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Research article

An equivalent photovoltaic solar system to solve the problems of electricity in Iraqi houses

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Abstract: Since 1991, Iraqi society suffers from the lack of electricity power because of an economic embargo imposed from 1991 to 2003 and the mismanagement that hit Iraq after its occupation in 2003. These reasons were leaded to major problems in the power plants and their transmission lines which led to insufficient power generation. To meet this problem, the Iraqi families were tended to use two types of generators (neighborhood and household generators) as alternative sources for compensating the lack of electricity. In this study, a 3 kW photovoltaic (PV) solar system was proposed to use the solar energy in Iraqi houses. An economic feasibility analysis by calculating the life cycle cost was investigated to compare the cost of PV system with the two alternatives sources of generators. At current market price of PV panels (700 IQD/W), a 3 kW PV system has the ability to supply the Iraqi house with electrical energy in total cost about (4,386,366 IQD ≈ 3655 USA$) for five years. The life cycle cost of PV system was investigated about 12.27% less than the two generators cost. Therefore, PV system is more economic in Iraqi houses under the deterioration in the electricity sector. Furthermore, the PV solar not pollutes the environment as the case of using generators.

Keywords: PV; solar; economic; feasibility; life cost

Symbols: A_m: Module area; C: Cost (IQD); C_{Ah}: Battery ampere capacity (A/h); C_{wh}: Battery watt capacity (W/h); d: Interest rate (%); E/m^2: Energy received by PV (kW/m^2); E_L: Energy consumed by the load (kW); I_C: Controller current (A); *i*: inflation rate (%); N_c: Number of controller; Npv: Number of solar cell; V_b: Battery voltage (V)

Abbreviations: MPW: Maintenance present worth; DOD: Permissible depth of discharge rate of a cell; IOP: Inverter output power; IQD: Iraqi Dinar; LCC: life cycle cost; ML: Maximum load; NC: Number of continuous cloudy days; PR: Performance ratio; SF: Safety factor
Greek letters: η_{module}: PV module efficiency; η_b: Battery efficiency
Subscripts: n-g: Neighborhood generator; h-g: Household generator; ins: Installation; O&M: Operation and maintenance; b: Battery; c: Controller; inv: Inverter

1. Introduction

The Electrical energy that produced from Photovoltaic solar system has become an excellant option to offset the growing demand of electricity around the world [1], reliable and has the potential to reduce the CO_2 emissions [2]. Many countries have effectively turned on this type of energy due to the availability of the solar radiation over a wide range of the year. This led many researchers to focus their attention on developing and increasing the efficiency of photovoltaic solar systems to achieve an economic feasibility. In the last years, some of studies in literatures have examined the performance evaluation of photovoltaic solar systems. The evaluation was based on some main indicators that reported in these studies including: the total energy production, performance ratio (PR), and the system efficiency. Renu S. and Sonali G. [3] examined the annual performance of 11.2 kWp in India. The experimental examination showed that the total energy, efficiency and PR were 14.96 MWh, 13.42% and 0.78 respectively. In Italy, the performance analysis of two systems 395.61 kWp and 1042.29 kWp showed that the PR of the two systems was 0.872 and 0.832 respectively [4]. In Morocco, Charaf H. *et al.* [5] examined experimentally different modules and sizes of PV systems and showed that the Twidell was the best module with PR = 0.8 and an average efficiency of 16%. The performance assessment of 4.5 kWp in Nigeria showed that the energy production of the system was 14.52% from the size of the system [6]. In addition, the performance analysis of 1.72 kWp system in Ireland was presented experimentally by Ayompe L.M. *et al.* [7]. The analysis showed that the annual total energy of the system was 885.1 kW h/kWp and system efficiency was 14.9%. On the other side, some of studies were focused on an economic feasibility of the PV solar systems depending on two main important indicators include life cycle and pay-back period. In Ireland, the experimental feasibility of 53.625 kWp PV system showed that the life cycle was 5.23 years [8]. In Japan, Yanxue L. *et al.* [9] simulated Techno economic performances of 5.0 kWp and showed that the net present value of system was over 20 years. As reported in Rodrigues S. *et al.* [10] study, the investment of 5 kWp system during 25 years in Germany and Italy was 13% higher than the most European countries. The payback period of 67.27 kWp system was recorded 11 years in United Kingdom [11]. In Palestine, the economic evaluation of 24.614 kWp system showed that dynamic pay-back period of system was 10.4 years [12]. The main goal of this work is to study the necessary of using the PV system to provide the required electricity for Iraqi houses. An economic feasibility investigation of 3 kWp PV solar system by calculating the life cycle cost was analyzed and compared with the two alternative sources represented in neighborhood and household generators.

2. Problem and aim of the study

The electricity sector in Iraq suffered from deterioration since 1991 till now due to:

1. Old power generation plants, distribution and transmision networks;

2. Economic embargo in 1991;
3. American invasion in 2003;
4. Vandalism and neglecting from Iraqi goverment.

These factors led to severe power shortages to households, with power being available for less than 12 hours per day. To meet these power shortages, Iraqi families were forced to use other alternative sources such as the diesel neighborhood generators together with small gasoline portable generators (household), both of which have added a considerable financial burden on people. The financial burden includes the prices of generators, fuel and maintenance costs. In view of this phenomenon, the main goal of this work was to suggest and analyze the feasibility economic of a 3 kW PV solar system and compare it with the financial burden of the two generators (neighborhood and household). The study was conducted for a period of five years from (2014 to 2019) according to the current Iraqi market price. Questionnaire form was prepared to facilitate the calculation cost of neighborhood and household generators as shown in Table 1. The information of a questionnaire form was taken in the region where the neighborhood generator installed. Numbers of parameters were included in the questionnaire form, some of these parameters were related to the neighborhood generator (number and price of ambers) and other parameters were related to household generator (purchase cost, operation hours and maintenance cost).

Table 1. Questionnaire form of generators information.

		Neighborhood generator		Household generator					
Family No.	No. of persons	No. of required amperes	Price (IQD/amperes*month)	Purchase cost (IQD)	No. of operating hours	Cost of fuel (IQD/day)	Period of oil change (hours)	Oil cost (IQD/year)	Maintenance cost (IQD/year)
1	3	4	8000	180000	4	1350	30–35	48000	80000
2	4	4	8000	210000	4	1350	25–30	58000	90000
3	5	4	8000	200000	4	1350	30–40	41000	90000
4	6	4	8000	225000	3	1013	30–40	31000	85000
5	4	4	8000	230000	4	1350	30–40	41000	90000
6	5	4	8000	230000	4	1350	25–30	58000	95000
7	5	4	8000	220000	4	1350	30–40	41000	85000
8	7	4	8000	240000	3	1013	30–35	36000	80000
9	5	4	8000	220000	4	1350	30–35	48000	85000
10	4	4	8000	240000	4	1350	30–35	48000	100000

3. Cost of neighborhood generator

Neighborhood generator is a private diesel generator widely used in Iraq after 2003 to provide the electricity during the duration of national power outage. It is invested by a person and placed in a small neighborhood. The Iraqi government supplies the fuel to the generators at a reasonable price.

So, the price of ampere from the neighborhood generator are controlled at 8000 IQD/ampere. According to the questionnaire form, the average of amperes demand of Iraqi family is equal to 4 amperes (equivalent to 1 kWh at 250 V supply). Therefore, the cost to be paid to the neighborhood generators for four amperes in one month is 32,000 IQD with total cost ($C_{n\text{-}g}$) in five years is 1,920,000 IQD ($C_{n\text{-}g}$ = 4 amperes × 8,000 (IQD/amperes×month) × 60 month = 1,920,000 IQD).

4. Cost of household generator

Iraqi markets contain different types of portable gasoline generators with different rated power (KVA) and different specifications. Gasoline generator model (Tiger-single phase-3KVA) with fuel capacity 10 liters and 0.5 liters oil were included in this study as shown in Figure 1. Schedule run of portable generator is from 5:00 am until 12:00 pm with an actual operation period 4 hours/day and the operation period depends on the national power outage and neighborhood generator off. The cost of household generator is listed in Table 2 including purchase, operation and maintenance cost. The cost calculation of household generator was investigated based on the data of Table 1.

Figure 1. Household generator.

Table 2. Cost of household generator.

Cost type	The explanation	Cost (IQD) per 5 years
Purchase	Average price in Iraqi market	210,000
Fuel	Consume 0.75 liter /hr (4 hours operation)	2,430,000
	Price of gasoline = 450 IQD/liter	
Oil	Oil capacity (0.5 liter)	180,000
	Period of oil change (30 hours operation)	
	Price of oil = 1500 IQD/liter	
Maintenance	Average cost in 1 year = 88,000 IQD	440,000
Total cost ($C_{h\text{-}g}$)		3,080,000

5. Proposed PV solar system

5.1. Load estimiation

The average maximum load was calculated in the summer and according to the actual need for household appliances as shown in Table 3. The actual operation period of appliances depends on the schedule of power shortages. Based on the table, the maximum energy demand is 1.11 kW then the maximum hourly load consumption should be 17.73 kWh. Figure 2 represents the actual load profile according to the number of operation hours.

Table 3. Measured appliances loads in Iraqi house.

Appliance	Watt	Number	Hours Used/Day	Watt Hours/Day
Refrigerator	350	1	12	4200
Ceiling Fan	80	4	12	3840
Light	60	8	8	3840
Television	250	1	10	2500
Cooling/heating water	300	1	10	3000
Laptop	70	1	5	350
Total power (E_L)	1110			17730

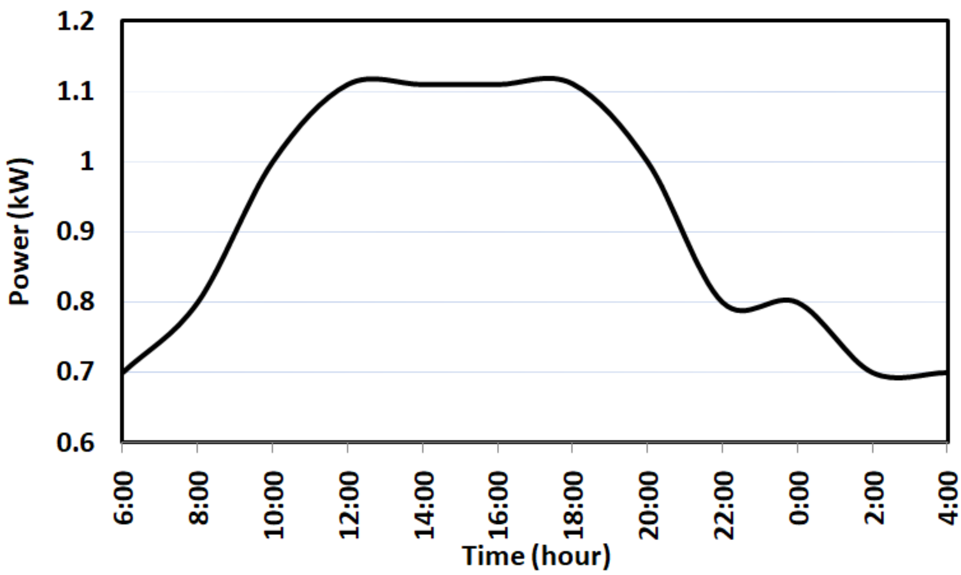

Figure 2. Actual load profile.

5.2. Description of the solar system

A 3 kWp system with twelve solar module (Dusol DS60260W Dubi) made from polycrystalline silicon was proposed in this study according to the calculation of the load and sizing of components.

The general specifications of the solar system components are summarized in Table 4 and its photograph shown in Figure 3.

Table 4. General specifications of the solar system components.

Component	Quantity	Model type and manufacture	Specification	Value
			Maximum power (Pmax)	250 W
			Open cicut voltage (Voc)	38 V
			Short circuit current (Isc)	8.79 A
			Peak voltage (Vmpp)	31.4
Solar module	12	Dusol DS60260W	Peak current(Impp)	8.28 A
		Dubi	Area	1.67 m^2
			Efficiency	14%
			Battery voltage	12/24/48 V
Solar controller	2	MPPT/China	Charger current	60 A
			Maximum power	840/1680/3360 W
			Maximum voltage	150 V DC
Inverter and charger	1	SAKO/SKN-S 1.5 kW	Input voltage	24 V DC
			Output voltage	220 V AC, 50 Hz
			Nominal voltage	12 V
Battery	2	Fortuner FR12-300D	Power	300 Ah

Figure 3. Proposed PV solar system.

5.3. Sizing of solar system

The sizing of the PV solar system components includes: number of solar panel, inverter output power, storage capacity of the battery and MPPT controller.

5.3.1. Number of solar cell

The total peak power and the module number of the proposed PV system can be calculated as [13]:

$$P_{PV} = \frac{E_L}{PSH \times \eta_R \times \eta_{in}} \times SF = \frac{17.73}{8.7 \times 0.9 \times 0.92} \times 1.2 = 2{,}855\ Wp \quad (1)$$

$$N_{PV} = \frac{P_{PV}}{P_{module}} = \frac{2855}{250} \approx 12\ cells \quad (2)$$

where: E_L: Daily Energy consumption (17.73) kWh, PSH: peak sun hours (8.7) hours [14], η_R and η_{in}: charge regulator and inverter efficiencies (0.9 and 0.92) [13], SF: Safety factor (1.2) [15] and P_{module}: module power is selected (250) W.

5.3.2. Inverter sizing

The inverter output power (IOP) calculated according to [16]: IOP = (25−30)% greater than maximum load (ML) = 0.25 × 1.11 + 1.11 = 1.38 ≈ 1.5 kW. Therefore, the inverter specifications is selected as 1500 W, 24 V DC, 220 V AC, and 50 Hz.

5.3.3. Sizing of battery

As reported in [12], the watt hour capacity of pattery can be calculated as:

$$\text{Watt hour capacity (Cwh)} = {}^{NC \times E_L}\!/_{DOD \times \eta_b} = {}^{0.5 \times 17730}\!/_{0.75 \times 0.85} \approx 13{,}906\ \text{Wh} \quad (4)$$

NC: Number of continuous cloudy days of the interested area = 0.5, DOD: Permissible depth of discharge rate of a cell = 0.75 [12], η_b: Battery efficiency = 0.85 [12].
The selected DC bus voltage is 24, therefore:

$$\text{Ampere hour capacity } (C_{Ah}) = C_{wh}/24 \approx 579.5\ \text{Ah} \quad (5)$$

Number of batteries = 2 batteries of 12 V and 300 Ah connected in series to give 12 hours operation.

5.3.4. Sizing of MPPT controller

$$\text{Total maximum power of PV } (P_{max\text{-}tot}) = P_{max} \times N_{PV} = 250 \times 12 = 3000 \text{ watts} \quad (6)$$

The maximum power of controller ($P_{max\text{-}C}$) and number of controller (N_C) can be calculated as [15]:

$$P_{max\text{-}C} = \text{Battery voltage } (V_b) \times \text{Controller current } (I_C) = 24 \times 60 = 1440 \text{ watts} \quad (7)$$

$$N_C = P_{max\text{-}tot}/P_{max\text{-}C} = 3000/1440 \approx 2 \text{ controllers} \quad (8)$$

5.3.5. Life Cycle Cost (LCC) analysis

The LCC of the PV solar system can be classified into three parts: (i) components cost (ii) installation cost (iii) operation and maintenance cost. The details of calculating the components cost of the proposed PV solar system are represented in Table 5.

Table 5. Cost calculations of proposed PV solar system.

Components	Quantity	Cost (IQD)	Total cost (IQD)
Solar cell	12 cells/250 W	700/W	C_{PV} = 2,100,000
Solar controller	2	80000	C_c = 160,000
Inverter	1	650000	C_{inv} = 650,000
Battery	2 batteries/300 A	1600 / A	C_b = 960,000
Wiring, base and installation	Total	100000	C_{ins} = 100,000
Operation and Maintenance (O&M/yr)	Total	2% PV cost	$C_{O\&M}$ = 79,400

The present worth of the maintenance cost for the proposed PV solar system in 5 years can be calculated as [16,17]:

$$C_{MPW} = \frac{M}{yr}\left(\frac{1+i}{1+d}\right)\left[\frac{1-\left(\frac{1+i}{1+d}\right)^{N}}{1-\left(\frac{1+i}{1+d}\right)}\right] = 336{,}966 \text{ IQD} \tag{9}$$

where: i is the inflation rate and assumed to be 3% and d is the interest rate assumed to be 9%. Therefore, the total life cycle of the PV system can be calculated as [18]:

$$LCC = C_{PV} + C_C + C_{inv} + C_b + C_{ins} + C_{MPW} = 4{,}386{,}366 \text{ IQD} \tag{10}$$

5.3.6. Evaluation of results

The Iraqi government has not given much attention to use of PV solar energy for solving the problems in the electric power sector. In this paper, the cost and an economic feasibility investigation of proposed PV solar system was analyzed by calculating the life cycle cost. A comparison between the proposed system and two alternative sources (generators) that used together in Iraqi house was investigated. According to the results analysis, the total cost of the financial burden in five years for neighborhood generator was found to be (1,920,000 IQD ≈ 1600 USA$) while the cost of household generator was found to be (3,080,000 IQD ≈ 2566.6 USA$). Totally, the cost of the two generators was recorded about (5,000,000 IQD ≈ 4166.6 USA$) in five years. As shown in Figure 4, the cost of household generator represents 61.6% from the total cost of the two generators. The cost of neighborhood generator increases with an increasing in number of amperes that the Iraqi family needed. While, the cost of household generator depend on two parameters (operations hours and maintenance cost). The operation hours of household generator increase in the event of breakdowns of the neighborhood generator causing an increase in the cost of fuel and oil consumption and maintenance. On the other side, the life cycle cost LCC of the proposed PV solar system is found to be (4,386,366 IQD ≈ 3655 USA$). As shown in Figure 5, the cost of PV system is less than the cost of two generators by (613,634 IQD ≈ 511.3 USA$). In the other words, the LCC of two generators is greatly higher than PV solar cost with 12.27%.

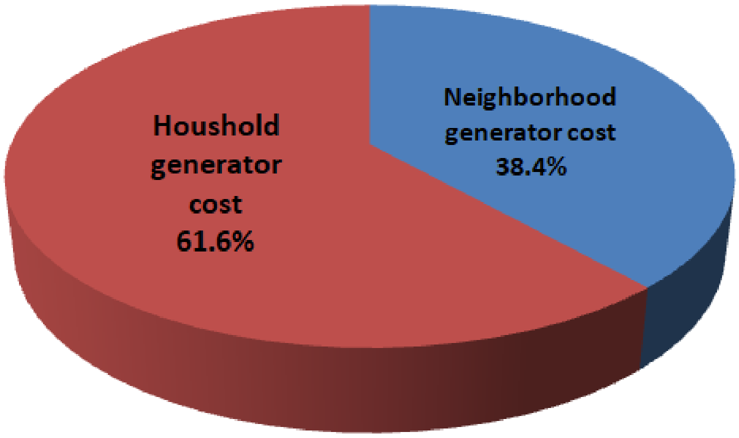

Figure 4. Total cost of generators.

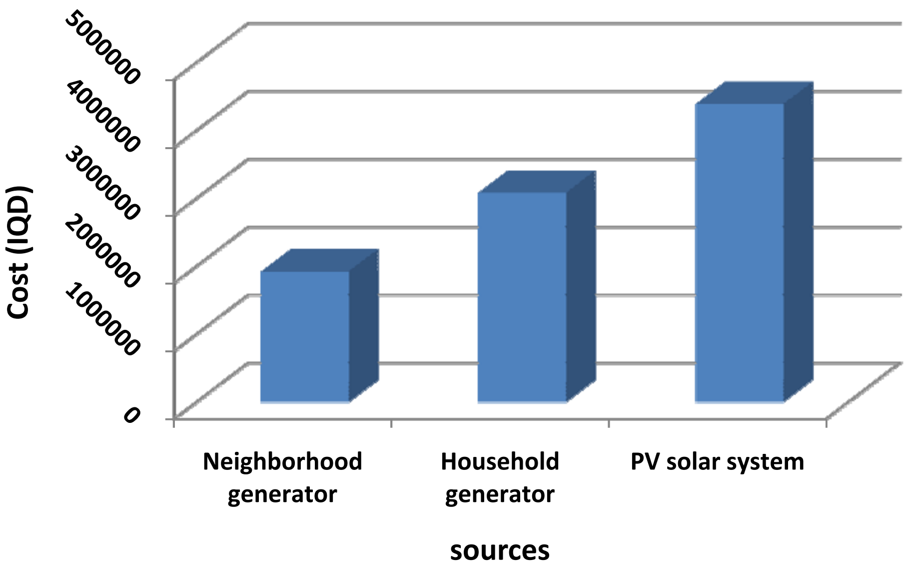

Figure 5. Costs of three sources.

6. Conclusions

According to the economic feasibility analysis of the PV solar system comparing with the two types of generators, the following conclusions can be made:

1. The cost of household generator is greater than the neighborhood generator about 42.6%;
2. The breakdowns in the neighborhood generator increase the operation hours of the household generator then increase the fuel, oil and maintenance costs;

3. According to LCC, the cost of two generators is greatly higher than PV solar cost with 12.27%;
4. The PV solar system is more economic in Iraqi houses under the deterioration in the electricity sector. Furthermore, the PV solar not pollutes the environment as the case of using household and neighborhood generators.

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Conflict of interest

All authors appear no conflicts of interest.

References

1. Nawaz I, Tiwari GN (2006) Embodied energy analysis of photovoltaic (PV) system based on macro- and micro-level. *Energy Policy* 34: 3144–3152.
2. Pearce JM (2002) Photovoltaics—a path to sustainable futures. *Futures* 34: 663–674.
3. Sharma R, Goel S (2017) Performance analysis of a 11.2 kWp roof top grid-connected PV system in Eastern India. *Energy Rep* 3: 76–84.
4. Ghiani E, Pilo F, Cossu S (2013) Evaluation of photovoltaic installations performances in Sardinia. *Energy Convers Manage* 76: 1134–1142.
5. Hajjaj C, Merrouni AA, Bouaichi A, et al. (2018) Evaluation, comparison and experimental validation of different PV power prediction models under semi-arid climate. *Energy Convers Manage* 173: 476–488.
6. Ismail OS, Ajide OO, Akingbesote F (2012) Performance assessment of installed solar PV system: A case study of Oke-Agunla in Nigeria. *Engineering* 4: 453–458.
7. Ayompe LM, Duffy A, McCormack SJ, et al. (2011) Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. *Energy Convers Manage* 52: 816–825.
8. Murphy F, McDonnell K (2017) A feasibility assessment of photovoltaic power systems in Ireland; a case study for the Dublin Region. *Sustainability* 9: 1–14.
9. Li Y, Gao W, Ruan Y (2018) Performance investigation of grid-connected residential PV-battery system focusing on enhancing self-consumption and peak shaving in Kyushu, Japan. *Renewable Energy* 127: 514–523,
10. Rodrigues S, Torabikalaki R, Faria F, et al. (2016) Economic feasibility analysis of small scale PV systems in different countries. *Sol Energy* 131: 81–95.
11. Lee J, Chang B, Aktas C, et al. (2016) Economic feasibility of campus-wide photovoltaic systems in New England. *Renewable Energy* 99: 452–464.
12. Mahmoud MM, Ibrik IH (2006) Techno-economic feasibility of energy supply of remote villages in Palestine by PV-systems, diesel generators and electric grid. *Renewable Sustainable Energy Rev* 10: 128–138.
13. Akel A, Mahmoud M, Shabaneh R (1996) Renewable energy assessment for Palestine (solar and wind). *Palestinian Energy Environ Res Cent*.

14. Al-Salihi AM, Kadum MM, Mohammed AJ (2010) Estimation of global solar radiation on horizontal surface using routine meteorological measurements for different cities in Iraq. *Asian J Sci Res* 3: 240–248.
15. Kebede KY (2015) Viability study of grid-connected solar PV system in Ethiopia. *Sustainable Energy Technol Assess* 10: 63–70.
16. How to design solar pv system-guide for sizing your solar photovoltaic system. Available from: http://www.leonics.com/support/article2_12j/articles2_12j_en.php.
17. Messenger R, Ventre J (2000) *Photovoltaic Systems Engineering*. CRC Press LLC: Boca Raton, Florida, USA.
18. Ajan CW, Ahmed SS, Ahmad HB, et al. (2003) On the policy of photovoltaic and diesel generation mix for an off-grid site: East Malaysian perspectives. *Sol Energy* 74: 453–467.