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A Techno Economic Analysis of 2MW On-Grid Solar Power Plant for Tourist City Chavy – Land

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Abstract

Iraqi Kurdistan Region has a big potential in solar energy, because of its location and territorial extension. Yet the exploration of this technology not widely accepted in this region due to some reasons including the high installation cost, the lack of experience and technical unknowns. In this paper, a techno-economic analysis has been carried out to resolve some of these unknowns using 2MW solar power system and Chavy land city as a test bed. The system tries to contribute to part of daily energy demand of the place. The well-known computational System Advisor Model (SAM) simulation used to run technical and financial analysis. Simulation results showed that the system contributes significantly to power the area and reduce the load on the national grid. Although initial installation cost shows high prices, within a short period it would not only recover installation costs but also help gain substantial disbursement through the lifetime of the system.

Introduction

The sun delivers energy to endure life in the solar system. During one hour, the earth receives sufficient energy from the sun to cover its energy requirements for around one-year [1]. The renewable-energy utilization lessens the dependency on fossil fuels, and it is proven that this new energy has great potential and can be used to satisfy world energy demand. Among renewable energy sources, PV system has become main alternative energy; because of its quick growth in the penetration level, i.e. over 40% annually with the rapid decrease in its technology costs has been noticed since last decades [2]. On the other hand, insufficient electricity power production in the Kurdistan Region of Iraq (KRG) necessitates the need for urgent research for alternative energy resources. The current energy scenario for the region is totally based on fossil fuel. It has been proven that the use of fossil fuels for electricity production in the Kurdistan Region of Iraq is neither a solution to the present electric power crisis nor a solution to satisfy the future electricity demand. Although the geographic location within the region is such that it receives adequate solar radiation for implementing PV and other solar systems such as solar thermal, enough attention have not paid to these green powers. Further, there are only a few research papers analyzing the applicability of renewable energy in this area. Desert type PV system is considered and analyzed for Muscat governorate in Oman. Many factors were measured such as radiation, efficiency, and energy production, etc for a period of a year. The paper concluded that the annual average efficiency of the system is 15% while the system performs better during winter days due to high summer temperature impacts [3]. The feasibility analysis of designing and sizing of stand-alone PV for a house in Hilla, Iraq has been carried out in [1]. The possibility of providing electric power to remote irrigation pumps from solar power is studied in [4]. The simulation results provide a design procedure and a good database source in order to implement the modeling of the systems using day sun radiation variations during different seasons in Iraq.

Thus, it is believed that solar system installations can easily reduce the effectiveness of the current national grid power issue at low prices. The objective of this paper is to design and analysis of 2MW grid-connected PV system for tourist city of Chavy Land, Sulaymaniyah. After that, the energy production from the designed system will be compared to the actual power production within the city showing the percentage of the covered part of the load with green energy. The geographical location of this place is at (35^{o} 33’ 59’’ N) Latitude and (45^{o} 26’ 37’’ E) Longitude makes it a relatively sun-rich province with an annual monthly average solar radiation to be between 2.297 kWh/m^2 and 7.938 kWh/m^2 [5]. This indicates that solar-energy systems would be efficient in this part of the world.

The rest of the paper is organized as follow: first, it provides theoretical background on how the weather data is prepared for the area. Second, detailed comparative analyses of the system using SAM are provided and then followed by the simulation results and conclusions.

The procedure of System Designs

A proposed tourist place Chavy Land shown in (*Figure: 1)*, is the area near to it, Sulaymaniyah city, KRG, Iraq, is considered for simulation in SAM. During the simulation, some parameters were changed based on the total monthly load, weather data, and incentives. Some of these parameters are presented as below:

- The system design capacity used is 2MW. It is enough to supply energy to more than 50% of the load of the place. The rest of the required electricity will be bought from the national grid.
- The tilt angle is 35 degree, based on the latitude of the location from NASA with a fixed panel is chosen.
- The DC to AC conversion ratio is set as 1.2.
- The annual degradation rate is considered to be 5% with 96% for inverter efficiency.
- For the financial parameters, the debt percentage is 90% with a loan term to 10 years and a loan rate of 9% per annum. Further, a nominal discount rate is set to 8.15% per year, which comes from considering the inflation rate to be 5% per year with the real discount rate to be 3% per year.

Regarding the electric load analysis section, the total monthly load for one year is calculated and inserted to SAM. Their values are going to be seen as the form of a graph during the simulation.

Figure-1: Landscape of Chavy land; ***(a)*** Chavy land***, (b)*** the required area for the PV system above the trees near Chavy land.

Data Estimation and Preparation

The solar data exist in Sulaimaniyah city for the specified station (College of Agriculture / meteorological units) is global Horizontal Irradiation GHI, but all Direct Horizontal Irradiation (DHI) and Direct Normal Irradiation DNI and GHI data are required to be uploaded for SAM software. Hence, DHI and DNI are estimated in steps as described in section *A*.

For the same meteorological unit, dried temperature data are recorded, while wet temperature data also required for the simulation purpose. Section *B* will present a description for estimation of wet temperature from dry temperature and humidity percentage. On the other hand, for the demand consumed and required for such a tourist area, a file for load profile is prepared from the existing consumed load data in 2014 as explained in section *C*.

A. DHI and DNI Preparations

Global Horizontal Irradiance (GHI) is the total amount of radiation hitting a surface horizontal to the earth's surface. This includes both direct normal irradiance and diffuse horizontal irradiance. While Direct Normal Irradiance (DNI) describes the amount of solar radiations hitting a surface perpendicular to the sun's rays [6].

Since weather data for the specified location in Sulaymaniyah city is not available in the SAM software, a CSV file is prepared and imported, which contains all the necessary data. The weather station of Bakrajo in Sulaymaniyah city collects only GHI data [5]. Both Direct Horizontal Irradiation (DHI) and DNI are estimated from the available GHI.

Firstly, the declination angle δ, which is the fluctuation of earth from its axis of rotation and the normal plane to a line from the center of the earth and the sun by an angle -23.45° to +23.45° are found by equation (1),

$$\delta = sin^{-1}\left(sin(23.45)sin\left(\frac{360}{365}(d-81)\right)\right) \tag{1}$$

d is the day of the year e.g. 1st January d = 1 and, δ is the declination angle.

After that, the Equation for Time (Eqt) which is the discrepancy in minutes between true and mean solar time, are calculated from equations (2) to (5), depending on *d*,

for d = 1 to 106

$$Eqt = -14.2\sin\left(\frac{\pi(d+7)}{111}\right) \tag{2}$$

For d = 107 to 166

$$Eqt = 4.0\sin\left(\frac{\pi(d-106)}{59}\right) \tag{3}$$

For d = 167 to 246

$$Eqt = -6.5\sin\left(\frac{\pi(d-166)}{80}\right) \tag{4}$$

For d = 247 to 365

$$Eqt = 16.4\sin\left(\frac{\pi(d-247)}{113}\right) \tag{5}$$

Then, solar time (Tsolar) at a specific local time (LT) could be estimated from equation (6),

$$Tsolar = LT + \frac{TC}{60} \tag{6}$$

Where time correction factor (TC) is in minutes and accounts for the variation from the solar time at a certain time zone. This disparity is a consequence of a change in longitudes within time zones and the equation of time Eqt. Now, TC could be calculated by equation (7) [6],

$$TC = 4(\lambda - LSTM) + Eqt \tag{7}$$

Where λ is the longitude, and $LSTM$ is the Local Standard Time Meridian [7], which is calculated by equation (8),

$$LSTM = 15^{o}\ .Time\ zone \tag{8}$$

Where the 15° is resulted from the spinning of earth approximately 15° per hour.

Next, hour angle (θhr) could be found using equation (9) which is the descriptive angle of the sun's position in the sky at a specific time.

$$\theta hr = 15^o(Tsolar - 12) \quad (9)$$

Then, the Elevation angle(α), which is also known as altitude angle that describes the sun's angular height above the horizon, can be calculated by equation (10). The sun elevation angle is 0° during both sunrise and sunset while its value rises up to a certain angle depending on location and time of year.

$$\alpha = sin^{-1}[sin\delta\ sin\varphi + cos\delta\ cos\varphi \cos\theta hr] \quad (10)$$

Similarly, Zenith angle (z) which describes the sun's position in the sky on the vertical axis rather than horizon can be determined from equation (11).

$$z = 90 - \alpha \quad (11)$$

To find the clearness index (K_t) that defines the ratio between GHI and extraterrestrial radiation hitting a horizontal plane (I_{oh}).

Extraterrestrial radiation is the insolation intensity on a plane perpendicular to the sun above the earth's atmosphere. This can be found using equation (12),

$$I_o = I_{sc}\left[1 + 0.033\cos\left(\frac{360\ (d-2)}{365}\right)\right] \quad (12)$$

Isc is the solar constant and its value is 1.353 kW / m^2.

The extraterrestrial radiation hitting a plane horizontal to the earth surface can then be estimated with equation (13),

$$I_{oh} = I_o\cos(z) \quad (13)$$

One of the most influential factors in the atmosphere is air mass (AM) which describes the length of the path that light takes through the atmosphere reaching the location. A simple estimation of relative air mass is by equation (14) [6],

$$AM = \frac{1}{\cos(z)} \quad (14)$$

In this paper, the values for zenith angle are z < 80° which in turn used for calculation of (AM) based on [8]. Then, the values of AM will affect the values of Kt parameter, if AM >0 then $K_t = \frac{GHI}{Ioh}$ else 0; Then, Kt parameter partitioned to three regimes [9];

$K_t > 0.80$

$$\frac{DHI}{GHI} = 0.165 = K_D \quad (15)$$

$0.22 \le K_t \le 0.80$

$$\frac{DHI}{GHI} = 0.951 - 0.160\ K_t + 4.388K_t^2 - 16.64K_t^3 + 12.34\ K_t^4 = K_D \quad (16)$$

$0 \le K_t \le 0.22$

$$\frac{DHI}{GHI} = 1.0 - 0.09K_t = K_D \quad (17)$$

From both equations (20 and 21) DHI and DNI are found [10] and [11],

$$K_D = DHI/GHI \quad (18)$$

$$GHI = DHI + DNI \quad (19)$$

$$DHI = K_D\ GHI \quad (20)$$

$$DNI = GHI - DHI \quad (21)$$

DHI and DNI are estimated from GHI data and they are plotted in (*Figure: 2)*, representing the data for both 4th January of 2014 and 1st of August of 2014 respectively. It could be noticed that the curve during January is mostly irregular because of cloud effects, while it is relatively smoother during August.

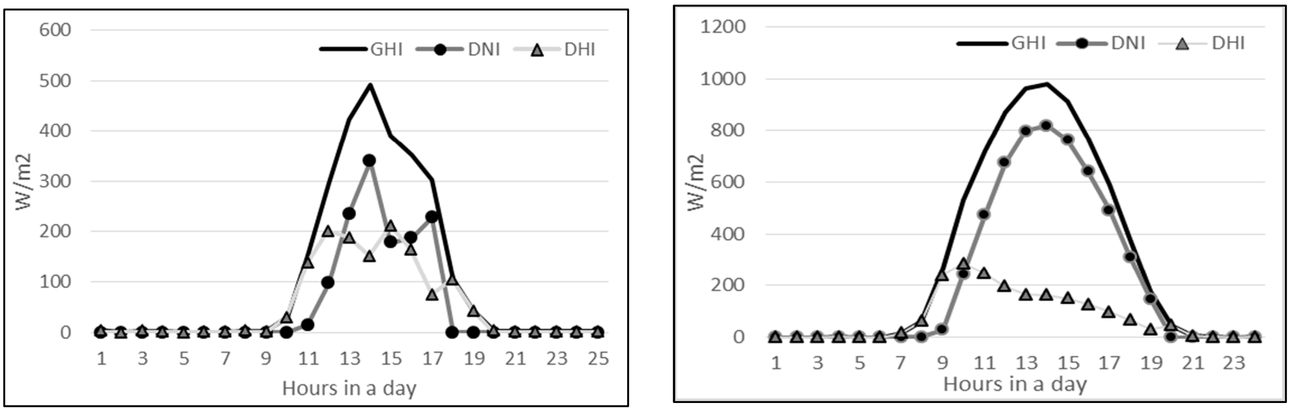

Figure-2: Prediction of DHI and DNI; ***(a)*** Estimated DHI and DNI from GHI for 4th January 2014, ***(b)*** Estimated DHI and DNI from GHI for 1st August 2014.

B. Estimation of Wet Temperature

The second weather data parameter required to be inserted in the SAM software is wet temperature (T_w). From dry temperature that is recorded by the station weather data recorder, Twet can be calculated using equation (22) as follow [12],

$$T_W = T\,\text{atan}\left[0.151977(RH\% + 8.313659)^{\frac{1}{2}}\right] + \text{atan}(T + RH\%) - \text{atan}(RH\% - 1.676331) + 0.00391838\,(RH\%)^{\frac{3}{2}}\,\text{atan}(0.023101RH\%) - 4.686035 \quad (22)$$

Where T_W is the wet temperature in ^{o}C, T is the dry temperature in ^{o}C, $RH\%$ is the humidity in percent shown in *(Figure: 3)* the hourly dry temperature and estimated wet temperature in degree Celsius for January 2014. It is clear that the dry temperature relatively higher than the wet bulb temperature. As it can be observed the dry temperature fluctuates between a minimum of 1.4 ^{o}C and a maximum of 15.6 ^{o}C respectively. Whereas wet temperature changes between 9.7 ^{o}C on its peak and -3.2 ^{o}C as the lowest value.

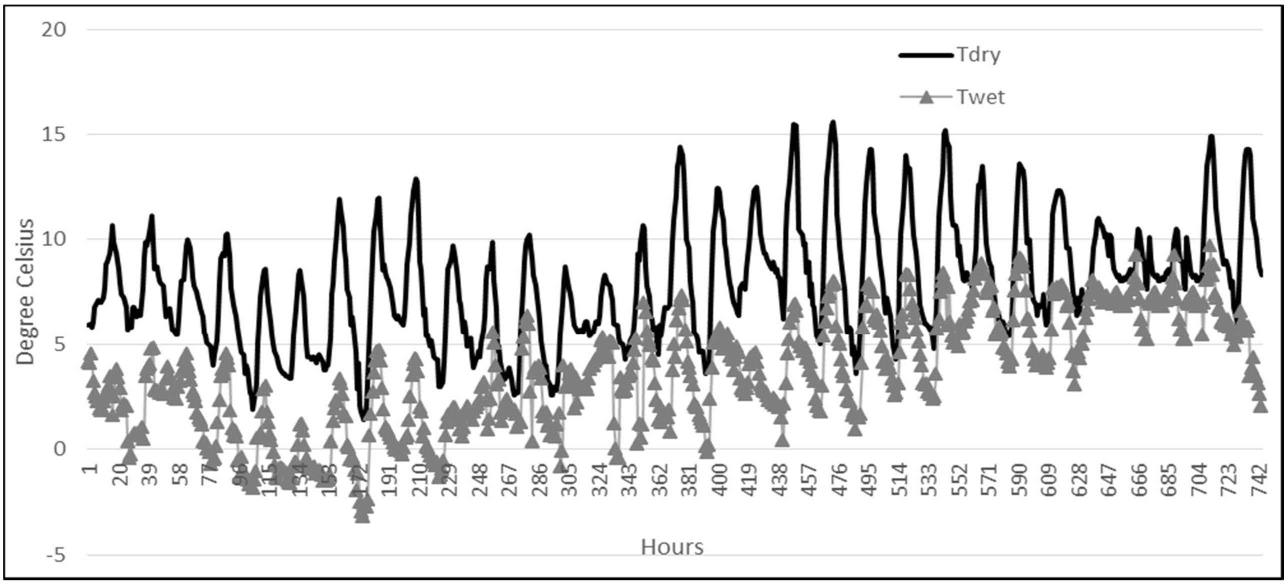

Figure-3: Hourly dry temperature and estimated wet temperature in degree Celsius for January 2014.

C. Load Flow Preparation

The city of Chavy land is currently supplied from a 33kV feeder which is considered as a short transmission feeder. Electric load flow data for Chavy Land city is gathered and imported to SAM using the same procedure as weather data implemented. The hourly real load data is collected from Electric Distribution Directorate of Sulaymaniyah city based on that load data is converted to kW format to be accepted by the simulation tools [13]. This makes it easy to be compared to the power generation from the proposed system. A minimum of 0 kW was recorded that is due to the regular power interruption of the region while a maximum 2.4 MW load was seen. It is important to take into account the economic view of power outage on such tourist places, Shown in figure 4, fluctuations in the monthly energy demand during a year where the minimum 2.5MWh occurred during November and maximum 6.59MWh during August of the same year. Clearly seen high demands during the summer times due to the acceptability by tourists than other times of the year. These are greatly important as it is simultaneous to the highest solar radiation of the region.

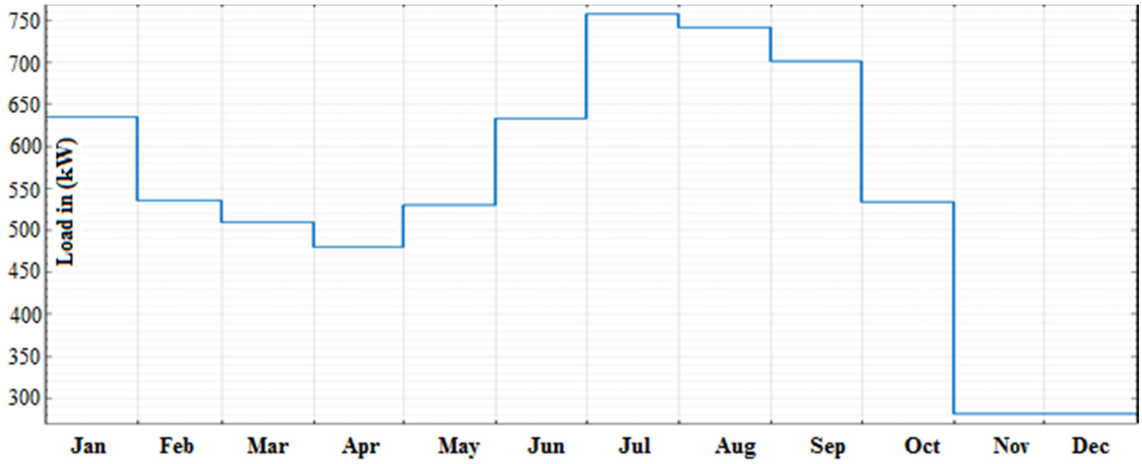

Figure-4: Monthly load flow for Chavy land in 2014

Detail of the proposed 2MW grid-connected PV power plant is shown in table 1. The table shows the selective PV module and inverter types with their technical details available from the National Renewable Energy Laboratory (NREL) [14]. The proposed system will contain 6342 fixed (no tracking) modules to provide the required energy. The simulation results show that an area of 25900 m^2 will be required for the system using the exact dimension of the modules plus the other components of the power station. The modules are tilted at an angle of 35^o equal to the site latitude and south facing while 0^o is chosen as the azimuth angle for the project. Further, six inverters are used to convert direct current to alternating current.

Table- 1: Summary of the basic design parameters for the system.

Module - Inverter Details	
Module type	SunPower SPR-315E-WHT
Module capacity	315.056Wdc
Module efficiency	19.32%
Total installed module capacity	1998.085kWdc
Number of Modules	6342
Modules per string	7
String in parallel	906
Inverter type	Solectria Renewables, LLC: SGI-266 480V 269.841kWac
Inverter capacity	269.841kWac
Inverter efficiency	97.6%
Number of inverters	6
Total land area	6.4 acres

Results and Analysis

After design completion, it is important to study its practical implementation applicability. Accordingly, a small area of 7.64 acres is chosen out of a large unused area around the Goizha mountain inside the Chavi Land as is shown in figure 5 to best fit with the project [15]. Clearly the bigger system can also be deployed in such a useless area. The area is highly recommended for solar power generation applications as it receives high-level of sun radiations during a year.

Figure-5: Predefined area for the proposed PV power system in Chavy land.

The performance of the system with the financial analysis are then observed from the SAM software over 25 years of the estimated lifetimes. The annual electric generation for the complete lifetime of the system is shown in *(Figure: 6)*. It is important to observe the system performance which decline gradually over the year of installation due to the degradation of the whole system components, including PV modules, wires, inverters, and batteries [16]. It is efficient and high during the initial years and low in the latest year of its lifetime with a smooth performance decrease. There is an output of over 2500 GWh recorded during the first year of its installation, and the output falls to below 2300 GWh at the end of the last year.

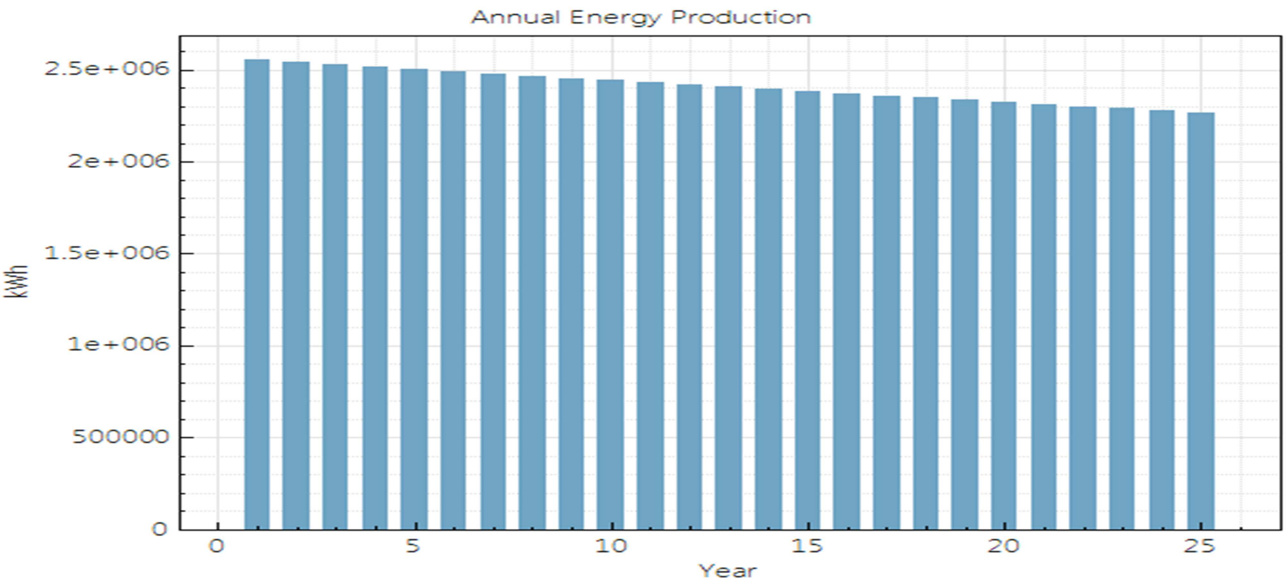

Figure-6: Annual output of the PV system.

The monthly energy production of the proposed net-metering design is shown in *(Figure: 7)*. It shows the highest production during the months with the highest solar radiation and lowest production will be in the months with the lowest solar radiation over a period of one year. This is due to the fact that Sulaymaniyah located in the northern part of Iraq, and hence this place is exposed and enrich to solar radiation that is direct between April and September. However, it is mostly reflective during the other months of the year.

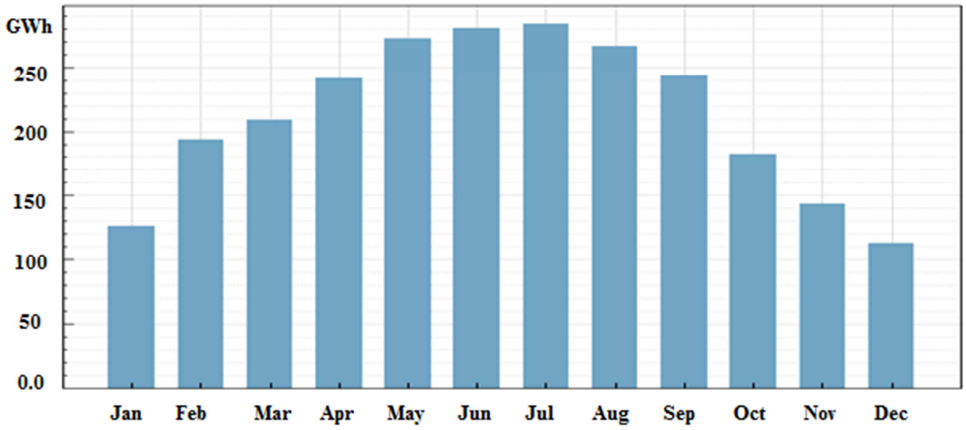

Figure-7: Monthly output power generation of the proposed system.

Shown in *Figure: 8* monthly energy production of the proposed PV system in comparison to the monthly load flow of the tourist Chavy land place. Clearly seen large levels of load variations in this place during different months of the year. There is a sharp increase in the load between April and August following by a sharp decrease from August to December. The reason for that is people normally visit the place between May and October due to the environmental condition of the region. It is also clear that the designed PV system can cover almost 50 % of the total load for some peak load months and even more than 50 % for some months.

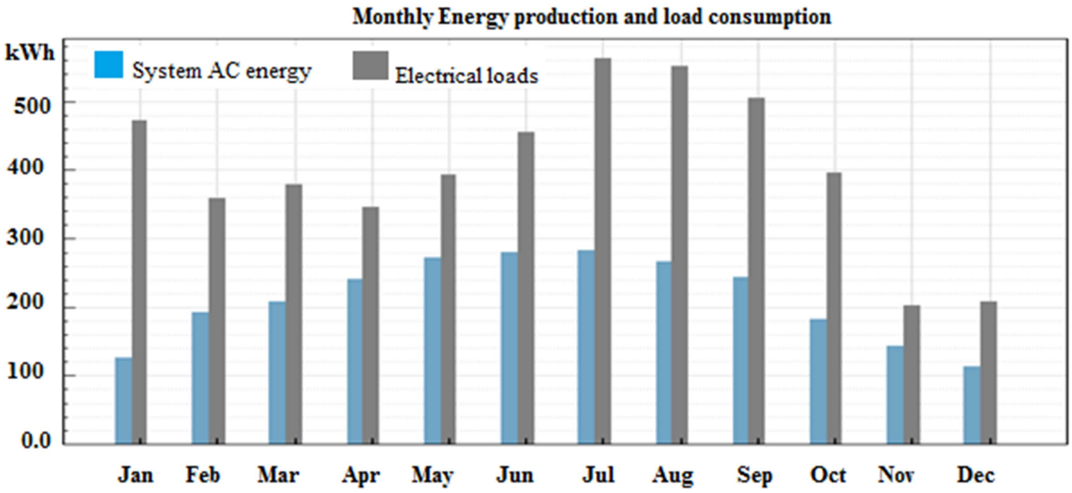

Figure-8: Monthly energy production compared to load of Chavy Land.

The financial results have been carried out using the same simulation and data of the designed system. It specifies the cash flow over a set period defined by the designer [17]. The financial and performance metrics for 25 years lifetime represented in Table 2. From there, total installed cost per capacity has been calculated using United States Dolar as metrics. Additional costs including regular maintenance could be added to the total system cost, which will appear later while the system is running, or it is under construction.

Table-2: Metric table for the simulation results.

Metric	Value
Annual energy	2,556,309 kWh
Capacity factor	14.6%
Total installed cost	$3,456,700
Total installed cost per capacity	$1.73/Wdc

Conclusions

The techno-economic analysis and optimization of a 2MW grid-connected solar photovoltaic system for a tourist city of Chavy land in Sulaymaniyah are presented. The work has been implemented using SAM software tools along with metrological data of the location. The paper looked at both technical and economical sides of the project in some details. From the analysis, it is revealed that an optimum azimuth angle of 0^o and module tilt angle of 35^o equal to the site latitude and south facing are viable to take advantages of the maximum amount of solar radiation. The simulation results illustrate that the installation of 2MW of solar will fed almost 50% of the total load in the area although it will cover a large geographical area of the place. Another importance of the project is its maximum energy production is going to be during summer days when the load of the area at its peak. However, the financial aspects of the system show high costs of capacity installation that will be around $1.73/kWdc. This concludes that the solar power generation can be a visible solution to shave part of the peak demand of the national grid and solve the issue of electricity interruption of the main power system.

The authors would like to suggest further works that could be presented in the future to enhance the project in its different feasibility aspects, such working on an optimized hybrid off grid system design and solar thermal system. Furthermore, different studies should be conducted on cost analysis for comparison between different power systems.

Acknowledgments

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