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Research Article

Design and Simulation of Grid-Connected Solar PV System Using PVSYST, PVGIS and HOMER Software

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ABSTRACT

In this paper, the design and simulation of a 5 MW solar power plant in Ghor province, Afghanistan have been investigated. A suitable place at a distance of about 8.17 km from the center of the province was selected as the power plant location. The main objective of this study is the investigation of solar renewable energy resources' capacity for generation of electrical energy from domestic resources to provide reliable and sustainable energy in the center of the Ghor province which is currently not connected to the national electrical grid. In this power plant, 6399 kWp, STP-320 W PV module, and 5300 kW Growatt convertor type were used. The PVSYST, PVGIS, and HOMER renewable energy simulation tools were used for analyzing the system. The results obtained from each simulation tool were compared together. Analysis of the results using HOMER and PVGIS shows that the annual energy generated using each simulation tool is about 11698 MWh and 10673 MWh respectively while the result from PVSYST is 11938 MWh per year. According to the obtained values, results from PVSYST depict 240 MWh more energy generation than HOMER and 1265 MWh than PVGIS simulation tools annually. These values indicate that PVSYST produces higher annual power for this system than HOMER and PVGIS. Comparing the annual generated power results of the simulations with reference to the PVSYST results, it can be concluded that PVGIS is 10.6% lower and HOMER is 2% lower. There is about a 2% difference between PVSYST and HOMER.

1. Introduction

Electrical energy is an important input for the economic and social development of every country. It plays a key role in the economy for both consumption and production of services and goods. It is also significant for scientific and technological developments, which are very important for improving the living standards of people around the world [1].

Afghanistan has good natural resources, but efficient electricity generation and consumption are still scarce [2]. Electricity infrastructures emerge as key prospects for Afghanistan's growth as industrialization and the economy are closely linked to energy access [1]. The current power supply system in Afghanistan is inadequate in several aspects such as capacity, flexibility capability, and domestic supply cost. On the other hand, electricity demand is increasing rapidly due to factors such as population growth, Gross Domestic Product (GDP) growth, changes in energy prices, changes in energy intensity, per capita consumption, local energy conditions, and energy availability. But there is a growing gap between this demand and supply [3].

According to the most recent and inclusive electricity demand forecast of Afghanistan that was developed as part of the preparation of the Afghanistan power sector master plan; net demand was projected to increase from almost 2800 GWh in 2012 to 15909 GWh in 2032, which represents 9.8 percent average annual increase rate. Peak demand was forecast to increase from about 600 MW at the beginning of 2012 to a projected 3502 MW in 2032. The government of Afghanistan is proposing to meet this demand at least in part with renewable energy [4].

This country has a large number of renewable energy resources with excellent and relatively good production potential. With having high-capacity renewable energy resources such as Hydro (23000 MW), Wind (67000 MW), Solar (222000 MW), Geothermal (3000–3500 MW), and Biomass (4000 MW), the country can produce around 318 GW of electricity. Unlike, other conventional, concentrated, and location-specific energy sources, these resources are distributed across large geographical areas across the country [5].

Ghor province is one of the central provinces of Afghanistan [6], which has an area of 36479 km2 [7] and is 2230 meters above sea level (Ghorprovince, n.d.). According to the National Statistics and Information of Afghanistan (NSIA), the total population of this province is approximately 751245. About 7918 of them live in urban and 743336 of them live in rural areas [8].

Ghor state has no electricity grid and the area is not powered by the national system. The load forecast marks a substantial load from 2015, reaching 55 MW in 2032 with a 70% connectivity rate. The proposal to expand the electric network in Ghor province

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includes four phases, which are phase A to 2015, phase B to 2020, phase C to 2025, and phase D to 2032, respectively. To develop the network in step B, the Construction of a new 220/110/20 kV substation in Chaghcharan with two Transformers 220/110 kV each with a capacity of 20 MVA and four transformers of 110/20 kV each with a capacity of 10 MVA and construction of a transmission line from Selma Dam to.

Chaghcharan with a length of about 135 km that required Capital Expenditure (CAPEX) of 53.2 million dollars has been suggested [7].

Currently, none of the proposed stages are implemented in the province and the electricity needs of Ghor city center are met by diesel generators. The total number of subscribers providing electricity from the diesel generator-based electricity network is 2267. About 30% of the people living in the city center of Ghor and about 70% of the people living in the city do not have access to the electricity grid. The tariff price for residential subscribers per kWh is 35 Afghan Afghani (AFN) (0.4605 USD/kWh) and for government and commercial subscribers per kWh is 56 AFN (0.7368 USD/kWh) [9]. The average household consumption of electricity in Ghor province is as low as 178 kWh/annual and it is the lowest level of electric consumption in the country [7].

2. Renewable energy potential in Ghor province of Afghanistan

The Harirud and Murghab are the two rivers in Ghor province. The capacity of these two rivers is 102 MW and 100 MW respectively. These two rivers make up about 0.87 percent of Afghanistan’s total hydropower capacity[10]. According to [11], the annual energy capacity can obtain from Municipal Solid Waste, animal manure and agricultural waste are 21109, 232387, and 406450 MWh respectively in Ghor province. The wind area in this province is estimated at 160 km2. The estimated potential from wind resources is about 336 MW and the feasible potential is approximately 84 MW[11].

There are approximately 300 sunny days in the country annually with 6.5 kWh/m2/day average solar irradiation that is significantly suitable for photovoltaic technologies in off-grid and on-grid implementations [10,12,13,14]. As shown in figure 1, Ghor province has the 6th position in the solar energy potential aspects in Afghanistan [15]. The solar resource potential in this province is estimated to be 10539 MW [11].

Figures 2 and 3 demonstrate Afghanistan’s PV power potential and Afghanistan's global horizontal radiation maps. According to the figures, this province is located in the region where the PV power potential is between 5.2 to 5.6 kWh/kWp and Global Horizontal Irradiance (GHI) is between 5.6 to 6 kWh/m2.The annual PV power capacity in that province is between 1900 to 2000 kWh.

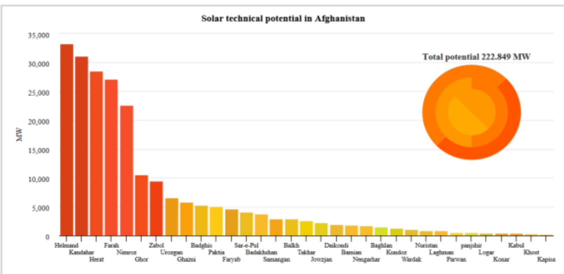

Fig.1. Solar technical potentials in Afghanistan provinces[15]

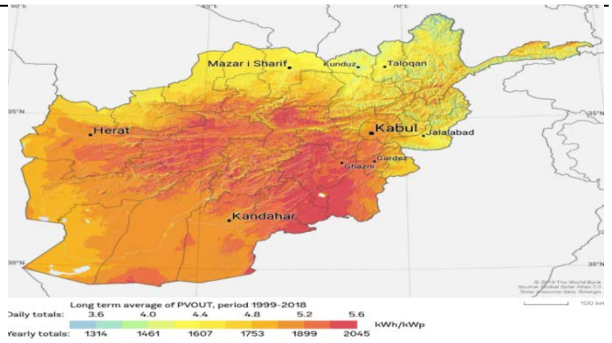

Fig.2. Afghanistan's PV power potential atlas [16].

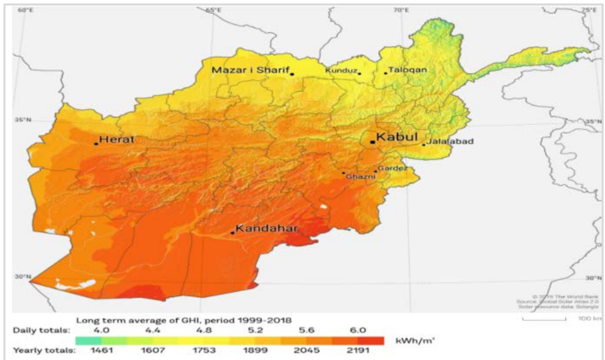

Fig.3. Afghanistan global horizontal radiation atlas [16].

3. Material and Method

In this study, the feasibility design and generation capacity assessment of the 5 MW PV system in the center of Ghor province of Afghanistan has been investigated. For analyzing the system, software such as HOMER, PVSYST, and PVGIS has been used. The geographical data has been obtained using each program’s feature and database.

3.1. Software’s Used in This Study

3.1.1. HOMER

HOMER software is a simulation tool that is widely used in the design of microgrid systems for both off-grid and grid-connected approaches and helps to configure different power technology components in a wide variety of applications. HOMER software has been developed by the National Renewable Energy Laboratory in the United States. This software simulates the system for 8760 hours per year and scales the optimized results according to the total net present cost. HOMER can identify the characteristics of the components as well as estimate different costs such as life cycle cost, operating and maintenance cost, net present cost, and energy cost. In addition, Sensitivity Analysis can be performed to reveal how the outputs change according to sensitivity inputs [17].

3.1.2. PVsyst

PVSYST is simulation software originally designed in Geneva to help calculate the functioning and operation of PV systems. This simulation tool helps design the system configuration and also allows you to evaluate the amount of energy produced. The output is based on the measurement system simulation, which is more dependent on the geographical location of the PV system site. The results may contain several simulation variables that can be displayed in hourly, daily or monthly values, respectively. The "loss table" estimates weaknesses in system design [18].

3.1.3. PVGIS

PVGIS is a solar photovoltaic energy calculator for off-grid or grid-connected PV systems online and free of charge. PVGIS is called a photovoltaic geographic information system. It provides information on solar radiation and PV system performance for any location in Asia, Europe, America, and Africa. This tool has extensive features including customizable maps for users, solar radiation and temperature, performance evaluation method and economic parameter estimations, and electricity generation potential and cost [19, 20].

3.2. Power Plant Location

For achieving better efficiency from power plants, determining the best site location is important. Therefore, different sites have been visited by engineers from the ministry of energy and water of Afghanistan to find a good place for the 5 MW solar power plants. Considering enough area and other characteristics, an area from Posht-e Qotoswhich is depicted in fig.4, was selected as the site location. The plant location latitude and longitude are 34° 53` and 65° 34` respectively [21].

As shown in figure 4, this site has located around 8.17 km far from the center of the city. This location has located toward the south with zero angles of azimuth and there is enough space in the site. The site has access to the road already. This location is a non-heritage area and very close to the Harirud River about 1.5 km with a slope of about 4-7 percent to the south [21].

3.3. Solar Horizon of the Site

There is no near shading from morning to evening and no other barrier to the implementation of the plant technically [19]. The horizon section shown in Figure 5, illustrates how accessible the sun is. The red line represents the shadow around the solar field, which is essentially away from the trees, while the blue line represents the automatic shadow of the photovoltaic modules.

3.4. Orientation

In the orientation section, the field parameters include (azimuth angle, tilt angle), quick optimization (winter Oct-Mar, summer Apr-Sep, yearly irradiance yield), and yearly ateo yield (global on collector plane, loss concerning optimum, transposition factor) are shown in figure 6. As displayed in the figure, for increasing the global collector plan, the plant tilt has been chosen to 34°, and panels oriented toward the south with zero azimuth.

3.5. PV System

In this section, the necessary parameters such as type and number of PV modules, inverter, regulation of modules in series and parallel, and amount of planned power are discussed. As displayed in figure 7, There are about 19998 Si monocrystalline modules from Suntech solar-type with the regulation of 18 modules in series and 1111 modules in strings that were used in this system. The array nominal capacity is 6399 kWp. For converting the DC power to AC, 53 Growatt inverter types with 100 kW capacity each and a total capacity of 5300 kW were used. The operating voltages of the inverter are 450-820 V.

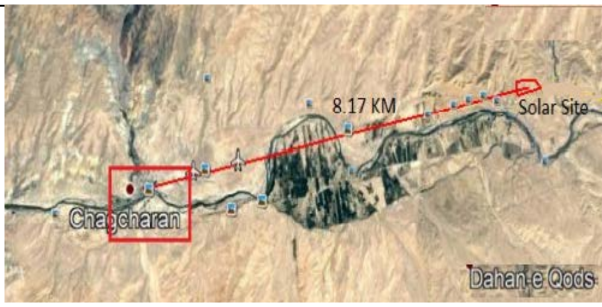

Fig.4. Site location and coordination of solar plant from the center of Ghor province [21].

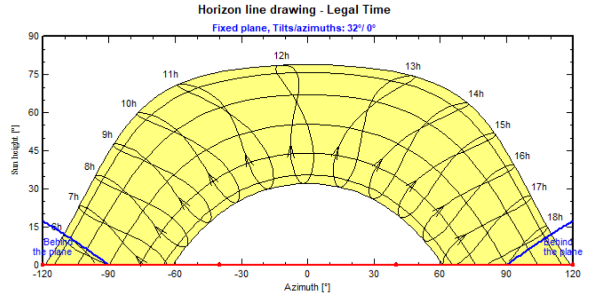

Fig 5. Solar Horizon

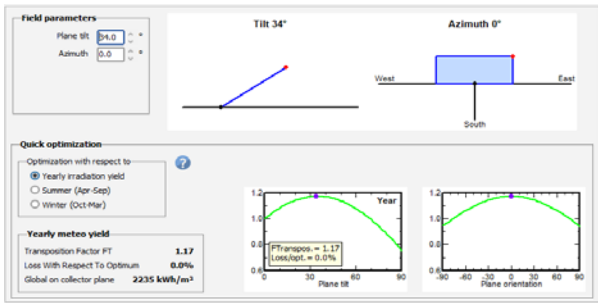

Fig 6. Module orientation and tilt angle

Fig7.PV system design parameters

4. Results and Discussion

The design and analysis of the photovoltaic plant were done using HOMER, PVGIS, and PVSYST tools. The monthly generated energy of the system analyzed by PVGIS and HOMER is shown in figures 8 and 9, respectively. The results obtained from the analysis of the system show that the annual energy produced using PVGIS and HOMER software is calculated as approximately 10673 MWh and 11698 MWh, while the energy produced from the system using PVSYST is 11938 MWh annually. Monthly energy Generation (G-Energy) of PVSYST, HOMER and PVGIS simulationtools and the difference between the production of each software are given in table 1. According to the results, the system analyzed by PVSYST produces 240 MWh more energy than the system analyzed using HOMER and 1265 MWh more than PVGIS. These values indicate that PVSYST produces higher annual power for this system than HOMER and PVGIS. Comparing the annual generated power results of the simulations with reference to the PVSYST results, it can be concluded that PVGIS is 10.6% lower and HOMER 2% lower.

There is about a 2% difference between PVSYST and HOMER. In this study, the results of PVSYST and HOMER simulation tools, which gave closer results, were found to be more significant. Therefore, the system analyzed with the PVSYST simulation tool is suggested as a viable and appropriate approach in this study.

The Global Horizontal Irradiation (GHI), Horizontal Diffuse Irradiation (HDI), Ambient Temperature (T_Amb), Global incident in coll. Plane (GlobInc), Effective Global, corr. for IAM and shadings (GlobEff), Effective energy at the output of the Array (EArray), Energy injected into the Grid (E-Grid) and the Performance Ratio (PR) of the system analyzed with PVSYST are given in table 2. The normalized generation and performance ratio of the plant using the PVSYST software is shown in figure 11. The useful energy production in the figure is 5.01 kWh/kWp/day and the performance rate is 84.88%, these two parameters show that the system is working in good condition.

Figure 8 illustrates the loss diagram of the system. As depicted in the figure, with 19% efficiency, array nominal energy at standard test condition is 13711 MWh/year. Due to the effects of field losses and system components, available energy at inverter output is decreased to 11938 MWh/year and shows that the system losses are about 12.93%.

Table 1. Monthly energy production(MWh) of PVSYST, HOMER, and PVGIS simulation tool

Months	G-Eenergy (PVSYST)	G-Eenergy (HOMER)	G-Eenergy (PVGIS)	PVSYST-HOMER	PVSYST-PVGIS	HOMER-PVGIS
January	852	817	455	35	397	362
February	812	795	420	17	392	375
March	925	918	795	7	130	123
April	986	977	939	9	47	38
May	1069	1057	1025	12	44	32
June	1039	1025	1056	14	-17	-31
July	1088	1070	1109	18	-21	-39
August	1104	1078	1157	26	-53	-79
September	1107	1103	1147	4	-40	-44
October	1160	1143	1100	17	60	43
November	999	934	815	65	184	119
December	797	781	655	16	142	126
Year	11938	11698	10673	240	1265	1025

Table 2. Solar irradiation data, Temperature, Performance ratio and energy generation using PVSYST

	GHI kWh/m²	HDIkWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	88.7	27.59	-4.38	146.1	143.4	885	852	0.912
February	100.2	33.04	2.98	142.4	139.5	842	812	0.892
March	138.6	48.98	1.70	165.5	161.2	959	925	0.873
April	174.0	56.10	7.66	180.9	175.2	1021	986	0.851
May	214.5	61.69	12.52	200.7	193.9	1109	1069	0.832
June	224.4	60.00	17.25	197.6	190.4	1077	1039	0.822
July	230.3	58.59	18.90	208.1	200.8	1128	1088	0.817
August	212.0	51.46	17.61	212.1	205.4	1144	1104	0.813
September	183.3	36.90	13.36	213.2	207.3	1147	1107	0.811
October	153.8	26.97	7.50	215.6	211.4	1202	1160	0.841
November	106.2	23.40	2.59	176.0	172.6	1035	999	0.887
December	81.2	24.49	-1.90	139.7	137.4	828	797	0.893
Year	1907.2	509.21	7.54	2197.8	2138.6	12377	11938	0.849

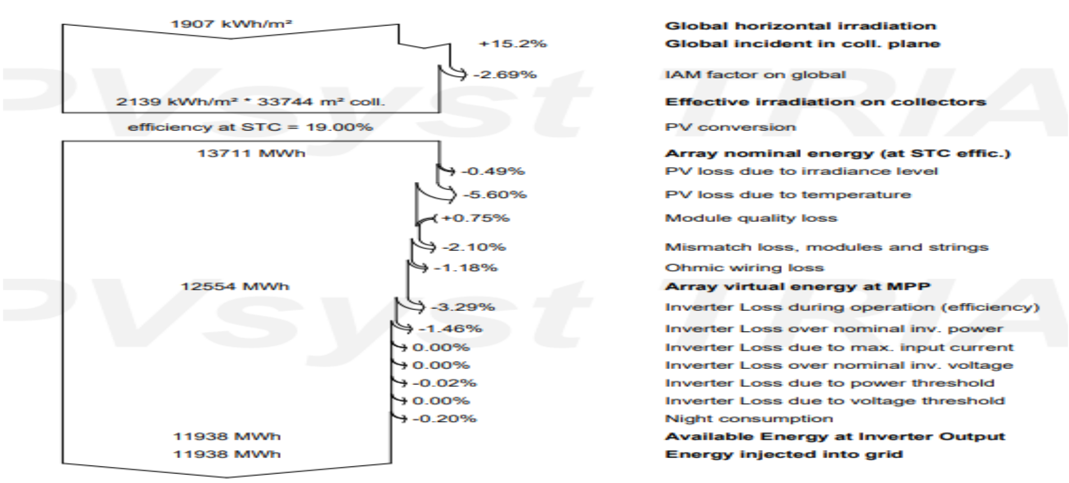

Fig 8. Loss Diagram

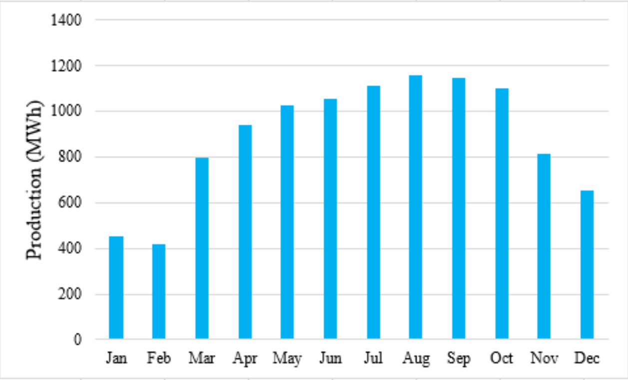

Fig 9. Monthly energy output from PV system analyzed in PVGIS

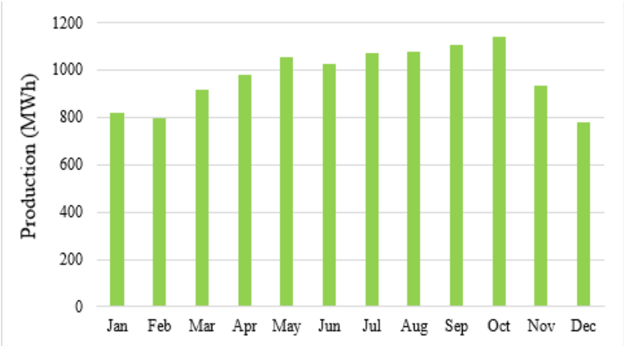

Fig 10. Monthly produced energy from the PV system analyzed in HOMER

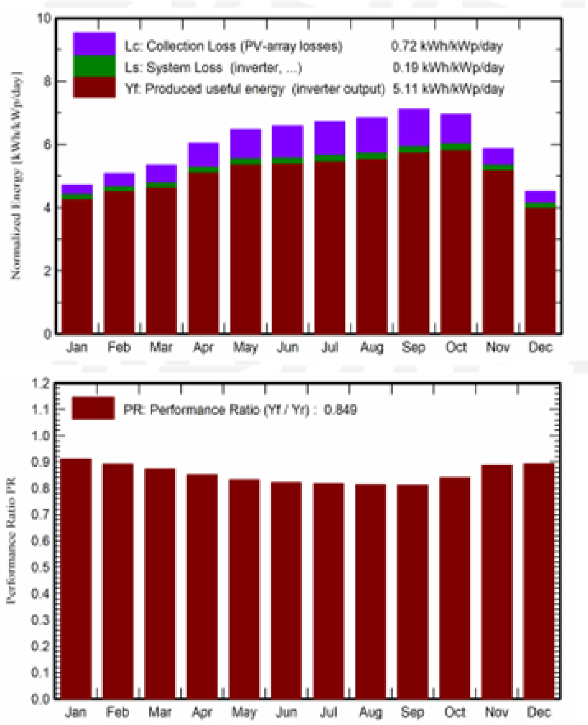

Fig 11. Normalized production (per installed kWh/kWp/day) and performance ratio

5. Conclusions

Feasibility investigation and performance analysis of the 5 MW PV power plant in Ghor province, Afghanistan have been conducted using PVsyst, PVGIS, and HOMER simulation tools. The system production using PVsyst, PVGIS, and HOMER tools are 11938 MWh, 10673 MWh, and 11697 MWh annually. Considering the two simulation tools' energy generation, it can be determined that the PVsyst software gives better results and shows more suitability. Results from PVsyst illustrate that the analyzed system's performance ratio is 0.849, collection loss is 0.72 kWh/kWp/day, system loss is 0.19 kWh/kWp/day, and produced useful energy is 5.11 kWh/kWp/day. The national grid extension is not in the short-term plan of the government of Afghanistan, so the electrification of this province considering the result obtained from this paper by renewable energy sources has priority as the best solution for power generation in a short period. Therefore, the construction of the solar power plant is one of the most useful and best solutions for the electrification of the Ghor Province.

Declaration of conflicting interests

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