



# Feasibility Study of Hybrid Energy System for off-Grid Electrification in Rural Areas

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## ABSTRACT

Hybrid energy systems is an energy system which employs the combination of various renewable energy sources (solar, wind, biomass, hydro, and hydrogen fuel) with conventional energy sources to supply electricity. These systems have become reliable and most cost-effective as compare to single-source energy system for rural electrification. The objective of the present study is to address the demand for electrification of remote rural village in eastern Iraq. The methodology is carried out for optimization of hybrid energy system comprising (Photovoltaic, battery, diesel generator) by using HOMER to minimize the cost of energy and the greenhouse gas emissions. For different configuration of energy sources, the capital cost, net present cost and cost of energy is determined for the optimized hybrid energy system on the basis of the electric consumption demand for the selected site. The simulation results show that the most techno-economic analysis for hybrid energy system can feed the rural village in eastern Iraq to meet a daily load of 30 kW has consisted of 6 kW photovoltaic array, 7 kW power inverter, 20 units of battery (305 Ah and 6V) and 35 kW wind turbines. The optimized energy system has a cost of energy about \$ 0.117/kWh and total net present cost by about \$14800. The environmental assessment of the hybrid system shows that the greenhouse gases emissions will reduce about 25ton CO<sub>2</sub>/year (16968 kg/year) in the local atmosphere.

## 1. Introduction

Most of primary energy needs come from conventional energy sources (crude oil, natural gas and coal). The finite resources of fossil fuels present a big challenge for many industrial and service sectors. Further, the production of electricity from fossil energy resources is causing a significant threat to the earth environment. The rapid depletion of conventional fuel sources and the adverse impact of the greenhouse gases (GHG) emissions on the earth energy balance and its climate have forced for applying renewable energy sources (RES) for power generation.

The utilization of Hybrid Energy Systems (HES) received the most consideration as an alternative to fuel sources in power generation. HES can be integrated with the energy system based on fossil fuels which play a significant role in reducing GHG emission. Design of single energy system results oversizing issue of the system and high initial cost. Therefore, HES could improve the reliability of supply and reduce the sizing of the power system and can overcome the intermittent nature of renewable sources of energy.

In recent decades, communities with universal access to the electric grid have increased exponentially. By the early of 1990, the number of people of approximately 71% had

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access to the power grid. This number reaches up from 87% in 2016 [1]. The global population of people without access to the power grid has reduced from 1 billion to 860 million in 2018 [2-4]. The challenge is still high for supplying electricity for people located in remote areas of the world. The distance between the remote rural areas and the electric grid makes the solution of supply of electric energy by power grid extension is not cost-effective. Due to the above reasons, several studies have been done in the optimization of HES.

Sen and Bhattacharyya [5] studied the economic feasibility of various configuration of HES in the off-grid mode for rural electrification of the village located in Chhattisgarh, India. Showed that hybrid combination of renewable generators is the most techno-economic solution as compared to grid extension. They found that the Photovoltaic (PV)/hydro/biodiesel/batteries are the most economically feasible combination.

Ramli et al. [6] presented a feasibility analysis for the hybrid power system in off-grid mode composed of PV, wind turbine (WT) and battery for power generation in Yanbu, Saudi Arabia. They found that the wind energy source is unviable as compared to solar energy.

In the study area of New Borg El Arab city in Egypt, Fahd Diab [7] determined that the hybrid system consisting of PV/WT/battery/diesel is a feasible solution to meet the electricity demand for environmentally factory and the city surrounded the factory.

Hassan et al. [8] analyzed the economic feasibility of HES in the off-grid mode for electrification a remote rural village in Iraq. They found that the HES namely (PV/diesel/batteries) can satisfy the load demand at a COE of \$0.321/kWh for the study area.

Aziz [9] modelled an off-grid HES for electrification of desert safari camp in United Arab of Emirates. The results showed that the combination of PV/WT/battery is the most economical configuration for the camp.

Shahzad et al. [10] analyzed the feasibility of hybrid energy system combination of PV/biomass to electrify a small village in the Punjab province of Pakistan. Their results

showed the utilization of HES is the least cost solution the most reliable option for the selected site.

Aderemi et al. [11] studied the electrification of the cellular base station located in South Africa using hybrid energy system. The simulated findings showed that the most viable option and environmental advantage could be performed using the optimized configuration of PV/battery system.

Ali Aziz et al. [12] investigated the economic feasibility and environmental assessment of HES for rural electrification in Sakran mountains in Erbil, Iraq. The optimization of a different configuration of the hybrid system has been carried out using the multi-year model. They found that the power system combination (PV/hydro/battery/diesel) has the least-cost combination to supply the demand for electricity for the study area.

Iraq is a country in Western Asia with a total area of 438,446 km<sup>2</sup> and lies between latitudes 29 °N and 37 °N and longitudes 39°E and 48°E. Two main seasons are observed during the year summer and winter, with short transitional periods between them. Long hot summer which continues from May to October, is characterized by extremely high temperatures, low relative humidity and clear skies. Almost, no rainfall occurs from May through September. July and August are considered the warmest month during the year with an average daily temperature of 38 °C. Highest temperature range is usually observed in the summer months and can reach above 50 °C [13]. Short cold winter is observed where the month of January is typically the coldest with an average daily temperature ranges from 3 °C to 12 °C.

Furthermore, most Iraqi remote rural areas are underdeveloped and have insufficient access to the power grid due to the distance between the remote rural area and the electric grid [13,14]. In addition, most remote rural areas using a diesel generator to satisfy their electric power needs.

Besides, the numerous potentials of fossil fuel resources such as crude oil and natural gas, Iraq has also a numerous solar energy potential [15,16] due to its location in the region of the sun belt.

The present study aims to develop and to model and optimized HES in off-grid mode to supply electricity to a remote rural village located in east Iraq. HOMER (Hybrid Optimization Models for Energy Resources) software is used for sizing and optimizing of hybrid system configuration. The criteria of minimum value of Net Percent Cost (NPC) and Cost of Energy (COE) are considered for evaluation of hybrid energy system.

## 2. Methodology

In the projects of HES, the adaption of appropriate assessment criteria has a significant impact on the operational behaviors of different scenarios that can be used in the present study. The specifications of the selected site, renewable energy sources and their availability, and energy of demand assessment are discussed below:

### 2.1 Selection of study area

A techno-economic feasibility analysis for HES is performed in a small remote rural village, located in Mendely city in the district of Diyala, Iraq. The selected village is located in the eastern part of Iraq with a latitude of 27.8 oN and longitude of 35.35 oE. The weather of the north-east parts of Iraq were moderate as compared to the (scorching) hot weather in the rest of Iraq. The temperature of this location is about 2-4 OC lower than the typical temperature in the rest of Iraq. The climate of the north-east part of Iraq almost a moderate as compared to the middle and south (rest) part of Iraq. This is due to the mountain nature and cold winds of the surrounding area.

The people live in the study area in the unelectrified village. Therefore, they had used their diesel generator to satisfy the daily needs of electricity. The expansion of grid electricity is difficult and not a viable solution. Numerous availabilities of renewable energy sources such as solar and wind exist over the study areas, and these sources can be used in off-grid mode.

### 2.2 Component of the hybrid energy system

The main components of HES for this study are PV, batteries, converter, and diesel generator. The specification of the different HES components such as sizes, costs, lifetime is given in Table 1. The other cost and technical parameters are considered in the analysis were taken from Ref. [12, 16-27].

For the hybrid power system, the electricity generated by PV and batteries has the priority to feed the load demand in the cycle charging mode. When the PV output power is not sufficient to supply the desirable electricity consumption, and batteries are discharged to their minimum acceptable values. The auxiliary diesel generator runs to supply energy demand to the load and instantaneously charge the batteries.

The proposed HES (PV/WT/batteries) is shown in Fig. 1. The output of PV modules is direct current (DC), while the alternating current (AC) is obtained by WT. The load of the village almost requires an AC power to run the electrical devices. The converter is used for conversion of power flow between the DC and AC sources.

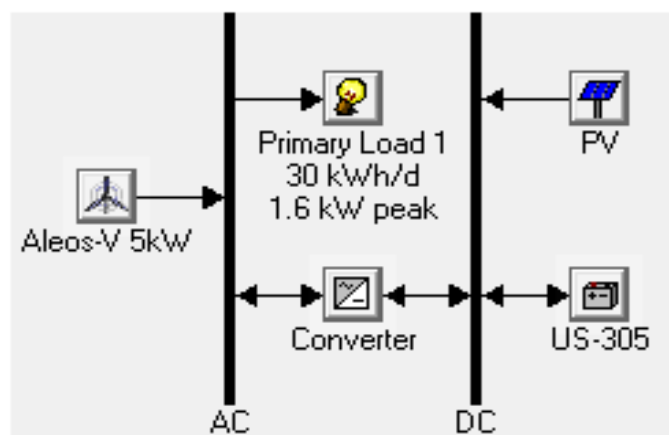


Figure 1. Schematic of the proposed hybrid energy system

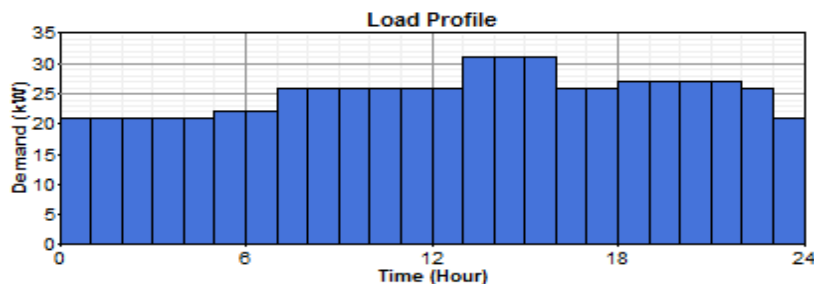
**Table 1.** Description and specification of HES components

Component	Description	Specification	Ref
PV system	Efficiency Temperature coefficient Nominal operating cell temperature De-rating factor Tracking system Capital cost \$ Replacement cost \$ 1000/kW Operating and maintenance Lifetime 25 years Model	13% -0.48% /oC 47 oC 80% Fixed \$ 1500/kW \$ 1000/kW \$ 5/kW/year 25 years *	[46,47]
2. Wind	Efficiency Capital cost Replacement cost Operation and maintenance cost Lifetime Model	75% \$ 1700/kW \$ 500/kW \$ 51/kW/year 25 years *	
3. Diesel generator	Capital cost Replacement cost Operating and maintenance cost Lifetime Model	\$ 500/kW \$ 450/kW \$ 0.02/kW/hour 15000 h *	
4. Batteries	Nominal capacity Nominal voltage Capital cost Replacement cost Operating and maintenance cost Lifetime Model	1156 Ah (6.94 kWh) 6 V \$ 1100 \$ 1000 \$10/year 9645 kWh Surrette 6CS25P	
5. Converter	Capital cost Replacement cost Operating and maintenance cost Lifetime Model	\$550/kW \$ 450/kW \$ 5/kW/year 15 years *	

### 2.3 Load profile of the study area

The electricity demand of the remote rural areas is not high as compared to urban areas. The most electric load for domestic use in the rural villages of Iraq is composed of fans, air cooler, compact lights, washing machine, refrigerator, television, water pump, computer, and iron box. These are about 40 houses in the village. The average of members in a family is assumed six, and there would be a total of 250

persons. Most of the power consumption of most appliances are considered at a different time of the day, and some of them are based for weekly usage. The calculations of the electric load consumption in summer peak season for the typical residential house has been presented in Table 2. The village daily load profile in the summer months is shown in Fig. 2. However, high load consumption occurs in the months from June to August.

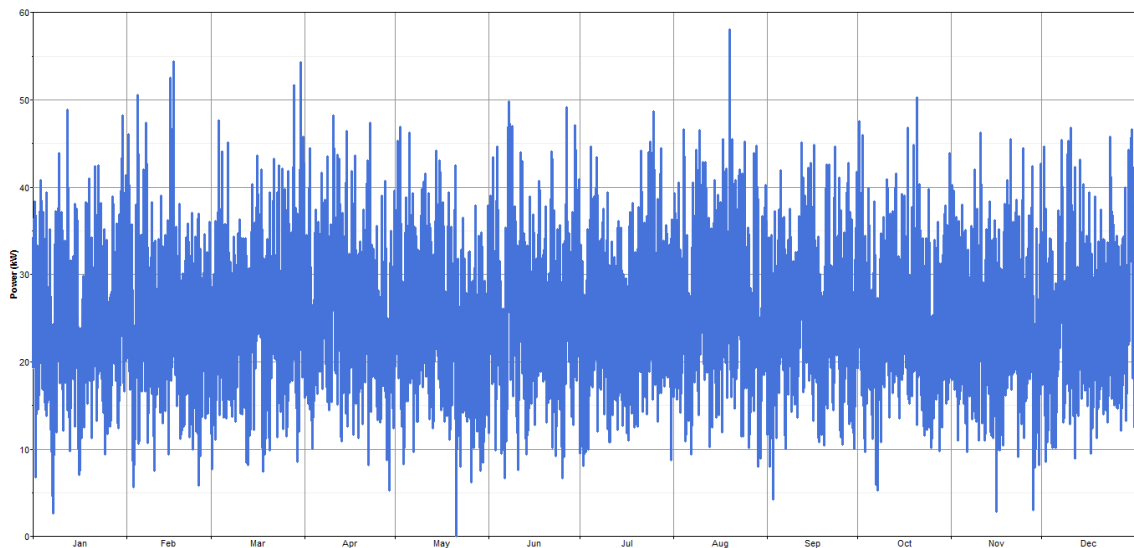
**Figure 2.** Hourly load profile for the study area

**Table 2.** Electric consumption of typical residential house in the selected site in the summer

Item	Power (Watts)	Operating hours	Number in use	Total load (Watt-hour)
Fans	40	12	4	1920
CFLs lamps	20	15	5	1500
Water pump	600	2.5	1	1500
TV	250	4	1	1000
Washing machine	300	1	1	300
Air cooler	325	14	1	4550
Refrigerator	325	24	1	7800
Iron	1000	1	1	1000

The load profile calculated every month is presented in Fig. 3. The calculation of the monthly load profile has been calculated with consideration of 5% random variability from day to day to improve. The reliability of the load calculation and takes into account the additional

electric load consumption comes from the appliances that are used weekly such as washing machine and iron. The village has an average residential load consumption of 48.5 kW with a peak load of 65 kW.

**Figure 3.** Distribution of monthly load profile of the study area

#### 2.4. Solar source assessment

Figure 4 shows the profile of annular daily solar irradiance and clearing index available for study location. These data have been collected from NASA website [21] for the village location (36° oN Latitude and 44° oE longitude). The study area receives an average annular solar irradiance reached to 6.9 kWh/m<sup>2</sup>/day, and the average clearing index recorded was observed to be 0.78. It is found the highest amount of solar irradiance was about 6.5 kWh/m<sup>2</sup>/day in July, while the lowest about 4.2 kWh/m<sup>2</sup>/day in December.

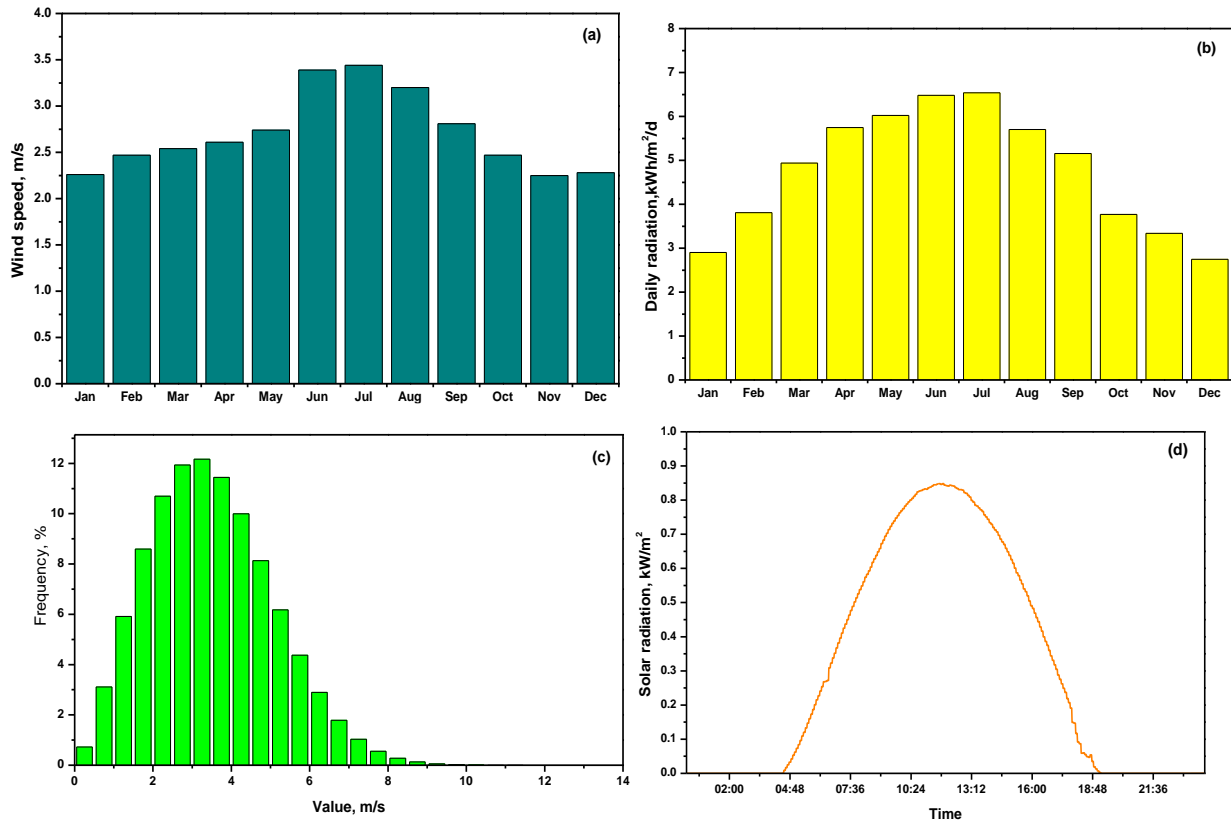
#### 2.5 Wind source assessment

The data of wind source for study location is essential to estimate the wind turbine output power over a typical year. The average wind speed data represents the most critical information used for wind system design and show the wind speed distribution during the year.

Figure 5 (a) - (d) shows the distribution of wind speed and solar irradiance for the selected site. The highest wind speed reaches up to 4.2 m/s, while the lowest wind speed is about 0.05 m/s. The selected site has a potential of monthly average wind speed, as shown in Fig. 4 (a) and

the monthly average of solar irradiance, as shown in Fig. 4 (b). The yearly average wind speed at this location is 4.7 m/s. Highest level of wind speed data was found in April as 7.5 m/s whereas the lowest as 5.5 m/s was observed in

November (from March to November) as shown in Fig. 4 (c). Fig. 4 (d) shows the daily solar irradiance for the sunny selected day of July 16, 2019.



**Figure 4.** Profile of monthly average wind speed (a) and solar irradiation on the horizontal plane (b), frequency of the wind speed (c) and daily solar irradiance for July 16, 2019

### 3. Results and discussion

#### 3.1 Optimization results

Many configurations of HES are possible to supply the electric load demand. HOMER software makes the energy balance calculations for each HES configuration. It determines the optimum configuration of energy sources corresponding to the selected area. A techno-economic assessment of different HES have been discussed includes environment assessment. The cost calculations of HES accounts for the costs such as capital cost, replacement, operational and maintenance. The interest and discount rate of 7% and 3% respectively are considered with a lifetime of the project of 20 years. The performance of HES is at the maximum capacity shortage of 2.5%. The calculation of NPC by HOMER is used for the representation of HES life cycle cost.

As described, the simulation process performed by HOMER has two advantages. First, it determines the feasibility of HES and eliminates all infeasible systems and display the results in ascending order depends on NPC value. Second, the estimation of the life cycle cost of the system can be performed using HOMER over its lifetime. The life cycle cost of HES represents the total cost of installation and operating the HES over its lifetime.

Figure 7 summarizes the optimum simulation results of HOMER for the optimum configurations. From the simulation results, the optimized hybrid model (PV/WT/battery) represents the viable option as compared to the other system configurations. This hybrid energy system consists of 6 kW PV, 20 units of batteries, 35 kW WT and inverter of 7kw.

The optimized hybrid system has a viable option with the cost of energy of \$ 0.117/kWh and net present cost of \$14,800. The optimum simulation results were calculated for.

The second viable option of power system comprises (PV/WT/battery). The HES has 6 kW PV, 20 units of batteries, 40 kW WT and inverter of 7 kW. This configuration has a value of NPC and COE of \$14,988 and 0.118 kWh respectively, whereas the initial cost reaches to \$ 8,810. The worst scenario for HES option comes when the diesel generator is used alone. The COE is high for diesel generator because of its low fuel efficiency.

The fraction of renewable energy (RE) for the system refers to the fraction of the power

supply from RE sources that feed the load. The greater utilization of RE sources leads to a high value of the renewable fraction. It is most essential to maintain the renewable fraction as high as possible. The higher renewable fraction is strongly recommended, mainly for environmental aspects, without increasing the value of NPC dramatically. The HES with higher renewable factor can be considered as a green system. The results show that the first optimal system has a high renewable fraction of 100% is due to the lowest contribution of diesel generator, and the electricity production is mainly obtained by RES.

Sensitivity Results		Optimization Results											
Double click on a system below for simulation results.													
Icons	PV (kW)	Aleos	US-305	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage			
	6.0	7	20	7	\$ 8,590	541	\$ 14,800	0.117	1.00	0.02			
	6.0	8	20	7	\$ 8,810	539	\$ 14,988	0.118	1.00	0.01			

Figure 7. Optimum simulation results of HOMER for HES

Figure 8 shows that the annual production of electricity by hybrid power system is 35,624 kWh/year in which 11,115 kWh/year about 31%

electricity comes from PV array, and 24,509 kWh/year about 69% electricity comes from wind turbine.

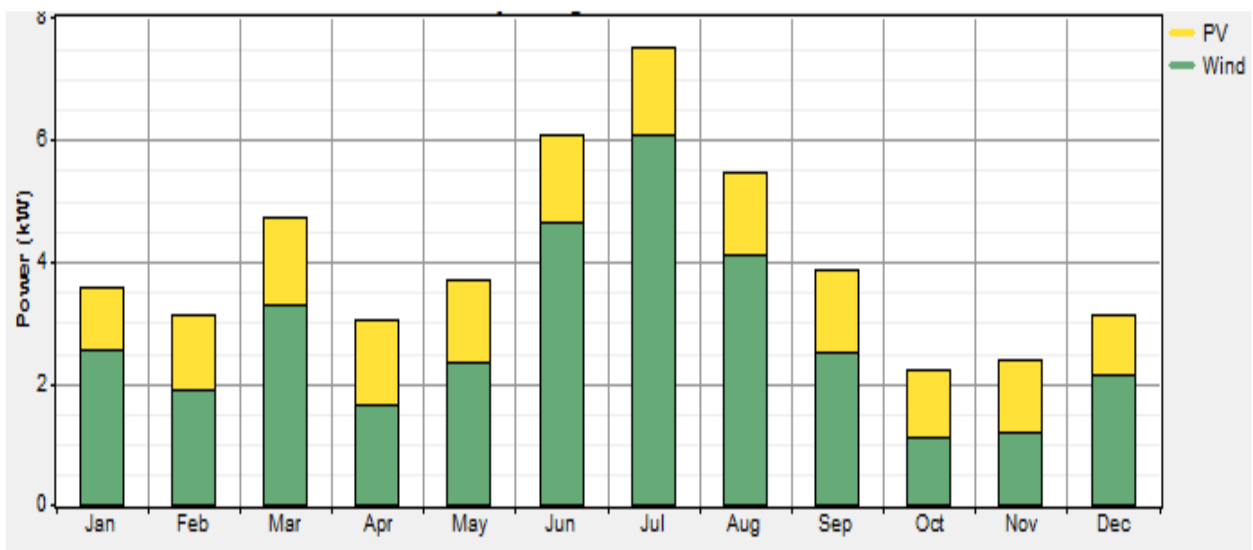


Figure 8. The annual production of electricity by hybrid power system

The summary of the cash flow for the optimized system configuration is given in Fig. 9. The cost analysis is detailed as follows:

- The optimized hybrid system has a capital cost of \$14,800. The cost of the batteries makes the biggest part \$7346 of the system total capital cost, while the cost PV modules about \$3417, the cost of WT about \$3636 and the cost of converter about \$1671 of the system total capital cost.
- There is no replacement cost for PV component since PV lifetime is more than the hybrid system lifetime. The total

replacement cost of the WT, converter, batteries, reaches about \$4253.

- The operational and maintenance (O & M) of the system components by about \$3498, batteries the highest O&M cost about \$1147.
- The remaining life of the system components provides a salvage cost of \$1541.

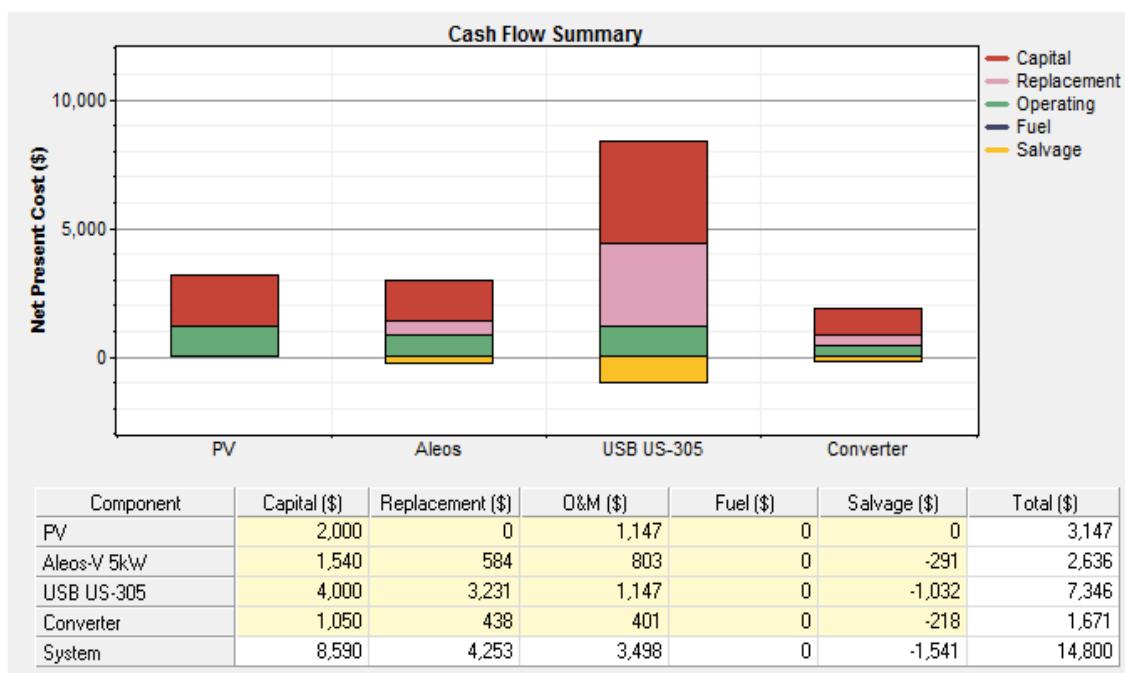


Figure 9. Summary of the cash flow for the optimized system configuration

### 3.2 Environmental assessments

Many pollutants emissions of greenhouse gases (GHS) are released during the combustion of conventional fuels. The GHG emotions damage the local atmosphere which effects diversity our normal life styles. The utilization of RE system reduces pollutant emissions and these gases could be prevented from entering into local atmosphere. In this analysis, the emissions released has come (come up) only from fuel consumption of diesel generator. Table 3 shows the GHG emissions obtained from the simulation of different HES. The generator releases number of emissions

proportional to the amount of its consumption of diesel fuel. The simulation results showed that the first system has the best environmental characteristics of minimum emissions. The third worse scenario (case 3) produces GHG emissions about 200 kg/year due to the highest amount of fuel consumed for this system (2000 L/year).

The most cost effective HES has a CO<sub>2</sub> emission reach to 1600 kg/year, which represents 30% lower the emission of case 5. As can be seen from Table 6, the minimum GHG emissions were released in case of PV/diesel/battery hybrid power system.



**Table 3.** Emissions of GHG calculated by HOMER with different HES configurations

Pollutant Emissions (kg/year)	Case 1	Case 1
Nitrogen oxides	0	0
Sulfur dioxide	0	0
Particulate matter	0	0
Unburned hydrocarbons	0	0
Carbon monoxide	0	0
Carbon dioxide	0	0

#### 4. Conclusions

The techno-economic and environmental feasibility assessment of hybrid power system is carried out for off-grid village in eastern Iraq. HOMER is used to determine the optimum configuration of HES. The simulation results showed that the optimal combination of hybrid system for the selected area having a daily load of 35.5 kW is consisted of 6kW PV array (20 modules), 20 units of storage battery, 7 units of WT (5 kW/unit), 7 kW power converter. The total NPC \$14800, and COE \$ 0.117 obtained from the optimal system combination.

The utilization of HES of PV/WT/battery can prevent the emission release of 14,927 kg/year of CO<sub>2</sub>, 36.8 kg/year of CO, 329 kg/year of NO<sub>x</sub>, 30 kg/year of SO<sub>2</sub>, 4.08 kg/year of HC, and 278 kg/year of suspended particles. The higher renewable fraction of the system (100%), the system has a low GHG emission and can be considered to be suitable for the environment.

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