Solar-Wind Hybrid Power System Analysis Using Homer for Duhok, Iraq

Abstract. The government of Iraq recently joined the Paris Climate Agreement, it has now begun to encourage the participation of small and large consumers to generate electricity from renewable energy resources. This article analyzes a hybrid solar-wind electrical system for Duhok city northern part of Iraq to know the feasibility of this system compared to the local electrical network. Firstly, an access to solar and wind resources have been ensured for Duhok. For evaluation and optimization study, both stand-alone (off-grid) and grid connecting (on-grid) systems taken into consideration to be optimized. HOMER is a software application employed to perform the power and cost analysis based on wind speed, solar irradiance and load profile. According to the numerous configurations. Simulation outcomes have been shown that the on-grid hybrid solar-wind energy system at Duhok site is most cost-effective than off-grid design for the same load, also it is better cost efficient than Duhok residential power grid, as our system cost unit COE is (0.0109 $/kWh) while Duhok residential electricity COE is 0.15$/kWh

Streszczenie. Niedawno rząd Iraku dołączył do paryskiego porozumienia klimatycznego, teraz zaczął zachęcać małych i dużych odbiorców do udziału w wytwarzaniu energii elektrycznej z odnawialnych źródeł energii. Ten artykuł analizuje hybrydowy system energii słonecznej i wiatrowej w Duhok. Do oceny i badania optymalizacyjnego brane są pod uwagę zarówno systemy autonomiczne (poza siecią), jak i systemy przyłączające do sieci (w sieci). HOMER to aplikacja służąca do przeprowadzania analizy mocy i kosztów w oparciu o liczne konfiguracje. Wyniki symulacji wykazały, że hybrydowy system energii słonecznej i wiatrowej w Duhok jest bardziej opłacalny niż projekt poza siecią dla tego samego obciążenia, a także jest bardziej opłacalny niż miejski system energii elektrycznej w Duhok, ponieważ koszt naszego systemu jednostka COE wynosi (0,0109 $/kWh), podczas gdy wskaźnik COE energii elektrycznej w budynkach miejskich Duhok wynosi 0,15 $/kWh. (Analiza hybrydowego systemu zasilania energią słoneczno-wiatrową przy użyciu Homera dla Duhok, Irak)

Keywords: Renewable, Hybrid, Solar, Wind.

Słowa kluczowe: energia odnawialna, ogniwa fotowoltaiczne, elektrownie wiatrowe.

Introduction

The Turning to the renewable energy resources and improving the efficiency of that environmentally, friendly power in the developed countries has been significantly noticed. This is because of rapid increase in normal or fossil fuel charge that leads to air pollution and global warming.[1] This kind of energy expected to be invested to cover around fifty percent of the total world's energy consumption by 2040. [2]. The dependency on nuclear power and fossil fuel can be reduced via growing the renewable energy applications. Renewable resources are unpolluted, sustainable and used as decentralized generation units. Moreover, it has an extra constructive position of being free energy [3].

The government of Iraq recently joined the Paris Climate Agreement, which aims to reduce global warming. The government has now begun to encourage the participation of small and large consumers to generate electricity from renewable energy resources. In the present work, we use HOMER Pro software to evaluate a suggested hybrid solar-wind electrical system at Duhok city to know the feasibility of this system compared to the local electrical network, also for more optimization details, both stand-alone and grid connecting systems taken into consideration to be optimized.

The suggested model at this article is unique because a similar study has not been done before in this site (Dohuk city) therefore cannot to be precisely compared among other available models at other sites. for the reason that the input parameters such as wind/solar/temperature can certainly vary from site to site making the optimization results varied and cannot be compared correctly.

System Description

The proposed hybrid solar-wind electrical system with battery bank and local grid, illustrated in simple diagram as shown in Fig. 1 below:

![Diagram of suggested hybrid solar-wind electrical system](https://example.com/diagram.png)

Fig. 1 The basic diagram for the suggested hybrid solar-wind electrical system

The solar system provides energy when the sun is shine( clear sky days ) whereas on frosty days which are frequently to be cloudy, the wind systems will substitute solar panels in providing more power for both off-grid and on-grid appliances. Here is a design of both on-grid in addition to the off-grid systems for hybrid solar-wind power system in Duhok city. The main reason of selecting Duhok site (Fig. 2) is location where the power grid availability is about 24 hours and the ease access for solar and wind resource.

The available sun radiation on earth computed in to two main approaches. The first method is calculated according to the Global Horizontal Irradiance GHI which is usually calculated by a pyranometer while the second technique is according to immediate normal irradiance DNI which is measured by a pyrheliometer [4][5].
Both wind speed and solar irradiance data have been obtained for Duhok, Iraq is determined by surface meteorology and solar energy project (SSE) of National Aeronautics and Space Administration (NASA) [6], which collects meteorology and insolation data for entire earth in order to help in the evolution of renewable and clean energy systems [7]. As showed in HOMER program software, the longitude and latitude of Duhok is 42°56'38.0" E, 36°51'36.4" N respectively. The mean daily irradiance per each month showed in Fig. 3 for an annual average 4.85 (kWh/m²/day), whereas Fig. 4 reports the mean daily wind speed per each month for annual average 5.67 (m/s), also the mean daily irradiance per each month showed in Fig. 5.

**Methods**

**Wind turbine system**

Wind turbine acquires the mean power production characteristic which varies according to determinations of the producer. Wind turbine starts generating electricity at their cut-in speed then power starts to increase until turbine reaches the rated speed. It should be noted that power curve of wind turbines is one of very significant characteristics, which describes the relation of the power produced by the turbine with a rotational speed [8][9]. The total annual power (\(W_E\)) in (kWh) generated by wind turbine can be represented via equation (1):

\[
W_E = \sum_{t=1}^{N_h} n_t P_{tr} (v_t)
\]

where (\(N_h\)) is the number of data hour in the year, (\(t\)) is the hour of the year, (\(P_{tr}\)) is the power output in (kW) as function of the average wind speed over a given hour, and (\(N_h\)) is the numbers of turbines at the site [7].

The wind power output (\(P_w\)) in (kW) is specified by the following relation in equation (2), where (\(\rho_a\)) is the air density \(\approx (1.22 \text{ kg/m}^3\)), (\(A\)) is the area of wind turbine rotor in (m²), (\(V_t\)) is the velocity of wind in (m/s), (\(C_p\)) is the wind turbine power coefficient, (\(n_g\)) is the efficiency of wind generator and (\(n_t\)) is the efficiency of wind turbine.

\[
P_w = \frac{1}{2} \rho_a C_p A_{\text{solar}} V_t^3 n_t n_g
\]

**Photovoltaic system**

The following relation in equation (3) can calculate the total annual power (\(S_E\)) results from Photovoltaic system in (kW). Where (\(N_h\)) is the number of data hour in the year, (\(t\)) is the hour of the year, (\(A_{\text{solar}}\)) is the fixed area of the solar field in (m²), (\(G_t\)) is the hourly insolation in (Wm⁻²), (\(n_{\text{SOLAR}, t}\)) is the solar system efficiency for a specified hour of day through a given month [10].

\[
S_E = \sum_{t=1}^{N_h} n_{\text{SOLAR}, t} A_{\text{solar}} G_t
\]

The output power of the photovoltaic system (\(p_{pv}\)) in (kW) expressed in the following relation in equation (4). Where (\(f_{pv}\)) is the derating factor percentage for the photovoltaic array, (\(Y_{pv}\)) is the photovoltaic array rated capacity in (kW), which is the power production under STC. (\(G_{STC}\)) is the incident solar insolation at STC (1 kW/m²), (\(G_t\)) is the solar insolation incident on the PV array at the current time step in (kW/m²), (\(T_{C,STC}\)) is the temperature of the photovoltaic cell under STC which is 25°C, (\(T_c\)) is the temperature of the photovoltaic cell at the current time step in (°C), and (\(\alpha_p\)) is the power temperature coefficient in (%/°C). [11][12][13].

\[
p_{pv} = Y_{pv} \cdot f_{pv} \left[ \frac{G_t}{G_{STC}} \right] [1 + \alpha_p (T_c - T_{C,STC})]
\]

The following relation in equation (5) determines the total annual power output in (kWh) obtained from the renewable hybrid system (\(H_E\)) that denotes to the sum of PV power (\(S_E\)) and WT power (\(W_E\)) [14]:

\[
H_E = W_E + S_E
\]

**HOMER program simulation model**

Hybrid optimization model for electric renewables (HOMER) is a computer model established by the National Renewable Energy Laboratory in the United States (NREL) to help designers to design renewable energy systems in both ON-grid and OFF-grid projects and ease the assessment of power generation technologies through an extensive variety of combinations. [15],[16]. A flowchart of HOMER simulation process can be found in Fig. 6 below which describing all the simulation stages in detail [17].
The hybrid power model designed in the HOMER program is shown in Fig. 7 & Fig. 8 respectively. This model consists of Generic 3 kW wind turbine, Generic PV flat plate, electronic converter, Generic Li-ion 1kWh battery and residential load.

**Optimization analysis**

HOMER simulates all the achievable solutions for the system, then shows a list of all feasible system patterns planned gradually from lowest to highest in NPC (Net Present Cost) and excludes all the infeasible configurations. HOMER uses a proprietary derivative-free algorithm to explore for the optimum solution among all these feasible systems. The least NPC is the optimum design for the system [18],[19],[20].

Many researchers have utilized HOMER for analyzing [21],[22],[23],[24]. Analysis with HOMER needs a wide range of data on renewable resources, energy storage systems, control algorithms and economic restrictions. The evaluation criteria of the HOMER assessment are the Net Present Cost (NPC) and the Cost of Energy (COE). The COE is defined in HOMER as the mean cost/kWh of valuable power generated by the system. To compute the value of COE, HOMER program will divide the yearly cost of electricity production by the beneficial generated electricity.

The COE can be calculated by the relation in the following equation (6):

\[
COE = \frac{C_{ann,tot}}{(E_{grid,sales}) + (E_{prim,DC}) + (E_{prim,AC})}
\]

Where \(E_{grid,sales}\) is the overall sold energy from the grid in(kWh/year), \(E_{prim,DC}\) is the DC primary load served in (kWh/year), \(E_{prim,AC}\) is the AC primary load served in(kWh/year) and \(C_{ann,tot}\) is the overall yearly cost in ($/year).

The total NPC is calculated in HOMER using the relation in the following equation (7), where \(C_{ann,tot}\) is the overall yearly cost in ($/year), \(CRF\) is the capital recovery factor, \((R_{proj})\) the project lifetime in year, \((i)\) the interest rate %, and the (CRF) is calculated by the equation (8) [11].

\[
NPC = \frac{C_{ann,tot}}{CRF(R_{proj})}
\]

\[
CRF = \frac{(1+i)^{1+[R_{proj}]/(1+i)^{1}]}-1
\]

In order to calculate the optimal cost, the model has been configured to simulate the same electrical load with the off-grid and on-grid design.

Table 1. The Data Input for Proposed Model.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>PV 1kW</th>
<th>Wind Turbine</th>
<th>Li-ion Battery (167Ah)</th>
<th>Converter 1kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>$500</td>
<td>$5000</td>
<td>$100</td>
<td>$200</td>
</tr>
<tr>
<td>Replacement Cost</td>
<td>$400</td>
<td>$4400</td>
<td>$80</td>
<td>$160</td>
</tr>
<tr>
<td>Operation &amp; Maintenance</td>
<td>8 $</td>
<td>10 $</td>
<td>1 $</td>
<td>1 $</td>
</tr>
<tr>
<td>Lifetime</td>
<td>25 year</td>
<td>25 year</td>
<td>-</td>
<td>25 year</td>
</tr>
<tr>
<td>Hub Height</td>
<td>- 17m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Efficiency</td>
<td>13 %</td>
<td>-</td>
<td>-</td>
<td>95 %</td>
</tr>
<tr>
<td>Derating Factor</td>
<td>80 %</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>47°C</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Initial SOC</td>
<td>-</td>
<td>100 %</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Minimum SOC</td>
<td>-</td>
<td>20 %</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nominal Voltage</td>
<td>-</td>
<td>6 V</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nominal Capacity</td>
<td>-</td>
<td>1 kwh</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maximum Capacity</td>
<td>-</td>
<td>167 Ah</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
A Generic PV flat panel is utilized, these photovoltaic panels are flat plate builds by Generic, the wind unit is an A.C Generic 3 KW, also a generic lithium-ion battery has been utilized with a nominal capacity of 1 kWh, and a generic converter this is important to supports the hybrid system design in off-grid configuration. From observing the cost curve in Fig. 9, it is clear that varying the amount of batteries will affect the cost, which will ultimately affect the total NPC.

The grid model unit is a local grid with 10kW capacity, power rate definition is 0.1\$/kWh and sellback rate of 0.05\$/kWh, when there is power shortage, the grid provides electricity to achieve a load request. Further, it receives electrical power when excessive energy is available.

**Results and discussion**

In this paper, a domestic load used in the proposed hybrid system. Supposing that the project life is 25 year. Results and discussion is presented in Fig. 10 and Fig. 11. The optimization outcomes for proposed model in both designs on-grid and off-grid respectively. Optimization progression has been executed during each achievable choice of variables of this hybrid system regardless the effect of sensitive variables. Fig. 12 shows the total annually production of proposed model 22,165 kWh/yr with 21,063 kWh/yr consumption in residential load.

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