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An Economic Study to Calculate the Cost of Electric Powered House Using Solar Energy in A Remote Area

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Abstract

The demand for energy is enlarged nowadays while the existing energy sources have decreased. So, efforts were adopted to search for alternative energy. One of the most common kinds of alternative energy is solar energy. The purpose of this work is to estimate the cost of building a standalone photovoltaic system to generate electricity for-farmer house and farmland in a remote area in Karbala City, Iraq, and compare this cost with the other generator sources. Methodology: First, the load, which is the central part of the design, must be calculated from the ordinary electrical devices usually used in a farmhouse and farmland, especially in Karbala. According to this load the design of the standalone photovoltaic system was achieved by selecting the proper components such as solar photovoltaic (PV) modules, batteries, solar charge controllers, and inverters. In addition, the total cost of the construction of the system and the annual maintenance cost will be estimated, and the cost will be compared with another kind of generator using gasoline. Simple manual calculations were used in all the theoretical design step Finding: The proposed Stand-alone system will satisfy approximately the energy for entirely the home applications chosen at complete load, at daylight, and provides about 2 days at days of autonomy for (50%) depth of battery discharge. The total cost of the system is about 15000 $, and the unit energy cost is 0.09 $/ Kilowatt-hour (KWh). Research implications: The cost of construction of a stand-alone photovoltaic system for a city consisting of a large number of houses will reduce the cost for one house and also enhance the stability of the demand load.Originality value: Using a solar-powered system is a suitable choice for a house in a remote area in Kerbala city instead of an oil generator for both cost and environment, and farmers must know that.

Keywords: Stand-alone, photovoltaic system, solar irradiance, system sizing.

1. Introduction

The shortage of existing energy is one of the major problems faced by the world in future. So, efforts were adopted to find another kind of energy generated by new sources instead of gas or oil. The Sun offers energy about 1.2 x 10^5 terawatts, which is more than the power needed for all the whole world [1]. Alternative energy has increased in the last few years because it is clean, not depleted, and doesn't harm the environment. Also, it is very suitable for use in rural areas far from the center of cities because of the expensive cost of transportation of energy from processing centers. Iraq receives about 2800 to 3300 bright sun hours per year [2]. In recent years the cost of equipment for solar-powered systems has decreased rapidly, and also the price of all kinds of oil has increased. This fact implies farmers in remote area far from the center of the city have to change their opinion towards using solar photovoltaic systems. In addition, Iraq locations are very suitable for generating energy.

The long periods of bright sun-hours and high solar radiation intensity makes the solar system a wisdom choice in Iraq. High temperature in summer caused to reduce the generated power because it's affected the PV voltage [3] [4]. The other major reasons affected the solar energy is the dust problem in Iraq. Where the dust reduces the solar radiation reaching the earth because of dusty storms happened in many days during summer in Iraq in last year (2022) due to climate change in recent years [5]. Also aggregate the particles of dust on PV modules reduces the power generated from the system. Many different methods of cleaning the photovoltaic cells. Darwish et al. [6] suggested using alcohol or sodium to clean the surface of PV panels give high rates of performance. Establishing solar energy system need high initial cost but no more expensive cost for maintenance [7]

The efficiency of silicon solar cells was still very low [8] due to two main many reasons. The first one is because the silicon can absorb a small part of solar radiation. In contrast, while the second reason is the high solar radiation reflected value from the surface of the photovoltaic converter, due the high solar radiation reflected value from the surface of photovoltaic converter which may be reachedreach 35% [9]. In order to which increase the efficiency of the solar system, a nanotechnology was has been used at in the last few years, where It. It enhanced the solar absorbance and also lowered the thermal entered tosolar absorbance and also lowered the amount of thermal energy entering the solar panels [10]. The system efficiency may be increased if any improvement happened happens in measured measuring the voltage-current characteristics of the used solar batteries [11].

2. Methodology

This work aims to calculate the solar system cost for remote areas and compare this cost with that of other electricity-generating sources. So, in order to design a solar PV system structure, many different components and equipment must be selected. These components equipment are wired together to represent the form of the system structure, which can supply electric current to the demand area [12][13][14].

These components are:

1- Load: It is the main part of the design which represent the electrical instruments applications linked to solar PV system structure such lights, refrigerator, etc. as shown in table 1.
2- PV module: A device convert sunlight to electricity. It is made from semiconductor and the common type include single, polycrystalline silicon and amorphous silicon as shown in table 2.
3- Battery: It is a storage energy device for demand area. The battery bank unit is the important components that must be satisfy the power demand at night and at cloudy days. The battery must be able to slowly recharge and discharge of 80% of their capacity hundreds of times.
4- Solar Charge Controller: The is a device which regulate the voltage and current to prevent battery overcharging and to enlarge the battery life as shown in table 3.
5- Inverter: It is a device which convert direct current DC output of PV panels to alternating current AC for in run the appliances.

The efficiency of the Inverter reaches its maximum value when the Load demand is greater than 50% of rated load [15]. The photovoltaic structures were classified consistent with: how the structure components were linked to other electrical sources such as Utility-Interactive or Stand-Alone systems [16].

A structure is designed to operate independently of the electric utility grid. In other words, it is a Stand-Alone structure designed and sized to supply a specific AC to an electrical load.

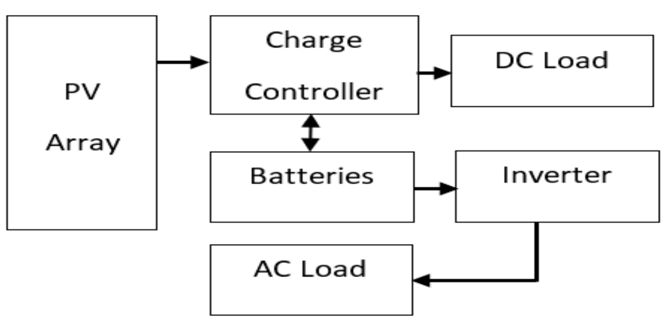

Figure 1. The Block Diagram of Stand-alone Photovoltaic System.

3. Case Study

The location of Karbala city, Iraq at 32.37 Latitude and 44.02 Longitude. This location is very suitable for solar energy systems because it is near the solar belt with average solar irradiance equal 0.604 KW-h /m^2 [17]. Iraq is rich of sun irradiance where the Sun is shining more than 3300 hours a year [18] [19].

System sizing is the process of choosing the adequate voltage and the current ratings for each component of the PV system to satisfy the electric demand. Also estimate the total price of the entire system from the design to the fully functional system. The first step in system sizing is to determine the total energy consumption of the appliances. The daily energy consumption in summer season is greater than in winter season in Karbala. So, the design load load was calculated in the worst conditions of summer season. So, all equipment and their ratings must be calculated as exposed in table1 below:

Table 1: Daily energy consumption of devices residence

Load	Number of devices required	Voltage Volt (V)	Power/device Watt (W)	Usage hour /day	Watt-hour /day Power Required
Refrigerator	1	220	200	12	2400
Ceiling Fan	2	220	160	6	960
Television & Satellite receiver	1	220	180	6	1080
Lights,6 Led	6	220	90	6	540
Freezer	1	220	150	12	1800
Air cooler	1	220	330	8	2640
Electric iron	1	220	1000	0.5	500
Water Filter	1	220	40	4	160
Total	AC Connected power load (Watt):		2150	AC Average Daily Load (Appliance load):	10080

The total daily energy demand is approximated to 10080 Watt-hour AC. In order to cover the requirement of water for both house and farmland irrigation a water motor is needed. The water motor is operated for 3 hours in the morning each two days while all unnecessary appliances are off.

MITSUBISHI PV-MF180UD4 (180W) Solar Panel from MITSUBISHI ELECTRIC were Choosing:

Table 2: PV Solar Panels Specifications

Dc Electrical Characteristics	**Mechanical Characteristics**
Max. Power Rate = 180 Watts (w)	Type = Polycrystalline Silicon
Ptc Power Rating = 160.7 Watts(w)	Output Terminal Type = Multi-contact Connector Type 4
STC Power Per Unit of Area = 12.1W/Ft2 (130.2W/M2)	Frame Color = Black
Peak Efficiency = 13%	Backsheet Color = data not available
Power Tolerances = -5%/+10%	Length = 65.3in (1,658mm)
Cells Number = 50	Width = 32.8in (834mm)
Nominal Voltage = Not Applicable	Depth = 1.8in (46mm)
Maximum Current (Im) = 7.45 Ampere (A)	Weight = 43lb (19.5kg)
Maximum Voltage (VM) = 24.2 Volt (V)	Installation Method = Rack-Mounted
Short Circuit Current (Isc) = 8.03 Ampere (A)	**Warranty and Certifications**
Voltage At Open Circuit (Voc) = 30.4 Volt (V)	80% Power Output Warranty Period =25yrs
NOCT Data = Not Available	90% Power Output Warranty Period data not available
Temp. Coefficient of Power = -0.45%/K	Workmanship Warranty Period = 1yrs
Temp. Coefficient of Voltage = -0.1V/K	UL Fire Classification data not available
Series Fuse Rating = 15a	Compliances UL 1703
Maximum System Voltage = 600v	CSI Listed = Yes
PV Array Efficiency 15.5 %	
Manufacturer: MITSUBISHI ELECTRIC	

The charge controller efficiency = 0.98 for (TriStar TS MPPT 60-24V) (table 3).

Table 3: Solar Controller, TriStar MPPT 60A 12,24,36 or 48V Specifications

Model/Description	Rated Voltage	Rated PV Current	Unit Load Current	Dimensions	Weight
TS-60	12/24/48V	60 amps	60 amps	10.1″ x 4.9″ x 2.3″	4 lbs

The approximately batteries efficiency = 0.90 for (UB-8D AGM-250 AH) and cable losses 3%

Extra charging to the batteries is offered by oversizing to reduce the effect of operation conditions on the output power of a PV array. The adopted oversizing ratio is 1.1 to maximize energy production. This is also useful in future energy demand expansion. To avoid system under sizing the total output efficiency of the system must be corrected as below:

The efficiency of subsystem (η_{out}) is:

$$\eta_{out} = \text{Charge Controller Efficiency x Battery Efficiency x Inverter Efficiency x Cable Loss} \quad (1)$$

$$\eta_{out} = 0.98 \times 0.98 \times 0.90 \times 0.97 = 0.84$$

So, the energy demand from the system array E_S is:

$$E_S = \frac{E}{\eta_{out}} \quad (2)$$

Where Es is representing the total Daily energy demand in Watt-hour/day

$$E_S = \frac{10080}{0.84} = 12000 \text{ Watt-hour /day}$$

So, the daily energy needed from the solar system is about 12000 Watt-hour /day.
But the peak power P obtained from dividing the daily energy E_s by the minimum peak time (T_{min}) in hours.

$$P = \frac{E_s}{T_{min}} \quad (3)$$

T_{min} = 6 hours/day for Karbala city at in December

$$P = \frac{12000}{6} = 2000 \text{ Watt-hour}$$

The total DC Current $$I_{DC} = \frac{P}{V_{DC}} \quad (4)$$

Where V_{DC} represent the system DC voltage which equal 24 volt

$$I_{DC} = \frac{2000}{24} = 83.34 \text{ Ampere-hour /day} \quad (5)$$

The peak power module must be adjusted due the factors decreased the performance of the module such as surrounding temperature and dust dirt. An experimental study in Kerbala city shows that the modules daily efficiency is about 48% at ambient temperature 24.9 ^{0}C [20].

The losses due dust dirt was adopted as 5% for Karbala city. Dust removal done by clean the board or prevent the accumulation of dust on the board using a dust sensor with servo motor to rotate the board down [21] [22].

The average of ambient temperature of Karbala city is about 25^0 C and the temperature coefficient is -0.43% ^{0}C is used:

Temperature losses = $T_{average}$ ^{0}C x (Temperature Coefficient) (6)

$$= 25^0C \times (-0.43) = -10.75$$

$$\text{Temperature derating factor} = \frac{100\% - Temperature\ Loss\ \%}{100\%} \quad (7)$$

$$= 1\text{-}10.75 = 0.8925$$

So, The Adjusted module power can be estimated as:

The Adjusted module power = the peak power module (w) x temperature derating factor x dirt correction factor (8)

= 180 x 0.8925 x 0.95

= 168 W

The individual solar modules are connected in series and parallel to satisfy the required power. The number of series modules (N_S) is estimated from equation (9),

$$N_S = \frac{V_{DC}}{V_M} \tag{9}$$

Where V_M is the rating voltage of one module so

$$N_S = \frac{24}{24.2} \quad =0.99 \text{ adjusted to } 1$$

The number of parallel modules of solar module (N_P) is obtained from equation (10),

$$N_P = \frac{I_{DC}}{I_M} \tag{10}$$

Where I_M is the rating current of one module so

$$N_P = \frac{83.34}{7.45} \quad = 11.19 \text{ adjusted to } 12 \text{ modules}$$

The total number of modules $N_m = N_S * N_P$ (11)

$N_m = 1 \text{ x } 12 = 12$ modules

The PV array of the system consist of 12 modules in parallel (figure 2).

Battery sizing depend on the days number with no sun irradiance and the structure will provide power with-out any input charge from the PV solar array.

Battery bank capacity is founded by the following equation (18):

$$\text{Battery Bank Capacity (Ah)} = \frac{\text{Total Daily Energy Demand (Wh) x Days of Autonomy}}{\text{Battery Efficiency x Battery System Voltage (V)xDOD}} \tag{12}$$

DOD: the max depth of battery discharge. Where a DOD of 50% was utilized.

Days of autonomy assumed 2 days to give safe charge power.

$$\text{Battery Bank Capacity (Ah)} = \frac{\text{10080 (Wh) x 2 Days}}{\text{90\% x 24 (V) x 50\%}} \quad = 1867 \text{ Ah}$$

$$\text{Number of batteries wired in parallel} = \frac{\text{Battery Bank Capacity (Ah)}}{\text{Battery rating (Ah)/battery}} \tag{13}$$

= 7.4 adjusted to 8 batteries

$$\text{Number of batteries wired in series} = \frac{\text{Nominal system voltage (V)}}{\text{Battery voltage (V)/Battery}} \quad (14)$$

$= \frac{24}{24}$ =1 battery

Total number of batteries = Number of batteries in parallel x Number of batteries in series (15)

= 8 x 1 = 8 batteries

The storage energy of battery bank capacity = 1867 Ah x 24 V x 50%

= 22404 Watt-hour

$$\text{The running time of the total load} = \frac{\text{storage energy of battery bank x DC cable losses x Inverter efficiency}}{\text{Appliance load x AC cable losses}} \quad (16)$$

$$= \frac{22404 \times 0.97 \times 0.98}{10080 \times 0.98} = 2.2 \text{ days}$$

The running time calculated above gives a very good indicator that the system was satisfied the appliances for two cloudy days.

The Invertor rating should be 20-25% (1.2-1.25) bigger than total appliance AC load [23]. In this study the Invertor rating was estimated as below:

The Invertor power P_{inv} = 1.25 x 2150 (power load (Watt)) (17)

= 2687.5 Watts.

Using Latronics inverter, LS 3024, 3000-W, 24-V_{DC}, 220-V_{AC} will be satisfied. The Invertor power required indicated in table 4 below:

Table 4: Latronics ls-3024 sine wave inverter 3000w 24vdc specifications

	INVERTER MODEL							
	LS-2012	LS-2324	LS-2548	LS-3024	LS-3548	LS-4024	LS-5048	LS-7048
Nominal D.C. Voltage	12V	24V	48V	24V	48V	24V	48V	48V
Continuous Power	2000W	2300W	2500W	3000W	3500W	4000W	5000W	7000W
1/2 Hour Rating	2200W	2800W	3000W	3700W	4100W	4500W	6000W	8500W
Surge Rating (5 Secs)	6000W	7000W	7500W	9000W	10500W	12000W	15000W	20000W
Input Voltage Range	10.5-17V	21-34V	42-68V	21-34V	42-68V	21-34V	42-68V	42-68V
Standby Current	75mA	45mA	35mA	50mA	40mA	60mA	55mA	60mA
Inverter ON - No Load	1.10A	0.51A	0.30A	0.60A	0.33A	1.10A	0.47A	0.49A
Peak Efficiency	90%	94%	94%	93%	94%	94%	95%	95%
Weight	22Kg	22kG	22Kg	24Kg	24Kg	30Kg	30Kg	34Kg
Dimensions	370mm(L) x 386mm(W) x 180mm(H)					475mm(L) x 458mm (W) x 187mm(H)		
Output Voltage	240Vac +/- 4%							
Output Frequency	50Hz +/- 0.1%							
Output Waveform	True Sinewave							
THD	< 4%							
Power Factor	All Conditions							
Autostart Sensitivity	0-20 W Adjustable							
Operating Temperature	-20°C to + 40°C							
D.C. to A.C. Isolation	3500V							
Protection Circuitry	Overtemperature, Overload/Short Circuit, Battery Undervoltage/Overvoltage							
Battery Leads	1.5m Long with 10mm Mounting Lugs							
A.C. Output Wiring	3 Terminal Hardwired Junction Box, Labeled 'AC Output'							
A.C. Input Wiring	3 Terminal Hardwired Junction Box, Labeled 'AC Input'							
A.C. Transfer Switch	240Vac, 40Amps, 50Hz (Surge 80a 0.5 Seconds) - Only with KX Option							
Chassis (Powder coated)	3mm Aluminium					4mm Aluminium		
Warranty	3 Years Parts and Labour (Back to Factory)							
Standards	IEC 62109-1, IEC 62109-2, AS3100, EN55014 & RCM							
Ratings	Specifications @ 25°C Ambient Nominal Battery Voltage & Unity Power Factor							
Operating Environment	5% - 95% (Non-Condensing) Humidity, up to 2000m About Sea Level							

$(I_{C.C}) = 1.20 \text{ x parallel modules number x } (I_{SC})$ (18)

Where Icc: The charge controller current

Isc: Short circuit current (8.03)

= 1.20 x 12 x 8.03/ module

= 115.63 Amps

$$\text{Number of Controller} = \frac{I_{cc}}{\text{Amps each controller}} \quad (19)$$

$= \frac{115.63}{60}$ =1.93 adjusted to 2 controllers

So two controllers (60 Amp. -24V) connected in parallel must be used.

The voltage of charge controller = 1.25 x (V_{OC}) x number of series modules

= 1.25 x 30.4 x 1

= 38 V

Two controllers connected in series must be used.

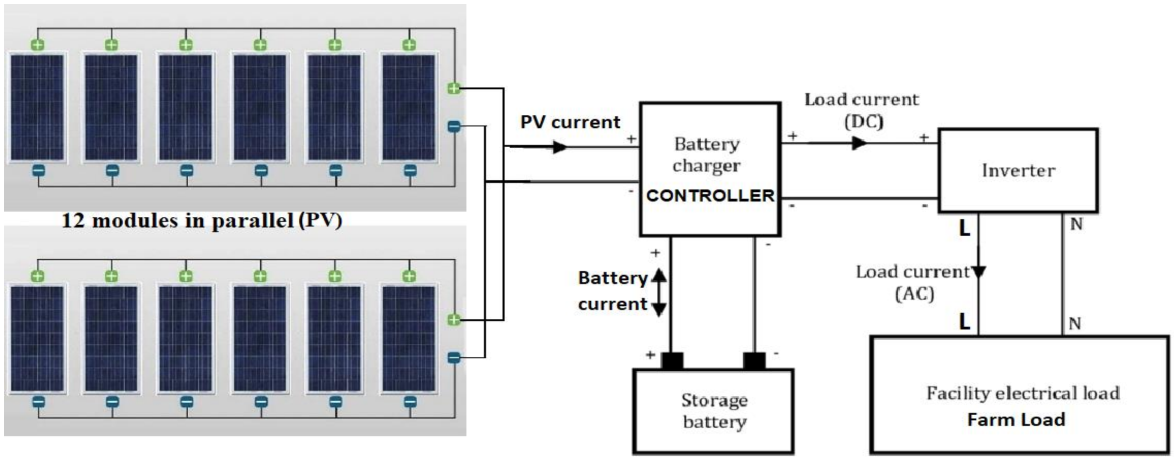

Figure 2. The Final Block Diagram of Stand-Alone Photovoltaic System.

Finally, the total cost of the equipment's of the system including the construction cost is about 15000$.This initial cost of the system is assumed almost constant for the initial system for 25 years (the life time of the system) with extra cost for maintenance and change exhausted batteries. Assuming the batteries life time equal two years. The annual cost of exchange batteries is equal to cost of all batteries divided by two which is about 1000$ per year. In order to compare the cost of using gasoline generator with photovoltaic system Table 5 is calculate the cost must be paid per day for both types.

Table 5. Comparison between cost of generating electricity by Solar panels system and Gasoline generator

Type	Price	Cost of gasoline		Cost of oil		Gasoline & oil		Total cost	Life time		Cost of one day ($)
		$/day	$/month	$/week	$/month	$/month	$/year	$/year	Year	Day	
Gasoline generator	250 $	16 $	480 $	7.5 $	30 $	510 $	6120 $	250+6120	1	360	17.7 $
Solar panels system	15000$	---	---	---	---	---	---	15000/25+1000	25	9000	4.45 $

Table 5 shows the consumption of gasoline generator is 2 Liters/hour, where the cost of 1 Liters = 450 ID (Iraqi Dinar) or 0.33 $. The generator needs 2 Liters of engine oil every week, the cost of engine oil =5000 ID or 3.75 $. The life time of Gasoline generator is one year. From table 5 it seems clearly that using solar system is cheaper than using Gasoline generator.

4. Work Simulation

The PV system is proved by simulation using Matlab 2021 Simulink on HP laptop, the Fig. 3, show the simulation of the PV standalone system, also the Fig.4, came with output AC voltage with an average voltage between somewhere between 2020 – 2060 V, the variation caused by the variation of sun irradiation.

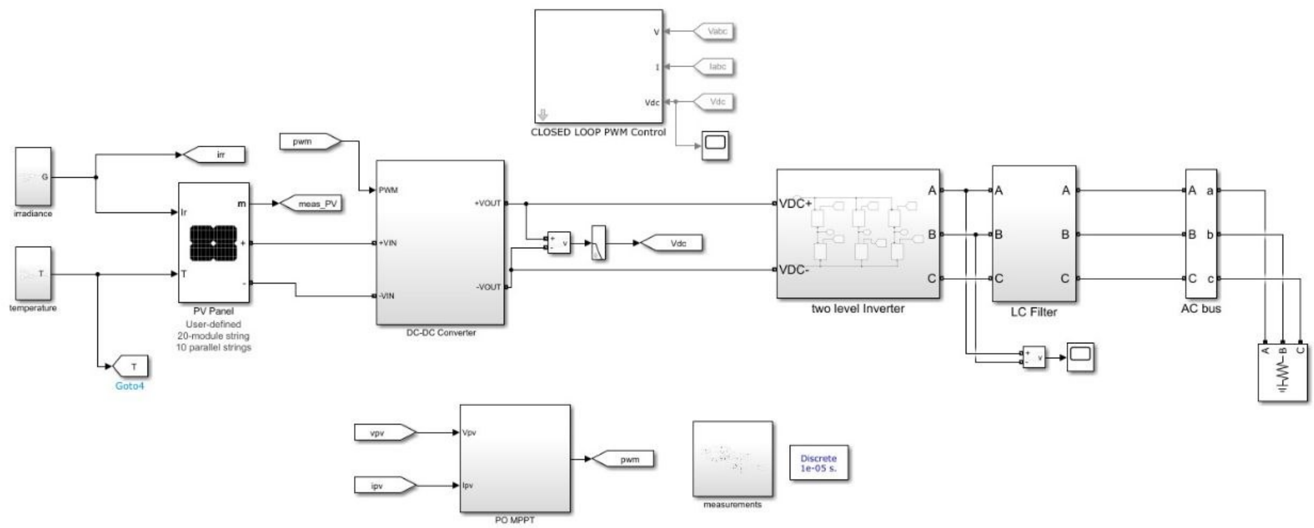

Figure 3. Matlab simulation of the PV system.

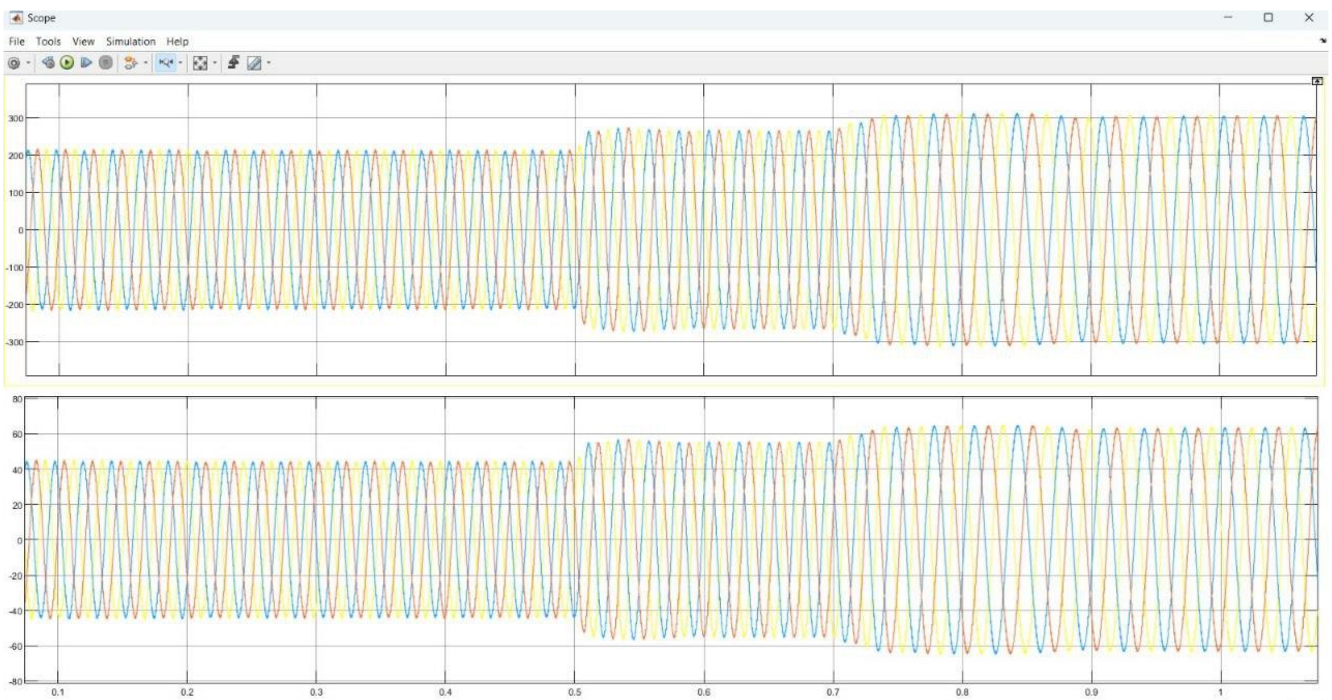

Figure 4. Output Ac voltage of the PV system

5. Conclusion

The proposed Stand-alone system will Approximately satisfy the energy for wholly the home applications chosen at complete load at daylight, and provides about 2 days of autonomy for depth of batteries discharge or 50%. The total cost of the system is about 15000 $ and the unit energy cost is 0.09 $/ KWatt-hour. Additional cost for maintenance and changing batteries was estimated.

Using a photovoltaic system is a wisdom choice to decrease the cost of generating electricity because the prices of solar photovoltaic equipment's is seeming to decrease in future while the Oil price is increased [24]. This is promising evidence that solar energy systems are not cost in the long term Therefore, it is a successful experience for remote areas and farmers' lands.

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دراسة اقتصادية لبيت يعمل بالطاقة الشمسية في منطقة نائية كربلاء العراق

الخلاصة:الغرض يتم توسيع الطلب على الطاقة في الوقت الحاضر بينما انخفضت مصادر الطاقة الحالية. لذلك ، تم اعتماد الجهود نحو البحث عن طاقة بديلة. واحدة من أكثر أنواع الطاقة البديلة هي الطاقة الشمسية. الغرض من هذا العمل هو تقدير تكلفة بناء نظام كهروضوئي مستقل بناء على طلب منزل المزارع في

منطقة نائية في مدينة كربلاء العراقية ومقارنة هذه التكلفة مع النوع الآخر من المولدات التي تستخدم البنزين.المنهجية: في البداية يجب حساب الحمل الذي هو الجزء الرئيسي من التصميم من الأجهزة الكهربائية العادية المستخدمة عادة في منزل مزرعة خاصة في مدينة كربلاء. وفقا لهذا الحمل ، تم تحقيق تصميم النظام الكهروضوئي المستقل من خلال اختيار المكونات المناسبة للنظام مثل الوحدة الكهروضوئية والبطاريات وأجهزة التحكم في الشحن بالطاقة الشمسية والمحولات بالإضافة إلى تقدير التكلفة الإجمالية لبناء النظام وتكلفة الصيانة السنوية ومقارنة التكلفة مع أنواع أخرى من المولدات التي تستخدم البنزين. تم استخدام الحسابات اليدوية البسيطة في جميع خطوات التصميم النظري.ايجاد: النتائج: النظام المستقل المقترح سوف يرضي الطاقة للتطبيقات المنزلية بالكامل المختارة عند التحميل الكامل ، في وضح النهار ويوفر حوالي 2 أيام في أيام الاستقلالية لعمق (50٪) من البطاريات التي يتم تفريغها. تبلغ التكلفة الإجمالية للنظام حوالي 15000 دولار وتكلفة طاقة الوحدة 0.09 دولار / كيلو واط ساعة.الآثار المترتبة على البحث: تكلفة بناء نظام كهروضوئي مستقل لمدينة تتكون من عدد كبير من المنازل سيقلل من تكلفة منزل واحد ويعزز أيضا استقرار حمل الطلب.قيمة الأصالة: استخدام نظام يعمل بالطاقة الشمسية هو الخيار المناسب لمنزل في منطقة نائية في مدينة كربلاء بدلا من مولد النفط من حيث التكلفة والبيئة ويجب على المزارعين معرفة ذلك.

الكلمات المفتاحية: نظام كهروضوئي قائم بذاته ، إشعاع شمسي ، تحجيم النظام.