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The Effective Analysis for East Karbala Diesel Power Station Photovoltaic System using Homer Pro Software

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Abstract

In Iraq, where electric generation is limited, a pilot work was conducted at East Karbala Diesel Power Station, in Karbala. This aimed to assess the implementation of PV solar systems on stations under both grid-connected and off-grid conditions. We will evaluate various factors, including net present cost, energy cost, operating and initial costs, and annual net energy consumption from the grid. The work analyzed various situations and considered the presence of backup generators (G1-250kVA) at the station. The first step is to conduct a walkthrough energy audit at EKDPS to determine the plant's load profile. By using HOMER Pro, further analysis is illustrated. Results indicated that integrating an on-grid PV system could reduce the cost of energy by 58%, making it the optimal situation when grid power is available. In this case, the Net Present Cost, operating cost per year, was $51,991. Conversely, in the absence of grid power, the best scenario involved a PV system with a 100-kWh lithium battery loading. Despite being the most effective resolution in this situation, the energy cost was 310% greater than the one-case energy rate in Iraq (0.1 $/kWh). Notably, both optimal scenarios did not require generators, highlighting a significant potential benefit for the Nero Zero system.

Keywords: Cost-of-Energy, Diesel Power Station, HOMER simulation, Nero Zero system, Photovoltaic System.

1. Introduction

It is universally acknowledged that electrical power is indispensable across all sectors of life, especially in education, where it significantly contributes to the development of countries. Iraq, unfortunately, experiences a deficit in electrical energy production, compounded by a grid that is unreliable and intermittently operational. This study has been conducted at EKDPS to explore alternative energy sources and reduce power usage inside the station. Research has shown that combining solar cells with battery energy storage is the most cost-effective [1]. The HOMER program has been utilized to evaluate the possibility of a diesel/PV/ hybrid system for considering various capital costs, fuel efficiency, COE, and NPC [2]. Moreover, HOMER Software has proven effective in identifying the best hybrid renewable systems (HRESs) with the deepest COE and NPC while decreasing carbon radiations [3].

RES planning involves assessing the site's wind potential, solar radiation, temp, annual load profile, system capacity, and grid power availability [4]-[6]. This study primarily focuses on designing an optimal standalone power supply for a minority of Australians, exploring various systems to determine the most cost-effective option. HOMER software plays a crucial role in this analysis, evaluating different energy storage methods, including hybrid systems, diesel-generator alternatives, wind generators, photovoltaic systems, and batteries [7]. Kumar et al. [8] showed that the HRESs, HOMER Pro, offer both cost-effective and indifference analyses. The application of simulation in examining rooftop on-grid systems is discussed. Sawle et al. Similarly, Pérez-Santiago et al. [10] highlighted the advantages of using HOMER to investigate planned systems cost-effectively, emphasizing their economic viability. Hybrid power systems combine backup batteries and diesel generators. Such systems must sustain reliability and stability to support the required load. The modeling of hybrid systems involves various methodologies for designing either off- or on-connected systems based on real-time information [11]. HOMER Pro is widely recognized for its capabilities in energy design and optimization [12], with its chief analytical approaches being simulation, optimization, and indifference [13].

Instead, the availability of RES varies as a result of location. While wind speed is adequate in Iraq, its direction is not seasonally consistent. Conversely, Iraq benefits from highly efficient solar radiation, making solar energy production economically feasible. Due to their low cost and lack of need for backup storage, on-grid systems are a practical solution. However, challenges arise from the grid's instability and difficulties in inverter synchronization during shutdowns. Synchronizing with generators presents technical hurdles because the generators used on the station are not remotely controllable [14], [15].

This article presents a pilot study comparing an HRES comprising two holdup lithium battery storage (100kWh and 1MWh), an existing diesel generator (250kVA), and a PV system. It aims to evaluate the power system's life cycle cost and assess its viability based on installation and operational costs.

The objective is to evaluate the implementation of PV solar systems on the EKDPS, both with and without grid power, and their impact on design considerations, including NPC, COE, operational cost, and annual grid energy usage. Forty-five scenarios are examined, considering the presence of backup generators (G-250kVA). The study begins with a value power audit at East Karbala to approximate the load sketch, followed by an HOMER analysis.

2. Methodology Process.

HOMER streamlines the process of designing RES and distributed generation systems for various uses, encompassing both on- and off-scenarios. The system's configuration is determined by selecting the components to include, along with their respective quantities and sizes. HOMER's optimization and sensitivity analysis capabilities aid in evaluating numerous potential system configurations.

Key functionalities of HOMER include Simulation, Optimization, and Sensitivity Analysis.

1. Simulation: At its core, HOMER operates as a simulation model. It simulates a system's operation by conducting energy balance controls for each interval throughout the year. HOMER assesses a configuration's feasibility and calculates the installation and operation cost over the project's lifetime.
2. Optimization: HOMER Pro, the advanced program optimizer, uses a unique, cost-effective procedure to recognize the best cost-effective method. At that point, HOMER presents a list of structures sorted by net current rate or life-cycle cost for assessing different system strategy selections.
3. Sensitivity Analysis: HOMER optimizes each sensitivity that is adjustable by the user. This optional phase enables modeling the effects of uncontrollable variables like wind speed and fuel costs, showing how the ideal system configuration varies in response. Fig. 1 illustrates the process of utilizing HOMER Software, while Fig. 2 shows the proposed system configuration.

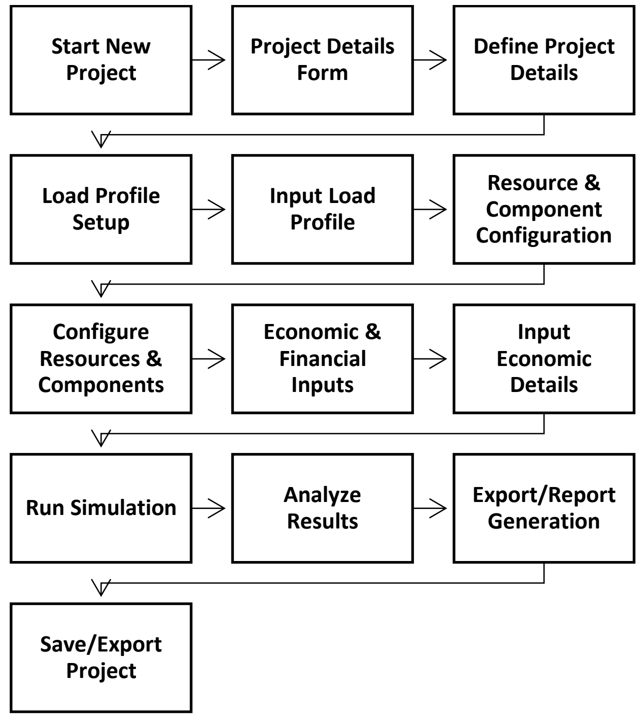


Figure 1. Homer Pro Software Procedure.

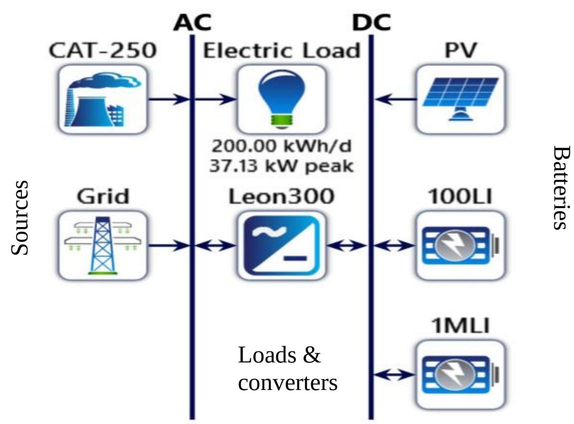


Figure 2. Homer Pro system configuration.

The methodology of this study is delineated through a series of steps, as depicted in the flowchart in Fig. 3, which outlines the strategy employed. Initially, a comprehensive energy audit of the station site was conducted, surveying all buildings for energy consumption, building and roof areas, load profiles, energy losses, and areas requiring heating and cooling. This audit encompassed eight existing buildings, detailed in a subsequent subsection.

The second step involved generating the total Power usage of the load profile, a crucial element for the subsequent design phase. In the third step, data regarding the project location, local resources, weather conditions, and values for sensitivity analysis were collected. This also included selecting components such as a generator, PV panels, batteries, and converters based on the site's suitability for effective renewable energy use and budget considerations.

The final step aims to determine the first cost, NPC, and COE. Given Iraq's power grid's unreliable and unstable nature, the study adopts a dual-track approach. The first track analyzes the system with grid power availability, while the second track considers scenarios where grid power is absent. The forthcoming subsection will explicate all input data and components utilized in this study.

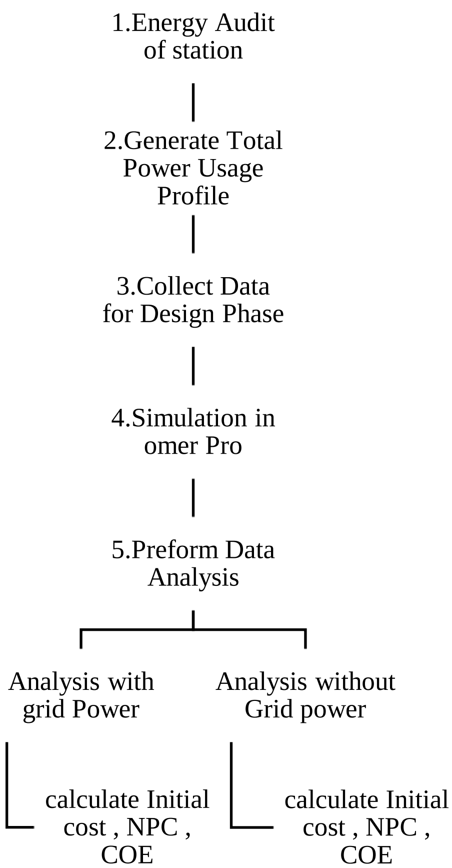


Figure 3. Outlines the strategy for a comprehensive energy audit of the station site (SWEA).

2.1. Station Walkthrough Energy Audit

The EKDPS is one of the Power stations under the Company of Electricity Production, Alfurat Middle Region in Iraq, located in East Karbala at coordinates 32°42'11.7"N 44°03'45.2"E. The SWEA encompassed all major buildings and layouts, as illustrated in Fig. 4. Key aspects of this audit included:

- Assessment of energy consumption in each building.
- Classification of load types, including heating, cooling, lighting, office equipment, and others.
- Identification of significant energy losses in each building and strategies for reduction.
- Measurement of the total area of each building, the working space, and the roof area.
- Determination of main obstacles to sunlight and potential sites for PV panel installation.
- Location planning for inverters and the distribution of PV panels.

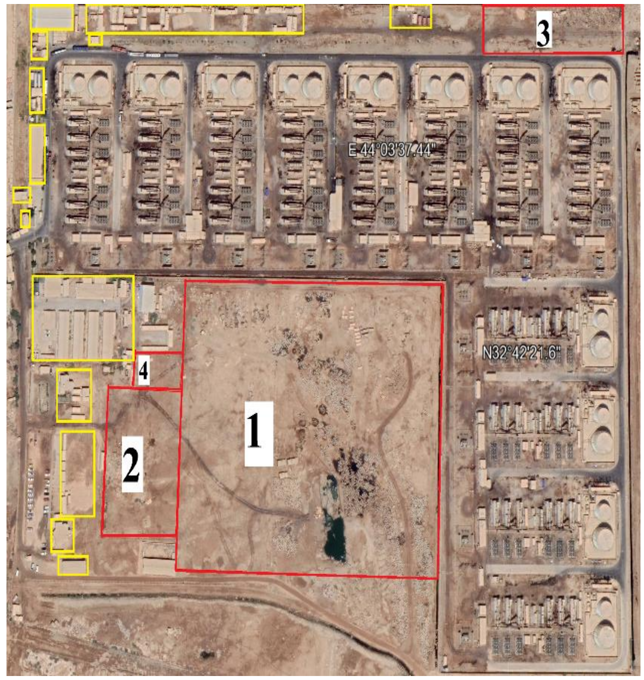


Figure 4. Layout and location of the study area

2.2. Load Profile Results

Following the Station walkthrough energy audit (SWEA), Table 1 presents a detailed breakdown of the loads, categorized by type. The audit's outcomes reveal that cooling energy constitutes most consumption, accounting for 60% of the annual total load. Office appliances represent the second largest load at 16%, followed by heating at 13%, lighting at 7%, and other at 4%, as detailed in Table 2.

Table 1. Load types.

No	Type	Load
1	LED Outdoor lighting	5 KW
2	Heating and cooling system	73 kW
3	Indoor Lights	2 kW
4	PC's and printers	75 kW

Table 2. Loads representation.

No	Type	%
1	cooling	60
2	Office appliances	16
3	heating	13
4	Lighting	7
5	other appliances	4
	Total	100

2.3. Site Weather Conditions

This section details the two primary weather factors that influence the performance of PVSs: the solar global horizontal irradiance (GHI) and ambient temperature.

2.4. Solar GHI Resource

Presented in Fig. 5 are the average monthly solar energy values recorded at The East Karbala Diesel Power Station (EKDPS). The data indicates that the minimum solar radiation in December is measured at 87 kWh/m². Conversely, the peak solar radiation, observed in June and July, reaches 216 kWh/m² and 217 kWh/m², respectively. An annual average of 152.4 kWh/m² is deemed acceptable.

In Fig. 6, the duration of daylight was illustrated.

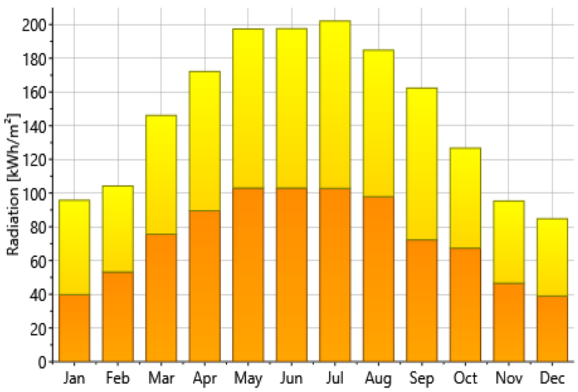


Figure 5. The average monthly solar energy.

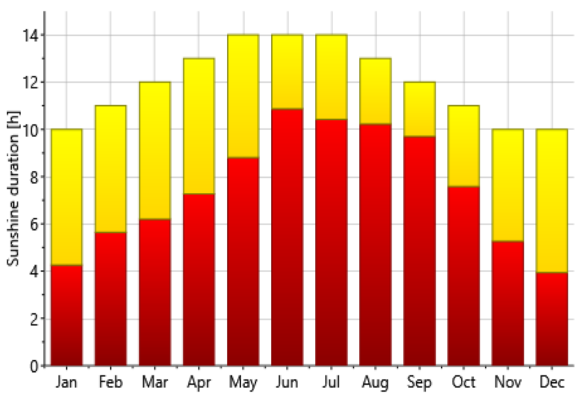


Figure 6. The average daylight hours during the year.

2.5. Temperature Resource

Fig. 7 illustrates the site's temperature data, indicating that the minimum temperature falls below 4 °C during the winter months (December and January); however, it exceeds 45°C in the summer (June, July, and August). The provided temperature information suggests that the environmental conditions are challenging and not conducive to PV efficiency during the summer months due to the increase in temperature at daylight [16].

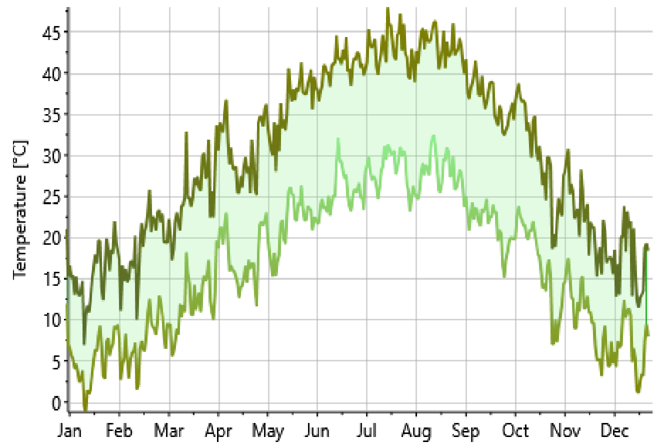
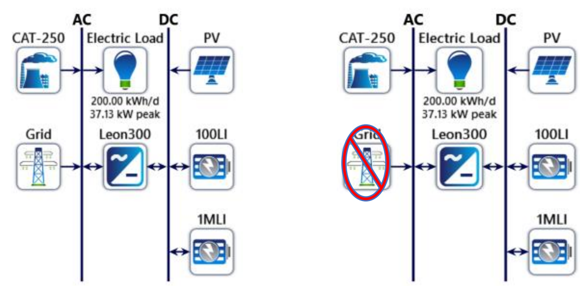


Figure 7. The temperature data of EKADPP

2.6. Project Component Setting

Fig. 8 (A and B) depicts the modules of the two planned hybrid solar systems. These systems are connected to the grid and supplemented with a backup generator and lithium batteries. These modules' initial costs, procedure and conservation expenses, replacement costs, and lifetimes were configured when selecting these modules. Below is an overview of these components:



A B

Figure 8. A) 100 kWh ON-grid PV scheme with battery,

B) 1 MWh off-grid PV scheme with battery.

- Diesel Generators: One diesel generator is currently in use. G, a Caterpillar-Model DE550E0 [17], has a capacity of 250kVA. The producer cannot fully support the peak load during the summer, often necessitating the disconnection of some loads. G is associated with a primary cost of $50,000.00, the same amount, and an operational lifespan of 90,000 hours.

- Solar PV Panels: The chosen model from the HOMER library is the Schneider Coexecutrix 540kWp [18] with Generic PV, expected to last 25 years. Installation is estimated at $900.00 per kW, based on local market prices, including the panel.

- Converter [19]: The Leonics MTP-4117H 300KW, with a capital and additional cost of $600/kW, offers η = 95% and an estimated lifespan of 10 years.

- Battery System: 2 styles of battery capacities have been selected for the HOMER. The original values are a general 100kWh Li-Ion model with also η= 90% [20], with primary costs assessed at $70,000 per set.
- Grid System: Utilized when RESs are insufficient to add the structure and meet load demand, with the cost regular at $0.10 per kWh.

3. Results and Discussion

For instance, depicted in Fig. 8, relevant information for this sector was input into HOMER PRO. The setup includes two buses, one AC and one DC, to which the respective AC and DC are connected. On the bus, connections include the two generators, the load, the grid, and the system. Meanwhile, the DC bus hosts the PV and the two batteries.

The smart grid was integrated with a net meter in the first test track. This meter was configured to sell energy at $0.1/kWh and purchase it at $0.8/kWh, as is the standard in Iraq. However, it is important to note that smart meters are not yet in use in Iraq, although the Ministry of Electricity plans to implement them soon.

Track 2 involved recalculating the equivalent structure but in the absence of a system to determine the COE, as illustrated in Fig. 8 B. Based on the audit report, the load profile was uploaded to HOMER Pro in table format, as shown in Fig. 8. Fig. 9 presents a histogram produced by HOMER Pro, which illustrates the frequency of different loads. The monthly load profile is displayed in Fig. 10, also generated by HOMER Pro.

3.1. Grid Presence System Analysis

The Grid Presence System Analysis involved the adoption of 24 various developments, as outlined in Table 3. For each process, HOMER calculated the NPC, COE operational costs, and primary capital in USD. Additionally, the energy formed and the fuel consumed by each generator were documented. The analysis also included data on the PV panels' capital cost and energy production. The results presented the yearly obtained, sold, and net energy of the grid.

The data for the scenario with the lowest COE identified the process as the most favorable, detailed as follows: -

- This procedure utilizes PV panels and a system grid.
- Regarding COE, this situation achieved $0.058, which is 58% less than the cost of grid power.
- It presented the lowest NPC over 25 years, with a primary cost of only $59,018.
- The annual energy purchased (31,802 kWh/year) was less than the energy sold (31,777 kWh/year), indicating a progression towards a NZS.
- Owing to extraordinary costs and environmental influence, no generator is necessary in this procedure, although generators will be considered in the following track where the on-system is absent.

Fig. 10 A displays the yearly purchases and net energy. The methods S1, S2, S3, S5, S12, S19, and S20 exhibit NZS values, but S1 has the last NPC and primary cost. Some methods present a negative NZS value, implying income for the EKDPS, but at the expense of a higher initial cost. Fig. 11 shows the COE and NPC. Lastly, Fig. 12 illustrates the initial capital in dollars and the operational costs in dollars per year for all scenarios.

3.2. Grid Absent System Investigation.

Grid Absent System Investigation in the (absence) of the grid, twenty-one scenarios were explored, as detailed in Table 2. This analysis also encompassed the calculation of NPC, COE, operational costs, and primary capital in USD. The energy manufactured and the fuel obsessive by each generator were also noted. The statistics included the capital cost and energy yield of the PV systems. Due to the grid's absence, the yearly purchases, sold, and NZS values were naturally zero.

After evaluating data for the lowest COE, the foremost setup emerged as the most favorable, and it is elaborated upon as follows: -

- This scenario comprises PV panels and a 100kWh lithium battery storage.

- It registered the final COE at $0.372, a 641% greater cost in the first track.

- No generator was employed in this scenario.

- Compared to the winner from the first track, this scenario exhibited NPC, COE, operational cost, and primary capital, as indicated in Table 3.

As of July 6, 2022, the current diesel cost in Iraq is $0.66. The report also presents the energy formed in kWh and its capital cost in USD. NPC and COE in USD are also presented and illustrate the initial capital and operational costs for the scenarios.

3.3. Grid Uncertainty Analysis

As detailed in the respective tracks, a comparative analysis was conducted between the winning scenarios from tracks (1 and 2).

- The initial capital required in Track 2 is found to be 301% higher than that in Track 1.
- In both track (1and2) settings, generators were not utilized.
- All methods in Track 2 operated without grid access, including Track 2, which consequently had no energy purchases from the grid, energy sold, or NZSB.
- The capital cost for PV in Track 2W is 77% higher than in Track 1W.
- Conversely, PV power manufacturing in Track 2 surpasses that in Track 1 by 77.

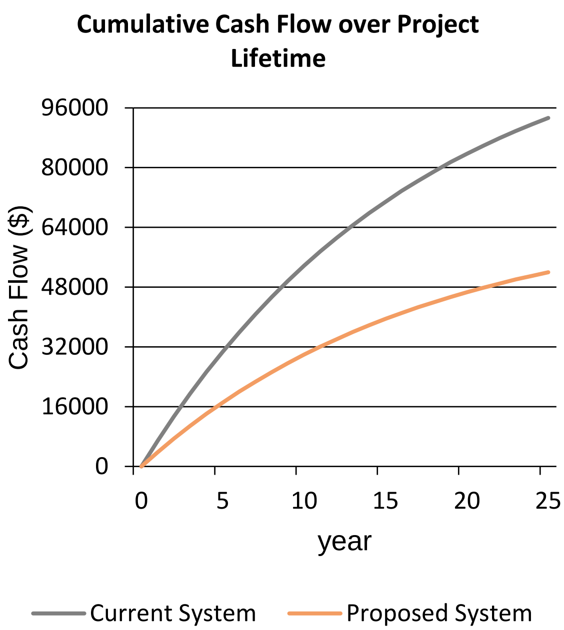


Figure 9. Cash flow and lifespan of the proposed system

To improve the dependability of Iraq's power grid, a comparison of the winning scenarios from Track 1 and Track 2 will be made, considering all potential scenarios of grid power absence. This comparison involves adopting varying annual grid availability percentages, ranging from 0% to 100%, as shown in Table 4. The worst-case scenario, with no grid access, is derived from Track 2 data. The outcomes demonstrate that as grid convenience fluctuates between 0% and 100%, there is a corresponding variation in NPC (from $77,680 to $337,291), COE (from $0.058 to $0.372), and operational costs from $1,460/year to $7,855/year. Given that grid obtainability on the location typically ranges from 40% to 60%, this range is considered in the analysis.

Table 3. The optimization of operation scenarios

Architecture/PV (kW)	Cost/NPC ($)	Cost/COE ($)	Cost/Operating cost ($/yr)
	51991.09	0.055714	4067.093
	93318.5	0.1	7300
0.261	368318.8	0.39469	14680.37
0.261	409143.5	0.438438	17873.96
	474212.4	0.508166	17539.4
1.25	477350.7	0.511529	17539.22
	515539.8	0.552452	20772.31
1.25	516302.7	0.553269	20586.31
	1433210	1.535826	43275.79
1.25	1436348	1.539189	43275.61
	1474537	1.580112	46508.7
1.25	1475300	1.58093	46322.7

Table 4. Monthly Energy Grid Request.

Month	Energy Procured (kWh)	Energy Sold (kWh)	Net Energy hd Procured (kWh)	Peak Load (kW)	Energy Charge	Request Charge	Overall
Jan.	578	0	578	5.36	$57.82	$0.00	$57.82
Feb.	494	0	494	5.37	$49.38	$0.00	$49.38
Mar.	531	0	531	5.37	$53.09	$0.00	$53.09
Apr.	521	0	521	5.37	$52.08	$0.00	$52.08
May.	574	0	574	5.35	$57.40	$0.00	$57.40
Jun.	538	0	538	5.37	$53.85	$0.00	$53.85
Jul.	590	0	590	5.36	$58.95	$0.00	$58.95
Aug.	489	0	489	5.37	$48.86	$0.00	$48.86
Sep.	474	0	474	5.37	$47.37	$0.00	$47.37
Oct.	536	0	536	5.36	$53.57	$0.00	$53.57
Nov.	545	0	545	5.36	$54.50	$0.00	$54.50
Dec.	574	0	574	5.36	$57.38	$0.00	$57.38
Annual	6,442	0	6,442	5.37	$644.24	$0.00	$644.24

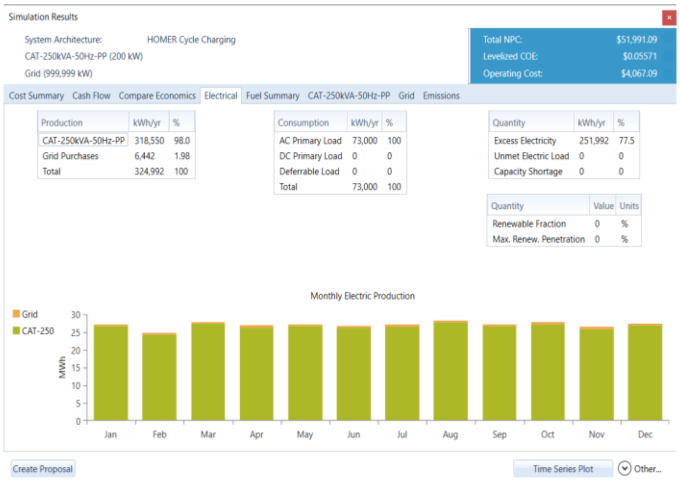


Figure 10. electrical summary.

Anticipating a forward-looking transformation, installing a solar system on the official government building, interconnected with the grid, holds immense potential to substantially impact the Iraqi grid while concurrently mitigating the costs associated with solar energy systems, obviating the need for extensive storage solutions.

Figure 11. Fuel consumption summary.

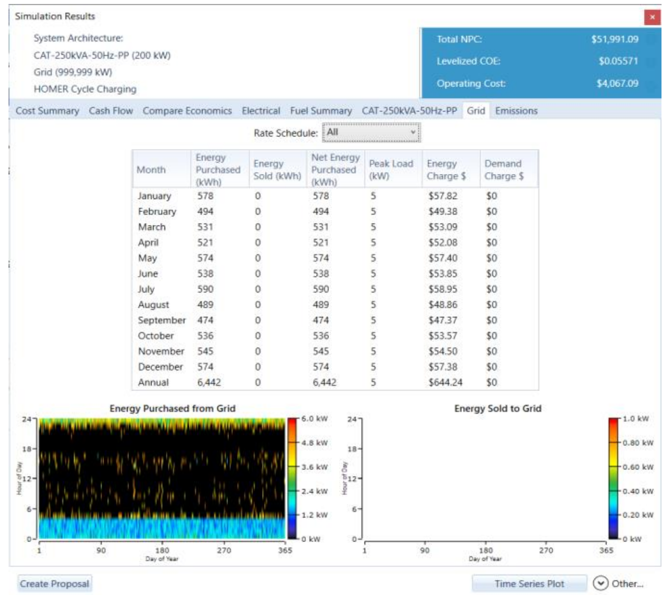


Figure 12. Grid Net purchased electricity in HOMER Pro.

4. Conclusion and Future Work.

The findings of this work underscore the economic viability and reliability of integrating PV within an educational institution, predicated on its unique load profile. Notably, the study reveals that on-off HRESs can significantly influence the overall energy cost, particularly when an available area is harnessed for solar installation. An engineering implication stemming from this research is the crucial role of conducting a comprehensive energy audit of the East Karbala Diesel Power Plant station, which furnishes the foundation for a robust design grounded in empirical data. This research paves the way for future endeavors to transition towards NZSBs and reduce power usage from the grid.

An exhaustive analysis of forty-five distinct scenarios was conducted, culminating in selecting two scenarios based on energy-related costs and associated expenditures. It is imperative to acknowledge that this study is contingent upon a specific geographical location with distinct renewable energy resources, weather conditions, and load profiles. Different scenarios may necessitate adaptation to divergent circumstances.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Haneen Flaih Hassan, Mohanad Aljanabi, and Bashar J Hamza proposed the research problem.

Haneen Flaih Hassan: performed the computations.

Haneen Flaih Hassan verified the investigation of using PV systems to reduce power usage.

All authors discussed the results and contributed to the final manuscript.

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