Cost and performance evaluation of hydrokinetic-diesel hybrid systems

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Abstract

The aim of this paper is to investigate the potential use of Hydrokinetic-Diesel generator hybrid systems for sustainable and cost-effective electricity generation in rural South Africa. For this purpose different potential supply options are simulated using HOMER and the results are analyzed based on the Net Present Cost and the Cost of Energy produced. The simulation results show that Hydrokinetic-Diesel generator hybrid systems have lower net present costs as well as lower costs of energy compared to other supply options such as standalone Photovoltaic, Hydrokinetic or diesel generator.

Keywords: Hydrokinetic, Diesel generator, Hybrid systems, Net Present Cost, Cost of Energy, Rural electrification

1. Introduction

The use of renewable energy source is still low in South Africa. The reason is due to the higher cost of energy produced by renewable sources compared to the one from the currently used coal power plants [1]; therefore it is imperative to explore the local renewable resources to provide sustainable electricity to the rural areas. Solar PV is one of the mostly used renewable sources in South Africa. Wind energy sources used mainly in the coastal region where the wind potential is very good. However, for inland areas where adequate water resource is available, micro-hydro is the best supply option compared to other renewable resources in terms of cost of energy produced [2]. Unlike conventional hydropower, hydrokinetic generates electricity by extracting kinetic energy of flowing water; therefore it is far less site specific and more competitive compared to traditional micro hydropower [3]. However the main disadvantage of these renewable energy technologies is their strong reliance on weather and climatic conditions [4]. Therefore, they cannot always produce enough energy to constantly match the load energy requirements.

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Hybrid renewable-diesel systems have been extensively studied well as solutions for supplying electricity to remote areas. However there is no literature currently available showing the use of hydrokinetic technology operating in combination with other power generation systems [5]. Therefore, in this study the cost and performance evaluation of a hydrokinetic-diesel hybrid energy system is done for a South African remote area using HOMER (Hybrid Optimization Model for Electric Renewable) [6]. The simulation results are compared with the one acquired from other supply options such as hydrokinetic turbines (HKT), photovoltaic panels (PV), DG alone based on the net present cost (NPC) and on the cost of energy produced (COE).

2. Hybrid system main components description

In this study, the hydrokinetic system has been selected instead of the traditional micro hydropower. Its operation principle is identical to the one of the wind turbine. Knowing that water is approximately 800 times denser than air, this means that the amount of energy produced by a hydrokinetic turbine is much greater than that produced by a wind turbine of equal diameter under equal water and wind speed. The energy generated \( E_{\text{HKT}} \) by the hydrokinetic system is expressed as [7]:

\[
E_{\text{HKT}} = \frac{1}{2} \times \rho_w \times A \times v^3 \times C_{p,H} \times \eta_{\text{HKT}} \times t
\]  

(1)

Where:
- \( \rho_w \) is the density of water (kg/m\(^3\)),
- \( C_{p,H} \) is the coefficient of the hydrokinetic turbine performance,
- \( \eta_{\text{HKT}} \) is the combined efficiency of the hydrokinetic turbine and the generator,
- \( A \) is the turbine area (m\(^2\)),
- \( \rho \) is the water density (1000 kg/m\(^3\)),
- \( v \) is the water current velocity (m/s),
- \( t \) is the time (s).

Diesel generators are normal diesel engines coupled to generator. To operate efficiently, most of DGs are designed in such a way that they always run between 80-100 % of their kW rating while supplying the load. The energy generated \( E_{\text{DG}} \) by a DG with rated power output \( P_{\text{DG}} \) is expressed as [8]:

\[
E_{\text{DG}} = P_{\text{DG}} \times \eta_{\text{DG}} \times t
\]  

(2)

Where: \( \eta_{\text{DG}} \) is the efficiency of the DG.

3. Simulation data

Two case studies are conducted on two different sites from which the environmental data, load energy profile and system component costs are acquired and used as input to HOMER.

3.1. Load descriptions

Fig. 1. (a) Load profile rural of household  (b) Load profile of the BTS site
A 24-h load data is obtained from a typical household situated in the KwaZulu-Natal province at 30.6 degrees latitude south and 29.4 degrees longitude east; corresponding load profile is illustrated on Fig. 1(a) [9]. The base transceiver station selected for this study is situated at 32.8 degrees latitude south and 17.9 degrees longitude east in the Western Cape region and the daily energy needed by the BTS communication equipment and the cooling is given Fig. 1(b).

3.2. Water resource assessment

The average of the water velocities for the household and the BTS site are given on Fig. 2 (a) and Fig. 2 (b) respectively [3].

3.3. Components sizes and costs

The HKT (1kW) has an initial cost of 7,500$; the O&M cost is $20/year; and a lifetime span of 25 years. The PV (1kW) has an initial cost of 3,590$; a lifetime span of 20 years with a derating factor of 90% and an O&M cost of $10/yr. The DG (7kW) has an initial cost of 1,240$; the lifespan is 15000 operating hours with an O&M of $0.50/kW. The price of diesel fuel and the lubricant are taken as 1.3$/l and 1.2$/l respectively. The converter (6kW) has an initial cost of 3,730$ with a lifespan of 15 years and an efficiency of 90%; O&M cost of $10/kW. The battery (6V, 360Ah) has an initial cost of 215$ with an O&M cost taken as $5/year.

4. Results and discussion

4.1. Case 1: Household case

From table 1, we can notice that based on the NPC, COE and the breakeven grid extension distance that the system composed of HKT (3kW) / DG (1kW) / 12 Batteries / Converter (7kW) is the best supply option for the load under consideration.

<table>
<thead>
<tr>
<th>Item</th>
<th>HKT</th>
<th>PV</th>
<th>DG</th>
<th>HKT+DG</th>
<th>PV+DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital($)</td>
<td>37,601</td>
<td>72,201</td>
<td>1,270</td>
<td>28,988</td>
<td>46,715</td>
</tr>
<tr>
<td>NPC($)</td>
<td>54,274</td>
<td>98,259</td>
<td>219,076</td>
<td>43,599</td>
<td>83,189</td>
</tr>
<tr>
<td>COE($/kWh)</td>
<td>0.33</td>
<td>0.601</td>
<td>1.33</td>
<td>0.265</td>
<td>0.505</td>
</tr>
<tr>
<td>Operation($/year)</td>
<td>1,304</td>
<td>2,038</td>
<td>17,041</td>
<td>1,143</td>
<td>2,853</td>
</tr>
<tr>
<td>Replacement($)</td>
<td>17,442</td>
<td>31,070</td>
<td>8,164</td>
<td>8,939</td>
<td>25,869</td>
</tr>
<tr>
<td>Fuel(L/year)</td>
<td>0</td>
<td>0</td>
<td>9,539</td>
<td>241</td>
<td>0</td>
</tr>
<tr>
<td>Salvage($)</td>
<td>-3,071</td>
<td>-11,403</td>
<td>-178</td>
<td>-827</td>
<td>-7,295</td>
</tr>
<tr>
<td>Grid extension(km)</td>
<td>2.7</td>
<td>6.6</td>
<td>17.3</td>
<td>1.76</td>
<td>5.26</td>
</tr>
<tr>
<td>Carbon dioxide(kg/year)</td>
<td>0</td>
<td>0</td>
<td>25,120</td>
<td>634</td>
<td>1,816</td>
</tr>
</tbody>
</table>
4.2. Case 2: Base transceiver station (BTS)

From Table 2 we can notice that based on the NPC, COE and the breakeven grid extension distance that the system HKT (4kW) / DG (2kW) / 8 Batteries / Converter (5kW) is the best of all the options considered in the simulation.

Table 2: Summary of the different supply options simulation results (BTS case)

<table>
<thead>
<tr>
<th>Item</th>
<th>HKT</th>
<th>PV</th>
<th>DG</th>
<th>HKT+DG</th>
<th>PV+DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital($)</td>
<td>71,684</td>
<td>140,994</td>
<td>886</td>
<td>35,183</td>
<td>29,201</td>
</tr>
<tr>
<td>NPC($)</td>
<td>76,277</td>
<td>186,170</td>
<td>194,547</td>
<td>51,887</td>
<td>135,803</td>
</tr>
<tr>
<td>COE($/kWh)</td>
<td>0.278</td>
<td>0.681</td>
<td>0.709</td>
<td>0.189</td>
<td>0.495</td>
</tr>
<tr>
<td>Operation($/year)</td>
<td>359</td>
<td>3,534</td>
<td>15,149</td>
<td>1,307</td>
<td>8,339</td>
</tr>
<tr>
<td>Replacement($)</td>
<td>2,233</td>
<td>57,136</td>
<td>6,353</td>
<td>3,139</td>
<td>12,858</td>
</tr>
<tr>
<td>Fuel(L/year)</td>
<td>0</td>
<td>0</td>
<td>8,870</td>
<td>619</td>
<td>4,788</td>
</tr>
<tr>
<td>Salvage($)</td>
<td>-367</td>
<td>-22,997</td>
<td>-83</td>
<td>-285</td>
<td>-4,739</td>
</tr>
<tr>
<td>Grid extension (km)</td>
<td>3.25</td>
<td>13</td>
<td>13.7</td>
<td>1.1</td>
<td>8.52</td>
</tr>
<tr>
<td>Carbon dioxide(kg/year)</td>
<td>0</td>
<td>23,356</td>
<td>1,631</td>
<td>12,608</td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusion

This paper investigated the use of hydrokinetic-diesel generator hybrid systems to supply electricity to isolated rural load in South Africa. For this purpose a typical rural household and a BTS load have been used as case studies. Simulations of 5 different options (HKT, PV, DG, HKT+DG, PV+DG) have been performed with HOMER. The simulation results have been analyzed and the best supply option has been selected based on the Net Present Cost and the Cost of Energy produced. For both case studies, the results have revealed that the hydrokinetic-diesel hybrid systems have lower net present costs as well as lower cost of energy compared to all other supply options. Apart from sensibly decreasing the costs, hydrokinetic modules heavily contribute to the reduction of pollutant emitted by diesel generators when combined in hybrid systems configurations.

References


Biography

Mr. K. Kusakana (MTech) is a lecturer and researcher in the Electrical, Electronics and Computer Engineering Department at the Central University of Technology. His research interests are renewable and alternative energies.

Prof. H.J. Vermaak (PhD) is the HOD of the Electrical, Electronics and Computer Engineering Department at the Central University of Technology. His research interests are evolvable manufacturing and renewable energy technologies.