Technical, Economic, and Environmental Analysis of Solar System with Management Considering Flexible Energy Sources in an Educational Building

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Abstract. Decades of persistent power outages in Iraq have triggered economic, environmental, and technical woes. Building-integrated solar energy offers a compelling solution. This study explores the viability of a hybrid system combining renewable and conventional sources to power an educational building. Technical and economic analyses using SAM software identified a (PV-DG-Battery-Grid) HES with 5.6kW PV, 400kW DG, 5.5kW inverter, and battery bank as the most feasible, optimal, cost-effective, and environmentally friendly option. Further analysis assessed the impact of factors like solar radiation, fuel price, battery state of charge, cost of energy, performance, and CO2 reduction. Solar panels are estimated to generate 10,210 MWh/year. This research promotes the shift towards renewable energy integration in Iraqi buildings, supporting improved energy management and a more sustainable future.

1 Introduction

At the present time, the local network in the country suffers from frequent and continuous power outages for long hours per day, and processing is sometimes less than four or six hours only per day and relying heavily on energy from the diesel generators of government building, it has become necessary to think about energy management, which includes planning, operation, production, and energy consumption. One of its most important goals is to conserve resources, protect the climate, and reduce costs (especially with the economic crises the country is going through) while maintaining the delivery of energy to its users in a reliable and continuous manner.

Due to the high growth rates witnessed by renewable energy in terms of percentage globally [1], and the unprecedented interest in renewable energy in Iraq, especially solar energy, and wind energy, which provide electricity without causing carbon dioxide emissions [2]. Energy management was studied in the field of production, conversion, and distribution of energy from (the local network, diesel generator and renewable energy). Hence, solar energy was added using photovoltaic solar cells to the electrical network in the building.

Studying energy management system EMS can lead to many outcomes, such as reduced energy consumption, lower operating costs, and more efficient operations [3] where energy management can help achieve:

• Lower power consumption: Simply, energy management can use less power. Once you can monitor energy usage, you can identify areas of opportunity to turn off certain systems or reduce their use at certain times of the day. It means using less energy, and this was achieved after using an electrical sub-network for a governmental building.

• Lower operating costs: Because the building uses less energy, operating costs will naturally decrease as well, and the systems will operate more efficiently and sustain less wear and tear.

• Additional Power: EMS adds a level of power while considering environmental and economic factors that cannot be easily obtained through classical control.

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Simulation software (SAM) produced by NREL (National Renewable Energy Laboratory, a national laboratory of the US Department of Energy) was used to estimate the performance and study of the solar power plant [4].

Data from solar energy systems has been relied upon for many benefits, including:

Performance Monitoring: Using data from solar energy systems to monitor system performance, including the amount of energy generated, the efficiency of the panels, and the effectiveness of the energy storage system. Use this data to identify any performance issues and make system improvements to save costs.

System Optimization, Analysis and Planning: Using data from solar power systems to optimize system operation, including adjusting the angle of panels to maximize power generation and optimizing the energy storage system to ensure energy is stored and used efficiently.

Maintenance and Repair: Using data from solar energy systems to identify maintenance and repair issues [5].

Overall, data from solar energy systems has provided valuable insights into system performance and operation, helping to improve system efficiency and effectiveness, reduce costs, and increase return on investment.

Buildings with renewable energy often face difficulties in providing energy due to the lack of energy generation that depends on the vagaries of the weather [6]. This obstacle is caused by the intermittent nature of the loads as well as renewable energy sources [7]. Therefore, the Energy Management System (EMS) is necessary to solve the power outages, as the energy was managed by integrating flexible energy sources (FES) (has short and long-term storage capacities) and based on forecasting and deep study of the weather and loads, the efficiency of the system was raised. Fig. 1 illustrates the generic concept of energy sources [3].

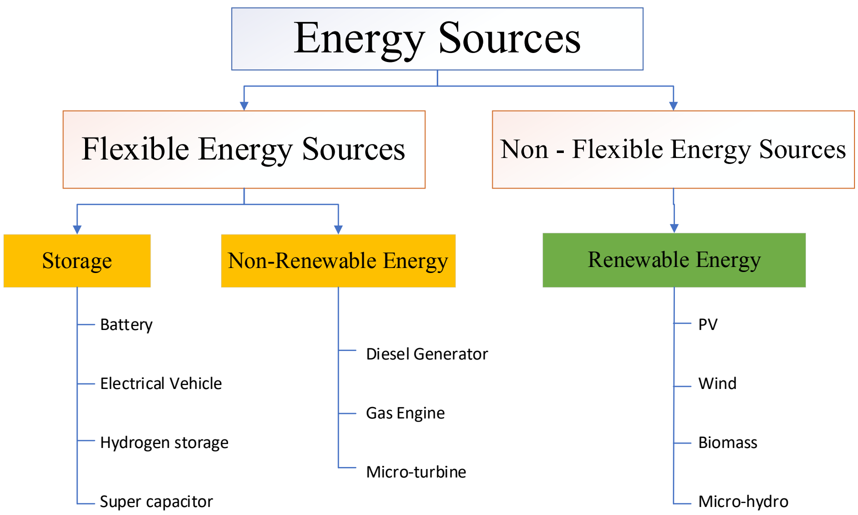

Fig. 1. Energy Sources.

1.1 Location description

The studied solar system was installed in a governmental building, Najaf, Iraq, at longitude 44.3 degrees east, latitude 32.03 degrees south and 23m (above sea level), to integrate with the electrical network of the building, as in Fig. 2.

The abundance of solar energy and the strategic importance of the building were taken into consideration when choosing.

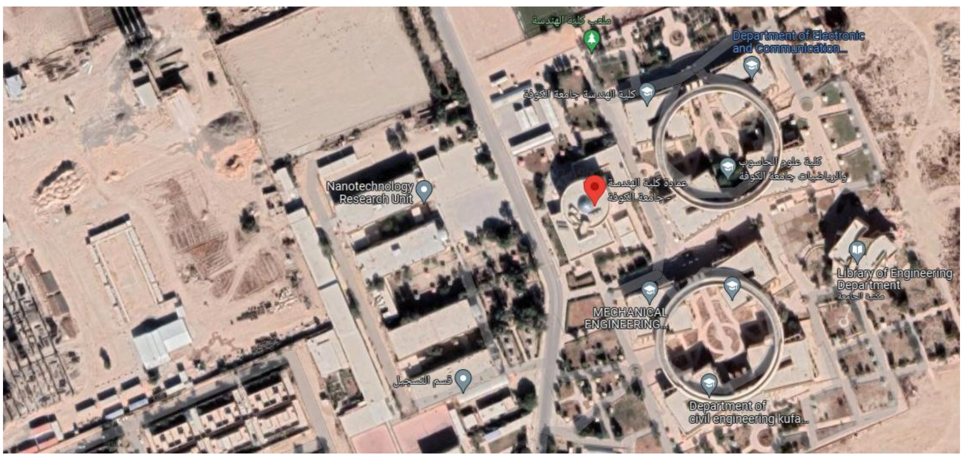

Fig. 2. Top view of the building by Google map.

1.2 Load Profiles

The electrical load profile is an essential parameter for this study, according to which power management and the system are built. The load profile of this building has been evaluated by considering various factors. The load profile is divided into two categories: a main part to operation the electrical load of the building at full capacity and eight secondary branches as in Fig. 3 to operation the primary loads uninterruptedly connected to solar energy.

The following expressions were used to calculate the energy demand per day:

$$E_d \left(\frac{kW}{h}\right) day = \frac{Na \times Pr \times H}{1000} \quad (1)$$

Where Ed is Energy demand (kWh/day), Na is number of appliances used, Pr is power rating of each appliance (W) and H is hours of operations.

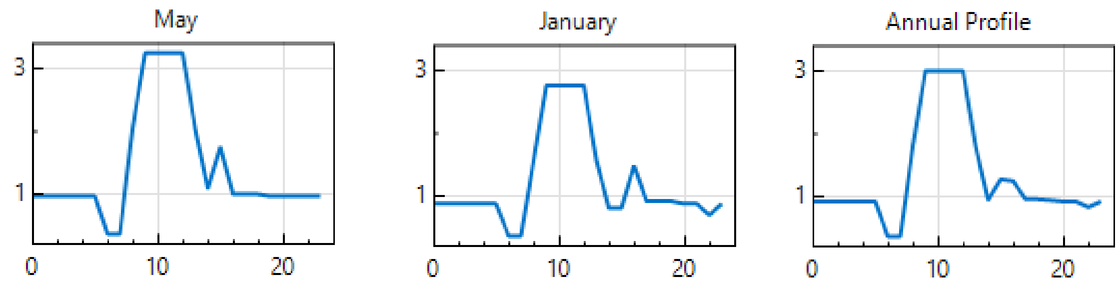

Fig. 3. Energy demand profile.

1.3 Solar Resource Assessment

Iraq enjoys more than 3,000 hours of bright sunshine per year, and direct normal irradiation (DNI) of about 6,3 kwh\ m2 in Jun as shown in Fig. 4. [8] Therefore, the solar energy source provides favorable capabilities for high electricity production for long hours during the day. Solar radiation reduces diesel generation operation times and fuel economy, and vice versa [9].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				1	21	45	28	2				
6 - 7			27	109	172	262	231	159	99	36	1	
7 - 8	63	139	259	272	297	406	382	351	356	253	203	72
8 - 9	338	366	415	379	405	514	495	469	480	372	381	364
9 - 10	442	468	526	465	489	600	585	561	577	466	468	457
10 - 11	513	558	618	526	545	652	642	624	645	540	524	513
11 - 12	555	601	656	557	564	676	667	652	667	553	536	540
12 - 13	564	587	628	549	556	673	668	650	659	528	530	532
13 - 14	534	566	586	501	521	649	646	628	630	489	495	511
14 - 15	486	518	532	442	463	597	597	575	568	418	433	460
15 - 16	400	434	446	364	381	512	513	489	474	321	339	365
16 - 17	120	264	327	267	277	402	401	369	322	114	63	69
17 - 18		14	78	120	155	272	268	191	53			
18 - 19					12	47	45	9				
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,015	4,513	5,098	4,553	4,857	6,308	6,169	5,729	5,532	4,093	3,974	3,883

Source: globalsolaratlas.info

Fig. 4. Direct normal irradiation [Wh/m²] for the selected sites.

2 System under study

2.1 PV Array (Solar PV energy system)

Many factors that impact the performance of solar PV module. For example, the effects of dust and soiling, impact of air pollution, effects of solar irradiance and temperature [10], wind velocity, effects of shading, the operational and maintenance factors, cost, and other miscellaneous factors on the performance of PV module [11]. Knowing these factors helps in selecting different photovoltaic panels to improve energy production and make it economically viable. However, this work mainly focuses on techno-economic performances. The specifications of the PV can be seen in Table 1. Information about the solar panels used in the system, including panel type, size, power rating, and efficiency.

Fig. 5. Array of solar panel on building roof

Table 1. Solar PV Module specifications

PANEL PARAMETER	Values
Model	JKM465M-7RL3-TV
Power (P_{max}) $_{(STC)}$	465 Wp
Voltage at Maximum Power (V_{mp})	43.38V
Current at Maximum Power (I_{mp})	10.72A
Open Circuit Voltage(V_{oc})	52.00V
Short Circuit Current(I_{sc})	11.44A
Module Efficiency STC (%)	20.43%
CELL TYPE	Monocrystalline Silicon
Dimensions	2205×1032×35mm
Number of Cells connected in parallel (N_p)	2
Number of Cells connected in series (N_s)	78
Number of Cells	156
Refer. Bifacial Factor	70±5%
Temperature coefficients of P_{max}	-0.35%/°C
Maximum system voltage	1500VDC (IEC)
Standard Test Conditions (STC): air mass AM 1.6, solar radiation 1000 W/m2, cell temperature 25 °C	

Bifacial solar panels with Half cut were used to achieve the highest efficiency, as Bifacial technology refers to solar panels that can produce solar energy from both sides of the panel [12].

The PV array was distributed into 2 row and 6 strings with aspect ratio of 1.7, as in Fig. 5 and using the following equation:

$$\text{Min. No. of modules in series } (N_{s.min}) = \frac{Min.MPPTvoltage\ of ch.inv.}{V_{mpp}/panel} \tag{2}$$

2.2 Converter system

The power distribution of the building was controlled in two ways to achieve energy management and reduction in costs. The first part is to control the full electrical loads (including high-power devices such as air conditioning AC) using an Automatic Transfer Switches (ATS). The second part, done through the solar inverter to control the energy by provide a continues energy to 8-section light electrical load.

Figure 6 shows an electrical diagram illustrating the method of distributing power to loads, installed in government building in Najaf city.

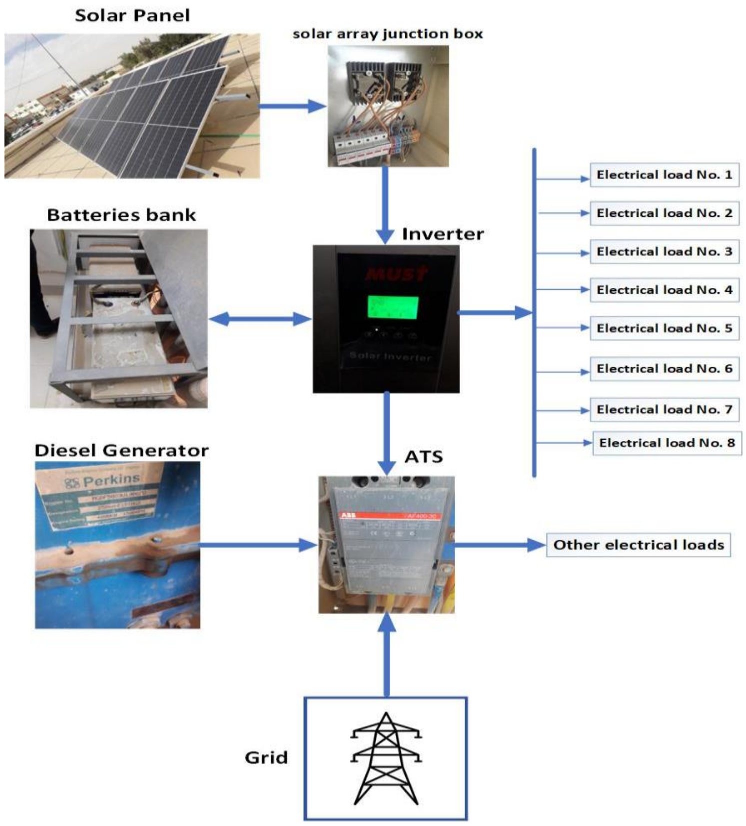

Fig. 6 Electrical flow diagram of the system

Therefore, the hybrid inverter (off grid) works by collecting energy sources from the utility, photovoltaic (PV), diesel generator (DG), Battery bank with load as shown above. Here, the solar inverter architecture (5.5kw) consists of DC Bus and AC Bus, where this architecture provided an efficient strategy for tracking the load and energy sources to achieve Techno-economic results. On this basis, priority was given to solar energy at high radiation, battery bank and grid, respectively. The specifications of solar inverter can be seen in Table 2.

Table 2. solar inverter specifications

MODEL	**PV18-5548 VHM**	
INVERTER OUTPUT	Rated Power	5500W
	Surge Power	11000W
	Waveform	Pure Sine Wave
	AC Voltage Regulation (Batt. Mode)	(220VAC~240VAC) ±5%
	Inverter Efficiency (Peak)	93%
	Transfer Time	10ms (UPS / VDE4105) 20ms (APL)
AC INPUT	Voltage	230VAC
	Selectable Voltage Range	170~280VAC(UPS) / 90~280VAC(APL) / 184~253VAC(VDE4105)
	Frequency Range	50Hz / 60Hz (Auto sensing)
BATTERY	Normal Voltage	48VDC
	Floating Charge Voltage	54.8VDC
	Overcharge Protection	60VDC
SOLAR CHARGER & AC CHARGER	Maximum PV Array Open Circuit Voltage	145VDC
	PV Array MPPT Voltage Range	60~130VDC
	Standby Power Consumption	2W
	PV Input Power	4000W
	Maximum Solar Charge Current	80A
	Maximum Efficiency	98%
	Maximum AC Charge Current	60A
	Maximum Charge Current	140A
MECHANICAL SPECIFICATIONS	Dimensions(W*H*D) (mm)	297.5*468*125
	Net Weight(kg)	13.3

OTHER	Humidity	5% to 95% Reality Humidity (Non-condensing)
	Operating Temperature	0°C~50°C

2.3 Battery Bank

Bank batteries are used to store energy for later use when the irradiation not enough or at night. By connecting multiple batteries together, the total capacity of the energy storage system can be increased. Energy Storage System (ESS) with capacity and nominal voltage of 9.6 kWh and 48 V, respectively, is used in this case study, and the battery has a 30% minimum SOC and a 90% roundtrip efficiency. Table 3. shows of battery specifications. Storage capacity is calculated by considering autonomous days and load profile as follows [13,14]:

$$\text{C}_{\text{TBB}}(Ah) = \frac{E_{total} * N_d}{DCBV_{\text{battery}} * \lambda_B * DOD * \eta_{inv}} * Fc \quad (3)$$

Where C_{TBB} for total battery bank capacity C_{TBB} (Ah), Etotal for daily load electricity (kWh/day), Nd for autonomous days, FC Correction factor, λB charging and discharging efficiency of batteries (roundtrip) and ηinv indicates inverter efficiency (90%), DOD for depth of discharge (70%), while DCBVbattery for DC Bus System voltage.

Meticulous design and management have been performed to ensure proper charging, discharging and maintenance of the battery bank in solar power systems and as per manufacturer's detailed data sheet, Table 3.

Table 3. Solar inverter specifications

Battery model	SG 2500H (12V250AH / 20 HOUR RATE)
	C20 (1.80VPC)
Capacity (@25°C)	250Ah
Weight (kg/lbs)	61.5kg (135.6lbs) ±3%
Internal resistance (mΩ)	2.10 mΩ ±10% (@25°C), full charged
Max. discharge current (5sec)	1770 A
Capacity affected by Temperature @30°C	105%
Self-discharge (@25°C,77F)	After 1 month ≤2%
Max. short duration discharge current (0.1sec)	4800A±10%

2.4 Diesel generator (DG)

A diesel generator system is a type of standby power system which uses a diesel engine to produce electricity, Table 4 shows the data of the generator used. The system includes a diesel engine, an alternator, a fuel tank, a control panel, and a battery. It mainly operates when there is a defect from the PV and Grid systems and leading to failing to satisfy the demand, and during this time, the battery bank is depleted. It mostly operates when there is a defect from the PV and Grid systems and leading to failing to satisfy the demand, and during this time, the battery bank is depleted. Fuel consumption per hour for DG, DF (t), can be obtained by [15,9]:

$$F_{DG} = (A \times T_{DG} + B \times P_{DG}) \quad (4)$$

Where FDG indicate the Diesel generator fuel intake rate (L/h), a mention to the coefficient of fuel intercept (L/kWh) (taken as 0. 408 L/kWh rated), TDG, for Diesel generator capacity (kW), B is the fuel slope (L/kWh) (0.236 L/kWh output) and PDG for the generated output (kW).

In the results of this paper, the diesel generator data will be studied (as Fig. 7), and the economic cost reduction will be analyzed because of lower dependence on this energy source.

Table 4. Diesel generator specification

MODEL	**Diesel Generator Set Powered by Perkins**	
Engine	Standby Power (ESP)	400BkW
	Rated Speed	1500 RPM
	Fuel	Diesel
	Starting voltage	24 Volts DC
	Fuel Consumption % 75 PRP 50 Hz	35 lt/h

	Fuel Consumption % 50 PRP 50 Hz	30 lt/h
Alternator	Manufacture	Stamford
	Voltage	400V
	Frequency Range	50Hz
	No of Phases	3P 4W / Y
	Power Factor	0,8
	KVA base rate (BR)	5000 KVA
	KW base rate (BR)	400 KW
	AMPS base rate (BR)	A

3 Techno-economic and environmental analysis

To confirm the results of this study and to provide the administrative leaders with a summary that contributes to the development of other state facilities, an accurate technical-economic analysis was carried out. According to the data in the previous tables, the equipment cost for the PV/diesel/batteries system used in this project is different from location to another. The difference may be attributed to the fact that the economics of such projects depend on the location, the study gives an insight into the evaluation of projects.

3.1 Economic feasibility

It should be noted that the economic viability of solar power systems can vary greatly depending on a number of factors, such as the location of the system, the size and type of the system, and the incentives available. As a result, it is important to carefully consider all of these factors when evaluating the economic viability of a solar energy system.

The economic viability of power systems refers to the evaluation of the costs and benefits associated with implementing a solar power system to determine whether it is a practical and cost-effective option for power production. This analysis includes comparing the costs of installing and operating a solar energy system with the costs of other energy sources, such as conventional fossil fuels - Table 5, where our study was based on the diesel generator used for a governmental building, taking into account factors such as the cost of electricity, the cost of financing, the availability of incentives and subsidies, the life expectancy and maintenance requirements of the power system.

Table 5. Cost of various components

Components		Initial Cost	Replacement Cost	Maintenance Cost
PV Module/ 5.6 kW dc		$2400	$2400	5$/kW/month
Inverter/ 5.5 kW ac		$700	$650	-
Indirect cost	System equipment	$100	$20	-
	Installation labor	$300	$50	-
	Installer margin and overhead	$100	-	-
	Grid interconnection	$334	-	-
Battery Bank DC capacity/12kWh		$1200	$1200	
Diesel generator		$37000	$37000	$5466/month

3.2 Financial accounts

In order to assess the economic viability of a solar energy system (SES), it is important to consider the initial costs of installing the system, in comparison to the costs of the ongoing operation and maintenance of a used diesel generator. This analysis can help determine the expected return on investment for a solar energy system and whether it is likely to be more cost-effective than other energy sources in the long duration. The required information can be found in the Table 6, to calculate the operating costs of the generator.

Table 6. Operational costs of the diesel generator for the site (400 KW)

No.	Description of the type of expense	Cost $/month	Comments
1	The cost of fuel consumption	4333	Per month
2	The cost of transporting fuel	66.6	Per month

3	Technical inspection fees for periodic maintenance	8.8	Per month
4	Generator operator salary/month	533	Per month
5	The cost of replacing 3 filters per 300 operating hours	100	Per month
6	Oil replacement cost 65 liters per 300 operating hours	390	Per month
7	Cost of replacing 2 batteries	35	Per month

The cost of operation a diesel generator can be calculated using following equation and steps [16]:
Operating cost = fuel consumption x fuel price x operating hours + maintenance costs + labor costs
Where:
For more details on Operational Cost within one month including, Fuel cost (FC), the cost of transporting fuel (TF), Technical inspection fees for periodic maintenance (PM), the cost of replacing filters (RF), the cost of replacing Oil (RO), the cost of replacing batteries (RB) and the labor of the generator operator(L):

$$\text{Operational Cost} = \sum FC + TF + PM + RF + RO + RB + L \qquad (5)$$

Operating cost of a 400kW generator – per month = (4333 + 66.6 + 8.8 + 100 + 390 + 35 +533) = $5466
It has been recorded that the cost of operating a diesel generator can vary greatly depending on a number of factors, such as the size of the generator, the frequency of use, and the efficiency of the generator. As a result, all these factors have been carefully considered when calculating the operating cost of a diesel generator.

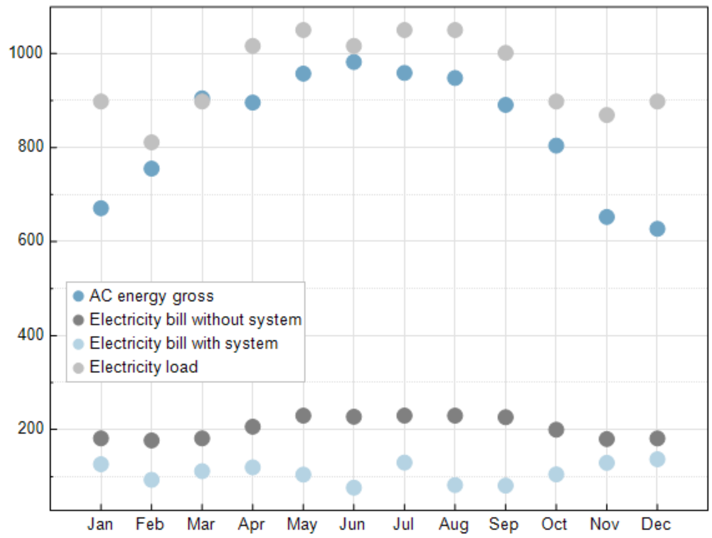

Fig. 7. Monthly Energy with Electricity bill

From Fig. 7, the electricity rate (ER) generation from the solar system for one month is 800 kWh. The unit cost of electricity (UCE) was considered $0.4/kWh, according to the supply prices of commercial generators.
By the formula:

$$Cost = ER(kWh) \times UCE(\$/kWh) \qquad (6)$$

Thus, the cost of the electricity bill will be reduced for one month = 800 * 0.4 = $320 per month, show Table 7.

Table .7 Data of annual estimates of economic savings and pollution using energy management with the solar system.

Energy cost	Equivalent emissions	Energy cost	Equivalent emissions
without EMS/PV system		with EMS/PV system	
65592$	`302ton	*3840$*	25.2 tons

3.3 Generation and consumption of electricity

The solar system achieved (648 kW) of energy in July, which is the highest across the year, while the lowest consumed power from the network was (314 kW) in June, we see the lowest batteries use in November (9 kW) as a result of the decrease in building load and the relatively better weather. The highest total power is (957 kW). Fig. 8 summarizes the annual and monthly performance of the solar PV system with battery bank energy, and energy purchased from the grid (Note that this purchased energy is the total of the grid and the diesel generator). The data was a simulator of the SAM software to power manage and control costs.

In order to compute and compare the energy output of the solar energy system (SES) with that of the Deiseal generator (DG), the overall annual energy output is 10210 kWh can be seen in Fig. 8.

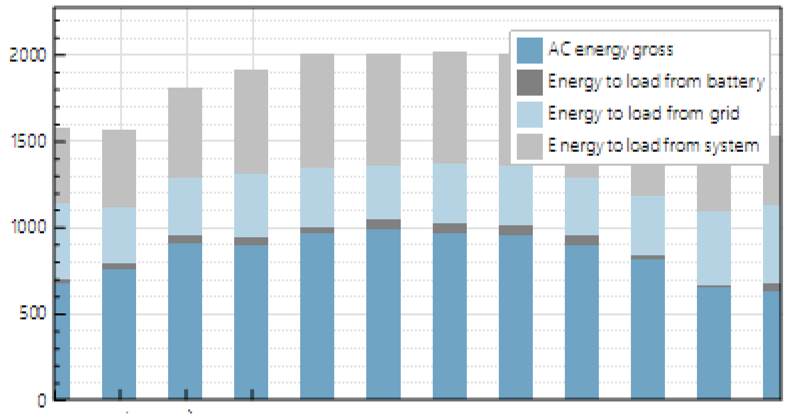

Fig. 8. Monthly graph for energy generation to load.

3.4 Reduce emissions.

Reducing emissions is a critical step in fighting climate change and preserving our planet. There are several ways to reduce emissions, including:

1- Transitioning to clean energy sources: This includes the use of renewable energy sources such as solar or wind energy, in addition to reducing our dependence on fossil fuels, (the transformation has been applied to two buildings so far).

2- Improving energy efficiency: This can be achieved through measures such as the use of energy-saving devices, improving building insulation, reducing waste, and controlling consumption (applied by isolating the loads that have high energy consumption - for a governmental building, the electricity department building, and the communications department building within the procedures taken as a savings policy).

3- The use of electricity in transportation: this can be done by promoting the use of electric vehicles, public transportation, and active means of transportation such as cycling and walking, (some electric vehicle that depend on batteries and others that depend on solar energy and some cycling activities have been used at our university).

It is important to note that reducing emissions is a complex issue that requires the cooperation of individuals, companies and governments. However, we can make significant progress in reducing emissions and mitigating the effects of climate change.

Compute the emission rate by multiplying the emission factor by the fuel consumption rate [17,18], In the results section, these values will be determined to 400kw DG:

In IC (internal combustion) engines: Emission rate (ton/month) = Emission factor (ton/unit) x Fuel consumption rate (unit/month)

(CO_2 emission for a 400kW generator = 9000 * 2.8 = 25.2 tons / month) see Table 8.

Table 8. Estimated cost and CO_2 emissions data for a 400kW DG

Data type	Amount of data
CO_2 emission	25.2 tons / month
Operational cost	$5466 per month

3.5 3.5. System outcomes and simulating data

In this study, the monthly and annual energy production of the hybrid solar system(5.5kW) was calculated using SAM software. First, meteorological data such as ambient temperature, global radiation, and wind speed were loaded, and then load profiles, mechanical and electrical specifications of the panels, inverter, and batteries, As in Tables 1-3 and other details. A comprehensive representation of system production results is provided in Fig. 9.

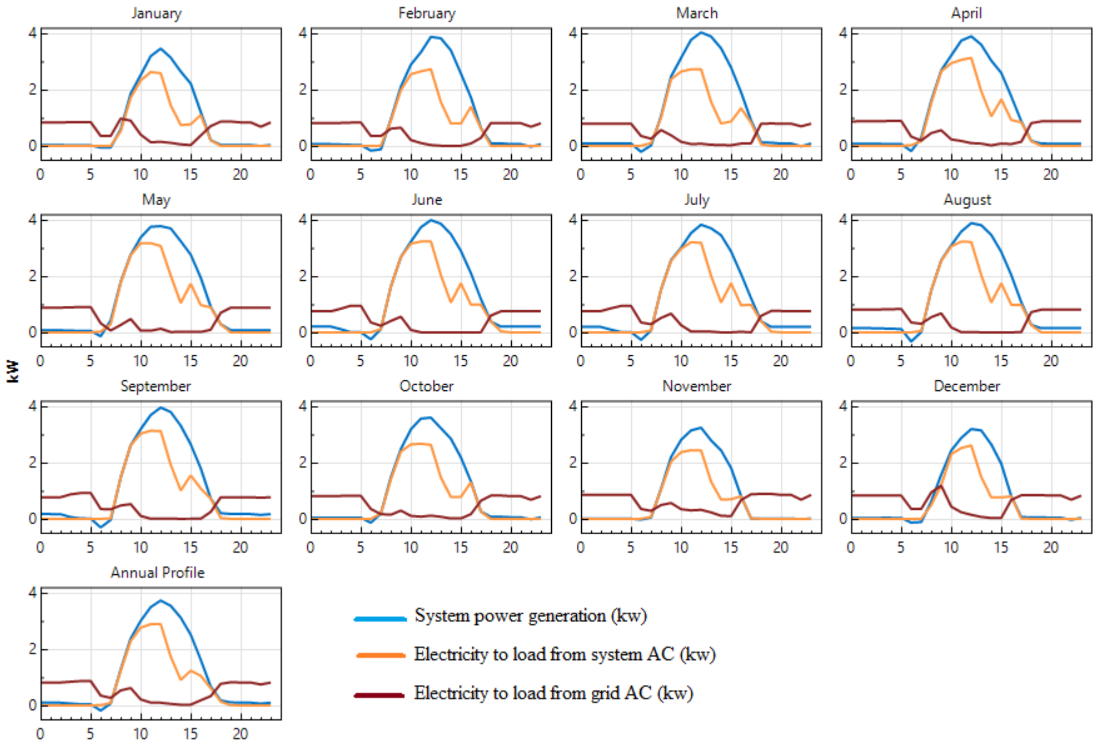

Fig. 9. Monthly and annual energy of the solar system

3.6 Effect EMS design

The previously optimized design by using energy management was analyzed by studying the effect of solar radiation on cost and overall performance. In Fig. 10, the energy has been managed with global solar radiation (GSR) values at 300 to 900 W/m2 in addition to the presence of batteries (SOC 30%) to work as flexible source to reduce dependence on energy from the grid or diesel generator (DG), which achieved zero kilowatts in July at some hours of the day. Here, the system has the lowest cost of energy (COE), in regard that solar energy is free.

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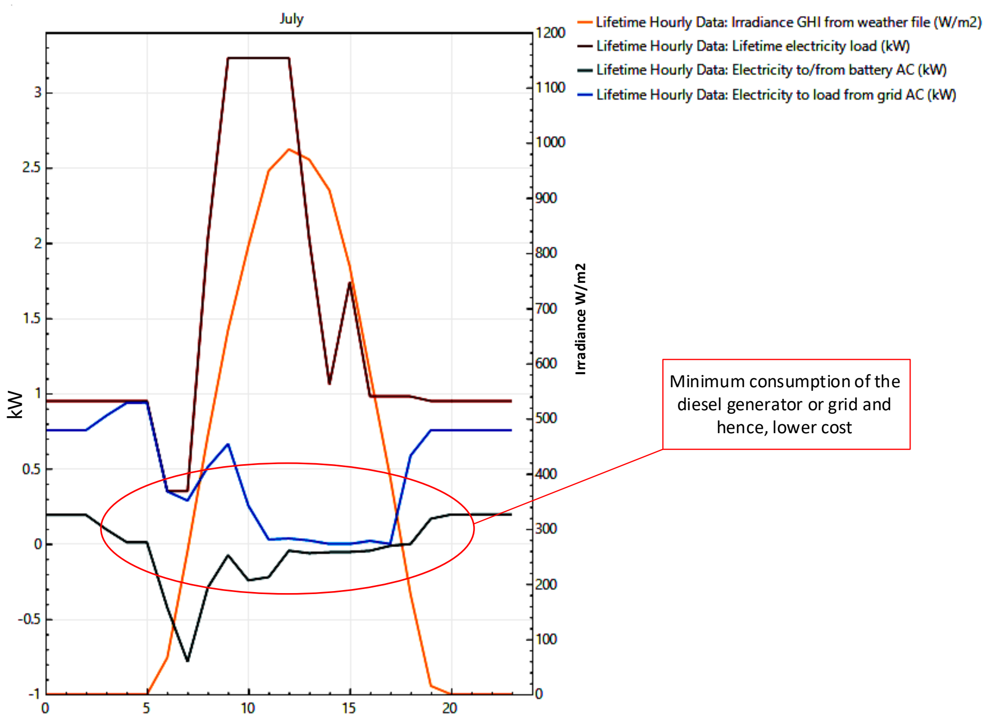

Fig. 10. Energy and solar irradiation for July

To indicate the effectiveness of the EMS used, a comparison between electricity bill with diesel generator and solar system, Fig. 11 shows the decrease in power cost between the previous two systems.

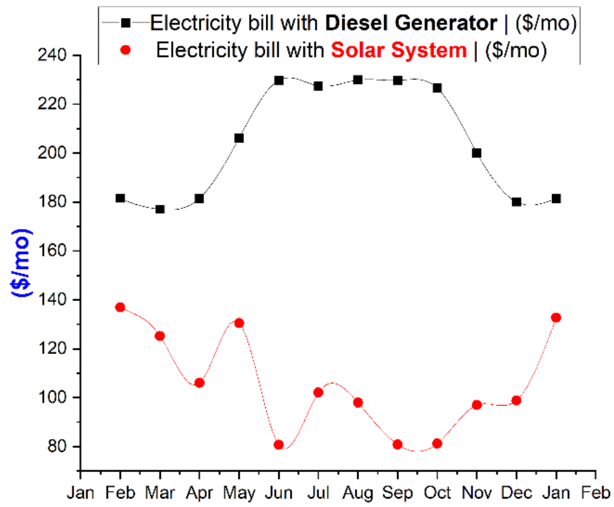

Fig. 11. Electricity bill with diesel generator and solar system

4 . Conclusions

In this paper, a technical, economical, and environmental assessment was executed using an energy management system for a government building. The main objective of this study was to analyze the technical and economic feasibility of the energy system, as it relied on two parts of the energy conservation policy: the first was to adopt the energy management system by redistributing loads to reduce dependence on flexible sources (diesel generator 400 kW) only when needed, and the second was to add renewable energy (solar energy). A load profile was created to achieve the first step and be able to size the solar system (5.5 kW) after simulating the system based on the annual radiation profile of the region. The results showed a decrease in the energy cost after using the EMS/PV system by $61,752 and that the applied system has reduced 277 tons of greenhouse gases (carbon dioxide) into the atmosphere, and therefore, this system is environmentally friendly. In addition, the capacity and depth of discharging the battery bank were carefully analyzed due to the high cost of installation and replacement, as it achieved fewer charging cycles (400 cycles) compared to high usage.

This study acting as a model to prove the technical and economic feasibility of the policy of developing solar energy for buildings in Iraq.

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