Optimization of PV/WIND/DIESEL Hybrid Power System in HOMER for Rural Electrification

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Abstract. A large proportion of the world’s population lives in remote rural areas that are geographically isolated and sparsely populated. The present study is based on modeling, computer simulation and optimization of hybrid power generation system in the rural area in Muqdadiyah district of Diyala state, Iraq. Two renewable resources, namely, solar photovoltaic (PV) and wind turbine (WT) are considered. The HOMER software is used to study and design the proposed hybrid energy system model. Based on simulation results, it has been found that renewable energy sources perhaps replace the conventional energy sources and would be a feasible solution for the generation of electric power at remote locations with a reasonable investment. The hybrid power system solution to electrify the selected area resulted in a least-cost combination of the hybrid power system that can meet the demand in a dependable manner at a cost about ($0.321/kWh). If the wind resources in the study area at the lower stage, it’s not economically viable for a wind turbine to generate the electricity.

1. Introduction
With about 1.3 billion people in the world (or about 1 in 5) without access to electricity in 2010 [1], the global challenge of providing reliable and cost-effective services remains one of the major challenges facing the world in this century. Although grid extension still remains the preferred mode of rural electrification [2], an extension of the central electricity grid to geographically remote and sparsely populated rural areas can either be financially unviable or practically infeasible. Stand-alone options can be helpful in such cases. The efforts in using renewable energies have often focused on single technologies. Reliance on a single technology generally results in an over-sizing of the system, thereby increasing the initial costs. Recently, the hybrid energy systems received most interest because of like these systems can overcome the intermittent nature of renewable energy sources, the over-sizing issue and enhance the reliability of supply. In the developed countries, often advanced fuel systems such as hydrogen are considered. Examples of such studies include the following Khan and Iqbal [3] who investigated the feasibility of a hybrid system with hydrogen as energy carrier in Newfoundland, Canada; Barsoum and Vacent [4]; Karakoulidis et al. [5], Giatrakos et al. [6] and Türkay and Telli [7]. To achieve this objective, an example of an Iraqi village was selected to estimate the potential demand, identify the available resources, model electricity generation based on multiple combinations of renewable resources. Then, select the best option based on the electricity cost and to compare these performance indicators to grid extension related costs.
2. System Modelling
We have considered a combination of the following technologies, namely solar (PV) system, wind turbine, batteries, and a diesel generator (DG) for back-up. In the hybrid system, the demand from the village is (AC) coupled, the (DG) are connected to the (AC) side of the network and the (PV) system and the batteries are connected to its (DC) side. Usually, a conventional back-up diesel generator (DG) is used to supplement the hybrid power system for peak loads and during poor resource periods.

2.1. Study Area
The selected off-grid remote rural village for this study is Budjah, a small village in Muqdadiyah district in the Iraqi state of Diyala. The details of the village are listed in (Table 1). The area around the village is partially hilly with flat plains constituting the rest. The village has water and drinking water facilities in the form of water-wells and hand pumps. The village has no access to grid electricity, which offers an opportunity for off-grid electrification of the village.

| Particulars                     | Details         |
|--------------------------------|-----------------|
| Village                        | Budjah          |
| District                       | Muqdadiyah      |
| State                          | Diyala          |
| Country                        | Iraq            |
| Latitude                       | 33°58’N         |
| Longitude                      | 44°56’E         |
| Rivers Available               | 1               |
| Grid Electricity               | 0               |
| Number of households           | 40              |
| Total Population               | 150             |
| Education facilities (Primary School) | 1               |

2.2. Village Load Assessment
The remote area residential unit is simple and does not require large quantities of electrical energy used for lighting and electrical appliances. (Figure 1) shows the proposed residential load profile. The load profile was proposed considering the general hourly based load usage. At midnight hours, the power consumption for the residential unit comes down where only basic electrical appliances are consuming power. The load demand rises up during morning hours when everybody gets ready either to leave for schools or offices. Throughout the noon hours, the load demand levels are minimum as most of the family members are outside. Again, during the evening hours when all the family members are present, the power consumption rises as everyone switches on various entertainment appliances. The average energy consumption of electrical appliances of a typical residential unit is assumed (92.6 kWh/day). According to the load profile shown in (Figure 1), the load requirement considered should be maximum hourly load consumption. (Table 2) shows the average and peak load of the study area.
2.3. Resources Assessment

Iraq is among the countries with remarkable potential in solar energy. The solar off-grid/PV system of the interest area that located in the remote village in Muqdadiyah district at Diyala state. The resource assessment is presented below. The solar resource used for Muqdadiyah village at a location of 33°58' N latitude and 44°56' E longitude was taken. The annual average solar radiation was scaled to be (5.45 kWh/m²/Day) and the average clearness index was found to be 0.64 (See figure 2). The highest solar radiation was estimated at (7.6 kWh/m²) in June while the lowest was (2.7 kWh/m²) in December.

The annual average wind speed for the location is (4 m/sec) with the anemometer located at height 20 meters. The monthly average wind speeds are calculated and shown in (Figure 3). It indicates that the annual average wind speed is (4 m/s). It can be also observed that in April to November the wind speed is lower than the annual average wind speed.

3. System Components Assessment

The energy system components are diesel generator, (PV) modules, wind turbine, battery and power converter. The cost, number of units to be used, operating hours, etc. need to be specified in HOMER software for each of this equipment. Description of these components is given in the following sections. In the present simulation, the mainly component is two major renewable energy components which (PV) panel and wind turbine. (PV) panel have the other component involved such as a battery (Trojan L16P model), inverter and (PV) itself. The current produced from (PV) panel is in (DC) and current from diesel generator and wind turbine in (AC). The inverter will change (DC) to (AC) current and vice versa. The electricity produced from the renewable device will be feed into loads. The schematic diagram of this system is shown in (Figure 4).
3.1. Diesel Generator Model
Diesel generators are commonly used for remote electrification. This is because they are low cost, easy to install and easy to operate. Diesel generators used in remote villages are mostly in the range of (16 - 20 kW). In this analysis, generator cost is taken ($2000/kW), (see Table 3). The rating lifetime is taken to be (15000 hr) and the price diesel is ($ 0.4/l).

3.2. Battery Model
Batteries are considered as a major cost factor in small-scale stand-alone power systems. A battery bank of commercially available units, Trojan L16P model (6V, 360 Ah) was considered in this simulation. The estimated lifetime is (5 years) and the cost of one battery is ($150) with a replacement cost of ($150) while the maintenance cost is expected at ($2/year). The battery to be considered in this simulation is range from 12 to 36 units. The battery cost, its replacement and O&M costs as used for simulation are shown in (Table 3).

3.3. Power converter Model
A power electronics converter is needed to maintain flow energy between the (AC) and (DC) components. As shown in (Table 3), (1 kW) system the installation and replacement cost are taken as ($500). The different sizes of the converter (8kW, 12kW and 16kW) are taken in the model. A lifetime of a unit is considered to be (15 years) with an efficiency of 90%.

3.4. Photovoltaic array Model
The installation cost of (PV) may vary from ($2 to $4/ W). Considering a more optimistic case, a 1kW solar energy system’s installation and replacement costs are taken as ($3000), (see Table 3). The different sizes are considered, which are (8kW, 12kW, and 16 kW). The lifetime of PV arrays are taken as (10 years) and no tracking system is included in the (PV) system.

3.5. Wind turbine
Availability of energy from the wind turbines shown in (Figure 3) depends greatly on wind variations. Therefore, wind turbine rating much lower compared to the average electrical load. In this analysis, Bergey wind power’s BWC E-S model with hub height (20 m) is considered. It has a rated capacity of 18 kW and provides (AC) voltage as an output. The cost of one unit is considered to be ($18000) while replacement and maintenance costs are taken as ($12000) and ($400/year), (see Table 3). To allow the simulation program find an optimum solution, provision for using 0 (no turbine), 1, 2 and 3 units is given. A lifetime of a turbine is taken to be (15 years).
Table 3. The input window of hybrid system components.

|          | Diesel generator | Battery | Converter | PV array | Wind turbine |
|----------|------------------|---------|-----------|----------|--------------|
| Size (kW)| 20               | 16      | 16        | 18       |              |
| Capital ($) | 2000            | 150     | 500       | 3000     | 18000        |
| Replacement ($) | 2000 | 150       | 500       | 3000     | 12000        |
| O&M ($/yr) | 10              | 2       | 400       |          |              |
| Lifetime (year) | 15000 hr     | 5       | 15        | 10       | 15           |

4. Results and Discussion

4.1 Simulation results

The project’s lifetime is considered to be (15 years) with an annual discount rate of 3%. The optimal combination of hybrid power system components for our case study is a (16kW PV-Array, 20kW Wind Turbine, 20kW DG, 36 Trojan L16P Batteries, and 16 kW Inverter). This system is considered at (4 m/s) of wind speed and ($0.4/l) of diesel cost. The total net present cost, capital cost and the cost of electricity (COE) for such a hybrid system are ($138,600, $41,200 and $0.321/kWh), respectively, (see Figure 5).

The COE of ($0.321/kWh) from this hybrid system is expensive than that of ($0.2/kWh) from grid extension as considered for this study. Therefore grid extension does not appear to be a viable option to meet the village load. But, if the cost of electricity from the grid supply goes up ($0.321/kWh), grid extension becomes viable. It is found that the wind resources in Muqdadiyah still at a lower stage not feasible for a wind turbine to generate the electricity.

(Figure 5) shows the monthly distribution of the electricity produced in kWh by the (PV) and (DG). From November to January, the diesel generator is mostly used combined with (PV). Also, from June to August the peak load is met by (PV) and (DG). The (PV) operates at full load along the year and produces (14,252 kWh/year), achieving a capacity factor of 36% (see Table 4). Only during the winter months when solar radiation is inadequate, diesel generator becomes the dominant producer. For the selected system the diesel generator operates for 1978 hours (capacity factor 64%), produces (25,491 kWh/year) and consumes 9,573 liters of fuel.

Table 4. Electricity production of hybrid system components.

| Production     | kWh/yr | %   |
|----------------|--------|-----|
| PV array       | 14,252 | 36  |
| Diesel Generator | 25,491 | 64  |
| Total          | 39,743 | 100 |
Figure 6. Monthly average electricity production from the optimal hybrid system.

(Figure 7) shows the cash flow summary for the optimal system. The capital cost of the diesel generator makes up only 5% of the system’s total capital cost, whereas almost 50% of the initial investments go to the (PV) arrays. Once installed, however, (PV) is cheap to maintain and operate compared to the (DG), which in the end is responsible for 51.5% of the system’s total annual cost of ($138,649), (see Table 5). The system fixed capital cost is considered to be ($41,200) for the whole project and the system fixed O&M cost is estimated to be ($6,284/year) for the project lifetime. The system fixed capital costs include various civil constructions, labor, logistics wages, required licenses, administration and government approvals and other miscellaneous costs.

![Cash Flow Summary](image)

Figure 7. Cash flow summary based on the selected components.

| Component     | Capital (US$) | Replacement (US$) | O&M (US$) | Fuel (US$) | Salvage (US$) | Total (US$) |
|---------------|---------------|-------------------|-----------|------------|---------------|-------------|
| PV            | 24,000        | 20,885            | 0         | 0          | -2,796        | 42,089      |
| Generator     | 2,000         | 2,643             | 5,057     | 48,769     | -328          | 58,142      |
| Trojan L16P   | 7,200         | 20,586            | 1,227     | 0          | -1,312        | 27,701      |
| Converter     | 8,000         | 3,338             | 0         | 0          | -621          | 10,717      |
| System        | 41,200        | 47,452            | 6,284     | 48,769     | -5,057        | 138,649     |

Table 5. Overall cost of the hybrid energy system.
4.2. Sensitivity and Optimization Results

Three sensitivity variables (PV size, battery size and power converter size) are considered in this analysis. The village load at (92.6 kWh/d, 14.9 kW peak), this system might majority consist of (16 kW PV array), 1 unit of a wind turbine, arrange (20kW) of the generator, 12 to 36 units of batteries and (5 to 16 kW) of the power converter. For each of the sensitivity values, HOMER simulates all the system in their respective search space.

For optimization result (Figure 8), the result produced consist of initial capital, total net present cost (NPC), cost of energy (COE), renewable fraction, diesel in litter and generator in hourly working it can be seen that the lowest (COE is $0.321), (Total NPC is $138,653) and the highest is (COE is $0.481), (Total NPC is $207,752). The different amount because the source involves between (PV, wind, generator, battery and converter) which group 1. Group 2 consists of no (PV) but only use the generator (20kW), battery (72 unit) and converter only (16kW). The one is group 4 which is use (PV 8kW), generator (20kW), and converter (16kW).

From Sensitivity result of group 1, the (PV, generator, battery and converter) based hybrid system is suitable for stand-alone loads around study area, the result present cost of the capital cost, net present cost and cost of energy for such a system is ($41,200, $138,653, and 0.321 $/kWh) respectively. The suggested price for diesel at ($0.4 /litter).

| PV (kW) | Gen (kW) | L1SP (kW) | Conv (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Freq. | Diesel (L) | Gen (hrs) |
|---------|---------|-----------|-----------|-----------------|------------------------|-----------|-------------|------------|------------|-----------|
| 8       | 20      | 48        | 16        | $41,200         | $7,623                 | $138,653  | 0.321       | 0.36       | 9,537      | 1,978     |
| 20      | 72      | 16        |           | $20,800         | $9,448                 | $141,572  | 0.328       | 0.00       | 14,572     | 2,735     |
| 20      | 20      | 16        |           | $10,000         | $14,288               | $192,644  | 0.446       | 0.00       | 28,039     | 8,759     |
| 8       | 20      | 48        | 16        | $34,000         | $13,592               | $207,752  | 0.481       | 0.23       | 23,887     | 7,425     |

Figure 8. Optimization results of the best hybrid configuration system.

Wind resources in the selected site still at the lower stage were not economically viable for a wind turbine to operate thus need some improvement in design to generate the electricity and could be termed as commercially feasible.

5. Conclusions

The simulation for the (PV/Wind/Diesel) hybrid power system has been discussed. From results, this system can give good profit with a reasonable investment due to the amount of renewable energy generated. It utilizes almost all renewable energy with a 0.36 renewable fraction. However, the system reliability cannot be ensured due to variable nature of solar radiation availability and lack of adequate wind speed in winter unless other technology options are considered. The solar PV and diesel generator contribute 36% and 64% respectively to electricity generation. The hybrid power system solution for off-grid electricity supply to a remote village such as Budjah resulted in a least-cost combination of solar (PV/Diesel) generator and batteries that can meet the demand in a dependable manner at a cost of ($0.321/kWh). If the solar (PV) panels are not available (or no solar resources are available), the electricity demand can be met with a hybrid system comprising of diesel generators. But the cost of electricity supply will increase, thereby making the system less attractive to users. Finally, in the case of the wind resources in the study area at the lower stage, it’s not feasible for a wind turbine to supply the electricity.

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