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Investigation of Converting a Building to Operate by Solar Energy

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Abstract*: *Many governments recognize the advantages of generating the electricity from solar energy and therefore, they offer generous incentives and cash rebates to install photovoltaic (PV) systems. Despite Iraq that is, as result of the electric shortages, 90% of its households are dependent on diesel generators that are controlled by independent operators, solar energy has not been widely utilized. This paper provides the fundamental information about design and constructing of PV system. It is also presenting a cost analysis of PV system that delivers about 1MWh per day. It is found that the solar energy price (0.1368$/kWh) is almost matching the actual cost of fuel-based electrical generation (0.13$/kWh [1]). Therefore, the PV systems can be competitive with the diesel power generators that are used by Iraqis if a source of funding is offered to offset the enormous up-front (initial) cost of PV systems.

Index Terms: PV system, Cost analysis, Levelized cost of electricity (LCOE), Electric demand.

I. INTRODUCTION

Highlight recently, different energy sources are becoming the main engine of the progress in the civilization and an essential element in human life. The typical energy sources that include oil (crude black oil that is extracted from the earth) are unable to meet the increasing demand for energy worldwide [2]. There are also growing concerns about decreasing the quantities of fossil fuel, increasing the oil prices, global warming, climate change, and air pollution [3]. Not surprisingly, the scientific community presented evidence that mankind has to decrease the gas emissions, particularly CO2 and methane, by 60 - 70% as a minimum until the year 2050 [4].

It has become a challenge that is how to find alternative power sources that are energy-friendly environment and to limit the depletion of non-renewable energy sources. As such sunlight, wind and biomass are typical sources that can be utilized to the forefront in electric power applications. Solar energy is in particular a source of interesting energy that can be used in various applications because it is free, renewable, non-transportation, and no pollution to the environment [2]. In that context, photovoltaic (PV) systems are widely used in either stand-alone configurations [5-6] or grid-connected schemes [7].

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Iraq, which has typical grid emission factor is about 0.82 kg CO2/kWh [8], extremely depends on fossil fuels to generate electricity. However, it faces the electrical energy shortages. Therefore, 90% of Iraqi households are dependent on diesel power generators that are controlled by private independent machinists [9]. As a result, the Iraqi cities suffer from air pollution that is above World Health Organization and Local references [9]. Moreover, the private diesel engines' gases that are spread by wind and rain cause pollution of rainwater and earth. Therefore, it is important to find other sources to generate the power. Iraq obtains about 3,000 hours of sunlight per year, making the solar energy ideal to generate electricity. Furthermore, the cost of PV system's elements on global markets continues to decrease. For instance, their prices today represent a tenth of what they were in 1990 [9].

This paper provides the fundamental information about design and constructing of PV system. It also presents a cost analysis of PV system that delivers about 1MWh per day. First the configuration of PV system is described. This is followed by the explanation of calculation of the maximum demand of electrical power. Then, the method of the cost calculation of the PV system is presented, and finally the comparison between the costs of solar energy and the utility grid energy is presented.

II. PHOTOVOLTAIC SYSTEM CONFIGURATION

As mentioned before the photovoltaic (PV) system is either a stand-alone scheme or connected (tied) to the utility grid; and it comprises solar panels, inverters, batteries, and charge controllers. Fig. 1 explains an 8-kilowatts PV system based on 100-watt panels and 5-hour solar day.

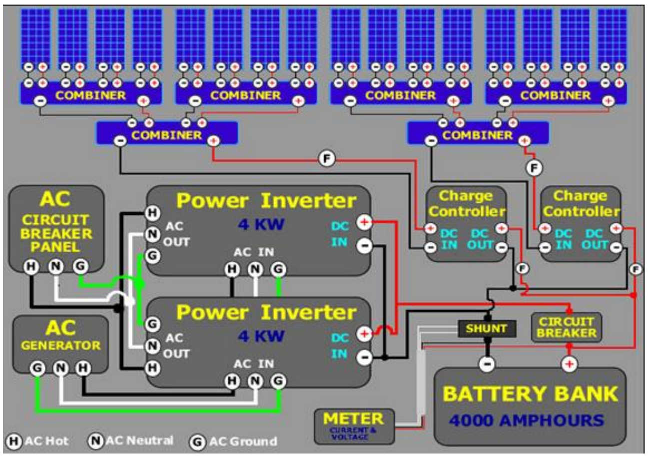

Fig. 1. The PV system [10].

Solar panel: Solar panel alters sunlight energy into a usable amount of direct current (DC) electricity [4]. There are typically three types of solar panels: monocrystalline, polycrystalline and amorphous [11]. The former consists of extremely pure silicon and therefore it is the most expensive and efficient type. Amorphous panels comprise of a thin layer of silicon deposited on a base material such as metal or glass. This type is the cheapest; however, its efficiency is the lowest than others. Solar panels range in power output from a few watts, up to 300 watts and they are also expected to operate for 25 years.

Inverters: A power inverter is an electronic device that transforms DC electricity, which is generated in the solar panels (or stored in the batteries), into AC energy that is utilized in almost all household applications. Inverters are typically divided into three types based on the output waves: the square wave, modified sine wave, and the pure sine wave [11]. The latter provide the electrical power that is exactly identical to the power produced by the utility company and therefore, these inverters are preferred.

Batteries: The batteries are employed to provide energy storage or backup power in case of a power interruption or outage on the grid. There are typically two types of batteries used within PV systems: lead-acid and lithium-ion batteries [12]. The former consist of lead grids mounted inside the acid. Three types of lead-acid batteries are produced: Flooded, Gel and AGM [12]. Flooded batteries are the most popular; however, they need maintenance and also require an especially constructed container because they produce toxic gases. Gel batteries employ a gelling agent such as fumed silica to immobilize the electrolyte. AGM (Absorbed Glass Mat) are the newest type of lead-acid batteries. As with the Gel cell, AGM battery is sealed and therefore it does not need maintenance. AGMs and Gel batteries can only lose 1 to 3% of the energy stored per month while flooded ones lose up to 12%. AGM cells convert 4% of the stored power into heat while Gel and flooded batteries lose about 10-16% and 15-20%, respectively [12]. Lithium-ion cell is the latest type of battery technology that uses Lithium in mixture with Yttrium Oxide to produce a cell that provides better performance in different environments. Lithium-ion battery is smaller (almost half) and lighter (third the weight) than an equivalent lead acid battery [12]. Lithium-ion batteries also have a better depth of discharge (DOD) which makes them optimal for PV systems. For instance, a system that needs a 100Ah discharge during 8 hours will request a 125 Ah lithium battery as compared to 230 Ah lead-acid batteries. In addition, the life cycle (the number of charge and discharge of the battery) of the lithium-ion battery is about 4 times of a comparable lead-acid battery [12].

Charge controllers: A charge controller is a device that essentially regulates the voltage and current coming to the battery from the solar panels. Charge controllers can be classified into shunt and series controllers [13]. The formers are simple and inexpensive; however, they are only used within small PV systems. The latter could be single-stage or multi-stage type. Most controllers that exist in the markets are three-stage controllers that have optimized charging rates and extended the life of batteries. Some chargers are programmable and they can be integrated with computers.

III. ELECTRICAL POWER DEMAND

The electrical power demand is always varying with the time of use, and it will not be constant. Normally, the connected load can be estimated and therefore it would be possible to figure the peak (maximum) power demand ($P_{peak,\ used}$), which is the highest of electrical power in a particular period of time and it is measured in Kilowatt (kW). The solar system needs to be designed to provide the maximum power whenever it is required by the user. As such, the peak load must be determined and then the PV system is accordingly designed. In this paper, the electrical department in Kut Technical Institution is used as an example to be provided with the solar electrical energy. This building has 7 laboratories, 4 classrooms, 3 staff rooms, and faculty and administrative offices. Table 1 shows the type, number and wattage of the devices that are used in electronics laboratory

Table (1): The Devices used in Electronics Laboratory

No.	Appliance	Qty.	Power (W)
1	Lighting	24	60
2	Air conditioner	1	2860
3	Exhaust fan	3	60
4	Ceiling fan	4	110
5	Experiment's board	6	300

The electrical power P, which is measured in Watts, of each device can usually be found on its nameplate. If the nameplate lists current, then

$$P_{(watts)} = V_{(volts)} * I_{(Amps)} \qquad (1)$$

where I is electric current in amperes, and V is electrical voltage in volts and it is 220v. Every type of the devices is then collected independently, and their power is calculated. It is assumed that the working hours vary from device to another as shown in Table (2). In order to calculate the average energy E in kilowatt-hours (kWh) per day for any electrical appliance, the following formula is used

$$E = P * t \qquad (2)$$

where P is the power in watts (kW), and t represents the number of usage hours per day. The total energy (E_{used}) per day is then calculated as shown in Table 2.

Electricity Cost Calculation: Cost of power generation remains the most significant factor in deciding whether a power technology could be commercial. To compute and compare the prices of energies across producing technologies, the levelized cost of electricity (LCOE) equation is employed [14-15]. For instance, the LCOE equation can be utilized to compare the price of energy produced by PV systems with that of a natural gas generating plant. The LCOE equation can be expressed as the following

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$$LCOE_{\$/kWh} = \frac{\text{Total lifecycle cost (\$)}}{\text{Total lifetime energy production (kWh)}} \quad (3)$$

$$= \frac{I - \sum_{n=1}^{N} \frac{d_n}{(1+r)^n} * \alpha + \sum_{n=1}^{N} \frac{c_n}{(1+r)^n} * (1-\alpha) - \frac{S}{(1+r)^N}}{\sum_{n=1}^{N} \frac{E}{(1+r)^n}}$$

where I is the initial cost; d and c denote to a depreciation tax shield and operating cost in year n, respectively; S represents the residual value of any physical parts at the end of lifecycle; N is the total lifecycle years; α represents the corporate tax rate; $[1/(1+r)]$ is the time value of money; and E means the energy production.

Table (2): The Total Energy Used and Its Cost

Applaince	Qty.		Power (W)		Hours Per Day		Energy per day (KW.h/day)
Lighting	262	x	60	x	8	=	125.76
Air conditioner	20	x	2860	x	6	=	343.2
Exhaust fan	25	x	60	x	8	=	12
Ceiling fan	71	x	110	x	6	=	46.86
Experiment's board	37	x	300	x	3	=	33.3
Computer	53	x	50	x	3	=	7.95
Refrigerator	4	x	330	x	8	=	10.56
Water heater	1	x	2200	x	8	=	17.6
Total AC power			Total energy per day			The cost $/kWh	
99500			597.23			0.146	
Total energy per day		X	Load correction factor			=	Energy used
597.23		X	1.25			=	746.5375

In Iraq, the actual cost of electrical generation is evaluated (by the Ministry of Electricity that owns and operates the Iraqi power sector) to be around 0.13$/kWh [1]. The Government divides public electricity consumers into four groups: home, trade, industrial, and governmental. Each group is considered within individual electrical prices. For instance, the prices of electricity to the governmental consumers (such as Universities) are ranging from 0.105$/kWh for consumption up to 5,000 kWh/month, to 0.188$/kWh for consumption over 40,000 kWh/month [1]. The cost of electricity per month in $ is equal to the total energy consumption E_{used} in kWh per month times the energy cost of 1 kWh in $/kWh

$$Cost_{(\$/month)} = E_{used\,(kWh/month)} * Cost_{(\$/kWh)} \quad (4)$$

The amount of the energy that is needed by the electrical department is shown in Table 2. The peak of the power $(P_{peak,\ used})$ is approximately (100 kW) while the energy E_{used} that is required during the day is approximately (598 kWh). This energy is what is needed from the solar cells. Note that the load correction factor is needed because of the losses that occur in the system [12]. Table 2 is also showing the average cost of the used electricity ($/kWh) and this will be compared with the solar power plant cost.

IV. PHOTOVOLTAIC SYSTEM COST

As mentioned the LCOE equation (3) is used to analyze the costs of electricity. To simplify this equation, it would be assumed that $N, \alpha,$ and $1/(1+r)$ are 25 years, 0, and 1, respectively. The operating cost (c) is assumed to be equal the residual value (S) and maintenance cost that includes the cost of replaced batteries. As cited before, the solar panel is expected to be active at least 25 years. This period of time will be used to estimate the total lifecycle cost that includes the initial cost and maintenance cost. The initial cost (I) that is the cost of the PV system elements, which is paid to install the PV power plant, is determined.

As stated above, the main components of PV system are solar panels, inverters, batteries, and charge controllers. The cost of each item in terms of some variables (which are the peak power demand, the total energy required per day, and the hours of sunshine) is firstly calculated. The costs of the PV system's elements are estimated by surveying present market prices. In that context, there are two costs to be considered for PV equipment: the energy cost and power cost. The former is the cost of batteries and it is expressed in US$ per kilowatt hour. The latter will include the costs of solar panels, power inverters, and charge controllers. The technique in [16] is adapted and used to determine the PV system cost and it is explained below. Table 3 shows the results of all calculations.

There are two types of electrical power that are required to be known before designing a solar system. The first is the peak power $(P_{peak\ used})$ that is provided to the load while the second is the peak power $(P_{peak\ panels})$ that is generated by the PV system. Note that the peak power $(P_{peak\ used})$ will be provided by the power inverters

$$P_{peak\ used} = P_{peak\ inverter} \quad (5)$$

The price of inverter is approximately 200 US$ per kilowatt; as such the total price is determined as

$$Cost_{inverters} = P_{peak\ inverter}\,(Kw) * 200\$/Kw \quad (6)$$

The total energy (E_{used}) that must be produced by the photovoltaic system and is consumed per day is used to determine the peak power of the solar panels $(P_{peak,panels})$ by using the formula

$$E_{used} = P_{peak\ panels} * T_{sun} \quad (7)$$

where T_{sun} is the average of the sunshine hours per day. As mentioned in Table 2, the energy used per day is approximately 747kWh and T_{sun} in Iraq is about 6 hours. As such, the $P_{peak,panels}$ is almost 125Kw. The number of solar panels that are used can be determined from

$$P_{peak\ panels} = \text{power per panel} * \text{number of panels} \quad (8)$$

The price of solar panels is about 1000$ per kilowatt; therefore, the cost will be

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$$Cost_{panels} = P_{peak\ panels}(Kw) * 1000\$/Kw \quad (9)$$

As with the solar panels, the total cost of charge controllers is evaluated by using $P_{peak\ panels}$. The price of charge controller is almost 50$/Kw and thus the cost will be

$$Cost_{controllers} = P_{peak\ panels}(Kw) * 50\$/Kw \quad (10)$$

The magnitude of the energy (E_{stored}) that is stored by the storage elements describes how much power can be applied during periods of the low power generation. This energy can be calculated from

$$E_{stored} = E_{battery} * n_{battery} \quad (11)$$

where $E_{battery}$ is the energy per battery and $n_{battery}$ is the number of batteries. As mentioned before the lifecycle of battery depends on number of charge/discharge the battery. It is also dependent on the amount of the energy that is discharged every time. As with [16], it will be assumed that the batteries are not discharged more than 50% and they will store two times of the quantity of energy that is used per day

$$E_{stored} = 2 * E_{used} \quad (12)$$

$$E_{stored} = 2 * 747kWh = 1494kWh$$

The cost of batteries mainly depends on their types. For instance, the price of lithium-ion batteries is about 600$/kWh while for Gel and AGM batteries is approximately 100$/kWh and 130$/kWh, respectively. AGM batteries will be considered and the cost will be

$$Cost_{batteries} = E_{stored} * 130\$/kWh \quad (13)$$

The cost of other equipment such as cables, battery racks, and meters will be also considered as shown in Table 3. The initial cost (I) of the PV system will be

$$I = Cost_{inverters} + Cost_{panels} + Cost_{controllers} + Cost_{batteries} + Cost_{equipments} \quad (14)$$

As with [16], the batteries are assumed to be working at least 6 years; therefore, they will be replaced about 3 times within 25 years. Thus, the lifecycle cost is calculated from

$$\text{Total lifecycle cost} = I + 3Cost_{batteries} \quad (15)$$

The total lifecycle energy production (E_{Total}) is calculated from

$$E_{Total}(kWh) = 25(year) * 365\left(\frac{day}{year}\right) * E_{used}\left(\frac{kWh}{day}\right) \quad (16)$$

The lifecycle cost ($/kWh) is then calculated by substituting Equations (15 and16) in Equation (3); and this yields

$$LCOE_{\$/kWh} = (I + 3Cost_{batteries})(\$)/[25(year) * 365\left(\frac{day}{year}\right) * E_{used}\left(\frac{kWh}{day}\right)] \quad (17)$$

V. DISCUSSION

It can be seen that the solar energy price (0.1368$/kWh) is almost matching the actual cost of fuel-based electrical generation (0.13$/kWh [1]). Therefore, the PV systems can be competitive with the diesel power generators that are used by Iraqis if a source of funding is presented to offset the enormous up-front (initial) cost of PV systems in comparison with the diesel-based generators. Many governments recognize the advantages of generating the electricity from solar energy and therefore they offer generous incentives and cash rebates with respect to the installation of PV systems.

The up-front (initial) cost can be dramatically reduced if the PV system elements are produced in Iraq. For instance, the cost of solar cells in China is between 450$/kWh and 720$/kWh while they are transported to Iraq to be cost around 1000$/kWh.

Many countries encourage their citizens to continue non-reliant on the electrical grid, to ensure a reliable source of electricity, and to improve mechanisms that will fund the initial cost (comprising selling the energy back to the public utility grid). However, in Iraq solar energy has not been widely utilized because of a number of barriers, practically: the Iraqi government supports the fuel-based electricity, and legislative framework that encourages the solar energy is lacking [9].

The energy storage elements (batteries) share the large amount of initial and lifecycle costs (see Table 3); however, solar lighting projects that were performed in Iraq have failed because the batteries were not lasting due to the extreme working temperature [9]. Therefore, it would be important to study and evaluate other storage technologies; such as pumped hydro [17], compressed air energy storage, and hydrogen [18].

If the solar electricity is produced in large scale, it can be sold to utility grid and yield some profits. The holydays in particular, the PV system will continue to produce electrical energy that will not be used .The production of solar energy in large scale can also produce solar energy regardless of the weather, whether it is sunny or not, making them sustainable and reliable production of electricity.

The PV system will not require a lot of maintenance work, once it is installed; it will work as efficiently as possible. This is supported by the progress in solar technology that continues to effect in economic terms to make them close to the cost of conventional electricity that is produced from fossil fuels.

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Table 3: The Initial and Lifecycle Costs

PV Equipment	Price	Power or Energy		Initial cost ($)	Lifecycle cost ($)
Solar panels	1000$/Kw	$P_{peak\ panels}$	125Kw	125000	125000
Batteries	130$/kWh	E_{stored}	1494kWh	194220	776880
Inverters	200$/Kw	$P_{peak,\ used}$	100Kw	20000	20000
Charge controllers	50$/Kw	$P_{peak\ panels}$	125Kw	6250	6250
Other tools	4000$		1	4000	4000
		The total cost		349470	932130
		$Cost_{\$/kWh}$		0.1368$/kWh	

VI. CONCLUSION

Iraq has faced electrical energy shortages, which force 90% of Iraqi households to be dependent on diesel power generators. The gases of those engines are spread by wind and rain; therefore, they cause pollution that is above World Health Organization and Local references. Iraq obtains about 3,000 hours of sunlight per year, making the solar energy ideal to generate electricity. However, the solar energy has not been widely utilized. This paper was presenting a cost analysis of PV system that delivers about 1MWh per day. It was found that the PV systems con be competitive with the diesel power generators that are used by Iraqis if a source of funding is presented to offset the enormous up-front (initial) cost of PV. The batteries are sharing the great amount of initial and lifecycle costs; however, solar lighting projects that were executed in Iraq have not succeeded because the batteries were not lasting due to the extreme working temperature. Therefore, it would be important as future work to study and evaluate other storage technologies such as: pumped hydro, compressed air energy storage, and hydrogen.

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