systems for usage in different parts of the world especially in Pakistan to overcome energy loss and heavy price of electricity bills.

## **2. Photovoltaic Site Selection and Sun Path**

PV Syst is used simulation program that may be used to completely study and assess both grid-connected and off-grid solar systems. Large datasets of geographic, meteorological, and PV component (modules and inverter) data are available. The findings of this study will also help electrical consumers install a grid-tie system to get rid of costly energy from WAPDA. The site's coordinates are latitude 25.4282° N, longitude 68.5308° E, and albedo 0.21 for a stationary plane. In Figure 1 sun path of the proposed location is described by the overall seven curves that describe the different curves of available solar radiation and the start of photovoltaic power generation for different months i.e 1<sup>st</sup> curve in Figure donate in June the longest available solar radiation for clean and green power generation. The minimum curve is the 7<sup>th</sup> one that shows the sun availability minimum in the time for the proposed location in December.

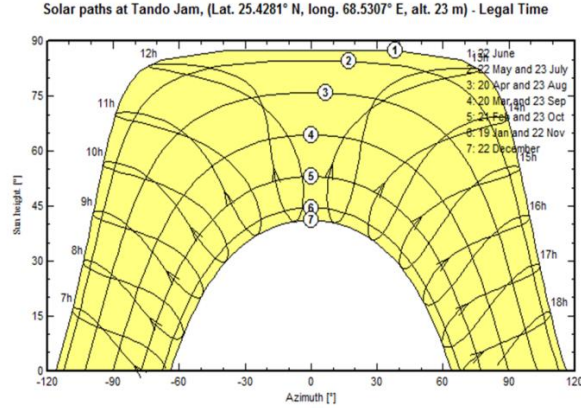


Figure 1: Solar Path for the Geographical Location, of Sindh

### 3. Simulation Design of the Proposed Model

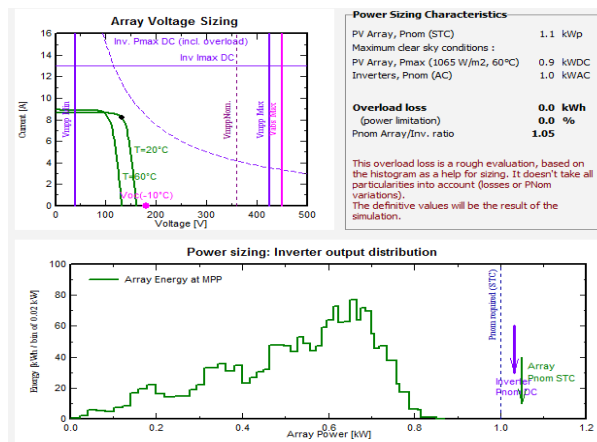
In this research work, a standalone Photovoltaic system is simulated using data from Mateonorm-8.1. Sites worldwide can access Mateonorm-8.1 data using the PVSyst simulator. For long-term predictions of system performance, Mateonorm-8.1 is suitable. One of the most populated areas in Pakistan, geographic location in Jamshoro, Sindh has a significant percentage of energy consumers, climatic conditions are one of the best conditions for the solar system and similar for all Sindh province in Pakistan, which is why it was chosen for the research.

Table 3.1: Proposed Photovoltaic cell data for Sindh region:

Manufacturer Type	Generic
Model	Polycrystalline 150 W <sub>p</sub> 24 cells
Nominal Unit Power	150 W <sub>p</sub>
Number of PV modules	7 units
Nominal (Standard Conditions)	1050 W <sub>p</sub>
Modules	1 String x 7 in series
<b>Total PV power</b>	
Nominal (STC)	1.05 kW <sub>p</sub>
Total	7 modules
Module area	7.0 m <sup>2</sup>
<b>At operating cond. (50°C)</b>	
P <sub>mpp</sub>	918 W <sub>p</sub>
U <sub>mpp</sub>	111 V
I <sub>mpp</sub>	8.3 A

**Table 2: Proposed Inverter data for the Sindh region.**

Manufacturer	Generic
Model	Sunway R5-1K-S1
Unit Nom. Power	1.00 kW <sub>ac</sub>
Number of inverters	1 unit
Total power	1.0 kW <sub>ac</sub>
Nominal Power ratio (DC: AC)	1.05
Operating voltage	40-425 V
<b>Total Inverter Power</b>	
Total Power	1 kW <sub>ac</sub>
Total Inverter	1 unit
Nominal Power Ratio	1.05



**Figure 2: Photovoltaic Array sizing and Inverter output distribution**

**Table 3: Normalized Power generation of proposed system**

	<b>Y<sub>r</sub></b> kWh/m <sup>2</sup> /day	<b>L<sub>c</sub></b> kWh/m <sup>2</sup> /day	<b>Y<sub>a</sub></b> kWh/m <sup>2</sup> /day	<b>L<sub>s</sub></b> kWh/m <sup>2</sup> /day	<b>I<sub>f</sub></b> kWh/m <sup>2</sup> /day	<b>L<sub>cr</sub></b> %	<b>L<sub>sr</sub></b> %	<b>PR</b> %
Jan	4.98	0.82	4.17	0.14	4.03	0.164	0.027	0.808
Feb	5.81	1.09	4.72	0.15	4.57	0.187	0.025	0.787
Mar	6.02	1.36	4.66	0.14	4.52	0.226	0.024	0.750
Apr	6.34	1.61	4.73	0.15	4.58	0.254	0.024	0.722
May	6.21	1.65	4.56	0.14	4.41	0.267	0.023	0.705

Jun	5.90	1.50	4.40	0.14	4.26	0.254	0.024	0.722
Jul	4.93	1.15	3.78	0.13	4.66	0.233	0.026	0.741
Aug	5.02	1.13	3.89	0.13	4.76	0.225	0.026	0.749
Sep	5.73	1.34	4.39	0.14	3.25	0.234	0.024	0.742
Oct	5.53	1.25	4.27	0.13	3.14	0.227	0.024	0.749
Nov	5.17	0.99	4.18	0.13	4.05	0.191	0.025	0.784
Dec	4.78	0.79	3.99	0.13	3.86	0.165	0.027	0.808
Year	5.53	1.22	4.31	0.14	4.17	0.221	0.025	0.754

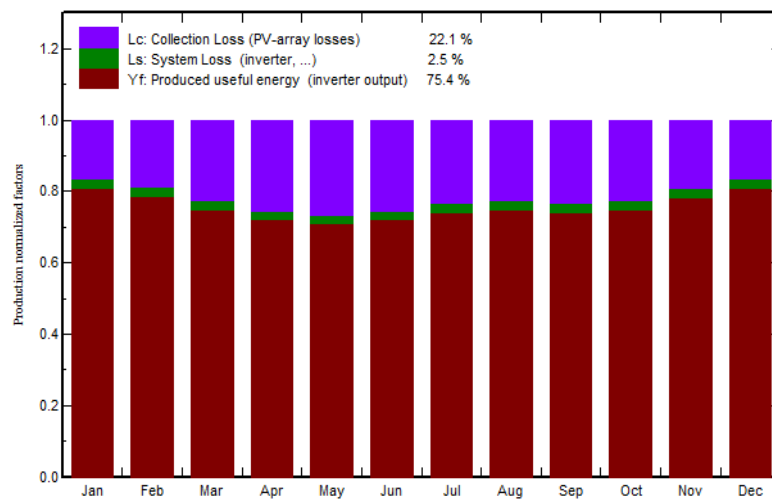


Figure 3: Losses for the Production of Normalized Factors

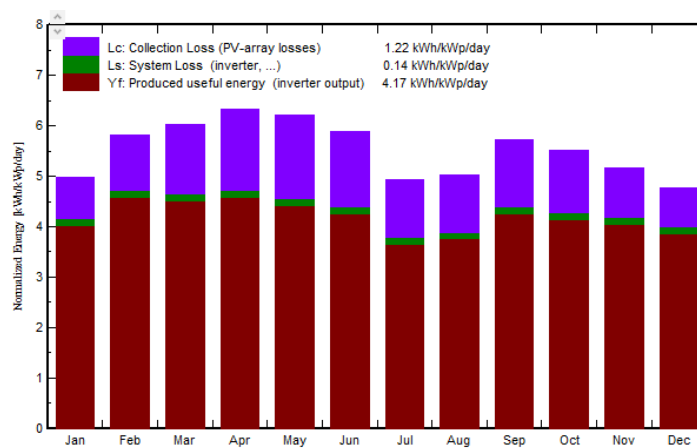


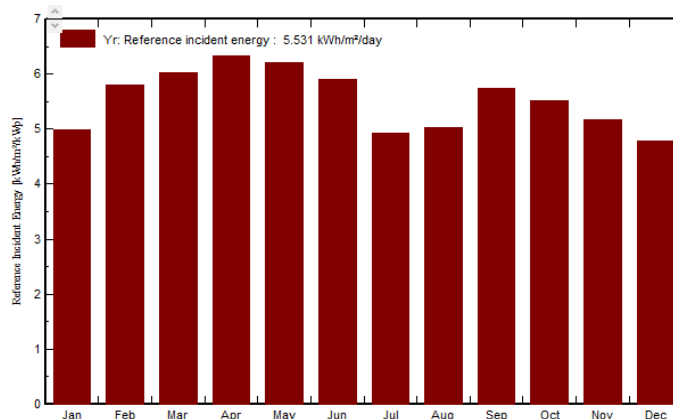
Figure 4: Normalized Energy Production of Proposed System

### ***3.1 Normalized Power Production (NPP) of Photovoltaic System***

The NPP factor represents the energy that is computed from the photovoltaic system's surface conversion of radiation into DC over the year. Losses from the inverter, array, and solar cell system are computed during this process to convert radiation into AC power. The renewable solar energy that remains usable is the amount that is left over after deducting the losses associated with the solar cells and inverters. Different NPP factors for the proposed geographical location are shown in Figures 3, and 4, respectively. Useable energy produced by the suggested system is represented as  $Y_f$ , inverter losses as  $L_s$ , and losses from the photovoltaic collection as  $L_c$ .  $L_c$  losses of 22.1% are recorded for the proposed model. While system losses  $L_s$  for the aforementioned geographic locations are 2.5% respectively, where  $Y_f$  useful energy produced 75.4% as depicted in figure 3. Collection losses, on the other hand, vary depending on the solar path and different irradiations and are essential for contributing useful energy. The performance of the solar cell is affected by variations in environmental temperature since most of the solar cell's properties are directly impacted by temperature. As a result, it is crucial to regulate to enhance the solar cell's output outcomes. The temperature produced in solar cell layers due to the conversion of irradiance into DC and the sun irradiance on the surface of the photovoltaic cell decreases the NPP output, which explains the improved NPP in March, April, May, and September as depicted in Fig. 04 for proposed location in Sindh, Pakistan. This is because excessive heat in June, July, and August also lowers the total efficiency of the NPP and solar cells as depicted in Figures 3,4 and Table 3.

### ***3.2 Incident Energy on Collector Lane***

After selecting a location, we used the PVSyst simulator to validate our suggested PV system and determine the best spot for solar power generation. According to the software's results, reference incident energy for the proposed geographical location is normally 5.531 kWh/m<sup>2</sup>/day. However, because of high temperatures, which also raise the temperature of the collection plane, it is greatest in April and lowest in July and August. This is illustrated in Fig. 5. The further proposed location is the ideal location for a solar power plant, however, it receives less sunlight in December, it is also a crucial parameter for incident energy on the collector plane for electricity generation.



**Figure 5: Incident Energy on Collector Plane**

#### 4. Overall Loss Diagram

The first computation of total losses included both the total energy produced and the excess energy added to the grid through a grid tie system. The loss diagrams for the proposed system are displayed in Figs. 6, respectively, below, due to their respective highest and lowest performance ratios (PR). While other losses matter, these two losses significantly affect the performance ratio for a certain geographic location. The two losses that matter are the temperature-effect-related solar losses and the inverter loss during operation (efficiency). Therefore, photovoltaic cells are directly affected by temperature and light exposure, and an essential aspect of performance assessment is the efficiency of inverters in converting DC power to AC power. According to recent studies, the position and amount of solar radiation received on the horizontal collector plane affect temperature-related PV loss. Inverter efficiency varies little for a suggested place, staying between 3.20%. Additionally, the location has a solar cell efficiency of 15.18% in typical temperature conditions, and the combined surface area of their 1.05kW<sub>p</sub> photovoltaic systems across all planned sites is 7m<sup>2</sup>. The total energy available at inverter output for the proposed system is 1598 kWh/year depicted in Figure 6.

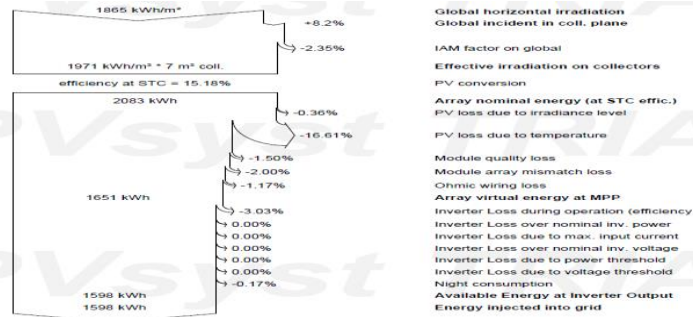


Figure 6: Overall Loss Diagram for Proposed System

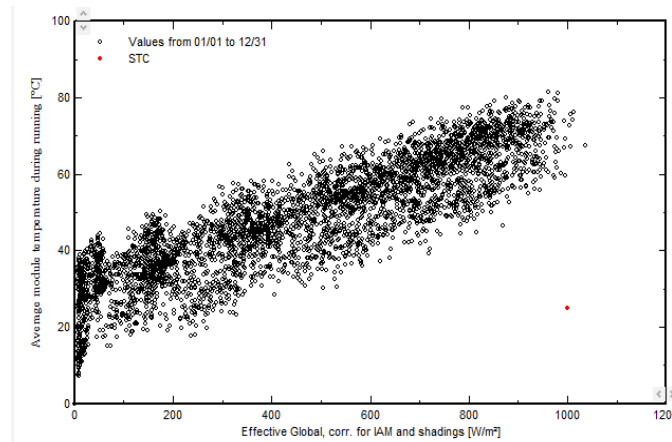


Figure 7: Daily input and output Power for the Proposed system.

### 5. Daily Input /Output Diagram of Proposed System

The amount of solar irradiation on the collection plane determines how much energy is injected into the grid, therefore, raising irradiation on the solar cell collector plane square area in kWh/m<sup>2</sup> on the horizontal plane power generated by the PV solar system. Daily solar radiation intake on the solar cell's collector plane throughout the year causes fluctuations in energy output, and the amount of power injected into the grid similarly fluctuates on the y-axis in response to sun irradiation. Figure 7 for the said geographical location shows the daily input and output together with the vertical axis representing the total solar radiation on the collecting plane and the y-axis representing the daily power sent into the grid is recorded as kWh/day. The grid connection mechanism allows for the maximum daily energy supply to be made to the proposed location. The daily energy input-output diagram of the site in Sindh is shown in Fig. 7, which makes it clear that the majority of the dots are concentrated above the 40 kWh/day energy delivered into the grid every day. According to the general interpretation of this data, the recommended PV

system may inject up to 40 kWh/day into the grid for most of the year. The highest amount of energy that may be injected into the grid each day is 40 kWh/day, with a daily injection limit of less than 80 kWh/day. Figure 7 shows the yearly input radiation from the sun together with the energy produced and added to the grid tie system in kWh/day. Since the dotted concentration is normally over 40 kWh/day and below 80 kWh/day maximum and lowest range for a day, this PV system can only inject 40 kWh per day.

## **6. Conclusion**

The current study provides options to deploy grid-connected solar systems for Pakistan's Sindh Province using PVSyst software and meteorological data. Solar PV grid-tied systems inject power into the grid with a performance ratio of 75.4%, which is higher than many grid-connected systems that Sindh province has already created. However, because of its annual average low ambient temperature, its total PR may reach 75.4%, adding 1598 kWh of energy per year to the grid. The findings of this study may be used to construct a solar power plant with low losses, a high-performance ratio, and the best PV cell and inverter selections at the right place geographically. A grid design for all distributed power generation through solar systems in remote regions may distribute power across the nation as a consequence of this ahead planning, solving the issue of energy shortages and bringing down high electricity bills. Furthermore, cooperation in the energy industry is making the energy imbalance in border regions and urban centers across all nations worse.

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