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Hybrid PV-Battery System Evaluation in Baghdad: ICOE and NPV Analysis using SAM Software

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ABSTRACT

In this study, The System Advisor Model (SAM) simulation software has been used to analyze a Hybrid PV-Battery System in a residential cite in Iraq-Baghdad. The proposed system is 5kW which is affordable and applicable from the cost and required area points respectively. The monthly averaged electrical load is approximately calculated. The performance ratio for the system is 0.75 and about 6834 KWh is generated by the system per year. The results showed that the initial capital cost is 4,167.01$ which is returned after six years, LCOE Levelized cost of energy real is 7.66 ¢/kWh and Net present value is $4,649 made the system are very economical/no maintenance project and can be hooked to any the peak time load.

1. Introduction

Hybrid residential photovoltaic systems with battery storage have gained significant attention as a viable solution for meeting the electricity needs of consumers in areas where only grid connection is either expensive or unreliable [1]. These systems offer the advantage of storing excess energy generated by the PV panels during periods of high solar availability and supplying it during times of low or zero solar energy availability [2] . This not only ensures a reliable electricity supply but also maximizes the utilization of solar energy. Moreover, in Hybrid applications, where only grid connection is not feasible, PV-battery systems provide the necessary flexibility for meeting the electricity demand and charge the battery from the grid at night. They are widely used in off-grid and hybrid applications such as rural electrification projects in developing countries. Furthermore, recent researches have shown promising results in combining solar PV power with other energy sources, such as Grid, wind and hydropower [3]. Hybrid PV-battery systems are particularly valuable in areas like Baghdad, Iraq, where stable energy access is crucial [4]. To achieve this goal, it is most crucial to have stable energy access, the installation of energy storage units is required. While designing an optimal Hybrid PV system in Baghdad, one of the main considerations is battery sizing, as it is a significant cost component. Moreover, the declining prices of PV components in recent years have made the initial cost of solar batteries more affordable. In order to determine the viability of the storage system in this specific scenario, it is crucial to identify the necessary photovoltaic field and battery capacity [5]. In summary, Hybrid residential PV-battery systems are necessary in regions

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where connecting to the grid is possible, offering flexibility, steadiness, and a dependable power supply. Hybrid residential PV-battery systems play a critical role in ensuring reliable energy access in places like Baghdad, Iraq see Figure 1 [6].

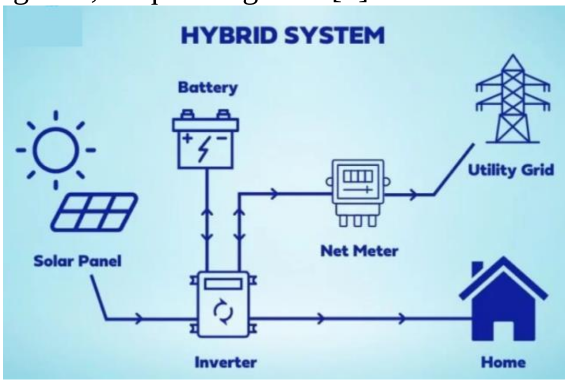

Figure 1. Sketch of the hybrid system

This study, analyze the performance and cost of a Hybrid residential PV-battery system in Baghdad, Iraq. Also, evaluate the system using two metrics, the levelized cost of energy (LCOE) and the net present value (NPV). By utilizing SAM software for analysis, the levelized cost of energy (LCOE) refers to the cost of implementing the system and the total project lifecycle cost expressed in cents per kilowatt-hour of electricity delivered by the system over its life to the grid for front-of-meter projects, or to the grid and/or load for behind-the-meter projects.

Whereas, the net present value (NPV) takes into account the time value of money and future cash flows, providing a measure of the economic viability of the system [7].

2. Overview of the SAM Software for Energy Analysis

The System Advisor Model software (SAM) is a powerful tool that is widely used for energy analysis in the field of renewable energy systems [8]. SAM software has been accurately analyze the performance and cost of a Hybrid residential PV-battery system in Baghdad, Iraq. Moreover, SAM can consider the geographical location and energy consumption patterns to determine the optimal size of the photovoltaic field and battery capacity. This analysis will help to determine the feasibility and viability of implementing a storage system in this specific scenario [9]. By applying SAM software, the Levelized Cost of Energy and Net Present Value of the Hybrid residential PV-battery system with proper sizing of the photovoltaic field and battery capacity has been evaluated in Baghdad, Iraq [10].

3. ICOE and NPV: Key Financial Indicators in Solar Investments

In the analysis of the hybrid residential PV-battery system in Baghdad, Iraq, two key financial indicators will be evaluated: ICOE and NPV. ICOE stands for the Initial Cost of Energy and represents the total investment required to install and operate the PV-battery system over its lifetime. It includes the costs of PV modules, batteries, inverters, charge controllers, and other components, as well as installation and maintenance costs [11]. By calculating the ICOE, the study can assess the initial capital investment needed for the PV system and compare it to the potential energy savings and cost reductions achieved over time [12] . This analysis will also include the calculation of Net Present Value, which takes into account the time value of money [13]. By discounting future cash flows, the NPV provides an estimate of the profitability and financial viability of the PV-battery system. In this case, the NPV will be used to evaluate the economic feasibility and financial viability of the hybrid residential PV-battery system in Baghdad, Iraq [14].

4. Case Study: Hybrid Residential PV-Battery System in Baghdad

This study focuses on evaluating the performance and cost of a hybrid residential PV-battery system in Baghdad, Iraq [15]. The research utilized the SAM software for the techno-economic analysis of the system. Based on their findings, they were able to determine the required PV area and capacity, the number of PV modules, battery capacity, inverter capacity, and charge controller capacity for optimal system performance. Furthermore, the life cycle cost analysis model was employed to assess the optimal cost solution for the PV system design [16]. This involved considering factors such as initial capital investment, present cost of components, and balance of system costs. The net present value of the PV system was also determined, taking into account the discount rates for each component [17]. The study also considered the future value of the system using appropriate discount rates. This comprehensive analysis allowed the researchers to evaluate the economic viability of the hybrid residential PV-battery system in Baghdad, Iraq. Based on the results of the analysis, the researchers were able to determine the ICOE and NPV of the system, which provided insights into its financial feasibility [18].

5. Methodology of Performance and Cost Evaluation Using SAM

This study employed the System Advisor Model software (SAM), developed by the National Renewable Energy Lab, to conduct the performance and cost evaluation of the hybrid residential PV-battery system in Baghdad, Iraq. [19] Figure 2. Shows the platform of the software.

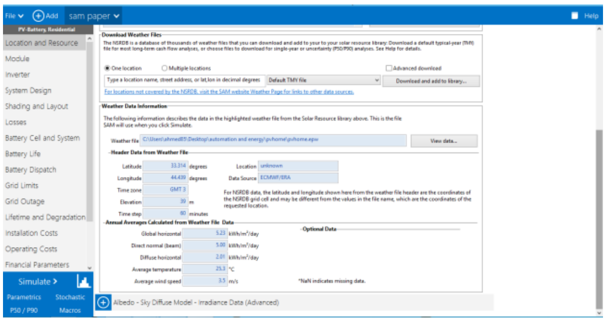

Figure 2. SAM Platform

5.1 Location and resources

The study was simulated with a residential site in the city of Baghdad with the details as shown in Table 1.

Table 1: the details of location and resources

Latitude	33.314
Longitude	44.439
Time zone	GMT 3
elevation	39
Global horizontal	5.23kWh/m^2/day
Direct normal	5.00 kWh/m^2/day
Diffuse horizontal	2.01 kWh/m^2/day
Average temperature	25.3 c$^{\circ}$
Elbedo	0.2

Elbedo (also called ground reflectance) value of 0.2, which is reasonable for grassy ground for most analyses. Albedo values must be greater than zero and less than one, where zero represents completely non-reflective ground and 1 represents completely reflective ground.

5.2 Module

Yingli energy YL450D-40d mono-c-Si has been selected in this simulation with the specifications are illustrated in the Table 2 and Figure 3 below:

Table 2: illustrated the module specifications

Nominal efficiency	21.27
Maximum power (Pmp)	450.846 Wdc
Max power voltage (Vmp)	41.4 Vdc
Max power current (Imp)	10.9 Adc
Open circuit voltage (Voc)	49.8 Vdc
Short circuit current (Isc)	11.4 Adc
Temperature coefficient	-0.331 %/C$^{\circ}$
Material	Mono-c-Si
Area	2.120 m^2
Number of cells	72

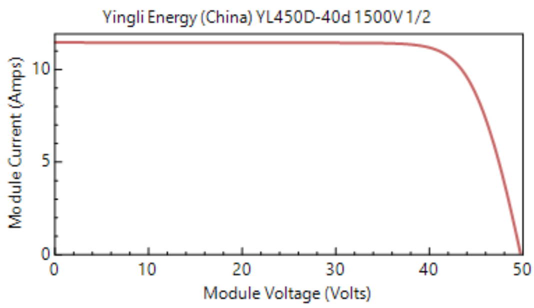

Figure 3. Shows the module relation between voltage and current

5.3 Inverter

The study assumed that the daily load is 5 KW. Therefore, hybrid Good we Technologies 5031W Inverter has been selected in this simulation the efficiency curve and characteristics have been shown in the Table 3 and Figure 4 respectively.

Table 2: the inverter characteristics

Number of MPPT input	1
European weighted efficiency	95.923%
Max AC power	5031 Wac
Max DC power	5198.53 Wdc
Power use during operation	31.6275 Wdc
Power use at night	1.5093 Wac
Nominal AC voltage	240 Vac
Maximum DC voltage	495 Vdc
Maximum Dc current	14.8529 Adc
Maximum MPPT DC Voltage	200 Vdc
Nominal DC voltage	350 Vdc
Maximum MPPT DC voltage	495 Vdc

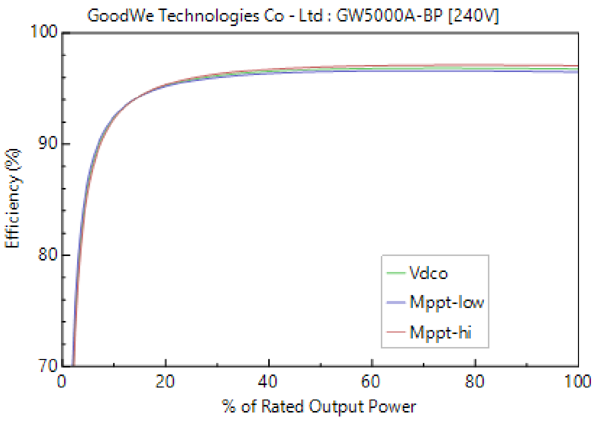

Figure 4. The efficiency curve

5.4 System design

The system design details have been shown in Figure 5. And presented the setting of seasonal tilt angle in the Table 3, no shades assumed in this simulation due to site location.

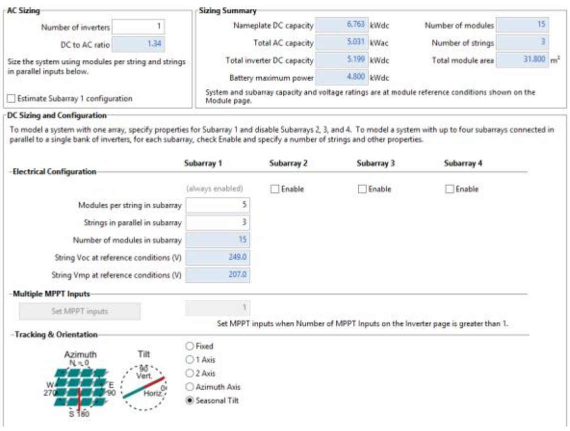

Figure 5. Shown the system design details

Table 3: shows seasonal tilt angel.

Jan	40
Feb	40
Mar	40
Apr	20
May	20
Jun	20
Jul	20
Aug	20
Set	20
Oct	40
Nov	40
Dec	40

Losses have been calculated with default values which presented from SAM.

5.5 Battery cell and system

Lead Acid VRLA AGM (Valve Regulated Lead Acid Absorptive Glass Mat (AGM) batteries are sealed, and the electrolyte is immobilized in porous separators) has been chosen in this simulation due its efficiency and yearly percentage of degradation, two batteries in parallel have been set in this simulation. Figure 6, 7. Shows the details and data sheet for the battery.

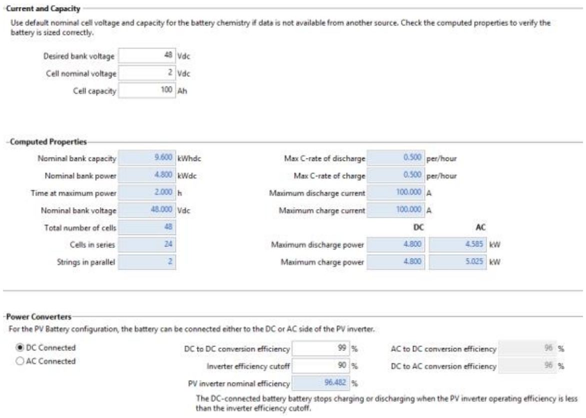

Figure 6. shows the details of the battery

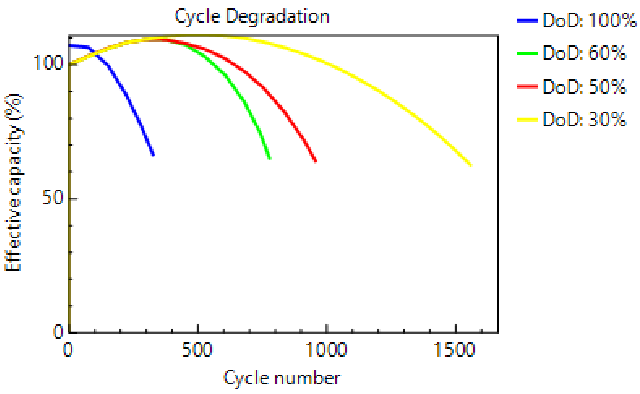

Figure 7. Battery cycle Degradation

DC connected side has been set for the batteries to decrease the losses from the Inverter as shown in the Figure 8.

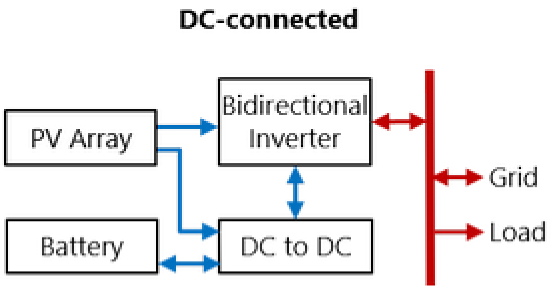

Figure 8. DC connected side

5.6 Grid limits and Grid Outage

The system has no interconnection limit with the grid, grid has been fed the load and recharge the batteries at night, the simulation has been assumed of 5- 6 hours per day with grid outage. Therefore, PV feeds the load at morning and batteries cover the load at night in the Grid outage period.

6. Analysis of Investment Costs for PV-Battery Systems in Iraq

The analysis of investment costs for this simulation involved evaluating the initial capital investment required for the PV system design. This included the costs of PV modules, batteries, inverters, charge controllers, and balance of system components [9]. The simulation considered the present cost of each component and used the life cycle cost analysis model to estimate the net present value of the PV system. The analysis also took into account any subsidies available for PV-battery systems in Iraq and considered the discounted cash flows associated with the system. The NPV is determined as follows [10].

$$NPV = \sum_{n=0}^{n} \frac{C_n}{(1+d_{nominal})^n} \quad (1)$$

Where C_n is the after-tax cash flow in Year n for the residential models, and the after-tax project returns for the PPA models, N is the analysis period in years that you specify on the Financial Parameters, and $d_{nominal}$ is the nominal discount rate from the Financial Parameters.

For the real LCOE, the real discount rate appears in the denominator's total energy output term:

$$levelized\ cost\ (real) = \frac{-c - \frac{\sum_{n=1}^{n} C_n}{(1+d_{nominal})^n}}{\frac{\sum_{n=1}^{n} Q_n}{(1+d_{real})^n}} \qquad (2)$$

Similarly, for the nominal LCOE, the nominal discount rate appears in the denominator's total energy output term:

$$levelized\ cost\ (nominal) = \frac{-c - \frac{\sum_{n=1}^{n} C_n}{(1+d_{nominal})^n}}{\frac{\sum_{n=1}^{n} Q_n}{(1+d_{nominal})^n}} \qquad (3)$$

Where:

Q_n	Electricity delivered by the system to the grid (and/or load if applicable) in year *n*.
N	Analysis period in years as defined on the Financial Parameters
C_0	The project's equity investment amount.
C_n	The annual project costs in Year *n*, as listed under costs and benefits above.
d_{real}	The real discount rate defined on the Financial Parameters page.
$d_{nominal}$	The nominal discount rate shown on the Financial Parameters page. This is the discount rate with inflation.

7. Results of the Baghdad Hybrid PV-Battery Study

The results and discussion of the Baghdad PV-battery study indicated several important findings. Firstly, simulation found that the performance Ratio (PR) is 75% for Hybrid PV-Battery system. Secondly, the techno-economic analysis of the PV-battery system in Baghdad, Iraq showed that it is feasible to implement such a system. The system was reported to produce about 6834 kWh of electricity per year as shown in Table 4 and Figure 9, which is enough to meet the electrical demand of the residents in Baghdad [18].

Table 4: Shows the summery of the system results.

Metric	Value
Annual AC energy in Year 1	6,834 kWh
DC capacity factor in Year 1	11.5%
Energy yield in Year 1	1,011 kWh/kW
Performance ratio in Year 1	0.75
LCOE Levelized cost of energy nominal	9.42 ¢/kWh
LCOE Levelized cost of energy real	7.66 ¢/kWh
Electricity bill without system (year 1)	$3,696
Electricity bill with system (year 1)	$2,833
Net savings with system (year 1)	$863
Net present value	$4,649
Simple payback period	6.2 years
Discounted payback period	8.7 years
Net capital cost	$4,167
Equity	$0
Debt	$4,167

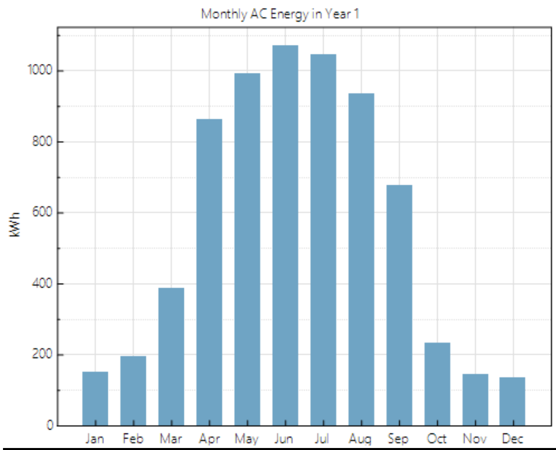

Figure 9. Indicates the monthly AC Energy in Year 1

Additionally, the cost analysis revealed that the initial capital investment for the system was $4,167 with 100% Debt fraction and 15 years loan term, with a payback period of approximately 6 years. Furthermore, the simulation determined that the optimal PV system capacity for meeting the electrical demand in Baghdad was 5 kW, with a battery capacity of 10 KW and an inverter capacity of 5 kW. It also found that the cost of the PV-battery system, including the initial capital investment, present cost of components, and balance of system costs, could be completely offset by the electricity generated by the system and even result in a profit [20].

8. Conclusion

The research conducted on the hybrid residential PV-battery system in Baghdad, Iraq using SAM software provided valuable insights into its performance and cost evaluation [4]. Furthermore, the findings emphasized the importance of considering both technical in PR and economic with LCOE and NPV aspects when analyzing the feasibility of hybrid PV systems [21]. SAM calculates both a real and nominal LCOE values. The real LCOE is a constant dollar, inflation-adjusted value. The nominal LCOE is a current dollar value, the

U.S. Department of Energy has used the real LCOE in its comparative analysis of photovoltaic project costs.

A project's net present value (NPV) is a measure of a project's economic feasibility that includes both revenue (and savings for residential and commercial projects) and cost. In general, given the discount rate you assume, a positive NPV indicates an economically feasible project, while a negative NPV indicates an economically infeasible project, in this simulation the NPV is positive indicates an economically feasible study to apply.

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