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RESEARCH PAPER

Design and Simulation of a Hybrid Wind/Solar/Diesel/Battery Off-Grid System for Rural Areas: A case Study in Al-Mahmudiyah Tribal Zone of Iraq

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A B S T R A C T:
This paper details a framework for designing appropriate hybrid power supply system for a tiny and remote off-grid rural locations. A combination of Solar PV/Wind turbine/Diesel generator have been simulated and tested in different cases. The optimization program 'Hybrid Optimization Model for Electric Renewables' HOMER is utilized in this study to discover the best architecture. Data from load forecast together with the solar/wind international atlases have been used in the design.
The total net present cost NPC and levelized cost of energy COE have been minimized to pick an economically practical and technically capable off-grid hybrid power_system._The simulated study showed that the solar generator offers the most assistance for power generation, accounting for around 77.3%, while wind accounts for approximately 19%. Also, the overall_net present cost (NPC) is $225,574.87, and the cost of electricity (COE) scheme is as low as $0.4037 per kWh.

KEY WORDS: Hybrid power system, PV, Wind energy, Battery Bank, HOMER, NPC, COE.
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I. INTRODUCTION:

The rapid growth of technologies behind renewable energy is promising to reduce the cost to the level that poor communities can afford it in the near future. In addition to the economic side, the usability and logistic feasibility, fuel-less generation strategy make renewable hybrid systems a reasonable solution for isolated rural areas, especially in developing countries.

Combining renewable energy production technologies, such as a hybrid solar-wind power generator system, may improve the reliability, affordability, and efficiency of renewable energy electricity (Karimi, 2014).

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The solar-wind hybrid system has several advantages: it may run throughout the day using solar energy, and it may continue to function utilizing potential wind energy after the sun has set. As a result, solar and wind systems function well together in a hybrid system and give more consistent production throughout the year than stand-alone wind or PV systems (Karimi, 2014). Almukhar (Almukhtar et al., 2019) proposed a design the optimal size of a hybrid system (PV, battery, diesel generator and the grid) by using HOMER software to supply electricity continuously with safeguarding both the environment and public health for Umm Qasr Primary School in Karbala, Iraq. Aziz (Aziz et al., 2022) investigated the best design of a grid-connected PV/battery that can meet residential home's load needs in Iraq. A fresh dispatch method was created using the HOMER software's MATLAB Link. Chaichan (Chaichan et al., 2016) presented the design and analysis of a hybrid system (PV/Diesel Generator) to provide a 10kW power supply to a telecommunications tower by utilizing the HOMER software in Al-Buraimi, Oman. Al-Shammari (AL-SHAMMARI et al., 2021) examined the viability of using diesel, batteries, wind, and solar by using HOMER software for Al-Faw, a city in southern Iraq close to Kuwait. These systems were constructed using various scenarios. The COE and NPC values for Scenario wind, diesel, battery storage, and Converters are the lowest of all the analyzed situations. Al-Janabi (AL-JANABI, 2022) suggested the hybrid system to support the national grid, which lacks electricity generation by using the HOMER software for three different regions of Iraq: Fallujah, Khanaqin, and Altun Kupri. According to simulation and optimization findings indicate that the "solar panel, battery storage, diesel generator, inverter, utility grid" hybrid system is the optimum system for the three locations. Hussain (Hussain et al., 2021) studied the design and implementation an on-grid PV system in Diyala Police Directorate, Iraq. this study focused on the economic analysis by delivering the necessary electricity for local load and investing the excess power into the national grid system with improved efficiency and lower losses. Al-Karaghouli (Al-Karaghouli and Kazmerski, 2010) suggests using a (PV) power system to run a clinic in a remote part of southern Iraq. The system size and lifespan cost are calculated using HOMER software. Mahmood (Mahmood, 2019) suggested a stand-alone PV system to provide electricity continuity to the loads throughout the working hours for three laboratories, Al-Nahrain University, Baghdad. In this study, simulation is accomplished using the Pvsyst6 software suite. Al-Sarraj (Al-Sarraj et al., 2020) investigated a hybrid system consist of (solar-wind-diesel-grid) by utilizing HOMER software for one station in the university of nahra, Baghdad, Iraq. Two systems were modeled, one with and one without a sellback price. The findings showed that the hybrid system with a sellback property was the best option. Jawad (Jawad et al., 2013) discussed the design and simulation of a hybrid wind/solar/battery/ diesel by using MATLAB/Simulink blocks in rural areas of Iraq. When compared to other topologies, it is discovered that Mixed-coupling HPSs can achieve the greatest efficiency in power consumption. Kazem (Kazem et al., 2017) presented the design and evaluate hybrid wind/solar/battery/diesel/ Battery system in term of emissions and cost by using HOMER software for an isolated island of Masirah in Oman.

According to the previous literature review, numerous studies have been conducted to identify the ideal layout, investigate potential, or examine the techno-economic viability from multiple perspectives and compare analyses by using HOMER software for remote rural areas in Iraq by taking into account the effect discussed parameters.

This paper focuses on the possibility of implementing a hybrid renewable off-grid power system to an isolated local community southern Baghdad called Al-Mahmudiyah. Al-Mahmudiyah is abundant in renewable energy resources, particularly solar and wind energy. The district, which is located at a latitude of 33.1209" N and a longitude of 43.5255" E, has a wind speed of 5.47 m/s at a height of 17m and solar radiation of 5.02 kWh/m2/day. The primary concerns of the local electricity utility are the cost of fuel and its transportation. The power supply system of this region is being studied, including the use of two types of renewable energy resources, energy storage devices, and a diesel generator. Different supply systems are assessed with the aid of the 'Hybrid Optimization Model for Electric Renewables' (HOMER) program to restrict the cost of the hybrid system and to provide the most economically possible option for this area (UL, 2022). The proposed solution is the system with the lowest cost of energy (COE) and the lowest net present cost (NPC).

II. Data Collection and Assessment

A. Location

Al-Mahmudiyah is an urban rural residential area in the middle of Iraq. Outside the centre there are tribes that live in spare un-electrical lands. Its geographical coordinates are 33.1209" North, 43.5255" East, as shown in fig.1 (U.S., 2022). Due to the shortage in Iraq-national grid's production, it is not planned to link the tribal families with the national grid.

In this study, a hybrid solar/wind/diesel system is designed for this place and simulated on HOMER. A hybrid renewable energy source is more suitable for the electrification in this area.

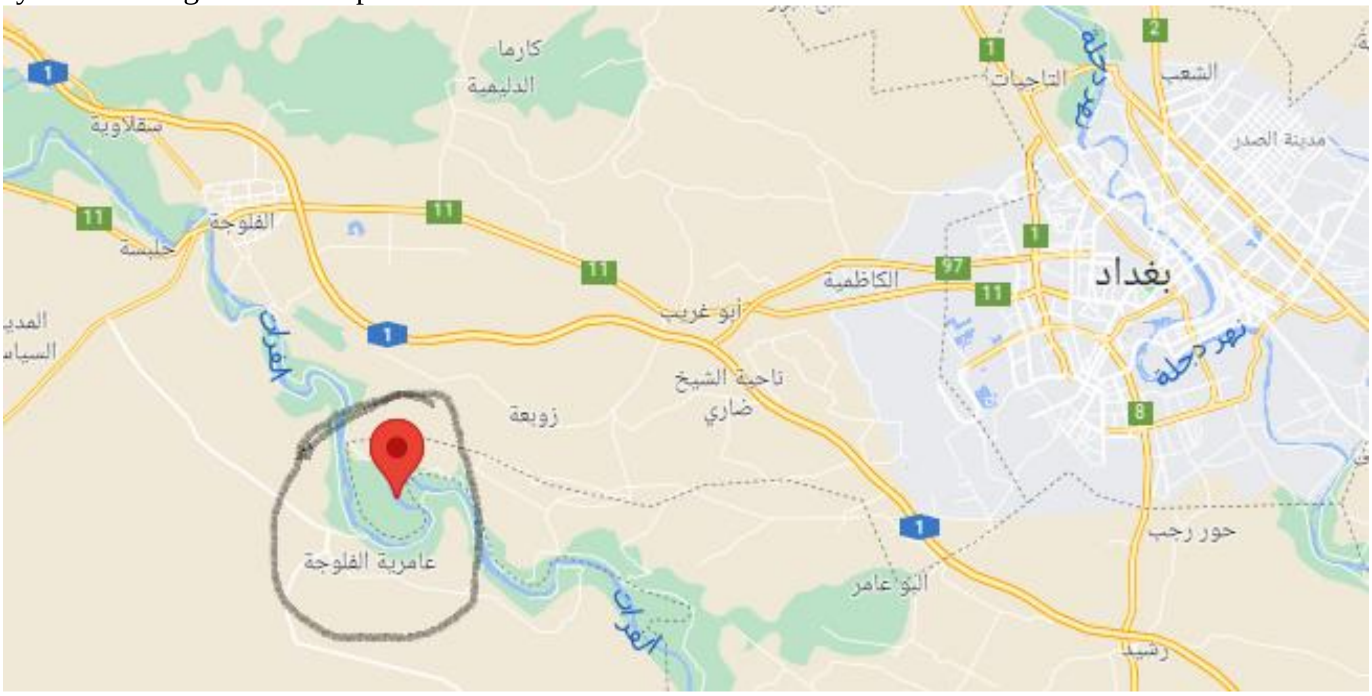


Fig.1 Geographical location of the study.

B. Electric load profiles estimation

In this research, Al-Mahmudya tribal zone has been selected to energized through an off-grid system. The zone consists of several tribal tent houses with an aquarium and animal facilities. Each one of these houses contains refrigerator, different lights, TV, fans, water heating, … etc. The aquarium consists of two motors. Table 1 shows the electrical consumption for Al-Mahmudiyah tribal zone. Therefore, the total electric load in the farm has been evaluated in order to examine the efficiency and reliability of the power producing system. The peak demand of the tribal zone is 19 kW, it has an annual average energy consumption of 118 kWh per day. Fig. 2 shows the daily, seasonal, and annually load profile. The load fluctuates throughout the day, as seen by the load profile. Furthermore, the highest demand is recorded during the evening hours, i.e., from 6 p.m. to 10 p.m. The following method is used to estimate the electrical load:

$$\text{Annual energy consumption (KWh)} = \sum_{i=1}^{n} [m(\text{ appliance(i)} * P_{\text{appliance(i)}} * \text{operation hour of appliance(i)}) / 1000] \quad (1)$$

Where:

n : appliance type.

m : number of appliance(i)

Table 1. Electricity consumption estimation at Al-Mahmudiyah tribal zone.

Appliances	Quantities	Power (W)	Total power (W)	Usage hour (h/day)	Day (Wh)	Night (Wh)	Energy (kwh/day)
Lamp (LED)	41	10	410	7		2870	2.87
Television	4	100	400	3		1200	1.2
fan	3	60	180	8	1080	360	1.44
projector light (LED)	12	150	1800	13		23400	23.4
Router	1	20	20	24	240	240	0.48
Mobile charger	5	4	20	4	80		0.08
Air cooler size 2.5	3	300	900	15	9900	3600	13.5
Refrigerator	3	450	1350	15	13500	6750	20.25
motor 1.5hp	1	1119	1119	5	5595		5.595
motor 2.5hp	1	1865	1865	5	9325		9.325
washing machine	3	2200	6600	2	13200		13.2
water heating	1	4300	4300	6	12900	12900	25.8
Subtotal peak load					**65820**	**51320**	
Average household daily load							**118 (kwh/day)**
Average household yearly load							**43070 (kwh/year)**

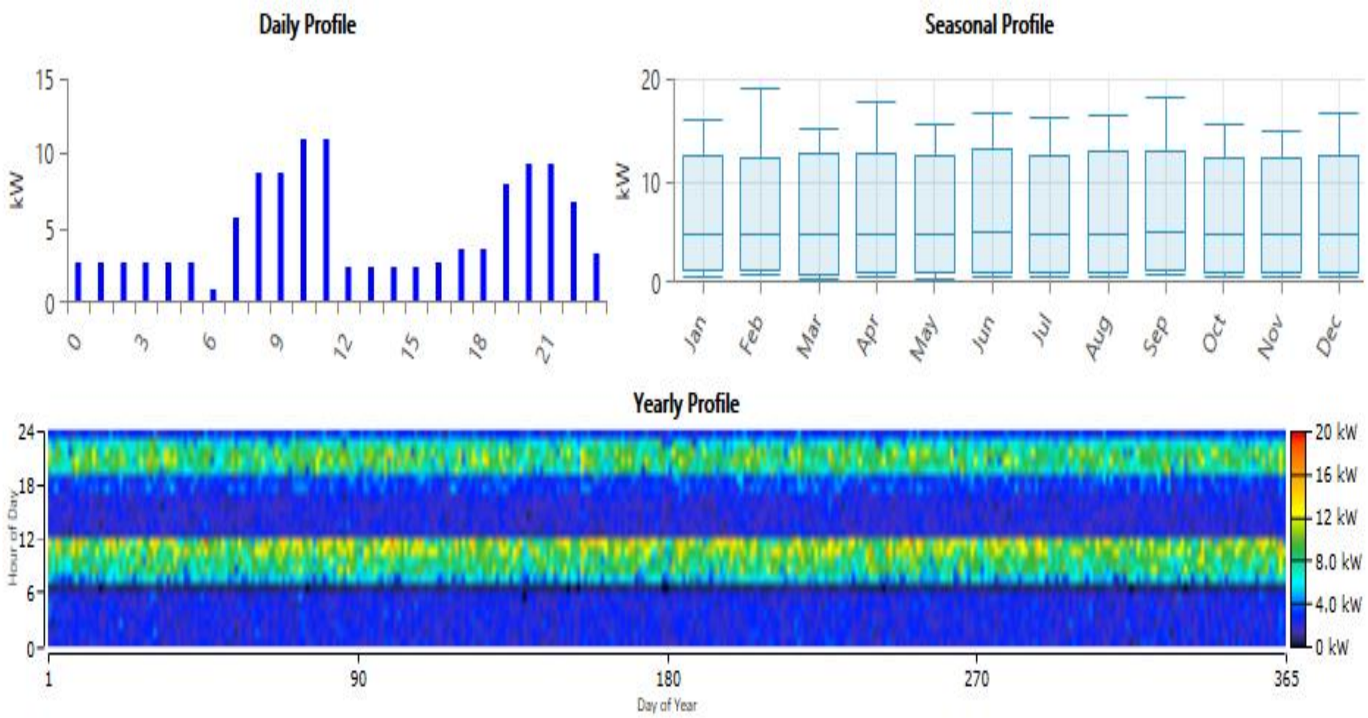


Fig.2 Load demand profile at Al-Mahmudiyah tribal zone.

C. Solar energy potential assessment

The remote area's clearing index and daily radiation are calculated using NASA surface metrology at latitude 33.1209'N and longitude 43.5255'E.

Solar radiation data is calculated to be between 2.62 and 7.56 kWh/m2. With considerable changes throughout the year, the annual average is scaled to 5.02 kWh/m2/day, and the average clearness index is determined to be 0.58. Fig.3 depicts the solar radiation profile throughout a year using NASA surface (Stackhouse, 2020).

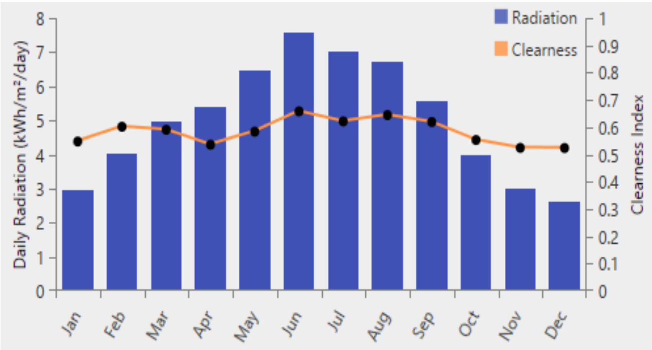


Fig.3 Monthly average daily solar radiation in latitude 33.1209" N and longitude 43.5255" E

It may be noted that from March to September, greater solar irradiance is received, whereas from October to February, less solar irradiance is projected, with the lowest value occurring in December. Solar irradiation fluctuation is an important factor to consider in order to guarantee that the service power required by the electrical load is always available.

D. Wind energy potential assessment

Wind speed data is collected by NASA from weather stations at a height of 17 meters. The annual wind speed average is scaled to 5.47 m/s, and the wind speed data is expected to vary between 4.67 and 7.00 m/s. Fig.4 depicts the wind speed profile over a year using NASA surface (Stackhouse, 2020).

The wind power formula is given in equation (2) (Rathore and Panwar, 2021):

$$P = \frac{1}{2}\rho A V^3 \qquad (2)$$

Where (A) is the swept area of the turbine (m^2), (ρ) is the air density (kg/m^3), and V is the wind speed (m/s).

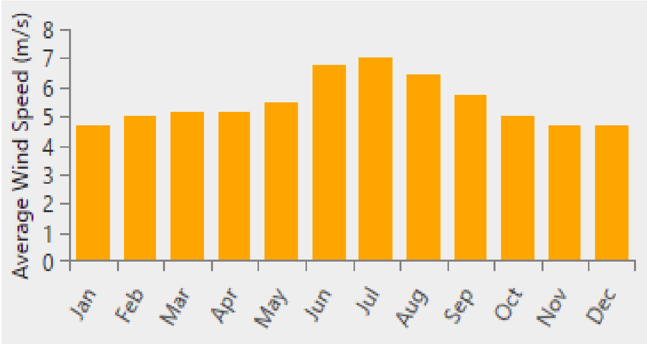


Fig.4 Monthly average wind speed in latitude 33.1209" N and longitude 43.5255" E

According to the data collected for the study area, higher wind speeds are projected from May through September, while lower wind speeds are expected in October and April.

III. SYSTEM DESIGN SPECIFICATION AND COST ESTIMATION

A. Design Methodology

The load demand has been calculated in the previous section to be 19 kW/day peak load and 118 kWh/day total energy. The project also includes the sizing and specification of the components: a wind turbine, a photovoltaic array, a diesel generator, a battery bank, and a converter. HOMER software was used to select and size the components for the hybrid power supply system.

B. PV array

The generic flat plat PV is chosen based on an annual average 5.02 kWh/m2/day. Generic flat plat PV gives a 40kW, however, the quantity of power generated is dependent on solar availability.

The cost of the PV array is taken as $24000 (estimated from the local market in Erbil, Kurdistan), while the operating and maintenance (O & M) cost per year is considered to be $200/year and the derating factor is considered to be 80%. The lifetime for this PV array system as offered by the manufacturer is 25 years. In table 2, the PV array cost inputs are presented.

Table 2. PV array cost inputs

Type	Generic flat plat PV (40kW)

Lifetime	25 years
Derating factor	80 %
Capital cost	$ 24000
Installation cost	$ 24000
O & M	$ 200/year

It's worth noting that this PV array would only produce power during the day, from 6 a.m. to 6 p.m. for winter and from 6 a.m. to 8 p.m. for summer. Because this source does not generate power at night, the solar output is 0 W. At night, the duty will be handed over to the battery bank (Barzola et al., 2016, Jiménez-Estévez et al., 2014). Due to superior solar insolation, the PV array generates more electricity than the wind turbines at the study zone, according to the measured data.

Selection of PV Module to be used: -

Module type: Mono Solar Panel STC 540watt
Maximum Power (Pmax): 540W
Maximum Power Voltage (Vmp): 49.60V
Maximum Power Current (Imp): 13.86A
Open Circuit Voltage (Voc): 1500V
Short Circuit Current (Isc): 12.97A
Dimensions(L*W*H): 2278*1084*35mm

In the system design requirement, the PV system delivers 540W and the number of modules in parallel is (Barzola et al., 2016):

$$\text{Average Amp h per day load} = \frac{\text{daily average system capacity/inverter efficiency}}{\text{DC system voltage}} \quad (3)$$

$$\text{Average Amp h per day load} = \frac{118000\text{w}/0.96}{48}$$

$$= 2560.76 \text{ Ah}$$

$$\text{Array peak Amps} = \frac{\text{average Amp h per day load/battery energy efficiency}}{\text{peak sun hours}} \quad (4)$$

$$\text{Array peak Amps} = \frac{2560.76/0.95}{2.62}$$

$$= 1028.83 \text{ A}$$

$$\text{Modules in parallel} = \frac{\text{array peak Amps}}{\text{peak Amps per module}} \quad (5)$$

$$\text{Modules in parallel} = \frac{1028.83}{13.86}$$

$$= 74.23 \sim 75$$

Which is interpreted as 75 modules in parallel.

Where:
Nps: is the number module per string.
Nsp: is the number of strings in parallel.
Vm: is the module design voltage.
Vs: is the dividing the system bus voltage.

$$\text{Nps} = \text{Vs/Vm} \quad (6)$$
$$\text{Nps} = 48/49.6 = 0.9 \sim 1 \text{ panel in series}$$

$$\text{Nsp} = \text{Np/Nps} \quad (7)$$
$$\text{Nsp} = 75/1 = 75 \text{ panel in parallel}$$

The total number of modules is 75*1=75 panels.

C. Wind turbine

High-scale wind turbines utilized for off-grid applications in isolated places are being examined in Al-Mahmudiyah zone because monthly average wind speeds are rather high.

The Generic G3 Wind Turbine is chosen based on an average wind speed of 5.47 m/s (height of 17 m). The wind turbine Generic G1 produces 3kW of alternating current. However, the quantity of power generated is dependent on wind speed changes and availability.

The installation and the operating and maintenance cost per year are considered to be $2500 and $200/year, respectively. The lifetime of this turbine is 20 years. In table 3, presents the wind turbine cost inputs.

Table 3. Wind turbine cost inputs

Type	Generic G1 (3kW)
Lifetime	20 years
Hub height	17
Capital cost	$ 2500
Installation cost	$ 2500
O & M	$ 200/year

D. Storage battery bank

A battery bank is proposed as a backup unit and storage energy system. The type of battery selected for this system is a Generic (1kWh) Lead Acid with a nominal voltage of 2V and a nominal capacity of 513Ah. The lifetime of this battery bank is 10 years. The capital cost and the installation cost for one unit of this battery are both considered to be $300. The operating and maintenance (O & M) cost per year is assumed to be $10/year for each battery. In table 4, the storage battery cost inputs are presented.

Table 4. Storage battery cost inputs

Type	Generic (1kWh) Lead Acid [ASM]
Lifetime	10 years
Nominal Voltage	2 V
Nominal Capacity	513 Ah
Nominal Capacity	1.03 kWh
Capital cost	$ 300
Installation cost	$ 300
O & M	$ 10/year

When the PV-Array and wind are working at maximum rated capacity, i.e., during the charging dispatch strategy cycle, the extra power is charged into the system's batteries.

State of charge (SOC) is a percentage of rated capacity measurement of how much of the initial battery capacity is really usable. For instance, a battery that has a 30% depth of discharge would have a 70% state of charge (Bhikabhai, 2005).

For solar power systems, batteries are an excellent option. They're very good at determining the amount of discharge they'll put up with. The battery's net capacity in Ah/day, based on the equation below (Amare, 2021):

$$\mathrm{Bcap} = \frac{\mathrm{Scap}}{\mathrm{V_{nom,batt}}} \tag{8}$$

$$\mathrm{Bcap} = \frac{118000\mathrm{w}}{48} = 2458.33\ \mathrm{Ah/day}$$

Where (Bcap) is the battery's net capacity, (Scap) is the daily Average System, and ($\mathrm{V_{nom,batt}}$) is the nominal battery voltage.

After that, the battery's overall commercial capacity ($\mathrm{Bcap.com}$) is computed as (Amare, 2021):

$$\mathrm{Bcap.com} = \frac{\mathrm{Bcap}}{\mathrm{DOD}} \tag{9}$$

$$\mathrm{Bcap.com} = \frac{2458.33}{0.8} = 3072.92\ \mathrm{Ah/day}$$

Where ($\mathrm{Bcap.com}$) is the total commercial battery capacity, and (DOD) is the depth of discharge.

And also selected nominal capacity battery is 513Ah. To calculate the number of batteries that must be connected in parallel to achieve the system's Ah requirement (Amare, 2021):

$$B_P = \frac{\mathrm{Bcap.com}}{B_R} \tag{10}$$

$$\mathrm{B_P} = \frac{3072.92}{513} = 5.99 \sim 6\ \text{batteries in parallel.}$$

The number of batteries that must be connected in series to get the voltage that the system requires (Amare, 2021):

$$\mathrm{B_S} = \frac{\mathrm{V_{nom.batt}}}{\mathrm{V_{batt}}} \tag{11}$$

$$\mathrm{B_S} = \frac{48}{2} = 24\ \text{batteries in series.}$$

Six batteries are to be connected in parallel and 24 batteries are to be connected in series.

The total number of batteries are connected in the system is (6*24 = 144) batteries.

E. Diesel generator

In the HOMER software, the Generic 25 Kw Fixed Capacity Genset is selected for this system. The capital cost and the installation cost of this generator are considered to be $12500, while the operating and maintenance cost per year is $0.750/year. The lifetime of this generator is 15000 hours. Table 5 shows the diesel generator cost inputs.

Table 5. Diesel generator cost inputs

Type	Generic 25 Kw Fixed Capacity Genset
Lifetime	15000 hours
Capital cost	$ 12500
Installation cost	$ 12500
O & M	$ 0.750/year

F. Converter

The converter is a component that transforms electric power from direct current (DC) to

alternating current (AC). The following method determine the size of the converter (Amare, 2021):
Converter size = maximum power of Ac loads * 1.1 (oversize factor)
Converter size (kW) = 19 * 1.1 = 20.9kW

For safety, the inverter must be considered larger than the size. As a result, the converter used in this system produces 25kW and has a 96% efficiency. The capital cost and the installation cost are considered to be $600. The lifetime of this converter is 10 years. Table 6 shows the converter cost inputs.

IV. Scenarios

Three scenarios (cases) were showed to deliver power to Al-Mahmudiyah tribal zone using various energy sources. To make sure that the Homer simulation procedures would be feasible and reliable, this study examined many cases with combinations of various components, including wind turbines, PV panels, diesel generator, converters and batteries.

Table 6. Converter cost inputs

Type	25 kW
Lifetime	10 years
Efficiency	% 96
Capital cost	$ 600
Installation cost	$ 600

A. Scenario 1:

In this scenario, PV and diesel generator provided the power to the load. PV, diesel generator, battery storage, and converters were the components included in this scenario as shown in Fig.5, and their simulation results is shown in Fig.6.

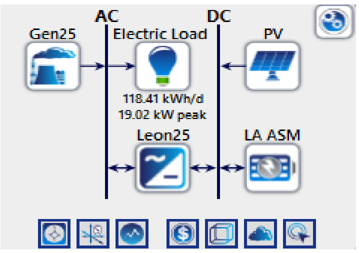


Fig.5 System Design (Case 1).

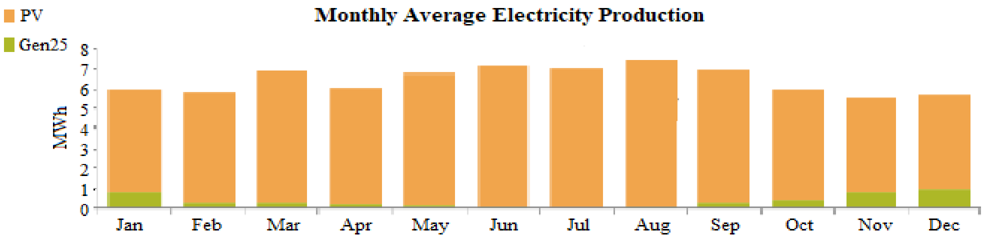


Fig.6 Simulation Results (Case 1).

B. Scenario 2:

In this scenario, wind turbine and diesel generator provided the power to the load. Wind turbine, diesel generator, battery storage, and converters were the components included in this scenario as shown in Fig.7, and their simulation results is shown in Fig.8.

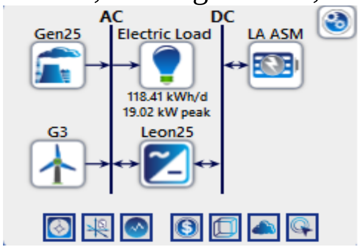


Fig.7 System Design (Case 2).

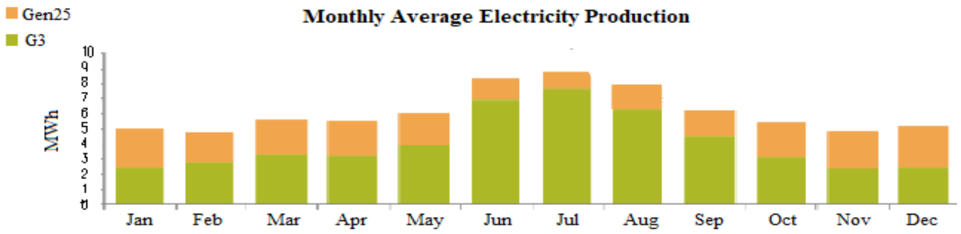


Fig.8 Simulation Results (Case 2).

C. Scenario 3:

In this scenario, PV, wind turbine and diesel generator provided the power to the load. PV, wind turbine, diesel generator, battery storage, and converters were the components included in this scenario as shown in Fig.9, and their simulation results is shown in Fig.10.

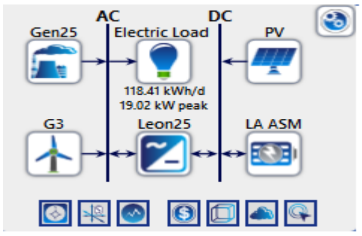


Fig.9 System Design (Case 3).

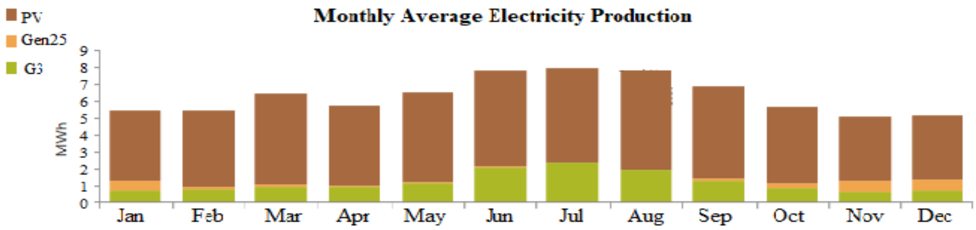
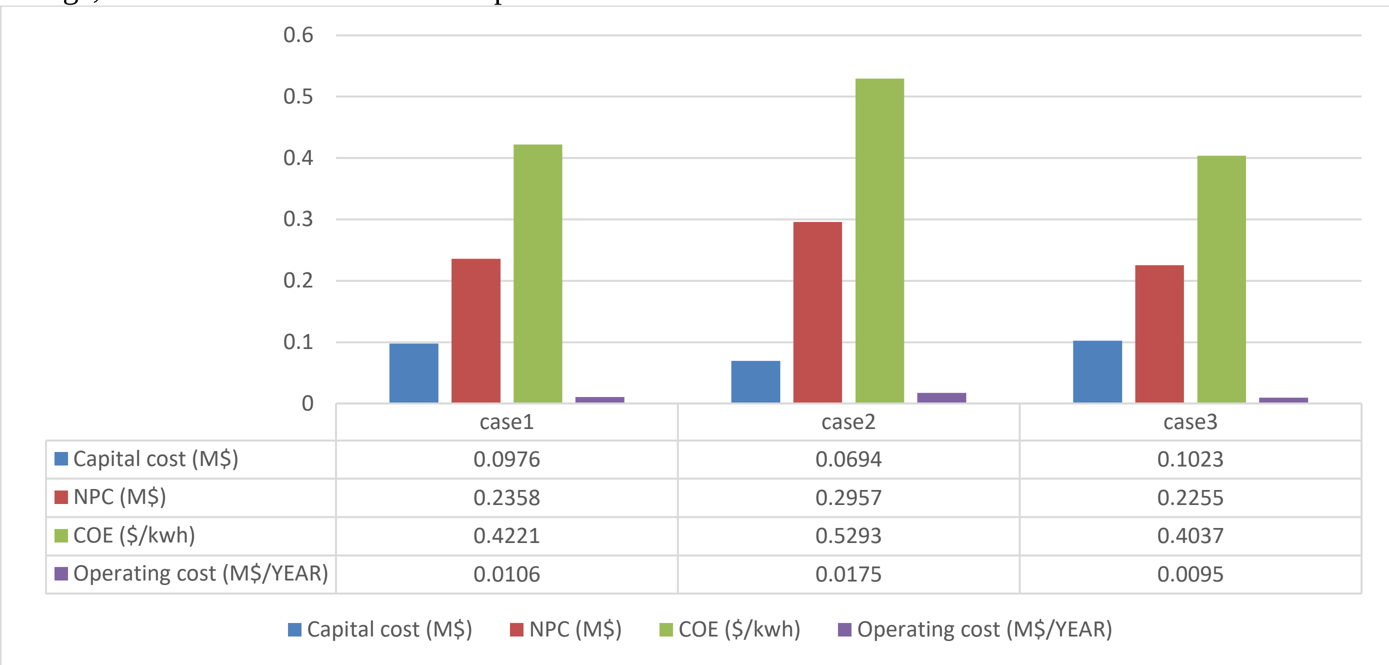


Fig.10 Simulation Results (Case 3).

V. Results of scenarios

In this study, three scenarios were considered to deliver power. Fig.11 shows total costs for all cases for the community under study. As a result, case (3) PV, wind, diesel, battery storage, and converters with the net present cost (NPC) and lowest cost of energy (COE) values are the most economically viable configuration for Al-Mahmudiyah tribal zone among all studied cases.



	case1	case2	case3
Capital cost (M$)	0.0976	0.0694	0.1023
NPC (M$)	0.2358	0.2957	0.2255
COE ($/kwh)	0.4221	0.5293	0.4037
Operating cost (M$/YEAR)	0.0106	0.0175	0.0095

Fig.11 System costs associated with each case.

A. The Estimation Cost

The total cost of the input parameters and costs of different components is:

PV cost = module price × number of modules
= $323.037 * 67 = $21,643.49

Wind cost = wind price * no. of wind
= $2,500 * 4 = $10,000

Battery cost = battery price × no. of batteries
= $300 * 144 = $43,200

Converter cost = conv. price * kw converter count
= $600 * 25 = $15,000

Total cost = PV cost + wind cost + generator cost + battery cost + converter cost + controller cost

Total cost = $21,643.49 + $10000 + $12,500 + $43,200 + $15,000 + $300 = $102,643.49

B. Economic Mathematical Models

NPC and COE are used to evaluate the optimum design of HESs. The Net Present Cost (NPC) represents the system's life-cycle cost which is calculated using equation (12):

$$NPC = C_{annual.tot} / CRF(i, L_{Project}) \quad (12)$$

Where ($C_{annual.tot}$) is the total annually cost, $CRF(i, L_{Project})$ is the capital recovery factor, (i)

is the interest rate (%), and $(L_{Project})$ is the lifetime of project.

The COE is the average cost of generating useable energy calculated using equation (13):

$$COE = C_{annual.tot}/E_{used} \quad (13)$$

Where $(C_{annual.tot})$ is the total annually cost, and (E_{used}) is the energy used to supply the load (kWh/year).

VI. The Control System

The different modules of the proposed system are synchronized and controlled via a PLC system. The flowchart for the procedure of the functionality of the control system is shown in fig.12:

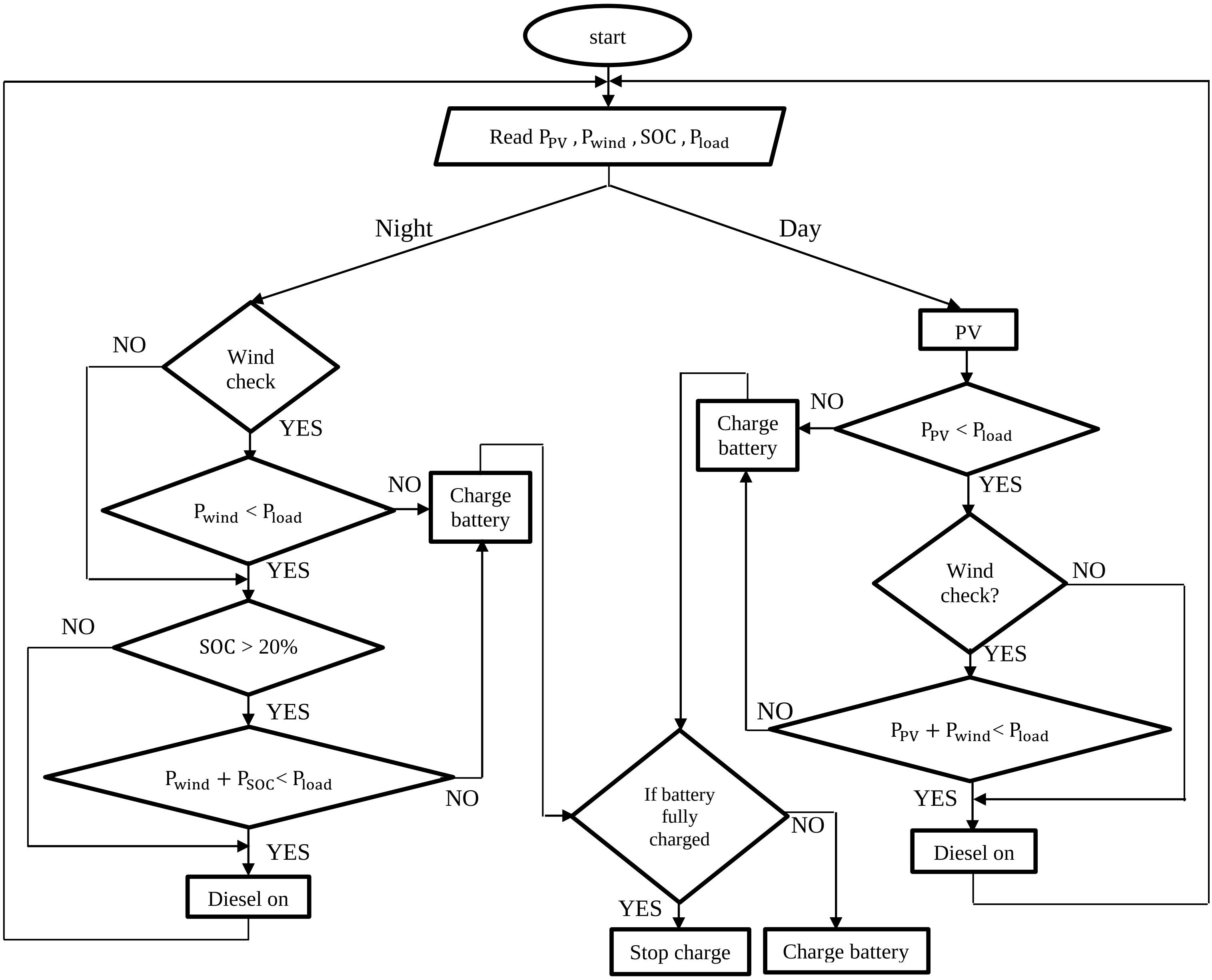


Fig.12 Flowchart of the control algorithm.

The components of the hybrid system have all been modelled and simulated using HOMER. Solar PV/wind turbine/Diesel Generator or stored energy provides the power to serve the linked loads, depending on the available energy resource. Fig.13 shows the block diagram of the hybrid system. As shown in this figure, all components of the hybrid system are controlled by a PLC controller. And solar represents solar energy generation; wind turbine represents wind energy generation; diesel generator represents electric energy from fuel; and storage battery represents battery energy stored during low load, high renewable energy generation, and discharged during low renewable energy generation.

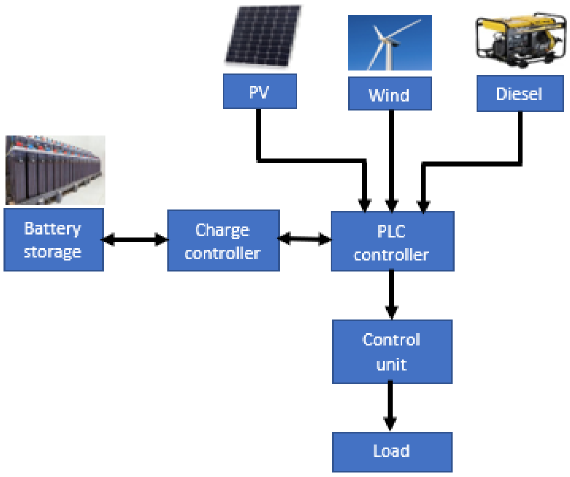


Fig.13 Block Diagram of Hybrid System with PLC Controller

VII. Results of The Optimized System

The proposed system has been simulated via HOMER. The optimum case shows a hybrid solar PV/wind/diesel generator/storage battery with an output power of 36.1kW solar PV, 12kW wind turbine, 25kW diesel generator, 144 ASM batteries (each with 315Ah capacity), and 25kW bi-directional converter. This "ideal" system (least TNPC) costs $225,574.87, with a capital cost of $102,343.49 and a COE of $0.4037/kWh. It consumes 96.3% renewable energy.

Fig.14 shows the monthly distribution of the electricity produced in kW by the PV-Array, wind generator, and diesel generator. The PV array provides the greatest power production accounts for 77.3% (58533kWh/year), wind turbine power production amounts for 19% (14371kWh/year), and diesel generator generation covered 3.72% (2817kWh/year) of total energy produced by the hybrid scheme.

The overall electric power generation of this power system configuration was 75721kWh/year (100%), but the total electric power consumption of the AC load was around 43220kWh/year, and the excess electricity was 27722kWh/year, or 36.6 percent of the total energy generated.

Fig.15 shows a screenshot of a cost summary in terms of NPC by component type. It displays a graphical depiction of each component as well as extra materials that are necessary for NPC ($). It also shows a table representation of the capital cost ($), replacement cost ($), salvage cost ($), operating and maintenance cost ($), and total cost ($) of each component.

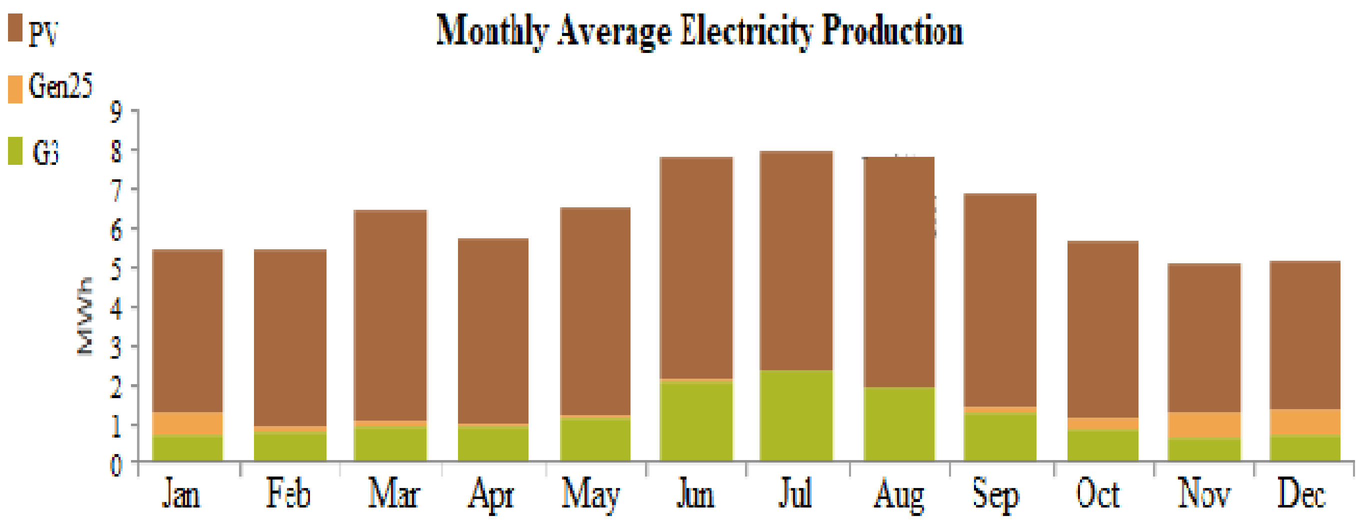


Fig.14 Monthly average electricity production.

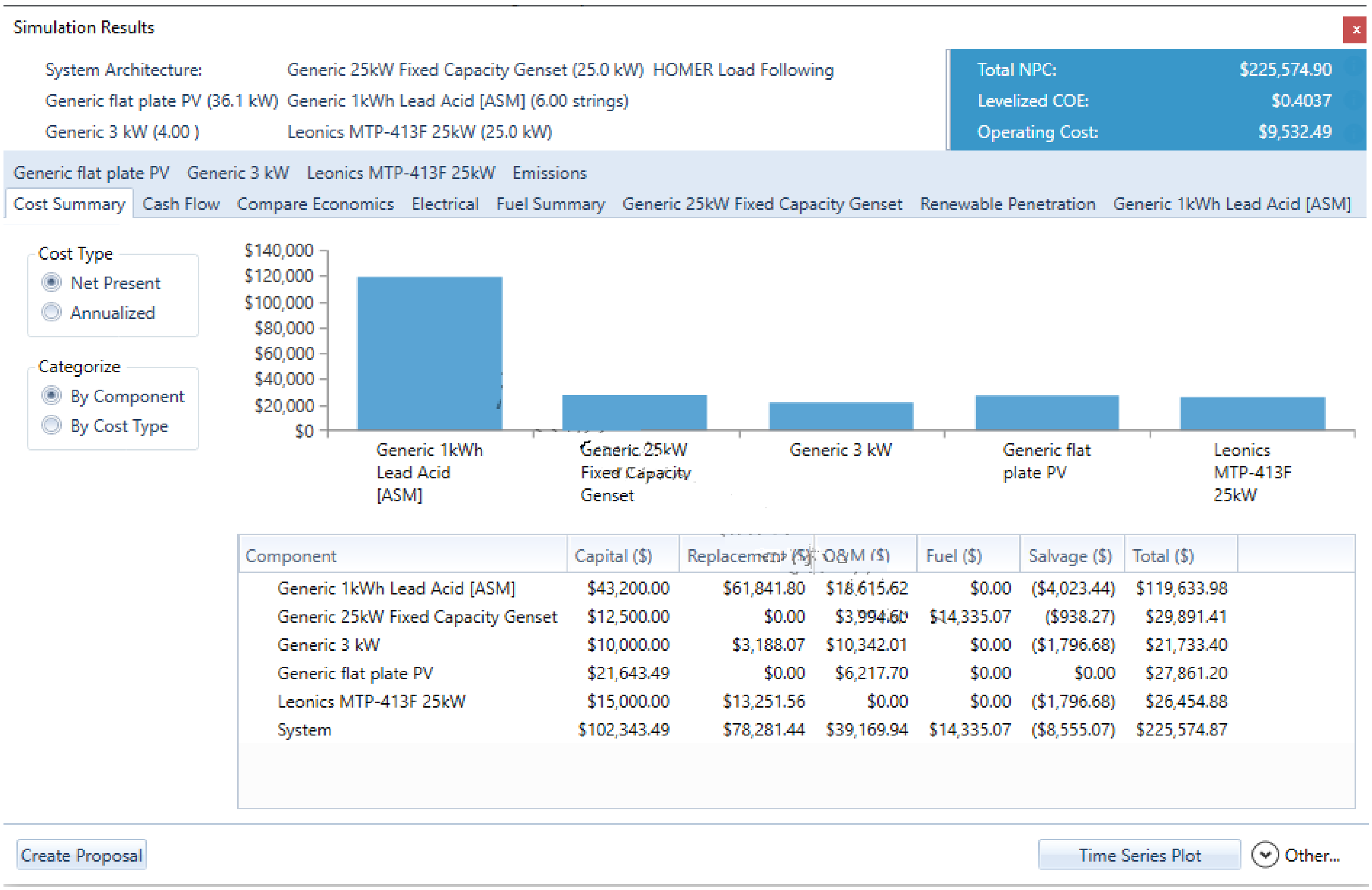


Fig.15 A screenshot of the cost summary of NPC by component type.

VII. CONCLUSION

The ideal framework for design and economically effective hybrid power system solution for a small isolated rural area has been designed and simulated in a solar PV/wind/diesel generator and battery bank have been combined and the performance has been studied using

HOMER software. The overall average energy consumption was estimated to be 118 kWh/day with a maximum load of 19kW. After choosing the best components and their properties, the proposed system overall net present cost (NPC) is $225,574.87, and the cost of electricity (COE) scheme is as low as $0.4037 per kWh.

The simulated study shows that the solar generator offers the most assistance for power generation, accounting for around 77.3%, while wind accounts for approximately 19%. This might be a chance to replicate the system in other distant areas with higher wind speeds.

The proposed framework is generalizable and may be used worldwide. The technology generates almost no noise or pollution. Although diesel generators emit some pollutants, their use accounts for just 3.72 percent of total electricity generation. The technology also aids in the connection of power plants in urban and rural locations. As a result of energy and related issues, the cultural gap between urban and rural communities is closing.

REFERENCES

AL-JANABI, E. M. S. A. 2022. DESIGN, AND COMPARATIVE ANALYSIS OF THE HYBRID RENEWABLE ENERGY SYSTEM: A CASE STUDY OF IRAQI REGIONS.

AL-KARAGHOULI, A. & KAZMERSKI, L. 2010. Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Solar Energy, 84**,** 710-714.

AL-SARRAJ, A., SALLOOM, H., MOHAMMAD, K. & GHAREEB, M. M. 2020. Simulation design of hybrid system (grid/PV/wind turbine/battery/diesel) with applying HOMER: A case study in Baghdad, Iraq. Int J Electron Commun Eng, 7**,** 10-18.

AL-SHAMMARI, Z. W., AZIZAN, M. & RAHMAN, A. 2021. GRID-INDEPENDENT PV–WIND–DIESEL GENERATOR HYBRID RENEWABLE ENERGY SYSTEM FOR A MEDIUM POPULATION: A CASE STUDY. Journal of Engineering Science and Technology, 16**,** 092-106.

ALMUKHTAR, H. M., AL-TAMEEMI, Z. H., AL-ANBARY, K. M., ABBAS, M. K., HUNG-YAO, H. & AL-MAMOORI, D. H. 2019. Feasibility study of achieving reliable electricity supply using hybrid power system for rural primary schools in Iraq: A case study with Umm Qasr primary school. International Journal of Electrical and Computer Engineering, 9**,** 2822.

AMARE, G. 2021. Design and Optimization of Hybrid Photovoltaic/Diesel Storage Battery Mini-Grid System for Rural Electrification (Case Study, Albasa Village in Benshangul Gumuz Region, Ethiopia). ASTU.

AZIZ, A., TAJUDDIN, M., ZIDANE, T., SU, C., MAS'UD, A., ALWAZZAN, M. & ALRUBAIE, A. 2022. Design and Optimization of a Grid-Connected Solar Energy System: Study in Iraq. Sustainability 2022, 14, 8121. s Note: MDPI stays neu-tral with regard to jurisdictional claims in ….

BARZOLA, J., ESPINOZA, M., PAVÓN, C. & CABRERA, F. Solar-Wind Renewable Energy System for Off-Grid Rural Electrification in Ecuador. 14th Latin American and Caribbean Conference for Engineering and Technology, San Juan, 2016. 20-22.

BHIKABHAI, Y. 2005. Hybrid power systems and their potential in the Pacific islands. SOPAC Miscellaneous, Report, 406.

CHAICHAN, M. T., KAZEM, H. A., MAHDY, A. M. & AL-WAEELY, A. A. 2016. Optimization of hybrid solar PV/diesel system for powering telecommunication tower. IJESET, 8**,** 1-10.

HUSSAIN, A. N., AL-TAMIMI, M. K. A. & ABID, M. 2021. On-grid Photovoltaic Power System for Governmental Office Electrification. Journal of Techniques, 3**,** 45-52.

JAWAD, Q. A.-J., JAWAD, M. R. & GASEM, K. K. 2013. Design and Simulation of Hybrid System for Electricity Generation in Iraqi Rural Regions. Diyala Journal of Engineering Sciences, 6**,** 38-56.

JIMÉNEZ-ESTÉVEZ, G. A., PALMA-BEHNKE, R., ORTIZ-VILLALBA, D., MATA, O. N. & MONTES, C. S. 2014. It takes a village: Social SCADA and approaches to community engagement in isolated microgrids. IEEE Power and Energy Magazine, 12**,** 60-69.

KARIMI, Z. M. 2014. Modelling, implementation and performance analysis of a hybrid wind solar power generator with battery storage. Universidade de Coimbra.

KAZEM, H. A., AL-BADI, H. A., AL BUSAIDI, A. S. & CHAICHAN, M. T. 2017. Optimum design and evaluation of hybrid solar/wind/diesel power system for Masirah Island. Environment, Development and Sustainability, 19**,** 1761-1778.

MAHMOOD, A. 2019. Design and simulation of stand-alone pv system for electronic and communications engineering department laboratories in Al-Nahrain University. EAI endorsed Transactions on Energy web, 6**,** e9-e9.

RATHORE, N. S. & PANWAR, N. 2021. Fundamentals of Renewable Energy, CRC Press.

STACKHOUSE, P. 2020. NASA POWER.

U.S. 2022. Google Maps.

UL 2022. HOMER Pro.