Optimized Photovoltaic System Using PV Syst Software For Residential Building Energy In Multan

Muhammad Muneeb Khan[1], Sadiq Ahmad[2], Ali Raza[2], Rana Gulraiz Hassan[2], Usman Tariq[2], Haroon Sikandar[3], Muhammad Amir Shafi[4]

[1]Institute of Southern Punjab, Multan, 6000, Pakistan

[2]COMSATS University Islamabad, Wah Campus, 47040, Wah Cant, Pakistan

[3]NUST, Islamabad, 44000, Pakistan

[4]COMSATS University Islamabad, 45550, Pakistan

Abstract: Any developing nation, including Pakistan, must have access to energy to sustain economic growth. The design and installation of a cost-effective renewable energy option are presented in this article along with a renewable energy solution for Multan, Pakistan's densely populated city of saints. Solar power is the energy source that is expanding the fastest worldwide. Installed photovoltaic power in Pakistan till 31st December 2022 is 785.42 MW which was 5 years ago 250 MW. Pakistan has a huge potential for photovoltaic (PV), The average value of solar irradiance on a solar plane surface is 5.5-6.5 kWh/m^2/day, according to geographic and climatic research. For the suggested location, geographic information, meteorological data, and energy demand consumption are gathered. PVSyst simulation software has also been used to analyze performance ratios and losses. The simulated system used little rooftop area and battery storage to fulfill the maximum demand, allowing enough room for the system to be expanded in the future to meet rising energy needs. Load needs, geographic coordinates, sun radiation, etc. all have an impact on this process. Based on estimations of watt-hour consumption, the stand-alone PV system's size and design are carried out. As a consequence, the system has demonstrated promise and validates its viability for the area while taking into account energy loss. The simulation's findings include the total energy produced by the PV array, energy that was not utilized and that was provided to the load, PV conversion efficiency, system losses, performance ratio (PR), and other data. According to the examination of performance ratios, the optimal Performance ratio of 92.9% was reached in January and the lowest PR was 82.5% attained in July. However, the average PR for 2023 is 86.2%. Different types of losses account for the system's decreased power capacity. By using the same methodology, this research will be useful in developing and scaling grid-connected PV systems for different sites around the globe.

Keywords: Photovoltaic system, PVSyst, Energy shortage, Renewable power generation, Grid-connected PV System, Optimized solar system.

Email: muneebkhan@isp.edu.pk

1. Introduction:

Electrical Energy plays a crucial role in maintaining the country's economy and overall development in lifestyle. A fundamental factor for removing poverty, enhancement of human well-being, and improving living circumstances globally is the availability of sufficient, inexpensive energy [1,2]. In the past, conventional sources like oil, gas, and coal have been the main sources of energy and have been crucial in supplying humans with energy and improving their lifestyles. Modern energy sources have been crucial to humans since the beginning of existence. Renewable energy sources are those that are produced from naturally occurring resources, such as wind, sun, and water. These sources are more environmentally friendly than other forms of energy. Utilizing plentiful, environmentally acceptable energy sources offer the ability to provide electricity with essentially zero emissions of pollutants and hazardous gasses [3]. The world's primary energy consumption would increase by 43% between 2015 and 2030, with an average yearly growth rate of 1.7%, according to the 2023 publication of BP Energy Outlook. The primary users of electricity will be the household user and agricultural sector [4]. Currently, there is an energy shortfall in Pakistan, where the majority of people lack access to power to meet their basic daily requirements. The primary energy consumption per person was 6.70 MWh in 2022 and 6.60 MWh in 2023, as opposed to 39.40 MWh and 36.60 MWh in industrialized countries such as the United Kingdom for the same year [5]. As its principal source of primary energy, Pakistan is heavily dependent on oil imports. Concerns about pricey energy have been raised in recent years due to the significant increase in crude oil prices. Given that there has been a power shortage since (2007) [6] the situation is significantly worse. The power shortage situation would persist through 2030 under existing policy and planning, according to NEPRA Energy Report (2020) [7].

Pakistan has a unique opportunity to generate solar power because of its location on the solar path, which reduces the burden of importing fossil fuels from Middle Eastern countries through Gawadar and Qasim Port. Pakistan can meet its energy needs by using all of the readily available renewable energy resources. The nation has adequate photovoltaic energy potential of 5.5–6.5 $kWh/m^2/day$ to cover the energy demands of a community. This is the only national resource independent of any social, political, or legal dispute [8,9].

The direct conversion of sunlight into energy is known as a photovoltaic (PV) system. The design of PV devices is straightforward, and they need very little maintenance. The fact that solar photovoltaic systems may be employed as both grid-connected and stand-alone systems is a key benefit. A PV system can be as little as microwatts or as large as megawatts [11,12]. Photovoltaics with concentrating cells and numerous junction layers have efficiencies as high as 38% in the simulation lab, whereas panels on the market have efficiencies in the 15% range [13-16]. PV panel costs dropped from $20 per W around 10 years ago to less than $2 per W in (2022). Due to price reductions over the past ten years, thin film solar cells have seen a rise in market share on a global scale. The market share of silicon-based panels now accounts for roughly 80% [17]. In the previous two years, the capacity of solar PV generation has dramatically expanded worldwide. The overall global capacity increased by more than 39 GW in 2013 to around 139 GW [18,19]. According to the new policy scenario from the IEA photovoltaic energy share in power generation would rise to 1000 TWh by 2040, increasing from 0.6 percent to 3.6 percent of total global electricity production [20]. Numerous researchers have developed grid

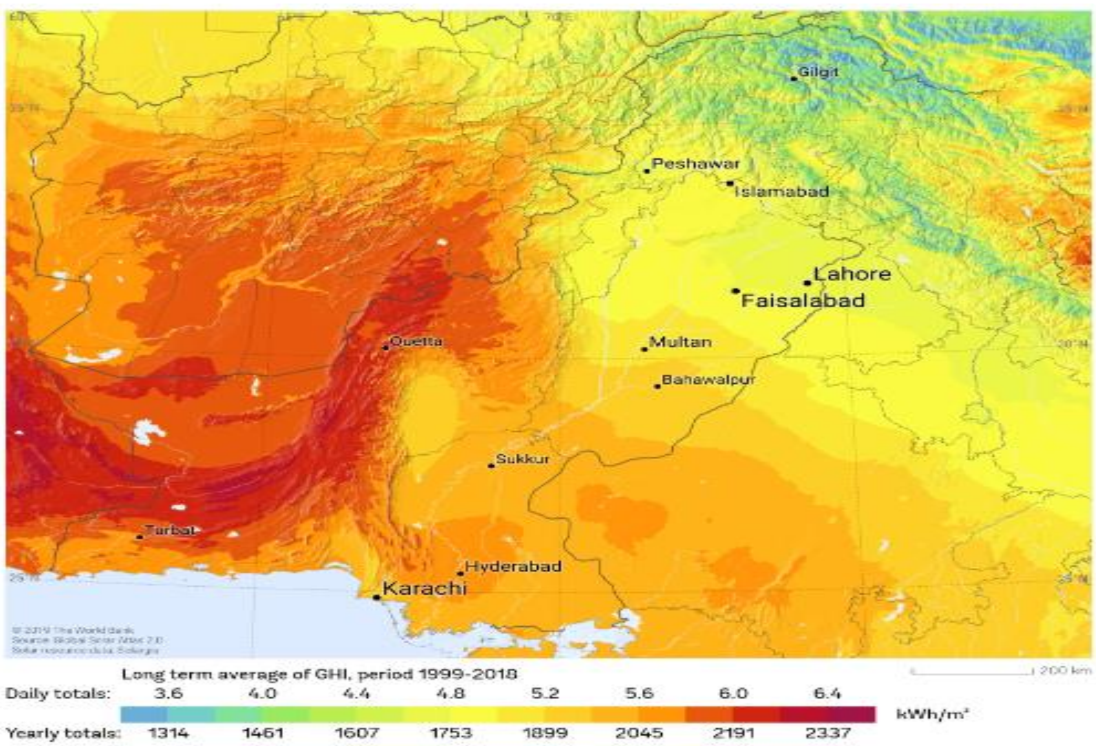

Figure 1: Available Solar irradiation map of Pakistan [10]

connected photovoltaic systems for use in various regions across the world using various methodologies and plans.

II. Site selection and simulation techniques:

A. Photovoltaic System Software

A grid-connected and off-grid solar system may be fully studied and analyzed using the simulation and design software known as PVsyst. It has substantial databases of geographical, climatic, and PV component data (PV modules and inverters). The output data includes the system's primary energy gains and losses as well as the total monthly energy production (kWh), performance ratio (%), and specific energy (kWh/kW) [22].

B. On-site climate factors:

With the use of data from Mateonorm-8.1, a standalone photovoltaic system is simulated in this research study. The PVSyst simulator offers the Mateonorm-8.1 data for sites all around the world. Mateonorm-8.1 is appropriate for long-term system performance forecasting. Multan was selected for the study because it is the most populous city in Pakistan, has a high rate of MEPCO energy customers, and has a climate that is typical of more than 50% of the nation [21]. The results of this research will also assist electrical users in setting up a grid tie system to eliminate expensive energy from WAPDA. The geographical location of the site has having Latitude of 46.20° N and a Longitude of 6.15° E with an albedo of 0.20 for the fixed plane. In Table 1, the Mateonorm-8.1 data for the Multan area is retrieved.

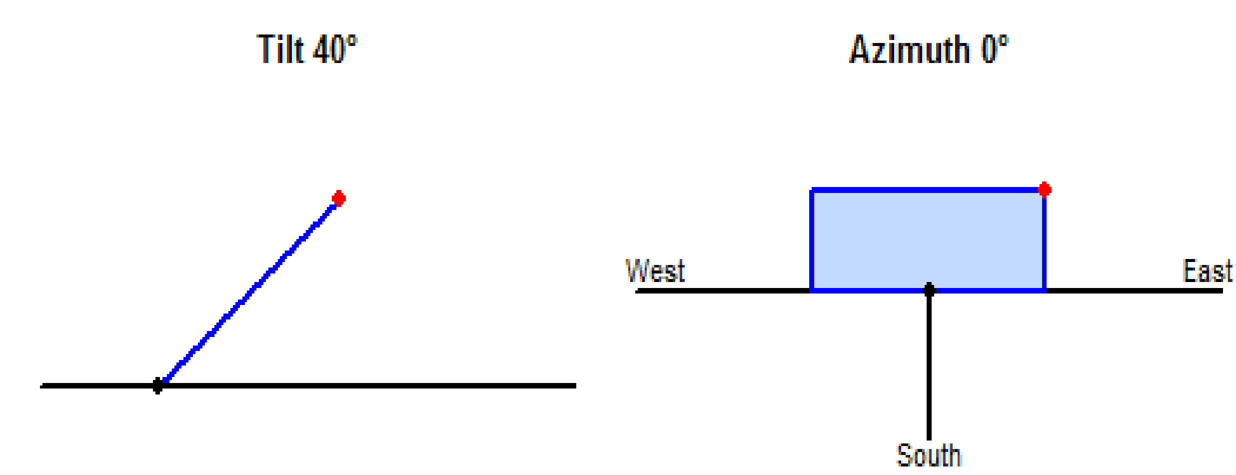

Figure 02: Tilt angle

The current study describes the usage of a tilt angle of 40° for solar cell setup on residential building roofs that face the sun throughout the day, while an azimuth angle of 0° is employed to gather maximum solar irradiation on the cell surface as shown in Figure 02**.**

The ratio of incident radiation to the solar cell collector plane facing the sun is known as the transposition factor, and it indicates the best sun rays that may be used by the solar cell to convert solar irradiance into electrical power. The transposition factor in Figure 03 indicates optimal losses of 0.0%, whereas FTranspos is 1.22. The sun's plane orientation is more head-on and in the optimal path.

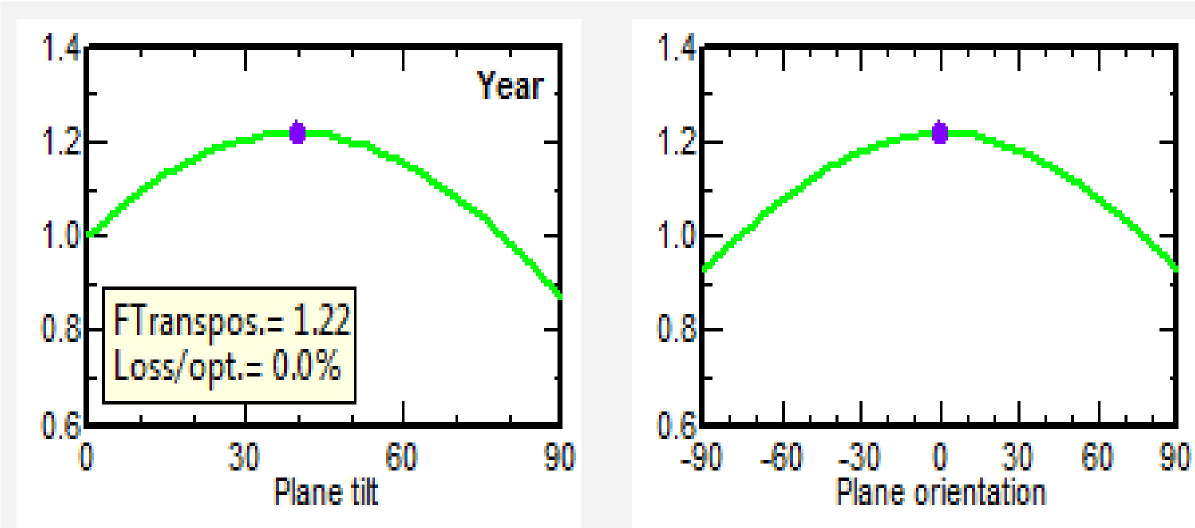

Figure 03: Yearly Irradiation Yield

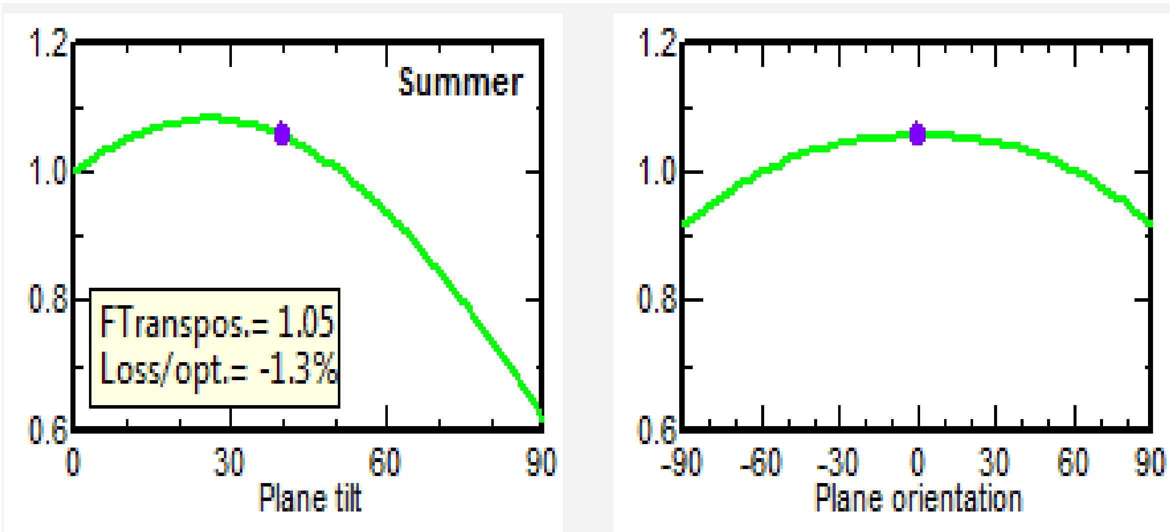

Figure 04: Summer Irradiation Yield

Figure 04 depicts the transposition factor 1.05 over the summer, or April to September, with losses of -1.3%. The summer transpose factor of 1.05 indicates excellent useable solar irradiation for the chosen location of Multan.

Figure 05 displays the transpose factor 1.67 for the winter season, which runs from October to February. This value is higher than the transpose factor for the summer, indicating that the summer's extreme heat also affects cell function. Consequently, the transpose factor is higher in the winter, although losses are significant -5.4%. The chosen site experiences relatively little solar movement.

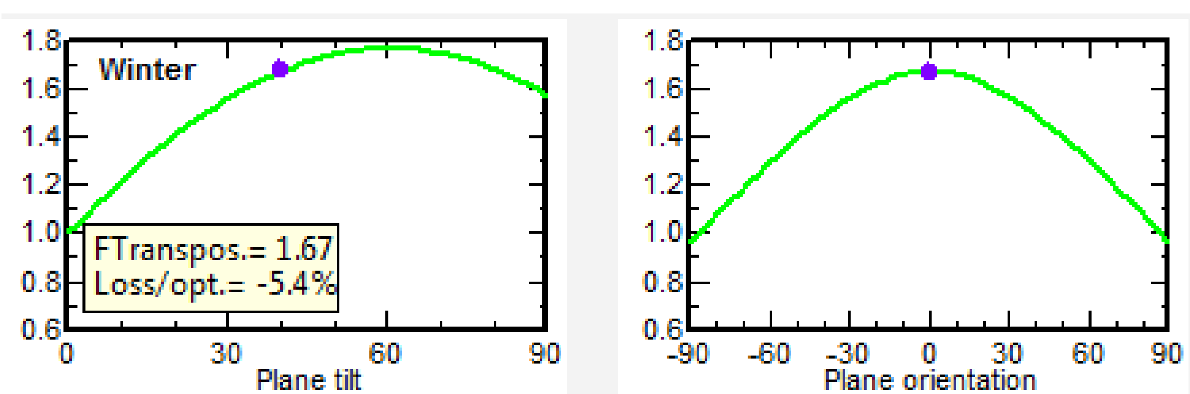

Figure 05: Winter Irradiation Yield

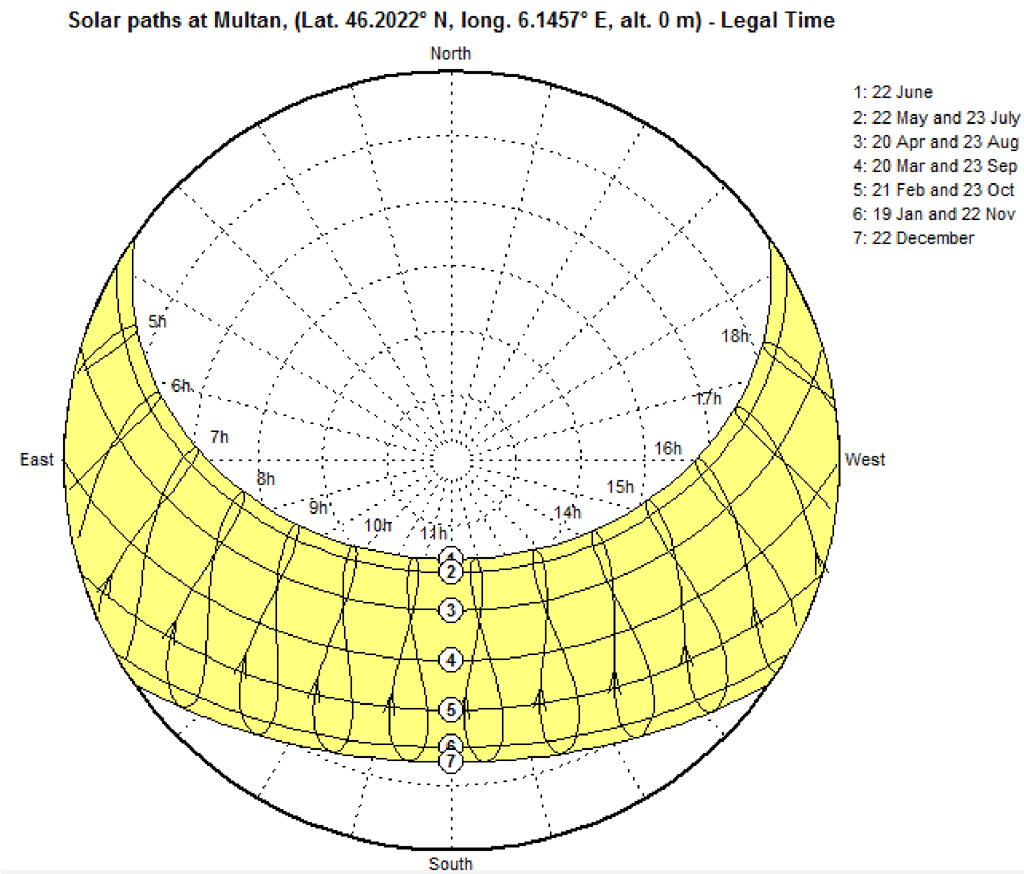

Figure 06: Sun Path for suggested location

22nd December is the shortest day for the selected location of 46.2°N, longitude 6.15°E and shows in the 7th curve and total of 11 hours in the day, The 6th curve shows for November and January curves, such as in the June 14 hours in the day. Days and hours throughout the years play a vital role in photovoltaic power generation and simulation design for the suggested location. The availability of sun in the daytime and sun irradiance can generate more solar power shown in Figure 06 and Figure 07.

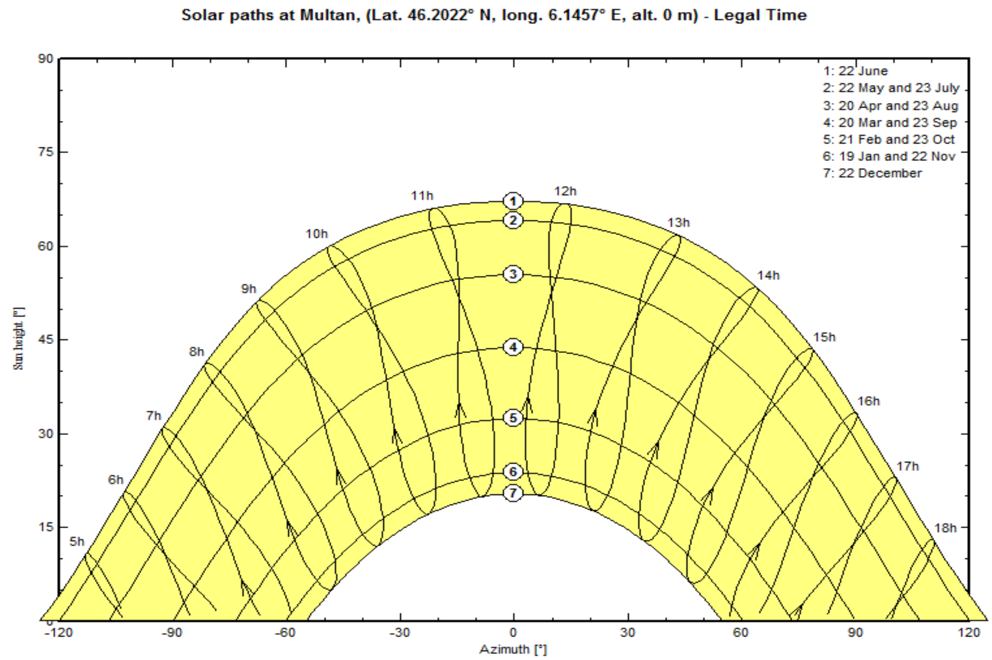

Figure 07: Solar trajectory at a specific geographical location

TABLE 2.1: Mateonorm-8.1 data of Geographical Site in Multan:

Month	**Direct irradiation on Solar plane ($kWh/m^2/day$)**	**Diffuse irradiation on Solar Plane ($kWh/m^2/day$)**	**Direct irradiation on Solar plane ($kWh/m^2/month$)**	**Diffuse irradiation on Solar plane ($kWh/m^2/month$)**	**Site Temperature (°C)**	**Wind speed (m/sec)**	**Relative Humidity (%)**
January	1.27	0.69	39.4	21.41	3.2	2.49	84.0
February	2.09	0.99	58.4	27.79	4.2	2.70	78.2
March	3.48	1.42	108.0	44.06	8.2	2.90	71.6
April	4.84	2.26	145.1	67.87	11.8	2.80	68.5
May	5.53	2.47	171.4	76.59	15.8	2.59	70.2
June	6.46	2.76	193.7	82.69	19.9	2.50	66.5
July	6.35	2.60	196.7	80.72	21.8	2.39	64.8
August	5.45	2.22	169.1	68.72	21.0	2.10	66.8
September	4.09	1.70	122.7	50.85	16.7	2.20	74.5
October	2.50	1.31	77.5	40.65	12.9	2.20	79.5
November	1.45	0.67	43.4	19.96	7.4	2.40	83.9
December	1.04	0.56	32.1	17.54	4.0	2.39	84.2
Yearly	3.72	1.64	1357.6	598.86	12.2	2.5	74.4

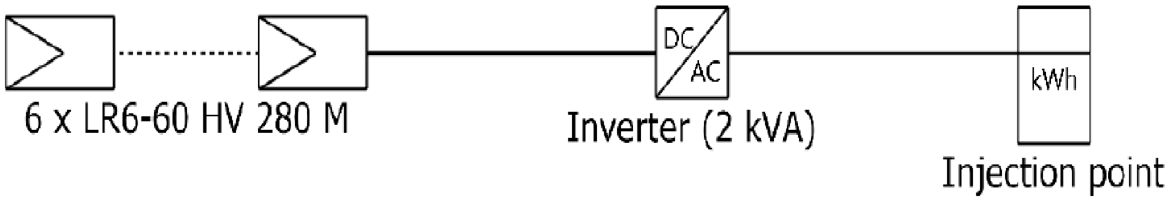

Figure 08: System Diagram

The data on solar irradiation available on a chosen site for each day and month of the year is displayed in Table 1. Other factors like temperature and wind speed have a direct impact on solar power output and are crucial for determining the viability and estimate of grid-connected photovoltaic systems. Direct irradiation on the collector plane is maximum in July which is 6.35 kWh/m^2/day and minimum in December 1.04 kWh/m^2/day overall yearly direct irradiation is 3.72 kWh/m2/day. Diffuse irradiation from shading is maximum in June and minimum in December overall yearly 1.64 kWh/m^2/day. Photovoltaic temperature is minimum in January 3.2°C and maximum in July 21.8°C overall yearly it is 12.2°C.

C. Modeling of PV system:

To meet the basic needs of a domestic setting for illumination, entertainment, and comfort while conducting everyday tasks within the house, a grid-connected photovoltaic system will be created. As noted in section 1, Pakistan is experiencing a power crisis. With a basic understanding of seasonal variations in load operation hours, the current model is created for a grid-tie PV system to satisfy a household's yearly electrical energy needs. In the summer from May to September, due to severe weather conditions Multan fans and AC are employed for comfort, and in the winter months especially from December to February a simple heater will do. The basic household consumer's monthly power usage ranges from 0 to 150 kWh, per the NEPRA report (2020) [7]. For this research, a typical house that consists of at least one bedroom, a kitchen, and a bathroom is taken into account. Every appliance's average daily consumption is taken into account, along with varying usage according to season for each month. Fluorescent lamps and televisions have load values that are obtained from the System standard library,

Figure 08 depicts the system diagram that uses solar array modules and a 2 KVA inverter to convert DC power to AC power, which is then injected into the MEPCO system. In contrast, products currently on the market are used to calculate power consumption and the extra power can be injected into the system.

TABLE 2: Grid Connected PV system Summary:

Sr. No	Components	Ratings
1	Solar PV array Units	1 string × 6 in series
2	Inverter unit	1.5 kW
3	Nominal DC Power generation	1680 Wp
4	Nominal AC Power Conversion	1500 Wp
5	Nominal Power Ratio (DC: AC)	1.120
6	Horizon	No shading

Photovoltaic system setup for the energy generation of the desired location, a typical roof size of 1025 m^2 is taken into account (author's observation). PVSyst modeling software offers a wide range of photovoltaic solar cells that are both suitable for the local site environment and highly efficient, making them easily accessible in the Multan market. Household Photovoltaic power systems typically employ a fixed 280Wp 6 units of LR6-60 HV Si-poly solar PV panel and CSI-1.5KTL1P-GI-FL of 1.5 kWac unit power. These specs are based on the equipment that is offered in Pakistan's market. Equipment utilized for the mounting and wiring methods for integrating photovoltaic cells with the home's structural and electrical systems. Disconnects for the inverter's AC and DC sides are part of the wiring systems. According to NASA surface meteorological and solar energy statistics from Matreonorm-8.1 for the Multan location, the solar cell tilt angle is set to 40 degrees in the fixed plane, and the azimuth angle is 0 degrees throughout the year from January to December.

III Findings and Discussion:

A. Inspection of Solar Panels Installed on Roofs

With an average load of 2.5–3.5 kWh/day, the solar PV system is built to completely meet the household's basic electrical energy needs remaining power generation is easily injected into the system of power supply companies like MEPCO in Multan. Useful irradiation on the solar cell collector plane is a maximum in July that is 188.3 kWh/m^2 in and a minimum in December that is 62.6 kWh/m^2 on the other hand irradiation after reflection with other objects on the collector plane is a maximum in July and a minimum in December. The output energy of the solar cell array is maximum in July which is 270.6 kWh and the minimum in December is 101 kWh likewise energy injected into the grid is maximum in July which is 261 kWh and the minimum in December 97.2 kWh. Overall annual energy injected into the grid is 2318.7 kWh which is a more economical and optimized photovoltaic system. Annual Average performance ratio is 86.2% of the system.

TABLE 3.1: Main Result of Grid Tie System:

Months	Irradiation on solar collector plane (kWh/m^2)	Effective global and shading irradiation (kWh/m^2)	Output Energy of Solar Array (kWh)	Energy Injected into Grid (kWh)	Performance Ratio (%)
January	72.7	71.9	117.9	113.5	0.929
February	93.1	91.9	148.2	142.9	0.914
March	146.3	144.1	225.5	217.7	0.885
April	162.8	159.8	246.1	237.5	0.869
May	167.9	164.4	247.6	238.7	0.846
June	181.1	177.0	263.1	253.7	0.834
July	188.3	184.1	270.6	261.0	0.825
August	182.6	179.0	262.7	253.5	0.827
September	152.6	150.0	224.9	217.0	0.847
October	111.7	110.0	171.7	165.6	0.883
November	79.4	78.5	125.1	120.4	0.903
December	62.6	62.0	101.0	97.2	0.924
Year	1601.0	1572.7	2404.3	2318.7	0.862

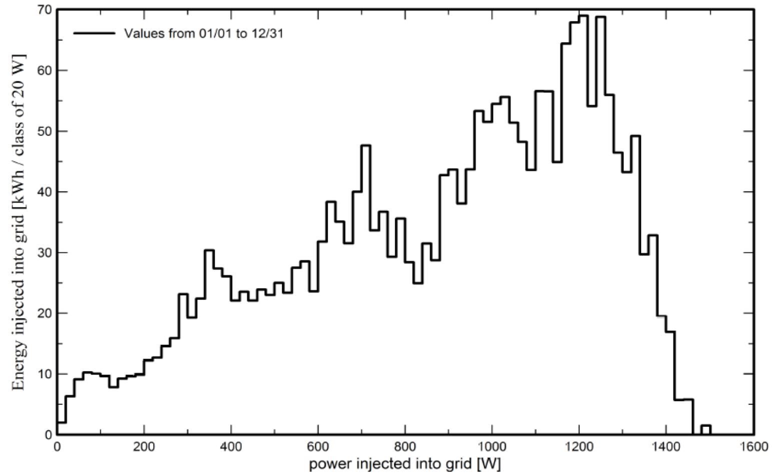

Figure 09: System output Power Distribution

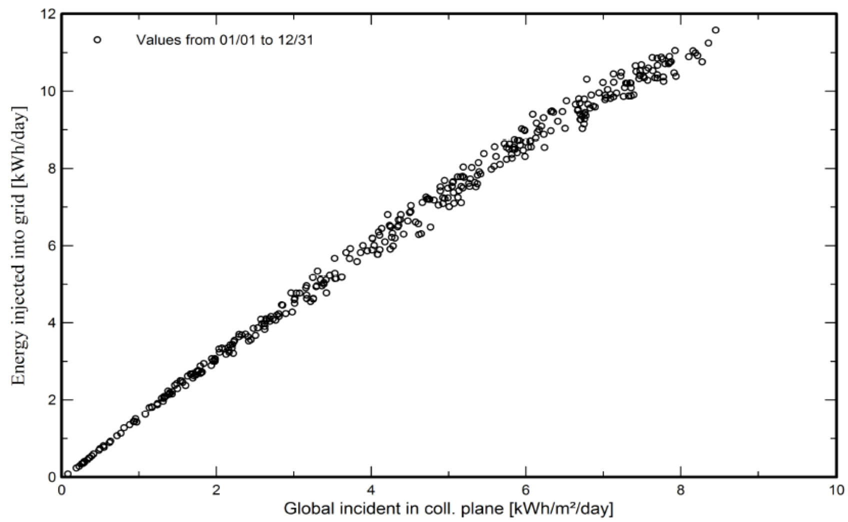

Figure 10: Daily Annual Input and Output Diagram

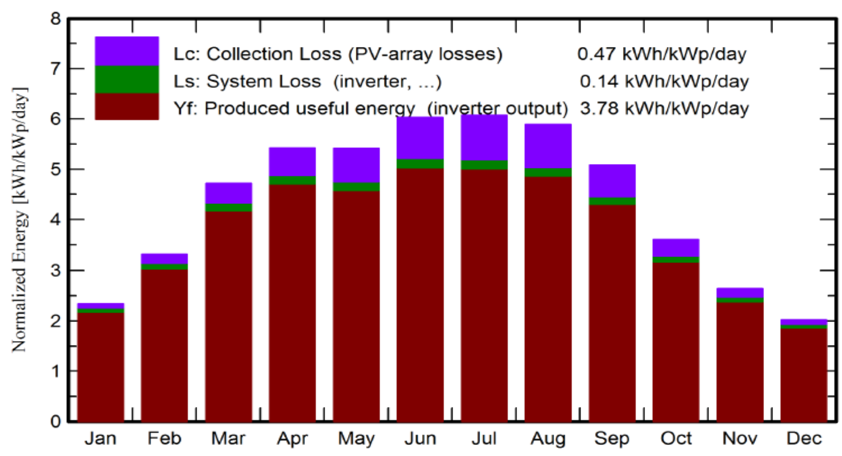

Figure 11: Normalized Power (Per Installed KWp)

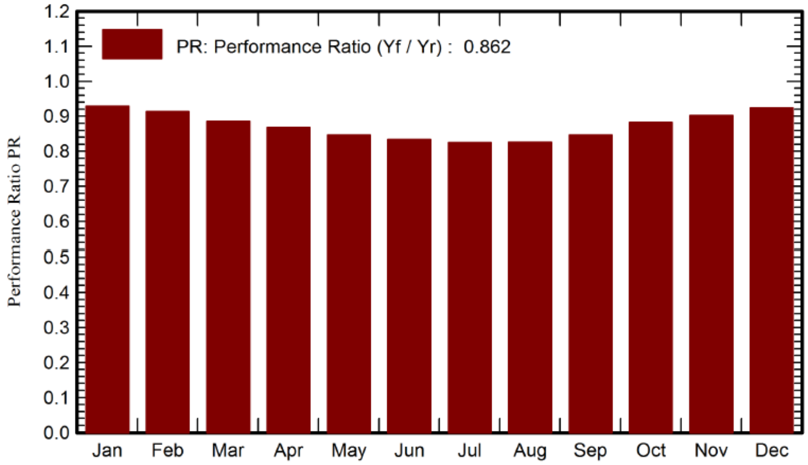

Figure 12: Annual Performance Ratio

The detail of energy generation on the solar cell collector plane is described in Figure 13 given below. The chosen solar panels' actual PV conversion efficiency is 17.13%. Different losses in the system also deduct the energy, overall energy generation from the grid-connected solar system is 2319 kWh and is injected into the distribution company system.

IV Conclusions

To meet the need for energy for essential home needs, a grid-connected PV system is designed using the PVsyst program. The Multan area was chosen for the study since it represented Pakistan's predominant population and overall climate. Pakistan has a huge potential for renewable energy especially photovoltaic energy, with an average value of 5 to 6 kWh/m^2/day or 1800–2200 kWh/m^2/year, according to a study of its geography and climate. All things considered, the system has shown promise and is viable for the region when energy loss is considered. The results analysis has demonstrated the technology's potential in the area. The system is installed at the normal roof top area available, including battery storage capacity, allowing plenty of room to expand the system to suit future requirements. With more energy generation, it was able to inject more energy into the grid-connected system to effectively contend with the season's peak load. Based on the seasonal needs, the excess energy can be advantageously injected into the system to lower the burden of national power distribution companies. A further change to the system will strengthen its feasibility, the efficiency of the system will be increased by adding a tracker with one or two axes over a fixed plane system to improve the efficiency of a photovoltaic system, to further solidify the implementation of the technology in the area, an economic study will be needed. The system's production may be increased by changing the collector slope in response to seasonal and monthly variations.

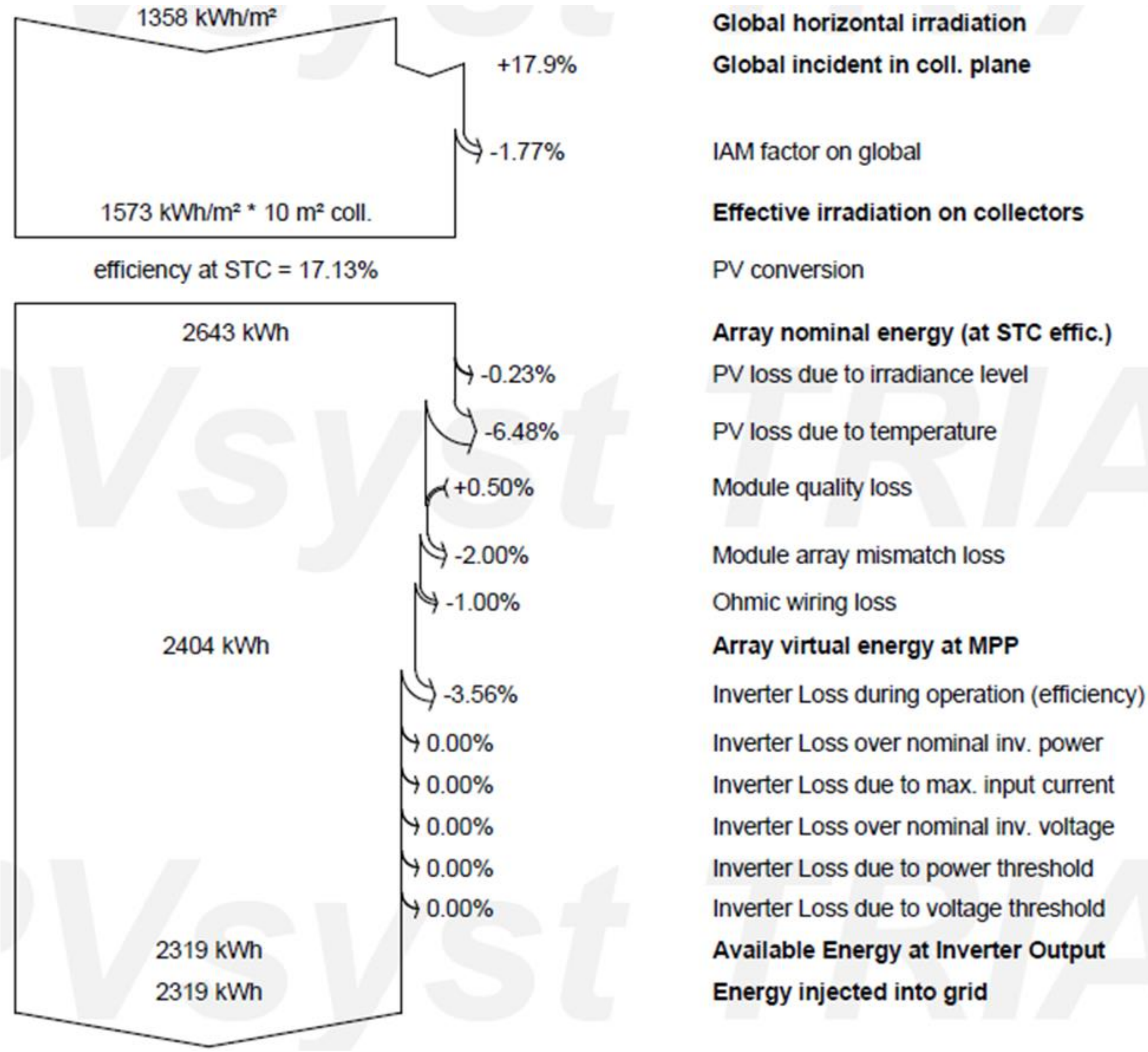

Figure 13: PV system energy losses

References:

Muneer, T., M. Asif, et al. (2005). "Sustainable production of solar electricity with particular reference to the Indian economy." Renewable and Sustainable Energy Reviews 9(5): 444-473.

M. M. Khan, et al. (2016) "Magneto hydro dynamic generation" International Journal of Scientific & Engineering Research, Volume 7, Issue 12.

M. M. Khan, et al. (2022) "Financial Analysis of PV-Wind Cogeneration for a Remote Village in Gwadar-Pakistan." Southern Journal of Research.

BP Energy Outlook 2030 (January 2023). "bp.com/energy outlook"

World Bank. (2014). 'Energy use per capita' http://data.worldbank.org/indicator.

Qasim mubashir, K. K. (2014). "An empirical analysis of energy shortage in Pakistan." Asia Pacific Development Journal 21(1): 137-166.

National Electric Power Regulatory Authority (NEPRA) Pakistan, 'state of industry report 2020'

Sher, H. A., A. F. Murtaza, et al. (2015). "Pakistan's progress in solar PV-based energy generation." Renewable and Sustainable Energy Reviews 47: 213-217.

Farooqui, S. Z. (2014). "Prospects of Renewables penetration in the energy mix of Pakistan." Renewable and Sustainable Energy Reviews 29: 693-700.

Solar radiation maps: 'South and South East Asia' Solar GIS, Geo model Solar 2015.

Tyagi, V. V., N. A. A. Rahim, et al. (2013). "Progress in solar PV technology: Research and achievement." Renewable and Sustainable Energy Reviews 20: 443-461.

Li, Y., G. Zhang, et al. (2015). "Performance study of a solar photovoltaic air conditioner in the hot summer and cold winter zone." Solar Energy 117: 167-179.

Razykov, T. M., C. S. Ferekides, et al. (2011). "Solar photovoltaic electricity: Current status and future prospects." Solar Energy 85(8): 1580-1608.

M. M. Khan, et al. (2016) "Development of Prototype of Grid Tie Inverter (Grid Synchronization and Load Sharing)" International Journal of Engineering and Advanced Technology (IJEAT), Volume 05, Issue 05.

M. A. Shafi, et al. (2022) "A numerical simulation for efficiency enhancement of CZTS based thin film solar cell using SCAPS-1D" East European Journal of Physics.

M. A. Shafi, et al. (2022) "Effect of parasitic parameters and environmental conditions on IV and PV characteristics of 1D5P model solar PV cell using LTSPICE-IV" East European Journal of Physics, 2022.

'Survey of energy resources 2013'. World Energy Council, UK. ISBN: 9780946121298

Renewable energy policy network for 21st Century, 'Renewable 2014; global status report' REN21-2014 Paris. ISBN: 9783981593426

M. M. Khan, et al. (2023) "An Analysis of Stochastic Wind Power Approach for Economic Load Dispatch Optimization Using Genetic Algorithm." Southern Journal of Engineering & Technology, Volume 01, Issue 02.

IEA. (2030). '' world Energy outlook 2023'' Pakistan Population (2010). "The World Gazetteer." Retrieved 15 October 2014, from http://www.grida.no/geo/GEO/Geo-2-234.htm.

Meteonorm handbook, Parts I, II and III. Meteotest, Bern, Switzerland. 2003