Modelling and simulation for installation feasibility of standalone photovoltaic system for Quetta, Pakistan

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Abstract. The impact and significance of renewable energy in developing countries is increasing rapidly in latest years. There is much need of energy dependence to be based on off grid photovoltaic systems in developing countries like Pakistan which are suffering from severe power shortfalls annually and load shedding concern. In this paper, a concept assessment and estimation of standalone photovoltaic system is done for the site of Quetta, Pakistan in comparison to the location of the Copiapo-Chamonate. Copiapo-Chamonate site is situated in Atacama Desert which is often labelled as the best solar irradiation receiving location in the world with maximum solar insolation reaching to 9.28 kWh/m²/day. The systems for both locations is modelled and simulated in PVSYST for a constant load of 11.9 kWh/day with seasonal tilt adjustment. According to the simulation, results of the parameters including performance ratio, solar fraction, energy supplied to the load etc. show that Quetta meet its individual household demand quite efficiently.

1. Introduction
The key issue in the world lately has been the damage of the climate conditions by greenhouse gases. The emission of greenhouse gases is related to various factors around the world. One of the main reasons is the burning of the conventional fuels like coal, oil and natural gas [1]. In order to reduce the pollution concerns and to meet the swiftly increasing energy demand, government is paying huge attention towards the non-conventional sources such as solar, wind and hydro [2]. Pakistan is a developing country which is unable to meet its energy demand with acute energy shortfalls reaching 5500 MW in 2015. The major reason of shortfall is heavy reliance on the thermal energy rather renewable energy [3]. The oil and gas are the major fuels in Pakistan to produce electricity with 80% and 6% of the whole generation respectively. However, the renewable energy has not been exploited fully until now. Pakistan is a favorable country for the solar energy exploitation which receives 15.5 ×1014 kWh/year. The solar energy potential can be used to produce 1600 GW per year [4]. Quetta is one of the major cities of Pakistan with considerably high level of irradiation up to 5.54 kWh/m²/day as compared to other main populated cities of Pakistan [5]. The similar country which is undergoing an enormous surge in exploiting the solar energy is Chile. In March 2016, the installed capacity of PV was 1.1 GW but many new projects have been carried out. Most of these projects are based in Atacama Desert. This place has been known as one of the places with the highest surface solar irradiation. The main characteristics of Atacama Desert are high altitude and clear sky days [6]. The
mean clearness index of Atacama Desert is 3% with global horizontal irradiation reaching up to 2500 kWh/m² and maximum temperature of 38°C [7]. On the other side, more than 40,000 villages have no access to the national power grid in Pakistan. The southern province of Pakistan i.e. Sindh and Baluchistan are suitable for solar energy with maximum daily sun hours of 7-8 [8]. Chile, similarly, is in its way to maximize the proportion of its solar energy percentage in national energy market. The 20% energy is intended to be produced by the renewable energy resources until 2020. However, there are lot of hindrances in the way of achieving this target such as lack of solar database and utilization mechanism [9]. The 50% Chile’s economy is based on mining industry (mainly coal industry) and 80% of energy demand is needed in the Atacama Desert [10]. Many countries are now adopting the off grid photovoltaic systems in public policies to ensure the easy access of energy by installation on remote places [11]. The standalone photovoltaic systems can be regarded as the best choice for rural areas because of simple installation system topology and control with a load demand of 1-100 KW [12]. Two geographical location are selected to be used in this study for power output potential production of off-grid photovoltaic system; Quetta, Pakistan and Copiapo-Chamonate (CC), Chile. The simulation software used here is PVSYST which is developed by EPFL for the reliable and efficient evaluation of various configurations of both off grid and on grid photovoltaic systems [13].

The fundamental purpose of this paper is to determine the potential of Quetta in comparison to CC for generating power from off grid photovoltaic system for a standard household consumer. This paper is structured in five sections. The first section is for the general description and introduction of the problem considered. The second section is for determining the geographical parameters including albedo and tilt angle. The third section is for designing the electrical parameters including electrical components and loads. In the fourth section the discussion of simulation results is presented and, in the section 5, the conclusions are drawn.

2. Geographical site parameters

2.1. Geographical location

![Figure 1](http://example.com/figure1.png)

**Figure 1.** Global Irradiation (kWh/m²) for Quetta and CC.

![Figure 2](http://example.com/figure2.png)

**Figure 2.** Monthly Average Temperature (°C) for Quetta and CC.

The sites chosen are Quetta and Copiapo-Chamonate (CC). The geographical coordinates of Copiapo-Chamonate are 27.30 S latitude and 70.42 W longitude. The elevation of the site is 301 m. The time zone is UT -4. The latitude and longitude of Quetta site is 30.1 N and 66.95 E respectively with an elevation of 1702 m with time zone of UT +5. Since, CC is located in the Southern Hemisphere and Quetta is situated in the Northern Hemisphere, the winter and summer months are different for these two places. In CC, the winters are in the months from May to August and the summer lasts from September to December. July is the month with lowest average temperature of 11.8°C and January with the highest temperature of 22.4°C. The temperature variance between summer and winter at CC is not significant. Quetta has a significant trend of variation in climate
between summers and winters. The summer season is from March to October with 30.5°C as the highest average temperature and the winter season is from November to February with average lowest temperature of 7.3°C.

The global irradiation GI (kWh/m²) and average month temperature of the two locations is shown in figures 1 and 2, respectively.

2.2. Tilt angle
The seasonal based tilt adjustment is used in this system. The average tilt angles for summer and winter months can be calculated from the equations (1) and (2).

\[
T_{sa} = \frac{\sum T_s}{N_s}
\]

(1)

\[
T_{wa} = \frac{\sum T_w}{N_w}
\]

(2)

Where Tsa, Twa, Ts, Tw, Ns and Nw are the summer average tilt angle, winter average tilt angle, individual summer months tilt angle, individual winter months tilt angle, number of summer months and number of winter months respectively. The individual tilt angles for every month can be obtained from [13]. The tilt angles for Quetta in summer and winter months are 16° and 53° respectively and 13° and 47° for Copiapó-Chamónate, respectively.

2.3. Albedo
The albedo is the characteristics of a surface linked with its proportion of reflectance or absorption. The usual range of albedo is 0.1-0.5 [14]. The dark black surface is considered to be at 0 while the pure white surface is termed to be 1. The albedo of the two sites considered can be obtained from [15]. The albedo of the two geographical sites is given in the table 1.

| Albedo | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|--------|-----|-----|-----|-----|-----|------|------|-----|-----|-----|-----|-----|
| Quetta | 0.16| 0.16| 0.17| 0.24| 0.25| 0.28 | 0.28 | 0.28| 0.25| 0.25| 0.25| 0.20|
| CC     | 0.13| 0.13| 0.11| 0.11| 0.11| 0.10 | 0.10 | 0.10| 0.11| 0.12| 0.13|     |

3. Electrical system

3.1. Electrical loads
The total daily energy load demand is 11.9 kWh/day and 4352 kWh/year. The local demand is designed according to the needs of an average domestic consumer. The consumption is mainly distributed along the duration time from 9 am to 6 pm. The loads used for the calculation are given in the table 2.

|          | Number | Power     | Use     | Energy       |
|----------|--------|-----------|---------|--------------|
| Lamps    | 10     | 10W/Lamp  | 5h/day  | 500Wh/day    |
| TV/PC/Mobile | 2    | 100W/Lamp | 5h/day  | 1000Wh/day   |
| Domestic appliances | 1  | 500W/Lamp | 4h/day  | 2000Wh/day   |
| Fridge/Deep-freeze | 2  | 24Wh/day  |         | 1000Wh/day   |
| Dish-&Cloth-washers | 1  | 2Wh/day   |         | 2000Wh/day   |
| Ventilation | 1   | 100W tot  | 24h/day | 2400Wh/day   |
### 3.2. Electrical components

The values of electrical components used in the simulation are provided built-in in PVSYST software. The photovoltaic module used here is Si-poly Model named AC-210 P/156-54S from Axitec USA. The nominal power of the module is 210 W. The PV array has 16 modules; 4 in series and 4 in strings. The total PV array power is 3360 W at STC conditions and 3058 W at 50°C. The total module area is 23.5 m². The maximum power point voltage and current of PV array are 102 V and 30 A respectively. The Dural SC battery of Electrona is used in this system. The voltage is 72 V and nominal capacity is 600 Ah. The high voltage is chosen for the battery system to reduce the cable wiring losses. There are 12 batteries connected in series and 2 in parallel. The temperature 25°C is considered as the temperature for keeping the batteries. The Universal controller is used for the direct control of the sizing of the battery pack and PV array. These components will automatically adjust to the whole system with minimum losses and maximum power production. The charging and discharging limits of universal controller are calculated according to the limits of state of charge (SOC) as shown in equations (3) and (4).

\[
0.92 < \text{SOC}_c < 0.75 \\
0.20 < \text{SOC}_d < 0.45
\]

Where SOCc and SOCd are the charging and discharging percentages of the battery by the universal controller, respectively. The approximate limit of voltage of the battery in charging mode is from 75.2 V to 82.3 V and for the discharging mode is from 70.8 V to 73.3 V. The both systems are designed for LOL of 3% and the 3 days of autonomy. The general electrical schematic diagram is given in figure 3.

![](image)

**Figure 3.** Schematic diagram of standalone photovoltaic system.

### 4. Model simulation and results

The available energy at CC is 4839 kWh/year and the specified production is 1440 kWh/kWp/year. Whereas, at the Quetta, the specified production is 1448 kWh/kWp/year and the available energy is 5001 kWh/year. The monthly available energy at Quetta and CC is shown in figure 4. The maximum available energy at CC is in the summer with maximum of 511.5 kWh in December and minimum in June in 305.3 kWh. The maximum available energy at Quetta is in June i.e. 481.7 kWh and minimum in March i.e. 350.2 kWh. The available energy at both sites in summers is almost same but Quetta has 42.5 kWh more available energy than CC in winters. The performance ratio of Quetta and CC is 56.9% and 56.2% respectively. The performance ratio is independent of the orientation and location and it is the ratio of actual obtained power versus the theoretical predicted power. The low PR at Quetta can be obtained to the output variation caused by operation of the system on STC and actual operating condition. While, the solar fraction of Quetta is 99.6% and for CC is 95.8%. The CC failed.
to meet the actual user demand and provided only 88.9% of the total load. The Quetta lacked only in January with the provision of 95% of the load need. The solar fraction for both sides is given in figure 5. The performance ratio and solar fraction can be calculated from the equations (5) and (6) respectively.

\[ PR = \frac{Y_f}{Y_r} \]  

\[ SF = \frac{E_u}{E_l} \]  

Where PR, SF, Yf, Yr, Eu, El are performance ratio, solar fraction, system yield, nominal system yield, energy supplied to the user and energy need of the user respectively. The performance ratio PR is the ratio of actual power produced by the PV array and the nominal power expected to be produced by PV array at STC conditions. The Eu is the actual power supplied to the load and El is the actual load demand. The solar fraction SF is the ratio of energy provided from the array to the load versus the actual demand of the load.

\[ \text{Figure 4} \quad \text{Solar Fraction (SF) at Quetta and CC.} \]

\[ \text{Figure 5} \quad \text{Comparison between Energy supplied to the load Eu and Energy demanded by the load El.} \]

The missing energy at CC has shown a downfall curve in the winters especially in June. The Eu at Quetta performed at capacity despite in January while, in winters, CC was unable to supply the load demand with 57.6 kWh energy shortfall in June. The energy supplied to the load Eu and energy demand of the load El for both sites is given in figure 6.

The missed energy is 183.66 kWh at CC with maximum of 57.65 kWh in June. The Quetta site performed well in terms of missing energy that is 17.93 kWh only in January. The total unused energy for Quetta is 534 kWh with maximum in the month of June and considerable average of 21.625 kWh in the winters. Whereas, the excess energy at CC is in the months of Summer with an average of 65kWh with the maximum value of 118.4 kWh in December. The various losses of the off grid photovoltaic system at CC and Quetta is given in figure 7. The most considerable losses at both sides is in the working of the system at MPP (maximum power point) and temperature loss. Temperature loss at Quetta is 6.6% and 5.5% at CC. The Quetta site has more temperature loss because of high temperatures as compared to CC. However, the performance of CC at MPP is very low and 1872 kWh energy is lost.
5. Conclusion

This paper simulates and compares the two geographical sites of Quetta and CC for an off grid photovoltaic system. CC, Atacama is considered to be one of the best receiving solar irradiation place. PVSYST model results show that Quetta performs well in comparison to CC. The following results are obtained from the studies done in this paper.

- Solar Fraction at Quetta site was 100% the whole year, however, lacking only in January with missing energy of 17.93kWh
- The energy used by the load at Quetta is 3.807% more as compared to CC
- Performance ratio PR at Quetta is 0.7% more than at CC
- The Quetta site has produced 3.96% excess annual energy as compared to CC

This paper can provide the further research on modeling the off grid photovoltaic systems in Pakistan for domestic consumers. According to the author, special attention should be paid in reducing the temperature losses, tilt angle adjustment and MPP running losses. The photovoltaic roofs with low reflectance and less albedo are recommended. The tilt angles should be modified according to the location temperature to increase performance ratio PR.

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