IRAQI Academic Scientific Journals
Al-Rafidain Engineering Journal (AREJ) Vol.28, No.1, March 2023, pp. 14-23

# Off-Grid Photovoltaic System for a Villa at AVRO City in Duhok

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Received: 2022-07-19 Received in revised form: 2022-8-10 Accepted: 2022-09-12

***ABSTRACT***

*The off-grid solar photovoltaic system is one of the promising technologies for generating friendly electricity. Duhok city suffers from energy shortages in that electricity comes from local generators to support national grid. The aim of the research is to eliminate local generators due to their high costs and noise levels. A photovoltaic (PV) solar system type (off-grid) was proposed for one villa in AVRO city Duhok. A calculation has been done to select size of the system and A PV Syst software was adopted to investigate the design of the proposed system and additionally examined the economic analysis as well as the net profit. The proposed system is used with an average electricity demand of 12.9 kW/day. A typical 3.3 kW PV system was determined to be able to meet the daily power requirements of an entire villa with 8 panels: two in series and four in parallel where each panel has a rating of 415W. The system includes 8 batteries of 12 V,200Ah, and a 5-kW inverter with MPPT tracker. The result shows that yearly average of the energy requirement of villa is 4728.9 kWh and energy available through Solar's panel is 5999 kWh/year.*

***Keywords:***

*Solar energy, Off-grid solar photovoltaic, Battery storage, PV Syst.*



## 1. INTRODUCTION

Energy is widely acknowledged as the driving force behind global economic development. The world's energy resources can be divided into three categories: fossil energy (oil, gas, charcoal, and so on), nuclear energy, and renewable energy (wind and solar and geothermal and airpower, biomass, hydrogen, ocean, etc). Renewable energy sources are defined as energy derived from non-fossil and renewable resources, such as wind and sun and geothermal, also ocean, hydropower, biomass, and biogas [1]. Due to the shortcomings of traditional fossil fuels and the greenhouse gas effect, demand for renewable energy has expanded rapidly in recent decades. Because of developments in power electronic systems for the production of electricity, solar and wind energy have become more promising and attractive amidst many forms of renewable energy resources[2].

Eighteen countries rely on renewable energy to meet more than half of their electricity demands. Iceland, Norway Those countries include New Zealand, Canada, and Brazil. There is no doubt that energy availability is critical to a society's prosperity and evolution. It also has solutions for other problems, like water and food, the environment, health, education, and the climate are all issues that need to be addressed. An adequate amount of energy is environmentally friendly. One of the benefits is that it minimizes high air pollution and greenhouse gas emissions [3]. as Foreign direct investment has been largely responsible for this expanding PV solar energy. Although many people still cannot afford solar technologies, steep price cuts appear to have given governments, multilateral organizations, and development agencies a renewed sense that Sustainable Development ensure access to affordable, reliable, sustainable, and modern energy for all by 2030[4]. Some consumers may want to explore and shift to alternate sources for meeting their demand. However, shifting to solar power requires upfront investment. The economic benefit has to be justified in order to convince the consumer to make the initial investment. A normal consumer may not have the technical and commercial knowledge to install and operate the solar equipment. Consumer has to get expert advice from companies how to choose PV system and which type of panels or batteries use it and, along with the calculation of payback time and economic profitability of the project[5]

Despite the fact that Kurdistan is rich in oil, the region has faced energy shortages since the starting of oil exploration the region till now, the Kurdistan-Region of Iraq experiences power outages that last higher than half of the day during some seasons. The problem was exacerbated by the economic downturn and political disputes between Kurdistan and Baghdad's central government. As a result, investments in the power sector, which were primarily based on producing power through none - conventional resources came to an abrupt halt [6]. As Kurdistan's energy supply is now mostly reliant on fossil fuels, gasoline and natural gas account for over 85% of total energy production. The remaining 15% is handled by hydroelectric energy and solar energy, which account for less proportion of total energy [7]. Thus, the paper aims to investigate the use of solar energy to replace the conventional diesel generators in a villa at AVRO city in Duhok city, Iraq.

## 2. SOLAR ENERGY AND OFF-GRID PV SYSTEM

### 2.1. Solar system development

Solar energy is the most cost-effective method of new electricity generation. There are two types of solar energy to produce electricity: the first one is the solar thermal power generation which can produce heat used for boiling water to produce steam. This steam is used to rotate a steam turbine connected to a generator (mechanical energy converted into electrical energy)[8]. The second type of solar energy that produces electricity is photo voltaic power generation (Sunlight is converted into direct current (DC) electricity via a photovoltaic (PV) module [9]. The International Energy Agency (IEA) published a report in 2019. According to the International Renewable Energy Agency (2018), installed solar PV capacity will probably increase from 223 Gegga watts in 2015 to 7122 Gegga watts by 2050, representing a 3093.72 percent increase[10].There are three kinds of Photovoltaic solar energy systems : off-grid and PV connected to grid and hybrid system[11].

PV system implementation has increased exponentially in recent years due to advancements in performance and cost reductions in technology. Shaping and channeling the global energy system's transition demands a thorough understanding of PV systems' sustainability - their environmental, resource, and social implications – which should be made available to a wide range of societal, political, and scientific stakeholders. Providing information for such assessments through the creation of methodology, case studies, and international recommendations, which began working on a revised work plan in 2018 and will continue through 2022 [12].

### 2.2. Off-Grid PV System

A system of photovoltaics that is connected to the grid with no batteries is the simplest and most cost-effective solar energy installation possible. It should be noticed that a grid-connected solar energy system feeds its solar energy directly return to the grid. If the photovoltaic solar system generates extra electricity on a sunny day, this solar energy is immediately reintroduced into the grid[13]. The off-grid technique is used to power an off-grid roof-top solar PV system, which is one of the most effective ways to electrify rural areas in poor countries and it is pollution-free. It can directly use electric power and also store the excess generated energy in the battery for usage when there is no sunlight. Rural inhabitants in evolution countries continue to live a relatively modest lifestyle, relying on electricity only for essential household devices such as fans, lighting, water pumps, and television. Off-grid solar PV options for these areas can also save money on transmission line upgrades to these remote settlements[14].

The benefits of stand-alone PV systems include providing enough electricity for a family and powering a location that is not connected to the grid. Off-grid systems involve additional components, and these systems are deemed more expensive PV than grid-direct systems Fig.1 shows the configuration of an off-grid PV system, where the ingredients of a stand-alone system are: solar PV array, charge controller, inverter, battery, cables and wiring, and Protection apparatus [15].

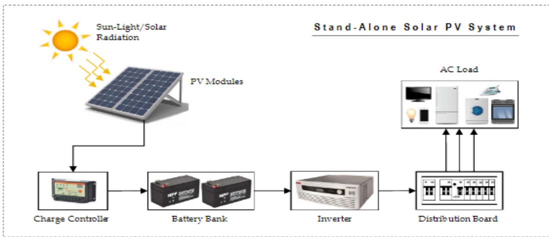


Fig 1.configuration of the off-grid PV system[16]

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### 2.3. Related Works

ChandragiriRadhaCharan, A. Jaya Laxmi, P. Sangeetha (2017) presented a model for the design of an off-grid PV power system. The system was simulated using the PV Syst program to conduct a complete analysis of an off-grid system during the year. The system loss represents the conversion efficiency and total energy output, independent system performance and losses in the form of wire loss, temperature loss, and battery loss unused[17].

Angga Romana, Eko Adhi Setiawan, and KurniantoJoyonegoro (2018) produced work for photovoltaic system design that uses Australian/New Zealand standards and manual calculations to come up with a cost-effective solution. The HOMER simulation indicates that applying the Australian/New Zealand standard instead of manual calculation produces a satisfactory outcome with surplus electricity[18].

Ayaz A. Khamisani (2019) made a work that the off-grid solar PV system was investigated. He factored in losses of system in his calculations and designed the charger with a PWM charge controller rather than an MPPT charge controller. photovoltaic solar system kind (off-grid) systems are more compatible with sites that choose consumer opts not to be supplied back the energy that is produced at this end and the electricity has not been done yet[19].

HananeYatimia, b, YounessOuberria, Sara Chahidc, and Elhassan Aroudam (2020) covered the modeling and management of a monocrystalline PV module, a DC load, a DC-DC boost converter. A maximum power point tracking (MPPT) block in an off-grid photovoltaic (PV) system is obtained. The proposed controller was used to boost converter to attain the ideal PV module output power, obtaining the greatest power for all climatic circumstances while testing the robustness of various levels of solar irradiation and module temperature. The lyapunov analysis is used to demonstrate the control algorithm's asymptotic stability in terms of tracking error. The controller design is validated by the simulation results [20].

## 3. DESIGN AN OFF-GRID PHOTOVOLTAIC SYSTEM AND COMPONENT SIZING

The design depends on the daily load requirements. Component properties are provided based on the availability of the best ingredients in the market, as well as a detailed cost analysis of the system. PV systems are deemed an easy implementation for the customers to install their loads to the grid. In off-grid PV systems, the battery storage system is used to provide electricity on overcast days and at night. Weather variations and year-round circumstances must be taken into account while building these systems when the sun does not shine for several days in a row.

### 3.1. Site Information, Meteorological Data, for the site proposed

The climate patterns differ depending on the location. Duhok is a suitable location for using photovoltaic solar energy in that it has (14 hours) of sunlight during the day in summer and (10 hours) of sunlight in winter. As a result, the location of the PV system is critical for PV design from a set of perspectives, consisting of the orientation of the panel, defining the number of days of autonomy when the sun does not shine, and selecting the ideal solar panel tilt angle as known weather data in found it like (wind velocity, ambient temperature, global horizontal irradiance) by meteorological long term derived data by PVsyst software as shown in Table 1. In Iraq, most cities have excellent sun irradiation. Iraq is located in a region with a yearly rate of daily energy from global sun irradiation ranging from 2000 kWh/m$^2$ to 2500 kWh/m$^2$. This puts the country in a very promising stature, at the forefront of countries that make electricity utilizing solar energy [21].

Table 1: Meteorological data for the location site by PV syst software.

| Months | GHI (kwh/m²) | Wind velocity(m/s) | Rate of air temperature °C |
|---|---|---|---|
| january | 78.8 | 3.10 | 6.5 |
| February | 91.2 | 3.20 | 8.3 |
| March | 136.8 | 3.29 | 12.9 |
| April | 173.6 | 3.20 | 17.3 |
| May | 202.3 | 3.20 | 24.2 |
| June | 239.2 | 3.59 | 30.7 |
| July | 236.7 | 3.30 | 34.7 |
| August | 217.5 | 3.00 | 33.9 |
| September | 180.1 | 3.00 | 28.7 |
| October | 128.6 | 2.80 | 22.9 |
| November | 89.9 | 2.70 | 14 |
| December | 74.3 | 2.99 | 8.6 |
| GHI= global horizontal irradiance | | | |

The design of an off-grid PV system for one villa in Avro city in Duhok requires the location that consisted of available area on the roof of to allocate the PV system, the geographical location (36.86ºN latitude and 42.92ºE longitudes), with an annual solar irradiance of about 2083 kWh/m$^2$ on average. It is worth mentioning that July has the most sunshine, while December has the least.

### 3.2. Load Estimation

It's critical to know the load that has to be powered in advance when designing a standalone (off-grid) PV system. Specifically, the appliances and how much electricity they consume [22]. The energy consumption and load data of the house are shown in Table 2. This table shows that the energy consumption per day was 12992Wh, and the total wattage requirement was 1542W.In Table 2, the electrical appliance load is abbreviated according to power rating, such as number (1) is air cooler, (2) is TV, (3) is refrigerator, (4) is freezer, (5) is fans, (6) is lighting and (7) is the mobile phone charger**.**

Table 2: Load data and daily average energy of the house.

| NO. | Qty | Power rating (W) | Wattage (W) | Operati ng (h/day) | Daily average energy (wh/day) |
|---|---|---|---|---|---|
| 1 | 2 | 200 | 400 | 8 | 3200 |
| 2 | 1 | 150 | 150 | 4 | 600 |
| 3 | 1 | 150 | 150 | 12 | 1800 |
| 4 | 1 | 150 | 150 | 12 | 1800 |
| 5 | 4 | 120 | 480 | 9 | 4320 |
| 6 | 10 | 20 | 200 | 6 | 1200 |
| 7 | 3 | 4 | 12 | 6 | 72 |
| Total | | | 1542 | DA L | 12992 |

### 3.3. Orientation of Solar Panel

Manyscholars used various ways to debate the ideal tilt angle in order to develop more effective solar system designs that use these techniques to reach the most appropriate implementation for the system. The majority of solar energy systems follow the sun's path to concentrate more solar radiation on the panel[23]. Direct solar radiation, sky scatter radiation, and ground reflected radiation make up the total quantity of solar radiation on the plane surface. The energy produced by the PV system depends on the location and weather conditions. A previous research on solar panel tilt angles suggests that the ideal tilt angle is equal to the local latitude [24]. So that the latitude of Duhok is 36°. So the tilt angle was like latitude and it is a fixed-tilt plane, and the PV array is facing to the south because Duhok city of Iraq is located in the Northern hemisphere as shown in Fig .2.

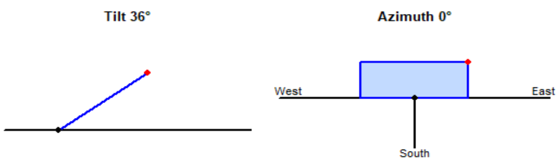


Figure 2. the orientation of the solar panel of the system**.**

### 3.4. Sizing of PV Panels

To design PV panels for the home, the following information should be allocated;
Voltage of direct current of the system (VDC) =48V because the energy consumption of the system is higher than 1KW.
Average irradiation of solar (R) of location is 5.07 kWh/m2 /day as found from location coordinates.
Sum of Daily (Average) energy is 12992 Wh/day.

The following presumptions were made:
The battery's efficiency is 0.98, the inverter's efficiency is 0.97 and the efficiency of the MPPT control charger is 0.80. Thus, for sizing the PV array, one should know VDC and R and the sum of energy demand per day (E) and efficiencies of devices (battery, inverter, charger controller) and voltage at Pmax . To avoid a reduction in size, the sum of daily average energy(E) is divided by the total efficiencies of the system ingredients to acquire the daily energy requirements of the solar array.

$$\eta\ all = battery\ eff. * inverter\ eff. * charger\ eff. \quad (1)$$

The demand of daily energy ($Ed$) for array PV sizingYou can apply as follows:

$$Ed = \frac{sum\ of\ daily\ average\ energy}{total\ efficiency\ of\ system\ components} = \frac{E}{\eta all} \quad (2)$$

The average of daily energy demand (Ed) derived from Eq. (2) is divided by the average solar irradiation (R) of the proposed site to acquire the required array power (P array)

$$P\ array = \frac{daily\ average\ demand}{average\ irradiation\ of\ solar} = \frac{Ed}{R} \quad (3)$$

For the Eq. (2) and (3) the daily energy demand ($E_d$) was 17083 Wh/day and the required array power was 3369.6W. In this paper, panels of monocrystalline type of silicon (AXIpremium X HC AC-415MH/144S) have been used with the rating of panel that equals 415W. Specifications of panel are shown in Table 3.

Table 3: specification of PV panel

| PV panel | Characterestic |
|---|---|
| Type | Monocrystalline silicon |
| Nominal power | 415Wp |
| Peak efficiency | 20.63 % |
| Voltage of maximum power | 41.98 V |
| Maximum power current | 9.89 A |
| Voltage of open ciruit | 50.08 V |
| Current of short circuit | 10.84 A |
| Weight | 23.5 kg |
| Net(gross)panel's surface | 2 $m^2$ |
| Model dimenstion | 2008x1002x40 mm |
| Number of cells | 144 high efficiency cells |

The total number of panels $N_{pt}$ for an off-grid system is determined by the Eq. (4):

$$N_{Pt}\ \textbf{(total number of panels)} = \frac{p\ array}{panel\ power} \quad (4)$$

The number of panels that are connected in series ($N_{ps}$) and the number of panels that are connected in parallel ($N_{pp}$) can be defined by:

$$N_{ps} = \frac{system\ DC\ voltage}{voltage\ at\ Pmax} = \frac{VDC}{Vmax} \quad (5)$$

$$N_{PP} = \frac{total\ no.of\ panels}{no.of\ series\ panels} = \frac{Npt}{Nps} \quad (6)$$

Using Eq.4,5 and 6, the number of panels can be determined. The system needs 8 panels. The number of panels that are series in connection was 2 and the number of panels that are parallel in connection was 4 panels.

### 3.5. Sizing Battery Storage

To calculate capacity of battery storage ($C_B$) for system., Eq. (7) can be usedcalculate it:

$$C_B = \frac{E * DOA}{VB * DOD} \quad (7)$$

where DOA stands for "days of autonomy," which is the number of days the system is intended to generate power without receiving a charge from the solar array. In this case using DOA set for 1 day. DOD is the permitted discharge depth that can be allowed, which is set to 0.8. $V_B$ is the nominal voltage of any battery utilized in the battery bank. from this table using the information to like $V_B$ was 12 and DOD was 0.8, and E the sum of energy demand we had it before by table 1 that calculate $C_B$ was 1353 Ah and using new max battery 12V and 200Ah as shown in Table 4.

Table 4: specification of the battery.

| Type | VRLA gel technology |
|---|---|
| Nominal voltage ($V_B$) | 12 V |
| Capacity (C) | 200 Ah |
| Dimenstions | 524x241x215 mm |
| Operating temperature | -20 ℃ to 50 ℃ |
| Cycling performance | 950 cycles at 80% |

The following equation can be used to calculate total number of batteries:

$$N_{BT} = \frac{CB}{C} \quad (8)$$

The number of batteries connected in series ($N_{BS}$) and number of batteries connected in parallel ($N_{BP}$) are calculated by:

$$N_{BS} = \frac{VDC}{VB} \quad (9)$$

$$N_{BP} = \frac{NBT}{NBS} \quad (10)$$

Therefore, the total number of batteries is about 8 batteries, and the number of batteries that are connected in series are 4 batteries and thebatteries that are connected in parallel are 2.

### 3.6. Sizing the Inverter

To transform direct current to alternating current, an inverter is necessary. It is essential that the designed system will not be overloaded. This can be assured if the inverter's power rating is not less than the total energy of the electrical load. Thus, the inverter's power rating should be 25% to 30% higher than the power of the appliances as a safety buffer[25]. The size of the inverter can be calculated by;

Inverter rate = power requirement X correction factor **(11)**

The correction factor for safety's value is 3 for motor loads and 1.25 for simple loads[26]. Using Equ.11, the results of the invertor size is 4.2 KW. Thus, using (Growatt 5kW off-grid) type (SPF 5000 ES) inverter single-phase model that output AC voltage 230 ± 5% and Nominal Output Frequency (Hz) is 50/60 Hz and has a surge power of 1000 VA.

### 3.7. Sizing Charger Controller

The charge controller's principal function is to prevent battery spoofing by keeping track of the battery's charging and discharging. This is critical since overcharging can cause the battery to fail, while undercharging reduces the battery's life. A charge controller is also necessary to prohibit a reverse current from flowing from the battery to the system. There are two kinds of charger controller, Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). Though the MPPT charge controller has better efficiencies and supply more power when compared to PWM for the same condition[27]. In this work, MPPT is adopted with an inverter that MPPT range@ and operating voltage 120VDC-430VDC. The number of MPPT tracker/strings per MPPT tracker 1/1 and the maximum solar charge current is 100A.

## 4. PERFORMANCE EVALUATION USING PVSYST SOFTWARE

In this work, PV Syst software version 7.2.13 has been used to simulate off-grid PV system. The PV Syst is used to investigate sizing, and analysis of data. The PV syst can be used for grid connected and off-grid, pumping system and public transit direct current networks (DC-grid). The PV syst has inclusive database and varied meteorological database source and consist of data of solar system required [28].

### 4.1. Data Identification and Component Selection

To obtain meteorological data, a house located at AVRO city has been selected as project site. The house power demand consumption based on the diurnal power needed and the time of working is conducted as seen in Table 1. The orientation of the system (tilt angle) is 36 like the latitude of the location and azimuth angle zero facing to the south. Specific information about the PV module and array connections, as well as batteries, inverters, and charge controllers have been collected. As mentioned in part 3, all components are chosen depending on the load's energy requirements.

### 4.2. Evaluation Results

#### 4.2.1 Collector plane incident energy and meteorological data:

Through the simulation, meteorological Data by the Meteonorm8 in PV syst at PV syst tools that data consist of Horizontal diffuse and Horizontal global irradiance (DiffHor) and (GlobHor), clearness, temperature of ambient, and wind speed.

#### 4.2.2 Normalized production:

The normalized production is shown in Fig.3. It shows that the losses of unused energy are 0.96 kWh/kWp/day and collection losses are 0.71 kWh/kWp/day. Moreover, system losses and battery charging are 0.42 kWh/kWp/day and energy provided to the user is 3.75 kWh/kWp/day.

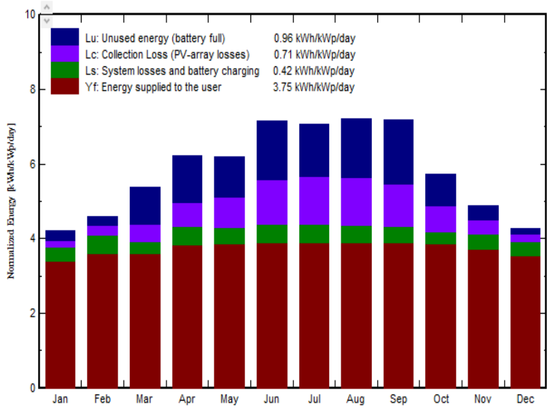


Figure 3. normalized production of the system.

#### 4.2.3 Performance ratio and solar fraction:

Performance ratio is the ratio between actual return (inverter's output) and target return (PV array's output). On the otherhand, the solar fraction is the ratio of energy that supplied to the total energy that required. That result shows that the solar fraction has a value of 0.962, whereas the performance ratio is 0. 642. On the other hand, losses diagram shows all losses occurred in the system step by step. At producing energy, a number of losses occur in PV panels and array like ohmic wiring loss whic is -1.59 percent, module quality loss is +0.29 percent and mismatch loss is -2.10 percent, that all depend on temperature and also converter loss during operation is -4.25 percent, loss in the converter due to threshold power is -0.04 percent, battery efficiency loss is -5.29 percent, charge/discharge current efficiency loss -2.08 percent battery self discharge current -0.27 percent etc. loss diagram of missing energy is 3.81 percent which is180.2 kWh for a year of a total 6958 kWh and direct PV solar energy use 27.5 percent and energy stored 72.5 percent as shown in Fig.4.

#### 4.2.4 Balance and main results:

Table 5 shows the results of the available energy (E-avail) 5999 kWh/year, energy unused (battery full) is 1159.7kWh/year, missing energy (E-miss) is 180.24kWh/year, energy provided to the user (E- user) is 4528.7 kWh/year, and energy needed of load (E-load) is 4728.9 kWh/year.

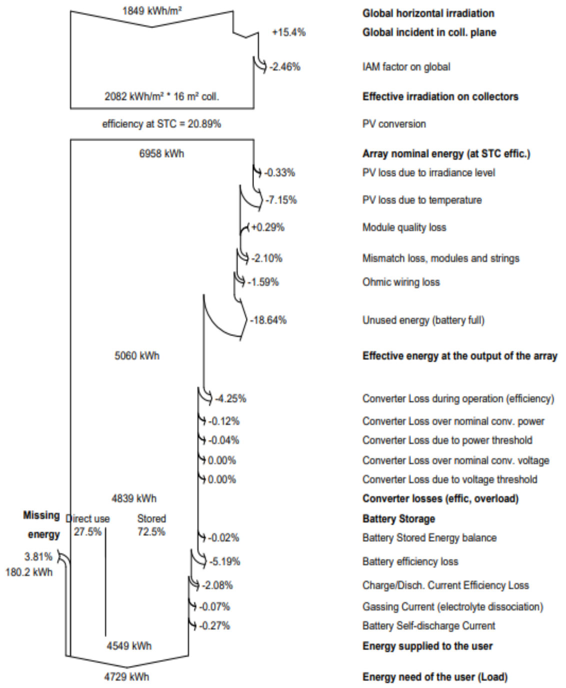


Figure 4. loss diagram of the system.

Table 5: Balance and main result of the system.

| | GlobHor kWh/m² | GlobEff kWh/m² | E_Avail kWh | EUnused kWh | E_Miss kWh | E_User kWh | E_Load kWh | SolFrac ratio |
|---|---|---|---|---|---|---|---|---|
| January | 78.8 | 128.4 | 398.2 | 26.9 | 50.90 | 350.7 | 401.6 | 0.873 |
| February | 91.2 | 126.3 | 385.6 | 21.9 | 27.10 | 335.7 | 362.8 | 0.925 |
| March | 136.8 | 163.3 | 488.8 | 104.3 | 31.63 | 370.0 | 401.6 | 0.921 |
| April | 173.6 | 181.6 | 536.4 | 124.4 | 7.49 | 381.2 | 388.7 | 0.981 |
| May | 202.3 | 186.5 | 532.8 | 110.9 | 4.28 | 397.4 | 401.6 | 0.989 |
| June | 239.2 | 207.9 | 575.4 | 157.7 | 0.00 | 388.7 | 388.7 | 1.000 |
| July | 236.7 | 212.0 | 575.1 | 144.1 | 0.00 | 401.6 | 401.6 | 1.000 |
| August | 217.5 | 217.5 | 590.9 | 162.2 | 0.00 | 401.6 | 401.6 | 1.000 |
| September | 180.1 | 209.8 | 581.6 | 169.7 | 0.00 | 388.7 | 388.7 | 1.000 |
| October | 128.6 | 174.3 | 501.8 | 87.4 | 5.38 | 396.3 | 401.6 | 0.987 |
| November | 89.9 | 143.7 | 431.1 | 37.2 | 17.93 | 370.8 | 388.7 | 0.954 |
| December | 74.3 | 130.2 | 401.4 | 12.9 | 35.53 | 366.1 | 401.6 | 0.912 |
| Year | 1849.0 | 2081.6 | 5999.0 | 1159.7 | 180.24 | 4548.7 | 4728.9 | 0.962 |

## 5. ECONOMIC EVALUATION

For the economic evaluation, it is essential to provide estimate of the cost of installation CAPEX, cost of (PV panels, battery storage, inverter, charger controller, wiring, combiner box, monitoring system, fasteners) and operating OPEX cost. More cost such as expenses for system administration, routine maintenance, and site supervision should be included on a yearly basis. Some portions of the system must be replaced to ensure continued operation and efficient system performance. The PV modules have an optimum life cycle of roughly 25 years, while the battery storage has a life cycle that can reach to 10 years. The batteries will need to be exchanged every ten years, based on a maximum life cycle of 20 years. For future estimations, inflation parameter should be considered too. The inflation rate represents the escalation direction in the prices over the all life of the system given an inflation rate 3%. The results presented in Table 6 show that using 8 panels, 8 batteries storage and 1 inverter with operating cost, the battery has 10-year lifetimes so that needs change batteries for each 10 years. The operating cost for the case in Table 6 will be 172$/year with inflation (3.00%). It will be 250.84 $/year. In Duhok city the price of 1 ampere is 15000 Iraq's dinar of local generators. Local generators give 12 hours per day of electricity to the consumer in Dohuk. To calculate feed in tariff for local generators, multiplying instant equipped capacity that is 230 W with day processing time that is 12 hours each day. This will give result 2760 Wh, energy supplied per day so that per month it will be 82800 Wh. Finally, dividing price of 1 ampere to the energy equipped within a month will gave price of electricity Iraq's 181.1 dinar/kWh for local generators and it will 0.12 $/kWh.

Table 6: Balance and main result of the system.

| Component of stand-alone PV system | Number | Cost | Total |
|---|---|---|---|
| Solar panel (415W) | 8 | 145$ | 1160$ |
| battery storage | 8 | 215$ | 17220$ |
| inverter with MPPT | 1 | 849.99$ | 849.99$ |
| (CAPEX) cost | | | 3729.99$ |
| (OPEX) cost | | | 172 $/year |
| (OPEX)cost including inflation (3.00%) | | | 250.84 $/year |

LCOE is a term that defines the lifetime cost compared with the energy produced. The results of economic evaluation show that LCOE of the system is 0.09 USD/kWh. Thus, the system is expected to save 300 to 400 USD per year in cash flow from the year of 2033 to 2043. The payback period is the number of periods required to recover one's investment in a project before profit can be realized. In this system 10 years with 8 months are needed. After that profits will start accumulating . The net present value (NPV) is the summation of whole present values of cash outflow and cash inflow regarding to the investment over a period that is 2546.04 USD.

The return of investment is 68.3% as shown in Fig.5.

**Financial analysis**

**Simulation period**
Project lifetime 20 years Start year 2023

**Income variation over time**
Inflation 3.00 %/year
Production variation (aging) 0.00 %/year
Discount rate 0.00 %/year

**Financing**
Own funds 3'729.99 USD

**Electricity sale**
Feed-in tariff 0.12 USD/kWh

**Return on investment**
Payback period 10.8 years
Net present value (NPV) 2'546.04 USD
Return on investment (ROI) 68.3 %

**Detailed economic results (USD)**

| | Electricity sale | Run. costs | Deprec. allow. | Taxable income | Taxes | After-tax profit | Cumul. profit | % amorti. |
|---|---|---|---|---|---|---|---|---|
| 2023 | 545 | 172 | 0 | 373 | 0 | 373 | -3'357 | 10.0% |
| 2024 | 545 | 177 | 0 | 368 | 0 | 368 | -2'989 | 19.9% |
| 2025 | 545 | 182 | 0 | 362 | 0 | 362 | -2'627 | 29.6% |
| 2026 | 545 | 188 | 0 | 357 | 0 | 357 | -2'270 | 39.1% |
| 2027 | 545 | 194 | 0 | 351 | 0 | 351 | -1'919 | 48.6% |
| 2028 | 545 | 199 | 0 | 345 | 0 | 345 | -1'573 | 57.8% |
| 2029 | 545 | 205 | 0 | 340 | 0 | 340 | -1'234 | 66.9% |
| 2030 | 545 | 212 | 0 | 333 | 0 | 333 | -900 | 75.9% |
| 2031 | 545 | 218 | 0 | 327 | 0 | 327 | -573 | 84.6% |
| 2032 | 545 | 224 | 0 | 320 | 0 | 320 | -253 | 93.2% |
| 2033 | 545 | 231 | 0 | 314 | 0 | 314 | 61 | 101.6% |
| 2034 | 545 | 238 | 0 | 307 | 0 | 307 | 368 | 109.9% |
| 2035 | 545 | 245 | 0 | 300 | 0 | 300 | 667 | 117.9% |
| 2036 | 545 | 253 | 0 | 292 | 0 | 292 | 960 | 125.7% |
| 2037 | 545 | 260 | 0 | 285 | 0 | 285 | 1'244 | 133.4% |
| 2038 | 545 | 268 | 0 | 277 | 0 | 277 | 1'521 | 140.8% |
| 2039 | 545 | 276 | 0 | 269 | 0 | 269 | 1'790 | 148.0% |
| 2040 | 545 | 284 | 0 | 261 | 0 | 261 | 2'051 | 155.0% |
| 2041 | 545 | 293 | 0 | 252 | 0 | 252 | 2'303 | 161.7% |
| 2042 | 545 | 302 | 0 | 243 | 0 | 243 | 2'546 | 168.3% |
| **Total** | **10'898** | **4'622** | **0** | **6'276** | **0** | **6'276** | **2'546** | **168.3%** |

Figure 5. financial analysis of the stand-alone system.

## 6. ASSESSMENTSAND RECOMMENDATIONS

The system consists of eight arrays with eight batteries and one inverter with a charging regulator. The system provides the required daily load of 12992 watt-hours using the PV Syst software and conducted a cost analysis for the system. The results (using PV Syst software) of this study indicate that the performance of the system is good and it meets the needs of consumers at home by using 27.5 % of photovoltaic energy and storing 72.5 % of the energy for the purpose of using it at night or on cloudy days. The first cost of the system installation is significant. yet, it is useful and appropriate in the long run. The investment of the payback period is 10 years and three months, and the average life of the system is about 20 years. To be anticipated, the growth in technology and the increase in production volume and then the recovery period will be reduced as well. Off-grid photovoltaic energy istherefore a valuable energy source even in populated areas.

## 7. CONCLUSION

Iraq in general and Kurdistan region in particular can benefit from solar energy to generate electricity. This paper suggested a source of energy that is renewable electricity for a residential house in Duhok, Iraq. The paper investigated an off-grid photovoltaic system instead of local generators that gives electricity 12 hours per day. The investigation involves the design and simulation of an off-grid PV system for 1 Villa at Avro city in Duhok. The energy consumption and sizing of the system have been computed together with the economoic evalution of the system. The results obtained show that the system works at a 48 V direct with unused energy of 17.6%, energy supplied to user is 63.9 %, system losses are 6.5% and collection losses are 12%. The results show that the performance ratio of the system is 0.639, the solar fraction is 0.96 in case of using a single-phase rating 5 KW inverter as it happened in this work. Finally, economic evaluation analysis shows that the payback period is 10 years and 8 months and net present value is 2546.04 USD and the return of investment is 68.3 %.

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# نظام طاقة شمسى كهروضوئى غير مرتبط في الشبكة لفيلا فى افروستي دهوك


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تاريخ الاستلام: 2022-07-19    استلم بصيغته المنقحة: 2022-8-10    تاريخ القبول: 2022-09-12



***الملخص***

يعد النظام الكهروضوئى خارج الشبكة أحد التقنيات الواعدة لتوليدالكهرباءالصديقةللبيئة. تعانيمدينةدهوک من نقص فى الطاقة الكهربائية مما يستوجب الحصول على الطاقةالكهربائيةمن خلال المولدات المحلية لدعم الشبكةالوطنية. الهدف من البحث هو التخلص من المولدات المحلية بسبب ارتفاع تكاليفهاوالتلوث البيئي واصواتها المنزعجة. تم اقتراح نوع النظام الشمسيالكهروضوئى (خارج الشبكة) لفيلا واحدة فيمدينة*AVRO*دهوک. تم إجراء عملية حسابية لتحديد حجم النظام وتم اعتماد برنامج *PV Syst* للتحقيق في تصميم النظام المقترح وفحص التحليل الاقتصادي والمالي بالإضافة إلى صافي الربح.يستخدم النظام المقترح بمتوسط طلب على الكهرباءيبلغ 12.9 كيلو وات / يوم. تم تحديد النظام الكهروضوئيالنموذجى بقدرة 3.3 كيلو واط ليكون قادرًا على تلبية متطلبات الطاقة اليوميةلفيلابأكملها مع 8 ألواح ، اثنان على التوالى وأربعة على التوازيكل لوحة لديها قدرة 415 واط. يشتمل النظام على 8 بطاريات بقوة 12 فولت و 200 أمبيرساعةوعاكس بقدرة 5 كيلو وات مع جهاز تعقب *MPPT*. تظهر النتائج أن المتوسط السنوى لمتطلبات الطاقة للفيلا 4728.9 كيلو واط ساعة والطاقة المتاحة من خلال لوحات سولار 5999 كيلو واط ساعة / سنة.



***الكلمات الداله :***

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