Optimal Design of Hybrid Renewable Energy System off grid in Al-Diwaniyah, Iraq

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Abstract. This research presents a hybrid renewable energy combined system (wind, solar, and with fuel gasoline energy resources) to replace an old energy source. The HOMER software has been used to optimize the cost and energy for the Diwaniyah, Iraq area to find alternative energy sources. Alternative combined clean energy sources (hybrid energy system) can be suitable as an energy source to control air pollutions and to find alternative power for uneconomical and difficult grid extension rural areas. Hybrid system can provide high reliable electricity more than a single renewable energy system (such as, photovoltaic only, wind only). In this work we mainly focus on combined of renewable energy systems that consists of PV-battery and wind system. The hybrid system has a huge potential to utilize compared with using only a generator system. The hybrid energy system has been developed an optimization model for optimal operating strategy of photovoltaic, wind and a generator. All meteorological & load data has been collected and modulated by HOMER software from selected area (Diwaniyah, Iraq).

Keywords: HOMER software, COE, NPC, Wind, PV, Hybrid system.

1. Introduction

Recently there is a huge interesting in a clean power generation and renewable energy technology as environmentally friendly to prevent global warming. Diesel generator has been known as main power source for a while and there is lots of research to replace the non-conventional power source with a stand-alone clean source such wind or solar sources [1]. However, energy fluctuation and non-continuous supply are considered the major drawbacks of the stand-alone power system to overcome these problems by using hybrid systems. The hybrid power system is a combination of various renewable power sources with diesel regenerator as backup set. The hybrid energy system consists of mainly renewable that combined with a standby non-renewable secondary source and storage unit. At Diwaniyah, hybrid energy system (solar and wind with gasoline) might offer alternative source to the electrical power demand [2].

There are many advantages of using the hybrid system. The main advantage of a hybrid system is easy to replace the low level power source with the higher other source. For example, in cloudy windy day, wind power source will be more effective than the solar power. Also, in the case of low renewable power availability or high loads, there is an emergency backup power supply using diesel generator [3,4].
This case study is done on the house remote area (Diwaniyah, Iraq) whose latitude is 31 degrees 59.88 minutes North and longitude is 44 degrees 53.13 minutes East as show in Fig 1. [2].

Figure 1. Diwaniyah Geographical images

2. Methodology
The simulated hybrid energy system included of photovoltaic (PV) array with power converter, wind turbine, battery and gasoline generator. Battery will be used as an emergency measurement for a backup unit to acts as a storage medium. This system is specifically designed for houses to supply power or 24/7 bases in off grid case. The required data for wind and solar resources for the Diwaniyah site was downloaded from NASA methodological department online data. The study has been found a relation between energy consumption of house and daily load profile. Simulations, optimization and sensitivity analysis were performed using HOMER software to determine the optimum sizing and operation strategy for a hybrid renewable energy system that based. Simulations, optimization and sensitivity analysis will be discussed in following sections.

3. Input data into modelling
3.1. Renewable Energy Resources
Solar energy is amount of solar radiation that hits surface of earth. For this study, solar radiation can be employed as a new clean source of energy area. Therefore, photovoltaic (PV) array with power converter was assembled to collect the solar radiation at Diwaniyah. The amounts of solar radiation have been calculated depending on the data from the NASA Surface Methodology. The data is shown in Fig 2., the optimum results have been found to be 5.16 kWh/m2/day annually average scaled and 0.539 clearness index or that specific area.
For several years, wind turbine has been used as a practice wind resources. Nowadays, the importance of wind as renewable energy system has been internationally recognized [5]. Worldwide, wind as energy sources has become an important source of renewable energy resource [4]. The measured wind speed variations during the whole year have been collected for the Diwaniyah area using NASA Surface database. By analyzing the collected data, optimum results for the mentioned area has been found to be 0.01m length surface roughness with the annual average wind speed at 50 m are 5.46 m/s.

3.2. Design the model in the hybrid system

The Diwaniyah area sustains a significant amount of wind and solar radiation energy over the whole year. Therefore, this study will be presented an efficient an alternative hybrid energy system for the area. The study model for the renewable energy resource system is illustrated in Fig 4. Where a system of PV array with converter, battery, and wind turbine are connected to the primary load (DC terminal) and a converter that is linked between the DC and AC bus bars.

A diesel generator is linked to the model system. The diesel generator is worked only if there is necessary to cover the required load in case no sufficient energy is available from other sources [3]. The summaries of HOMER sensitive variables are shown in Fig 4.

4. Design the model in the hybrid system
4.1. Load Descriptions
The average consumption energy (demand load) for a typical home in Diwaniyah area is demonstrated in Fig 5. Constant annual energy consumption has been assumed. For more realistic energy consumption reading a random of daily energy consumption had been added using HOMER software. The average consumption is 10 kW/day average load, and 0.42 kW average load, with calculated Peak load of 1.65kW and load factor 0.25
HOMER is simplified the proposing of hybrid renewable energy system by generating an hourly wind speed data and solar radiation data depending on the monthly average values that is designed of an off-grid and a stand-alone power systems and distributed generation application see Table 1 and 2.

Table 1. System Architecture.

| Component | Name     | Size  | Unit |
|-----------|----------|-------|------|
| Pv        | Pv       | 1.00  | Kw   |
| Storage   | Battery  | 4     | Strin|
| Wind turbine | Wind     | 3     | Ea.  |
| System    | Converter| 2.00  | Kw   |
| Dispatch  | Homer cycle |       |      |

Table 2. System Architecture.

| Component               | Consumption (kwh/yr) | Percent |
|-------------------------|-----------------------|---------|
| Ac primary load         | 3,617                 | 100     |
| Dc primary load         | 0                     | 0       |
| Total                   | 3,617                 | 100     |
4.2. Wind turbine
In this case the rated capacity 1.8 kW wind turbine is used.

4.3. Solar PV Array
In a photovoltaic array, solar radiation has photons that were absorbed by a semiconductor material. The movement of electrons has converted the absorbed solar radiation into a voltage [4]. Slope is 31.998 degree, ground reflectance is 20%, derating factor is 80%, Lifetime is 25 yrs., no tracking system, scaled annual average of 5.16 kWh/m2/day and clearness index of 0.539 is obtained for the study area. In this case the 1.8 kW PV array is used. Capital and replacement cost for 1kW bidirectional converter is assumed to be 300$. 

4.4. Battery
Battery voltage 48V capacity Ah=417, kWh=20 maximum charge, current =105 A, with the specification mentioned in Table 3, that was working during emergency as a backup for load shading. The capital and replacement cost assumed to be 300 $.

4.5. Converter
Rectifier and inverter modes have been used in converter. A 1kW is the converter size with a 300$ capital and replacement cost for the bidirectional converter as estimated cost for a lifetime 15 years.

4.6. Gasoline Generator
The off-grid generation was a gasoline generator with some advantages of high shaft efficiency, Lower installed capacity, designed for on/off operation and high exhaust heat. The used generator is 2.6 kW capacity, and 1.3kW optimization with capital and replacement cost are assumed to be 900 $ and fuel price 0.250 $/L.

5. Homer: simulation, optimization, and sensitivity analysis
This process includes a calculation of energy balance performed by HOMER depending on the system characterizations. The variables are wind turbine, PV array, diesel generator system for [5]. After several iterations in simulation process, the best optimum configuration has been chosen as to supply the demand energy. All variables (interest rate installing and replacement cost, maintenance and operation cost, and fuel) are simulated and designed by HOMER [6].

The simulation demonstrates an optimal configuration for hybrid renewable energy system. Total Net Present Cost (TNPC) represents the entire configuration and it depended on selected variable. HOMER analyzes the various power system configurations from the minimum TNPC value to maximum TNPC value. For each system several iterations are performed on wind, global solar and diesel fuel cost by HOMER software to reach an optimal result.

6. Results and Discussion
For the optimal result of the hybrid renewable energy system HOMER software was used with numbers of iterations for wind, global solar and diesel fuel cost will be repeated Table 4.
The best optimal system has been found by analyzing energy source components such as Wind, PV, and battery with or without gasoline generator Table 5. Several load models have been proposed which are PV system with diesel generator, PV system and wind turbine with diesel generator, wind turbine with diesel generator, and PV system and wind turbine without diesel generator Fig 6. Annual performance of each energy sources model Fig 7 has been simulated for net present cost, initial cost, operating costs, and renewable energy fraction using HOMER. Equation below is calculated the renewable fraction using HOMER.

\[
f_{\text{ren}} = 1 - \frac{E_{\text{nonren}}}{E_{\text{served}} + E_{\text{h,nonren}}} \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdOTS
\]
Where, 
\[ f_{\text{ren}} \] = the fraction of the energy 
\[ E_{\text{grid s}_{\text{ale}}} \] = energy sold to the grid [kWh/y] (included in E_{\text{served}}) 
\[ E_{\text{nonren}} \] = nonrenewable electrical production [kWh/y] 
\[ H_{\text{nonren}} \] = nonrenewable thermal production [kWh/y] 
\[ E_{\text{served}} \] = total electrical load served [kWh/y] 
\[ H_{\text{served}} \] = total thermal load served [kWh/y]

HOMER calculates the net cost of each renewable power sources in the system, and of the hybrid energy system as a whole with the renewable fraction in Fig 8. By using the different model set to find the most energy efficient in terms of the fraction renewable energy, the optimum result was by using the combination energy source (hybrid renewable) with maximum renewable energy friction and without using diesel generator and no fuel consumption. The life-cycle cost (net present cost) of each renewable power sources is a value of all the operating and installing cost over the project lifetime, minus the value of all the revenues that it earns over the project lifetime [7,8]. Fig 7. shows the NPC and initial cost for different renewable energy. Analyses of the initial capital cost are high for hybrid renewable (10900.0).

The Batt-PV-Wind system having the highest initial capital cost while the diesel generator has the lowest initial capital this was revers with the operating cost and the Batt-PV-Wind system has the lowest cost. In general, the NPC for diesel generator was the highest cost and that could be explained by the highest operation cost of a new generation unit compared to other model sets due to the assembling, transmission, and distribution and land costs for new generator plants as Fig 8. therefore, the Batt-PV-Wind system considers better renewable power sources alternative with lowest operation cost.
Figure 8. Renewable fraction for different model sets.

The levelized costs of electricity COE has been used to compare the various technologies of power generating in this study Fig 9. The COE is defined as the ratio of the average energy cost of (kWh) per the useful produced electrical energy by the system. For the COE calculation, HOMER finds the ratio of the total annualized cost subtraction the thermal load serving cost (annualized cost of producing electricity) per the total served load of electric, by applying the following:

$$\text{COE} = \frac{C_{\text{ann,tot}} - C_{\text{boiler}}H_{\text{served}}}{E_{\text{served}}} \quad (2)$$

Where:
- \(\text{COE}\) =levelized cost of energy
- \(C_{\text{ann,tot}}\) = total annualized cost of the system [$/y]
- \(C_{\text{boiler}}\) = boiler marginal cost [$/kWh]
- \(H_{\text{served}}\) = total thermal load served [kWh/y]
- \(E_{\text{served}}\) = total electrical load served [kWh/y]

The production of the electricity for each source using HOMER software is shown in Fig 10. It could be observed that the highest power production was for Batt-PV-wind (hybrid renewable energy) with low COE (0.28), low net present cost of $13286, and lowest operating cost of $184.6/y compared to results obtained in load profile of diesel generator, with highest net present cost and operating cost. The Batt-Wind-Gen system was the lowest COE with power production of 5222.76 KWH for wind source and 776.24 KWH for diesel generator source and lowest $9835.7 net present cost and $269.6/y operating cost, therefore, the Batt-PV-wind (hybrid renewable energy) was chosen to be the optimal hybrid renewable energy due to the low operating cost and net present cost with highest clean power production with 100% renewable energy friction and low COE.
7. Conclusion
This research introduces optimization of three power sources: photovoltaics, a 1 kW wind turbine, and a 2.6 kW gasoline generator, as well as battery storage of hybrid renewable electric to design based on a wind speed, PV array and the price of gasoline an efficient renewable energy. Different energy technologies were simulated using the HOMER software to optimize different configurations. The outcome of the various renewable technologies was optimized to select the lower net present cost was examined to find the lower expensive and higher performing system with high efficient power production. The HOMER recommends hybrid renewable energy system (PV system and wind turbine without diesel generator) for a large area (Diwaniyah) of the sensitivity space. This is because the PV array and wind turbine are completed each other. The simulation data show that the hybrid system with 5 kW wind system with 100 initial state of battery charge configuration. The Batt-PV-wind has lowest operating cost of $184.6/y and low net present cost of $13286, with the highest power production.

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