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Evaluation Of An Off-grid Photovoltaic Technology For Household Application In Iraq

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ABSTRACT

Diversity of energy sources become an imperious need for the sustainable energy utilization and provision of alternative sources to fossil fuels. The rapid growth in renewable energy uses encouraged numerous to invest and research in different fields of renewable energy. Using of Photovoltaic (PV) technology to generate electricity was one of the most advanced technologies that attracted the attention of companies and researchers to focus on especially in the applications that touches people's life. In this study, off-grid PV system was suggested as an alternative source supplying electricity to a typical household located at latitude (30.5˚N) and longitude (47.8˚E) in the capital Baghdad, Iraq. The electrical power consumption compared with the electricity providing by the national grid using of design and simulation software (sunny design. 3). Electricity demand of the house was estimated based on the daily electricity usage in summer season, assessed taking the cost of electricity and environmental impact into considerations. The outcomes demonstrated that the PV system can handle more than (77.3%) of the apartment electricity within a year, while, the rest electrical shortfall compensates using genset system (local diesel generator). Moreover, the generated CO_2 emissions from traditional electrical power source was reduced to approximately (22.7%) when PV technology introduced. The study also evident the feasibility of using such system by comparing the price of total power consumption in kWh/ month with the national grid price for the same power consumed where was very competitive.

Keywords: Photovoltaic system, off-grid PV systems, Storage battery, Sunny design.3.

I. INTRODUCTION

Improving the performance of photovoltaic systems have become essential to achieve wide utilization in the area of energy planning, taking cost reduction of PV module manufacturing into consideration, which allows the consumer to compare the energy price produced from PV system with traditional systems [1]. PV systems are not used only for producing power, it can be used in other aspects as an external wall in buildings, roof, window, facade and shading while retaining greater efficiency for photovoltaic module [2]. Recently, solar energy utilization has been growing as an alternative to existing power generation systems which depends on fossil fuel, with expect to improve the efficiency of solar power generation at a sensible cost [3]. Using of renewable energy will contribute to reduce environmental degradation, such as CO_2 emissions by relying on the most reliable energy conversion systems which helpful maintain the sustainable energy system [4]. After choosing the type of PV module and solar cells, there are many factors control in produce energy of solar power which lead to raise yield energy such as radiation intensity, surrounding temperature of PV module and load resistance [5], and, to provide the maximum energy from the photovoltaic system several methods have been used that may contribute to a large scale in develop solar systems operation during climatic changes such as high temperatures and various solar radiation.

Usually, the photovoltaic operation which extract energy from the sun and form it as a direct current (DC) electricity will be influenced by some factors such as shading and operating temperature, that will affect the performance ratio for PV system which will be clear during system outputs and the efficiency as well [6]. A statistics analysis used some photovoltaic simulation programs showed that a PV system improved significantly using interconnection model and the equation of photovoltaic in both winter and summer season depends on various combinations of tilted surfaces [7]. Moreover, it is necessary to know the path of maximum power point of photovoltaic and achieve maximize efficiency of PV system which associated with changing environmental

conditions such as quantity of solar radiation and solar cell's temperature [8]. To provide a dependable services able to meet the consumers' needs with sufficient way - especially at populated rural areas, photovoltaic Off-grid system can be helpful to meet the electricity energy demand in an efficient and sustainable method [9].

II. METHODOLOGY

This study conducted using of sunny design-3 software package. This software provided and developed by a German company called SMA (System, Mess and Anlagentechnik). SMA is a producer and manufacturer of solar inverters for photovoltaic systems with grid connection, off-grid power supply and backup operations. The software uses for planning and designing PV systems and PV hybrid systems. it gives PV system recommendations and proposes a combination of PV array(s) and inverter(s) which meet, as closely as possible, with house requirements regarding power class, energy yield and efficiency. In addition, it has the option of determining and optimizing the potential self-consumption, sizing the cables, evaluating efficiency.

PV module data that used in the study were provided from the datasheet specifications of the manufacturer where some technical, operational and economic advantages were taken into consideration. The software dealt with data of 4-people house located at latitude (30.5˚N) and longitude (47.8˚E) in the capital Baghdad in Iraq. The necessary metrological data were included in the software such like latitude, longitude, ambient temperature, solar irradiation etc., see Fig. 1, where those data reflect the feasibility of selecting the proper PV modules according to the Iraqi weather conditions. SMA has integrated the other available data into the software with the greatest care possible.

III. PV SYSTEM CONFIGURATION

1. PV module

To achieve highest power extraction from the PV modules requires selecting of good sort of solar cell in the system which can operate efficiently under different conditions. In this study, the polycrystalline module was selected based on technical, operational and economic considerations. This type of PV modules is available in the Iraqi market, and has an outstanding performance especially at low solar radiation and different temperatures as well as a good performance under standard test conditions (STC), as it shown in Table 1, from the manufacturer's datasheet. All PV modules used of the same type and they have connected identically in series taking into consideration the case study household area and all modules were installed at one tilt angle (37˚) with an orientation toward the south in mounting type. It is worth to mention that the case study house is not surrounded by trees or high buildings in all respects, which ensures the successful installation of PV system on its 150 m^2 roof.

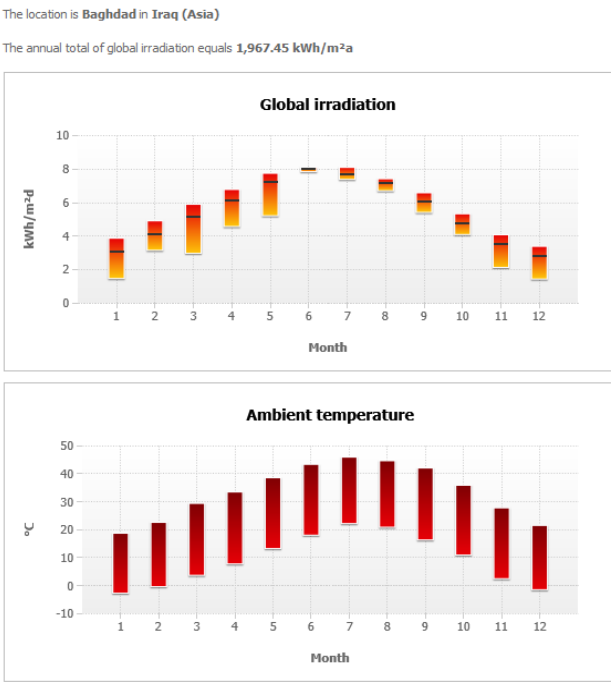

Fig. 1 The annual solar irradiation and ambient temperature variation of Baghdad 2018.

Table 1
The properties of PV module.

Manufacturer	Canadian Solar Inc.	**Cell technology**	**Poly**
PV module	CS6X-320P Maxpower (05/2017)	**Certification**	EU
Electric properties			
Nominal Power	320.00 Wp	**Mechanical Properties**	
Performance tolerance	-0.00/+5.00 W	No. of cells in PV module	72
MPP voltage	36.80 V	Width	982 mm
MPP current	8.70 A	Length	1954 mm
Open-circuit voltage	45.30 V	Weight	22.00 kg
Short-circuit current	9.26 A	connector	Andere
Permissible system voltage	1000.00 V		
PV module efficiency (STC)	16.68 %		

2. Battery-Storage System

Power generation and power load produced from photovoltaic off-grid system are not similar. Therefore, it became necessary to control on the variation of solar power- the fluctuation of solar radiation during the day - using storage system with different sizes as a suitable solution to reduce this issue [10].

Some important factors have been taken into consideration when we have select the type and size of battery such as night hours when the sun goes down, cloudy days, load profile, etc. it is necessary to know the time period that battery can supply the load just from the battery and planned at least for two days for bridging time. It is also important to select the battery that has the ability to charge and discharge depending on battery capacity. In our study, 16 storage batteries of 200 A were used in the system to maintain energy requirments and load demand at different situations .

3. PV inverter

The inverter plays an important role to regulate energy balancing of the supplied and consumed energy by house load. The inverter is regulating voltage and frequency of an off-grid PV system and conserve the input DC voltage of the battery at fixed value for better stability. Moreover, the average lifetime of inverter is long compared to the other parts of system, where contribute to reduce cable losses and has a significant role on the system performance especially when the connection between components of PV systems is robust.

Type of the two inverters selected for the study has the characteristics shown in Table 2 where they are appropriate for installation at extreme climate conditions in Iraq.

Table 2
Characteristic of PV inverter.

Inverter SB5.0-1AV-40		**Input data**	
General data		Max. DC power	5.35 kW
Degree of protection	IP65	Max. input voltage	600 V
Width	435 mm	Rated input voltage	365 V
Height	470 mm	Min. input voltage	100 V
Depth	176 mm	Start voltage	125 V
Weight	16.0 kg	Max. MPP voltage	500 V
Efficiency		Max. operating input current per MPPT	15 A/20 A
Max. efficiency	97 %	Max. input short circuit current per MPPT	20 A/20 A
European Weighted efficiency	96.5 %	Strings per MPP input	2 / 2
Output data			
Max. AC apparent power	5.00 kVA	Rated power	5 Kw
Min. displacement power factor	0.8	Nominal AC voltage range	180-280 V
AC Power frequency	45-65 Hz	Feed-in phases	1

4. Power consumption

The photovoltaic off- grid system designed to supply electricity to 4-people house. The amount of electricity consumption is unstable within the year where electricity demand maximizes during summer period due to the temperature rising and the consumption will reduce to a certain extent throughout the winter.

A diesel genset (local diesel generator) can be used as an external electrical power source to meet the power shortage during cloudy days or to keep continuous energy supplied during the night. Using of diesel generator will provide the energy when the batteries drop or when the PV array unable to meet the energy consumption in the house sometimes. For eco-protection considerations, It is worth to mention that the use of genset will be seasonal (often during the peak period in summer) as the PV system will be sufficient in the transition period between summer and winter where the electrical load is relatively low.

The total electrical power assumed as an input to the software which consumes by the house was estimated based on the typical house (4-people) usage of electrical devices. The family is consuming about 1 329.25 kWh per month which is equal to 15,951 kWh per year, see Table 3, where the total peak load has estimated during summer season.

Table 3
Typical electrical power consumption values according to MOE of Iraq.

Elec. Device	**No.**	**PWR Cons. (watt)**	**Work hrs./day**	**No. of days**	**PWR Cons. (W/month)**
Economic lamp 20 W	10	20	12	30	72 000
Fridge	1	250	12	30	90 000
Freezer	1	300	12	30	108 000
TV + Satellite	1	250	6	30	45 000
Dishwasher	1	1250	0.5	30	18 750

Fan	3	200	10	30	180 000
Water pump	1	800	0.5	15	6000
Iron	1	400	0.5	10	2 000
Washing machine	1	1200	1	8	9 600
Computer	1	100	4	20	8 000
Microwave oven	1	1200	0.25	15	4 500
Vacuum cleaner	1	1250	0.5	12	7 500
Kettle	1	1000	0.25	30	7 500
A/C(1.5 tone)	2	2000	6	30	720 000
Total power consumption (kWh/yr.)			1 329 250 Watt.h * 12 /1000 **= 15 951**		

5. The cost

The cost of PV modules is the most important problems facing this technology at the beginning of its development. However, it has become somewhat stable in the last few years because of the reduction in price of manufacturing and increasing number of competitors in the market. The price of electricity generated from the PV system depends largely on its size, the large system size the lower price and viseversa. So, it is normal to conclude that small PV systems at the household level are the highest price.

Generally, the cost of PV systems can be calculated from the initial cost plus the operational cost. Total initial cost depends on the type of PV module(s) used and other system parts which include the storage battery, PV inverter, frame, electrical and electronic accessories as well as the cost of transportation, installation and maintenance. Table 4, contains the initial cost of PV system used in the study based on the Iraqi market where the prices are a little bit high because of the lack of companies deal with such systems.

The operational cost is the other significant part of photovoltaic off-grid system total cost with an operating lifetime ranged from (20 – 25) years. This cost is what makes such systems a good competitor to the traditional systems and worth to invest in addition to being an environmentally friendly technology.

Table 4
Typical prices of PV system parts. [11]

PV system component(s)	No. in use	Component Cost ($)
PV module 320 Watt (polycrystalline)	21	190/ module
Storage battery 200 A	16	250/ battery
PV inverter 8000 VA	2	2000/ inverter
Frame, cables, wires, transportation, installations	--------	1 500
Total PV system cost	--------	13 490

IV. RESULTS AND DISCUSSION

In Iraq, it is locally known that energy consumption is variety within the day during the summer period where the peak load is associated with the human activities and the need to use electrical devices. Air-conditioning systems and cooling devices are the most which consume electric power due to the hot summer season in Iraq that requires such devices for long time hot weather during the day.

Fig. 2 and Fig. 3 show the variation during the day where the peak load can be noticed from the first hours in the morning to the late afternoon, and the variety of power consumption per each month within the year, respectively.

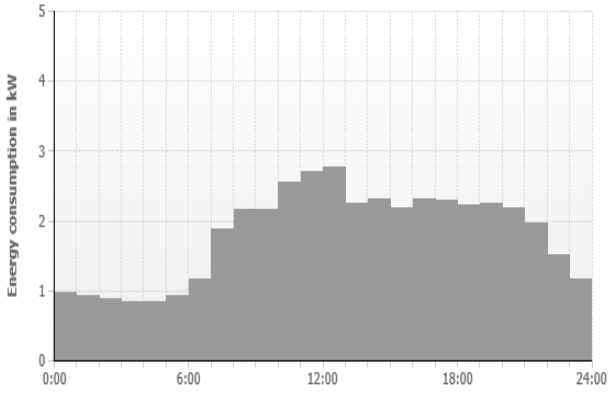

Fig. 2 Peak load variation during the day of study.

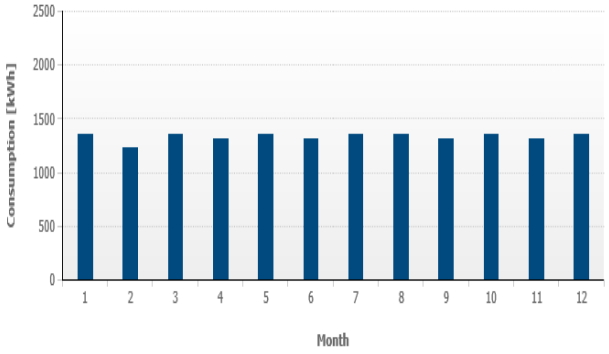

Fig.3 Power consumption of PV system per month

Table 5, and Fig. 4 detailed the power analysis and operating results generated by the software where they conducted that

off-grid photovoltaic system can produce (12 332 kWh/yr.) out of (15 951 kWh/yr.) the total electrical power demand of the house during peak load and the rest can be maintained using the genset system.

Table 5
Annual power analysis of the system

Operating Parameter	Value (kWh)
Annual energy consumption	15 951
Max. available PV energy	12 332
Used PV energy	12 332
Diretly consumed PV energy	7 936
Intermediately stored PV energy	4 396
Annual energy generation of the genset	5 697

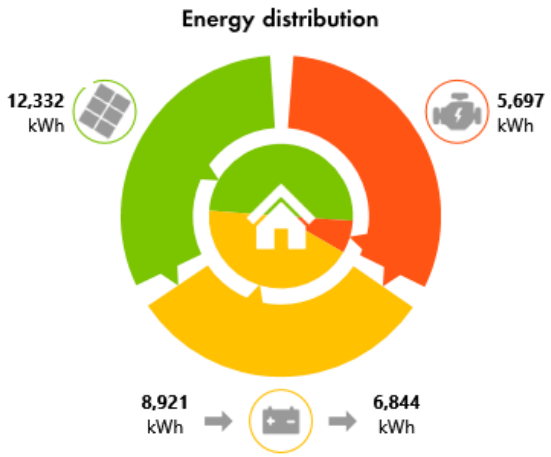

Fig. 4 Energy distribution of PV system

For the environmental point of view, Table 6, evedint that the use of PV system reduces CO_2 emissions generated from the power plants used to provide electricity to the national grid. According to the International Energy Agency IEA, Iraq is one of the countries that has a high CO_2 emissions ratio (about 1002.8367 gms./kWh) due to the use of petroleum products (gasoil, natural gas etc.) to generate electricity [12].

Table 6
Annual reduction of CO_2 emissions

Power (kWh)	CO_2 grammes/ kWh	CO_2 kg emissions
12 332	1002.8367	12 366.9822

Finally, It is very important to know the economic feasibility of using such system and compare the cost of each kWh produced with the official price of the governmental national grid. As it mentioned before, the total initial cost of the PV system is (13 490 $) with operational lifetime up to 25 years. It means that it costs (540 $) yearly, and (45$ ≈ 56 250 ID) for each operating month which represent the approximate cost of total electrical power consumed per each month (1 329.25 kWh). On the other hand, the same total consumption costs about (44 230 ID/ month) according to the new prices of Iraqi ministry of electricity [13].

V. CONCLUSIONS

The study indicates that PV system could be a suitable alternative to traditional systems that rely on fossil fuel sources to produce electricity, especially in areas away from national power transmission lines or that do not have at all. The study also pointed out the importance of this system in terms of protecting the environment from CO_2 emissions associated with the production of electricity in conventional ways. Economically, the evaluation of such systems comparing with the new governmental electric power price is important and necessary in the study, in addition to suitability of the application and its ability to supply electricity efficiently. There is no doubt that there are other aspects that were not considered in the study, which may constitute an important reason for not using this technology in Iraq including: high initial cost, complex maintenance of the system, lack of expert hands in this area, Iraqi weather conditions especially when it comes to dust which negatively affects the efficiency of the system, etc.

The proposed system has proven successful where it produces about (77%) of the total house power consumption during peak period, and this amount is sufficient during other times when the need for electricity is low. On the other hand, since the most important characteristic of these systems is that they are environmentally friendly, so the percentage of CO_2 emissions decreased to about (23%), which is associated with the operation of the diesel generator to maintain the shortage of energy supplying.

The fact that Iraq is one of the oil-producing countries and depends on petroleum products in power generation does not mean that these systems are not feasible economically when compared to national networks. The study concluded that the monthly cost of power consumed by the house increases by only (12 000 ID ≈ 10 $) using PV system compared to the cost of the national network which present a few cost taking other benefits into consideration.

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