An Analysis of Solar and Wind Resources for Building a Hybrid PV and Wind Power Plant

Presenter: Yuqing Yang
Co-authors: Dr. Merlinde Kay, Dr. Chris Menictas and AProf. Stephen Bremner
Outline

• Introduction on hybrid PV and wind power plant
• Complementary feature investigation on synergy
• Complementary feature investigation on ramp rates
• Complementary feature investigation on prolonged lulls
• The potential roles of battery in the hybrid systems
• Conclusions
Hybrid PV and Wind Power Plant

- Retrofit an existing solar/wind farm into a hybrid one
- Start an entirely new (green field) hybrid power plant

Advantages

- Solar and wind are separately dominant at the day and night time.
- Complementary feature of solar and wind will improve the capacity factor of power plant.
- Many locations in Australia are both sunny and windy.
- For retrofitting, many costs and effort will be saved.

The figures are from AECOM, Co-location Investigation, A study into the potential for co-locating wind and solar farms in Australia, 2016
Hybrid PV and Wind Power Plant

- GHI
- Wind speed

- PV power
- Wind power

• Data Used – Goulburn 2001 to 2010
  Hourly Global Horizontal Irradiation (GHI) data
  Hourly Wind speed data
Why complementary feature analysis is important?

• There are quite a lot of studies on hybrid renewable energy system.

• The previous studies only assessed the complementary feature from a macro scope, whereas how the solar and wind complement each other in each time step or a specific condition is not clear.

• The complementary feature in each time step will strongly influence the operation of the hybrid systems or the operation of the battery energy storage system in the hybrid system.

The second figure is from AECOM, Co-location Investigation, A study into the potential for co-locating wind and solar farms in Australia, 2016.
Complementary Feature of Solar and Wind Resources

- Synergistic assessment
- Ramp rate assessment
- Prolonged lulls assessment
Complementary Feature Investigation on Synergy

Estimate the probability applying Prasad’s approach \[^1\]
- Solar complements wind (SCW)
- Wind complements solar (WCS)
- Wind and solar synergy (WSS).

\[
WCS(\%) = \frac{\text{Number of hours (WPD > 240Wm}^{-2} \text{ AND GHI} \leq 170\text{Wm}^{-2})}{\text{Total number of hours}} \times 100\%
\]

\[
SCW(\%) = \frac{\text{Number of hours (WPD} \leq 240\text{Wm}^{-2} \text{ AND GHI} > 170\text{Wm}^{-2})}{\text{Total number of hours}} \times 100\%
\]

\[
WSS(\%) = \frac{\text{Number of hours (WPD} > 240\text{Wm}^{-2} \text{ XOR GHI} > 170\text{Wm}^{-2})}{\text{Total number of hours}} \times 100\%
\]

Complementary Feature Investigation on Synergy

The right figure on the right hand side is from Prasad, Abhnil A., Taylor, Robert A. and Kay, Merlinde, Assessment of solar and wind resource synergy in Australia, Applied Energy
Complementary Feature Investigation from Ramp Rates

**Ramp Rate of GHI**

\[ \text{Ramp Rate of GHI} = \frac{\Delta \text{GHI} (kWm}^{-2})}{\Delta t} (h) \]

**Ramp Rate of Wind Speed**

\[ \text{Ramp Rate of Wind Speed} = \frac{\Delta \text{Wind Speed} (ms}^{-1})}{\Delta t} (h) \]
Complementary Feature Investigation from Ramp Rates

Evaluate the occurrence probability of the four different scenarios:
• Solar Increase Wind Decrease (SIWD)
• Solar Decrease Wind Increase (SDWI)
• Solar Increase Wind Increase (SIWI)
• Solar Decrease Wind Decrease (SDWD)

\[
SIWD(\%) = \frac{\text{Number of hours (ΔGHI > 0 AND ΔWS < 0)}}{\text{Total number of hours}} \times 100\%
\]

\[
SDWI(\%) = \frac{\text{Number of hours (ΔGHI < 0 AND ΔWS > 0)}}{\text{Total number of hours}} \times 100\%
\]

\[
SIWI(\%) = \frac{\text{Number of hours (ΔGHI > 0 AND ΔWS > 0)}}{\text{Total number of hours}} \times 100\%
\]

\[
SDWD(\%) = \frac{\text{Number of hours (ΔGHI < 0 AND ΔWS < 0)}}{\text{Total number of hours}} \times 100\%
\]
Complementary Feature Investigation from Ramp Rates

- SIWD: 7.87%
- SDWI: 10.44%
- SIWI: 14.55%
- SDWD: 14.05%
Complementary Feature Investigation from Ramp Rates

Sudden changes: Top 5% largest ramp rate
Extreme changes: Top 1% largest ramp rate
## Complementary Feature Investigation from Ramp Rates

The number of hours that sudden changes in GHI and wind speed coincide

<table>
<thead>
<tr>
<th>Ramp Rate GHI</th>
<th>(+5%)</th>
<th>(+5%)</th>
<th>(-5%)</th>
<th>(-5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Rate Wind Speed</td>
<td>(+5%)</td>
<td>(-5%)</td>
<td>(+5%)</td>
<td>(-5%)</td>
</tr>
<tr>
<td>Total</td>
<td>562</td>
<td>35</td>
<td>197</td>
<td>152</td>
</tr>
<tr>
<td>2001</td>
<td>65</td>
<td>3</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>2002</td>
<td>49</td>
<td>4</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>2003</td>
<td>52</td>
<td>3</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>2004</td>
<td>68</td>
<td>2</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>2005</td>
<td>55</td>
<td>2</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>2006</td>
<td>60</td>
<td>4</td>
<td>32</td>
<td>17</td>
</tr>
<tr>
<td>2007</td>
<td>50</td>
<td>8</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>2008</td>
<td>61</td>
<td>2</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>2009</td>
<td>55</td>
<td>2</td>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>2010</td>
<td>47</td>
<td>5</td>
<td>13</td>
<td>9</td>
</tr>
</tbody>
</table>

The number of hours that extreme changes in GHI and wind speed coincide

<table>
<thead>
<tr>
<th>Ramp Rate GHI</th>
<th>(+1%)</th>
<th>(+1%)</th>
<th>(-1%)</th>
<th>(-1%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Rate Wind Speed</td>
<td>(+1%)</td>
<td>(-1%)</td>
<td>(+1%)</td>
<td>(-1%)</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>1</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>2001</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2003</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2004</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2005</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2006</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2007</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2008</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Complementary Feature Investigation from Prolonged Lulls

- **Solar prolonged lulls**
  - with the GHI < 170 kW/m² for more than 24 hours
- **Wind prolonged lulls**
  - with the wind power density < 240 kW/m² for more than 24 hours

The frequency that more than 24 consecutive lull hours occurred

<table>
<thead>
<tr>
<th>more than 24-hour consecutive lull happened</th>
<th>Solar</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>2002</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>2003</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>2004</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>2005</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>2006</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>2007</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>2008</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>2010</td>
<td>2</td>
<td>31</td>
</tr>
</tbody>
</table>
Complementary Feature Investigation from Prolonged Lulls

- Three scenarios that solar is experiencing prolonged lulls in 2001
- All of the cases that wind is not experiencing the prolonged lulls, with the third scenario that wind just reach the boundary
The Potential Roles of Battery in the Hybrid Systems

- Macro-scope: complement
- Micro-scope: quite low chance to complement each other (ramp rates).
- Necessary to use the battery to address the sudden and extreme ramp rates

- Prolonged lulls: low chance to coincide
- Standalone system: low chance to require more than one day supply from battery.

- Renewable power plants: important for designing a hybrid power plant.
- For the operation: combine the complementary features with forecasting
Conclusions

• From the weather data we used from Goulburn, Australia, it demonstrated a relatively high chance of synergy from the synergistic assessment, whereas a relatively low chance that solar and wind ramp rate can compensate for each other. This needs to be cautious when operating the hybrid systems.

• Moreover, the assessment also shows that there is a remarkably low chance that the extreme severe ramp rate or prolonged lull will coincide for solar and wind recourses.

• The complementary feature analysis will provide valuable information for determining hybrid system and battery sizes and make sure the hybrid systems can ride through the weather lulls and extreme conditions.

• Future work will perform more quantitative studies on how the complementary features will direct the sizing process for the hybrid systems. Another potential dimension is to evaluate the complementary features of the forecasting results of solar and wind power.
Thank you!