“Optimal Sizing, Modeling, and Design of a Supervisory Controller of a Stand-Alone Hybrid Energy System”

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Outline

• Thesis objectives
• Introduction
• The system sizing
• Renewable resources
• Sizing results
• Modeling and simulation
• Experimental set-up
• Conclusion and future work
Thesis Objectives

• Sizing and profitability study for a stand-alone telecommunication site in Labrador, Canada.

• Modeling the system using Matlab/Simulink

• Experimental testing of proposed supervisory controller
Introduction

A photograph of Bell-Aliant’s telecommunication site at Mulligan, Labrador

Microwave Relay Tower

Accommodations, Diesel Generator and Battery Bank
Sizing the hybrid system

The existing power system

The proposed power system
Electrical load

Monthly load profile of Mulligan site for a year

Daily load profile of Mulligan site for a year
Renewable resources

Monthly solar radiation produced by HOMER

The average monthly wind speed for a year
Basic concepts

PV cell, module and array
Sizing and Comparison Results

The existing system

Optimized result for the non-renewable energy system

Monthly average electric production for non-renewable energy system
The proposed system

Optimized result for the renewable energy system

Monthly average electric production for renewable energy system

Energy production for proposed system from HOMER software

Excess energy for proposed system from HOMER software
**Comparison: Based on the coat and fuel consumption**

<table>
<thead>
<tr>
<th></th>
<th>Existing system</th>
<th>Proposed system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial capital cost ($)</td>
<td>$197,237</td>
<td>$968,420</td>
</tr>
<tr>
<td>Total NPC ($)</td>
<td>$823,072</td>
<td>$1,011,514</td>
</tr>
<tr>
<td>Fuel Consumption in a year (L)</td>
<td>12,672L</td>
<td>335L</td>
</tr>
<tr>
<td>Fuel consumption in 20 years (L)</td>
<td>253,440L</td>
<td>6,700L</td>
</tr>
<tr>
<td>Total cost in 20 years ($)</td>
<td>$2,090,272</td>
<td>$1,045,014</td>
</tr>
</tbody>
</table>
Comparison: Based on emissions

### Emission values in the existing system produced from HOMER tool

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>33,370</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>82.4</td>
</tr>
<tr>
<td>Unburned hydrocarbons</td>
<td>9.12</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>6.21</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>67</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>735</td>
</tr>
</tbody>
</table>

### Emission values in the proposed system produced from HOMER tool

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>883</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>2.18</td>
</tr>
<tr>
<td>Unburned hydrocarbons</td>
<td>0.241</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>0.164</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>1.77</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>19.4</td>
</tr>
</tbody>
</table>
Modeling and simulation

Wind Turbine

Simulink model for the wind energy conversion system

\[ \lambda = \frac{\omega R}{v} \]
A typical wind turbine power curve
The effect of wind speed

Wind Speed = 12(m/sec), Power = 7500W

Wind Speed = 10(m/sec), Power = 5500W

Wind Speed = 8(m/sec), Power = 3700W
Photovoltaic System

\[ I_D = I_0 \{ \exp \left[ \frac{eV_b}{(kT)} \right] - 1 \} \]

\[ I = I_0 \{ \exp \left( \frac{eV_b}{kT} \right) - 1 \} - I_L \]

\[ I = I_{sc} - I_{01} \left[ e^{\frac{(V+I R_s)}{kT}} - 1 \right] - I_{02} \left[ e^{\frac{(V+I R_s)}{2kT}} - 1 \right] - \left( \frac{V+I R_s}{R_p} \right) \]
Subsystem model of the solar cell
Photovoltaic System (cont)

P-V output characteristics with 1000(W/m²)

P-V output characteristics with 800(W/m²)

P-V output characteristics with 600(W/m²)
Photovoltaic System (cont)

- P-V output characteristics with MPPT technique

The effect of solar irradiance

- Solar irradiance = 800 W/m², P = 225 W
- Solar irradiance = 600 W/m², P = 170 W
System configuration of the proposed alternative hybrid energy system
Simulink model for the whole hybrid power system
Case 1: Step change in wind speed

Current, voltage, and power of the system 10m/s to 12m/s wind speed

Current, voltage, and power of the system 12m/s to 14m/s wind speed
Case 2: Step change in solar irradiation

Current, voltage, and output power of the system 1000W/m² to 800W/m² solar irradiance
Case 3: Change in load

The system output when the load is increased

The system output when the load is decreased
Experimental set-up

The experimental setup in the lab with various components
Experimental set-up (cont)

Schematic diagram of the experiment setup
Wind speed measurements

<table>
<thead>
<tr>
<th>Wind speed at the middle of the tunnel (m/s)</th>
<th>Blades rotational speed (rpm)</th>
<th>Wind speed where the wind turbine is in the tunnel (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.9</td>
<td>185</td>
<td>4.78</td>
</tr>
<tr>
<td>10</td>
<td>971</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>1157</td>
<td>7.26</td>
</tr>
<tr>
<td>14</td>
<td>1446</td>
<td>8.5</td>
</tr>
</tbody>
</table>
Experimental set-up (cont)

CR5210 current transducers
Experimental set-up (cont)
## Experiment Results

### Case 1: Sunny day

Experiment results in first 7 minutes

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Battery Voltage (V)</th>
<th>Load Current (A)</th>
<th>PV Current (A)</th>
<th>Wind Current (A)</th>
<th>Diesel generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>12.16 v</td>
<td>7.72</td>
<td>2.38</td>
<td>4.47 (4.41-4.60)</td>
<td>off</td>
</tr>
<tr>
<td>3-4</td>
<td>12.14 discharging</td>
<td>7.69</td>
<td>0</td>
<td>0</td>
<td>on</td>
</tr>
<tr>
<td>4-7</td>
<td>12.16 v</td>
<td>7.72</td>
<td>2.38</td>
<td>4.47 (4.41-4.60)</td>
<td>off</td>
</tr>
</tbody>
</table>
Experiment Results (cont)

PV Output

Wind Turbine Output

Battery State of Charge

PV output current in first 7 minutes

Wind current power in first 7 minutes

Battery state of charge in first 7 minutes
Experiment Results (cont)

Scope display of wind turbine and PV Output
Case 2: Wind speed is zero

Experiment results when there is no wind

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Battery Voltage (V)</th>
<th>Load Current (A)</th>
<th>PV Current (A)</th>
<th>Wind Current (A)</th>
<th>Diesel generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-71</td>
<td>12.11 v</td>
<td>7.65</td>
<td>2.41</td>
<td>0</td>
<td>off</td>
</tr>
<tr>
<td>71-72</td>
<td>12.06</td>
<td>7.65</td>
<td>0</td>
<td>0</td>
<td>on</td>
</tr>
<tr>
<td></td>
<td>discharging</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72-73</td>
<td>12.08 v</td>
<td>7.65</td>
<td>2.41</td>
<td>0</td>
<td>off</td>
</tr>
</tbody>
</table>

Battery State of Charge

Battery state of charge when there is no wind
Experiment Results (cont)

Case 3: Cloudy day

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Battery Voltage (V)</th>
<th>Load Current (A)</th>
<th>PV Current (A)</th>
<th>Wind Current (A)</th>
<th>Diesel generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>12.03 V</td>
<td>7.65</td>
<td>0</td>
<td>4.47 (4.41-4.60)</td>
<td>off</td>
</tr>
<tr>
<td>2-3</td>
<td>12.09</td>
<td>7.69</td>
<td>0</td>
<td>0</td>
<td>on</td>
</tr>
<tr>
<td>3-4</td>
<td>12.03 V</td>
<td>7.72</td>
<td>0</td>
<td>4.47 (4.41-4.60)</td>
<td>off</td>
</tr>
</tbody>
</table>

**Battery State of Charge**

![Graph showing battery state of charge over time]
Experiment Results (cont)

- Experiment Results with Battery Connected and Disconnected

The load brightness when the renewable systems and battery are connected

The load brightness when only the renewable systems are connected
Conclusion

• HOMER software is used to determine the best optimal sizing and a pre-feasibility study of the system and sensitivity analysis is done when designing the system.

• A comparison between the existing and the proposed systems has been made based on system cost and emissions.

• System components have been modeled in Matlab/Simulink individually first and then a combination system has been modeled.

• Different scenarios have been considered for wind and solar subsystems and for the load as well.

• Wind turbine and solar panel data have been studied, and training in how they work has been done with the lab manager.

• A real time on/off supervisory controller has been proposed and implemented for a small scale system.
Future works

• Simulation for longer time.

• Additional controllers are highly recommended for some power components.

• It should be implemented for the same scale system.

• Grid connection can be considered in both dynamic modeling and for the experiment setup.
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Publications


Thanks for your Attention