Assessing of renewable energy for electrical household ancillary based on photovoltaics and wind turbines

Qusay Hassan
Department of Mechanical Engineering, University of Diyala, 32001, Diyala, Iraq
Corresponding e-mail: qusayhassan_eng@uodiyala.edu.iq

Abstract. The importance of renewable energy provides a great opportunity to meet the demand for household electricity located in Baqubah, Diyala, Iraq. Intentionally, there are to renewable energy components have been selected wind turbine (1 kW) and photovoltaic array (1.65 kW) for assessing the sources of renewable energy to serve household desired load. The current work analysis is executed by using experimental data for the load demand, solar irradiance, ambient temperature and wind speed for the selected site. The work targeted to shed light on the technical and economic feasibility of integrating renewable sources to feed the desired load by renewable energy. The results show that the renewable energy system based on grid connection can feed the desired electrical load by about 90% as well as a support grid system by renewable energy by about 3114 kWh/year. The system economic aspects show the initial capital cost, net present cost and cost of energy are $2615; $53449; $0.25 respectively, for 25 years project lifespan. The results are very encouraging to use renewable energy resources in the selected site.

Keywords: Renewable energy sources, Hybrid energy system, Optimisation, Household electrification

1. Introduction
The growing electricity demand continuous the needs and efforts to expand the grid systems. In many cases, the consumer site makes its connection to the network uneconomical. The cost of providing electricity at any given site can be determined by several factors such as the cost of installation, length of transmitted lines, load capacity, terrain nature, etc.

The supporting of conventional energy by renewables is an effective solution and more reliably in the future [1]. Solar and wind energies are the most effective among other renewable energy sources for wide availability. One of the most weakness of solar and wind energies its intermittent nature [2]. Combining more than one renewable energy sources as hybridisation make more effective and robust energy systems. There are several articles has been investigated hybrid energy system at different sites and scenarios. Pascual et al. [3] investigated the strategy management for microgrid energy flow. The study aimed to feed the load peaks by using renewable energy exchanged with the grid. The results suggest that combining thermal storage systems with the electrical system is a promising technique that can increase the penetration level of renewable energy. Lim et al. [4] investigated the load distribution system for independent operation based on a microgrid energy system. The study abstracted that the shifting of the thermal load during the day time when photovoltaic array (PV) can produce energy is the promising solution for increasing renewable energy fraction. Yoo et al. [5]
tested decision-making of two layers control schemes strategy for the hybrid energy system. The results show that the lower layer, smart agents determine optimal operating strategies for individual system components. While at the upper layer, the system coordinates multiple factors that can meet the required load reduction by the grid. Palej et al. [6] optimised renewable energy system for household electrification at two optimisation objectives (environmental and economic). The study targeted to find the relation between these objectives, and the results showed that the relation between these objectives is polynomial from the second-order degree.

Jaszczur et al. [7] optimised four scenarios of hybrid energy systems for household electrification. The study showed the optimisation at environmental criteria generated high energy, low CO$_2$ emissions and high investment cost. In contrast, the optimisation at the economic criteria generated low energy, high CO$_2$ emissions and low investment cost. Hassan et al. [8] carried out a study for assessing the potential of renewable energy resources for rural village electrification. The study investigated the optimising of hybrid renewable energy system consisting of photovoltaics (PV) and wind turbines (WT) connected with a diesel generator. The results showed that the suggested system could feed the village desired load at the cost of energy by about $0.32/kWh. Ceran et al. [9] investigated sizing hybrid renewable energy the system consists of a WT, PV and fuel cell (FC) for residential unit electrification. The optimisation methodology consists of utilises FC capacity based on the renewable energy generated by the WT and PV components. The presented results demonstrated the effectiveness of the suggested approach, where the site available renewable energy resources can feed the desired load by about 54%. Dagdougui et al. [10] adopted predictive control for hybrid energy system integrated to dynamic decision model to size the capacities of the components. Fiorentin et al. [11] use a predictive control model to implement demand response to building heating systems. The results showed great success in durability and feasibility to reduce the proposed objective functions. Lu et al. [12] approached non-linear programming for solving optimal scheduling problems for building energy management systems with integrated power generation and heat storage. A hybrid renewable energy system has been optimised at different objective and purpose prepared by Jaszczur et al. [13,14]. There are several indicators and criterial for optimising hybrid renewable energy systems. Liu [15] indicated eleven indicators of sustainability for optimisation hybrid renewable energy systems, categorising mainly them into economic and environmental, social, technical and technological. Beccali et al. [16] classified the hybrid energy systems optimisation criteria at multi-objective based on doing energy planning. Authors are grouping them into three categories: technological, energy and environmental, social and economic. Nadjemi et al. [17] optimised hybrid renewable energy system based on PV/WT/Batteries (Bat) by using hourly experimental data. The optimisation process conducted by using particle swarm algorithm. The result demonstrated that the selected optimisation methodology has accurate results based on the economic objective, which minimise total cost and energy taken from the grid. Clúa, et al. [18] investigated WT/Hydrogen energy (HE) system connected with the grid for household electrification. The study optimised system based on the environmental objective to reduce CO$_2$ emissions. The results demonstrated the using environmental objective leads to high investment cost. Berrueta et al. [19] designed and optimised PV/Bat renewable energy system connected with the grid for resident building electrification. The study conducted based on hourly data and optimised by using an economic objective. The results demonstrated that the system has a better performance by using energy dispatch strategy. A study executed by Shi et al. [20] for optimising PV/WT/Bat energy system at different scenarios. The results showed that the system based on WT/Bat is the most economic other scenarios. Bilal et al. [21] designed and optimised off-grid hybrid renewable energy system based on PV/WT/Diesel generator (DG)/Bat. The study investigated the fluctuation of the desired load on the components capacity. Guo et al. [22] carried-out an overview of the combining system integrate the wind, solar, biomass and geothermal energy. In this research, more attention given to micro-grid hybrid systems based on off-grid scenarios. The study targeted to evaluate hybrid energy systems performance during the designing process. Luo et al. [23] proposed a method for sizing energy storage unit for wind turbine/storage energy system connected with the grid. The study targeted to optimised storage unit capacity to meet
desired energy during the grid maintenance periods. Yahyaoui et al. [24] prepared an approach for a sizing off-grid PV/Bat storage energy system to ensure supplying electricity to the desired load. The results indicated that the suggested system capacity meet the desired load without an exceed energy. Li [25] designed and optimised a renewable energy system at different scenarios based on PV/FC/Bat by using technical-economic optimisation criteria. The authors investigated feasibility for optimum configuration can supply electricity to the community centre. The results demonstrated that the suggested system is an optimum solution. A review for optimisation hybrid renewable energy system present in [26,27].

The quality of renewable energy sources varies from country to country and from site to site. In the literature, there are several hybrid renewable energy systems has been designed at different sites and purposes. Such analysis did not conduct in the selected site, where the analysis was done based on the experimental measurements of the desired load and weather data for the year of 2019 from January 01, to December 31. The novelty of the work is to evaluate potential renewable energy sources in Diyala, Iraq, which can be used to electrify homes. In addition to finding a vision for potential investment electrification and the construction of renewable energy plants in the future.

2. Experimental measurements

Electrical load demand: In this analysis, the electrical load demand has been measured experimentally for a household in Baqubah, Diyala, Iraq, Latitude and longitude 33.7733°N, 45.1495°E respectively. The measurements executed by the electric meter for the period of (01 Jan. 2019 - 31 Dec. 2019) at 1-minute resolution. The average of the daily energy consumption recorded 5.5 kWh/d. The daily and monthly average of electrical load consumption are presented in Figures 1 (a), (b), respectively.

Solar radiation: The solar irradiiance was measured on the horizontal plane for the same period of (01 Jan. 2019 - 31 Dec. 2019) at the same site of Baqubah. The daily average of solar irradiance recorder 4.6 kWh/m2/d. Figures 2 (a) and (b) presented the daily for two selected days (Jan. 02, Jul. 02) and monthly solar irradiance, respectively.
Figure 2. The daily (a) and monthly average (b) of the solar irradiance.

Ambient temperature: The data of ambient temperature acquired by the thermometer of (01 Jan. 2019 - 31 Dec. 2019) and the same site of Baqubah. The resolution of the measured data acquired at 1-minute time step, the yearly average of the ambient temperature recorded 39.3 °C. Figures 3 (a) and (b) presented the daily and monthly average of the ambient temperature, respectively.

Figure 3. The daily (a) and monthly average (b) of ambient temperature.

Wind speed: The data of wind speed acquired by anemometer for the same period (01 Jan. 2019 - 31 Dec. 2019) and the same site of Baqubah. The resolution of the measured data acquired at 1-minute time step, the yearly average of the wind speed recorded 4.8 m/s. Figures 4 (a) and (b) presented the frequency and the monthly average of wind speed, respectively.

Figure 4. Frequency (a) and monthly averaged (b) of the wind speed.
3. System modelling and description
In this work, there are two selected renewable energy components: PV and WT are used to supply renewable energy to the desired load at any time for the system connected with the grid. Figure 5 shows the suggested hybrid renewable energy system scenario. The advantage of combining more than one renewable energy source that supports each to guarantee supply energy to the desired load.

![Hybrid renewable energy system](image)

**Figure 5.** Hybrid renewable energy system.

The hybrid renewable energy system generated power is a combining of the system components. The power generated by the suggested system (refer Figure 5) can be described as:

\[
P_h = P_{WT} + P_{PV} + P_{Grid}
\]

where \(P_h\) is the total generated power (kW), \(P_{WT}\) is the wind turbine unit power (kW), \(P_{PV}\) is the photovoltaic array power (kW) and \(P_{Grid}\) is the power from grid (kW).

The PV array power \(P_{PV}\) can be described as [28,29]:

\[
P_{PV} = C_{PV} \mu_p \left[ 1 + \gamma_p (T_c - T_{c,STC}) \right] \left( \frac{h_i}{h_{i,STC}} \right)
\]

where: \(C_{PV}\) is the PV array capacity (kW), \(\mu_p\) is the system derating factor (%) taken in this study 90%, \(h_i\) is the incident solar irradiance (kW/m²), \(\gamma_p\) the PV cell temperature coefficient of power (%/°C), and \(T_c\) is the PV cell temperature (°C). \(h_{i,STC}\) and \(T_{c,STC}\) are the solar radiation and PV cell temperature at Standard Temperature Conditions (STC) respectively.

The wind turbine power \(P_{WT}\) can be described as the following [30,31]:

\[
P_{WT} = P_a \frac{\phi_r}{\phi_s}
\]

where \(P_a\) is the wind turbine output power at standard conditions (kW) (which is evaluated based on the power curve of the wind turbine), and \(\phi_r\) and \(\phi_s\) are the standard and real air density (kg/m³) respectively.

The cost of the energy (COE) for the suggested system including several factors, initial capital cost, operation and maintenance cost (OMC), component replacement cost etc., which can be defined [31]:
where \( E_L \) is the primary load and \( A_{\text{con}} \) is the system total annualised cost. The system total net present cost (NPC) can be calculated by using the formula [32]:

\[
NPC = \frac{A_{\text{con}}}{CRF(i, L_{\text{proj}})}
\]

where, \( CRF \) is the capital recovery factor, \( L_{\text{proj}} \) is the project lifespan (year), and \( i \) is the real interest rate (%).

The economic setup of the suggested renewable energy components is presented in Table 1.

**Table 1.** Renewable energy component economic aspects

| Component            | Type       | Capacity (kW) | Cost ($) | Replacement cost ($) | Maintenance cost/year ($) | Lifespan (year) | Efficiency (%) | References |
|----------------------|------------|---------------|----------|----------------------|--------------------------|-----------------|----------------|------------|
| Wind turbine         | Aeolos     | 1–1.2         | 470      | 400                  | 20                       | 20              | Max 93         | [33]       |
| Photovoltaic module  | Dokio      | 0.275         | 120      | 100                  | 30                       | 20              | 19             | [34]       |
| Inverter             | isolar sm  | 5             | 285      | 200                  | 20                       | 15              | 90 ~ 93        | [35]       |

4. Results and discussion

The analysis was performed by using experimentally measured data for the desired electrical load of household and weather data at 1-minute time step resolution. The simulation process was carried out at 1-minute to achieve the techno-economic optimisation objective. The project lifespan is considered 25 years, the annual inflation is considered 5%, the annual discount rate has taken 4%, and the real interest rate taken 3%. The prices for grid energy based on prices set by the Iraqi ministry of electricity, for purchasing energy equal to 0.35 $/kWh for energy selling is equal to 0.09 $/kWh. The PV modules were positioned on the optimum tilt angles for getting maximum irradiance based on the selected site (sloping angle \( \beta = 30 \) and azimuth angle faced to the south \( \gamma = 0 \)).

Figures 6 (a)-(b), shows the power flow distribution for two selected sunny day (July 02, 2019) and part cloudy day (August 05, 2019). For the sunny day, the photovoltaic system 1.65 kW (6 modules) generated energy higher than a part cloudy day due to higher irradiance.

![Figure 6](image_url)

**Figure 6.** Power flow distribution for two selected days.

Figures 7 (a)-(b), shows the energy consumption with renewable energy generated by PV and WT for two selected sunny day (July 02, 2019) and part cloudy day (August 05, 2019). It’s very clear for sunny day, the renewable energy generated by PV array is higher than a part cloudy day due to higher irradiance.
irradiance. Table 2 shows the energy values of the selected days; on a sunny day, the PV system generated energy higher than a part cloudy day for higher solar irradiance. In contrast, in the part cloudy day, the WT unit generated higher than on a sunny day for availability higher wind speed.

![Figure 7](image1.png)

**Figure 7.** The energy combustion and generated by PV and WT for two selected days.

| Day               | Load (kWh) | PV (kWh) | WT (kWh) | From grid (kWh) | Fed to grid (kWh) |
|-------------------|------------|----------|----------|-----------------|-------------------|
| **July 02, 2019** | 6.52       | 10.66    | 4.73     | 1.66            | 8.98              |
| **August 05, 2019** | 5.13       | 7.56     | 8.73     | 0.77            | 10.30             |

Figures 8 (a)-(b) demonstrated the monthly required energy to serve the desired load based on each component in (a) and the percentage in (b). Based on the yearly energy consumption 5629 kWh, the PV array generated about 2559 kWh/year with 45.46% of the total required energy. Figures 7 (a) show during summer months (Apr. - Sep.) the PV array generated energy more than winter months due to higher solar irradiance (refer Figure 2) and longest day hours. The yearly energy generated by the WT unit about 2511 kWh, with 44.61% form the total desired energy, about 559 kWh energy taken from the grid. The renewable energy components (PV=1.65 kW, WT= 1 kW) can serve the desired load by about 90%, which gives a high renewable energy fraction of about 0.901.

![Figure 8](image2.png)

**Figure 8.** Value (a) and percentage (b) of the required energy can serve the desired load.

Figures 9 (a)-(b) shows the frequency of the energy generated by WT and PV array, respectively.
Figure 9. Frequency of the energy generated by WT (a) and PV (b)

Figure 10 shows the monthly energy taken/fed to grid (generated by WT and PV array). The yearly energy taken from the grid about 559 kWh, and the yearly energy fed to grid about 3411 kWh. The highest energy fed to grid during the summer period (Apr. - Sep.) due to higher energy generated by PV array. The WT energy fluctuated from month to another due to fluctuation of the wind speed.

Figure 10. Monthly energy taken/fed to grid.

The economical cost presented by using US ($) currency. The annual and the total net present cost for the system and components are presented in figures 11 (a)-(b) and tables (3)-(4). The system yearly cost about $ 501, and the total NPC $5349, and the total initial capital, replacement, operation, and maintenance and salvage value are presented in tables 3 and 4, respectively.

Figure 11. The yearly (a) and total NPC (b) for the suggested system.
Table 3. System yearly cost.

| Component | Capital ($/yr) | Replacement ($/yr) | OMC ($/yr) | Salvage ($/yr) |
|-----------|----------------|--------------------|------------|---------------|
| PV        | 67             | 12                 | 180        | -6            |
| WT        | 44             | 12                 | 20         | -2            |
| Grid      | 0              | 0                  | -85        | 0             |
| Converter | 133            | 30                 | 100        | -5            |

Table 4. System Total NPC cost.

| Component | Capital ($/yr) | Replacement ($/yr) | OMC ($/yr) | Salvage ($/yr) |
|-----------|----------------|--------------------|------------|---------------|
| PV        | 720            | 129                | 1,921      | -66           |
| WT        | 470            | 126                | 213        | -19           |
| Grid      | 0              | 0                  | -904       | 0             |
| Converter | 1,425          | 315                | 1,067      | -49           |

Figure 12 shows the yearly cost during the project life span (25 years); the initial system capital cost $2615. In the year 15, it has the replacement of WT and converter, and in the year 20, it has the replacement of PV modules.

Figure 12. The project lifespan cost for the suggested system.

5. Conclusions
This work outlined a new simulation and optimisation method for assessing the renewable energy resources for household electrification located in Baquba, Diyala, Iraq. The selected renewable energy components and capacity are WT 1 kW and PV array 1.65 kW (6 modules* 0.275 kW). The simulation process was conducted at a 1-minute time step by using experimental data for the electrical load, wind speed, solar irradiance, and ambient temperature at 1-minute resolution. The obtained results are very encouraging to used renewable energy (solar radiation and wind speed), which the
renewable energy fraction for the suggested renewable component capacity about 0.9. For the average of the daily energy consumption 5.5 kWh/d, the availability of renewable energy resources can serve the desired load by about 90%. Furthermore, it delivered renewable energy to the grid system by about 3114 kWh/year. The result of the economic aspects shows that the system NPC by about $5349 levelized COE $0.25, and this is a cheap value comparing prices of energy available in Iraq. The system electrical energy generated and economic results encourage the exploitation of renewable energy resources located in the specified site

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