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

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Outline

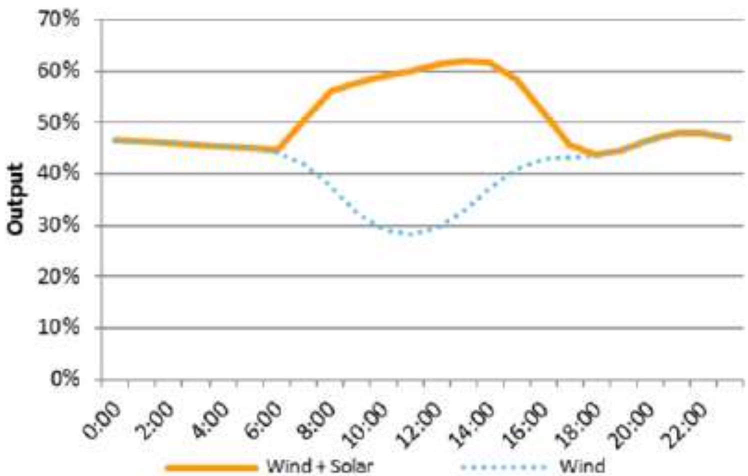
- Introduction on hybrid PV and wind power plant
- Complementary feature investigation on synergy
- Complementary feature investigation on ramp rates
- Complementary feature investigation on prolonged lulls
- The potential roles of battery in the hybrid systems
- Conclusions

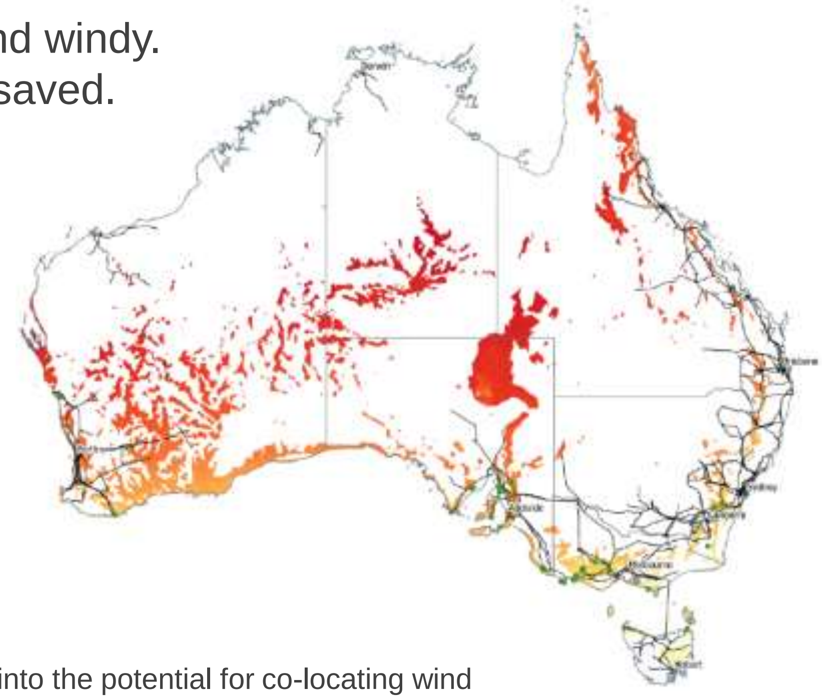
Hybrid PV and Wind Power Plant

- 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

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Hybrid PV and Wind Power Plant

GHI → PV power

Wind speed → Wind power

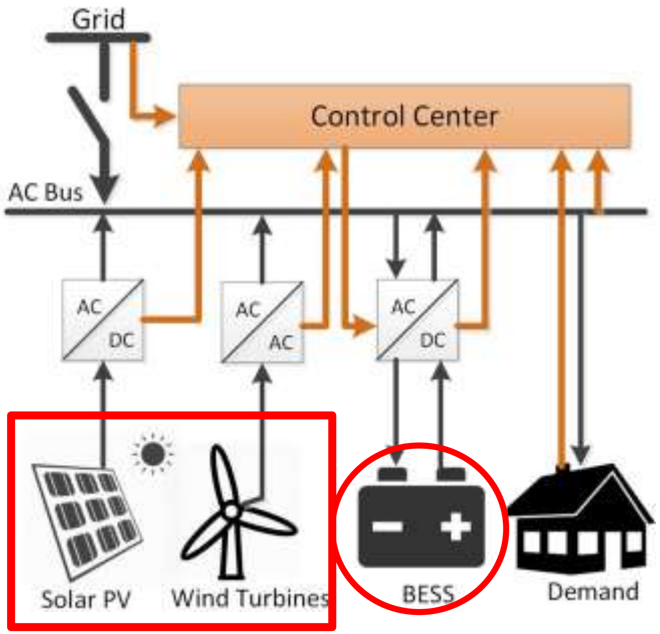
- **Data Used – Goulburn 2001 to 2010**
  Hourly Global Horizontal Irradiation (GHI) data
  Hourly Wind speed data

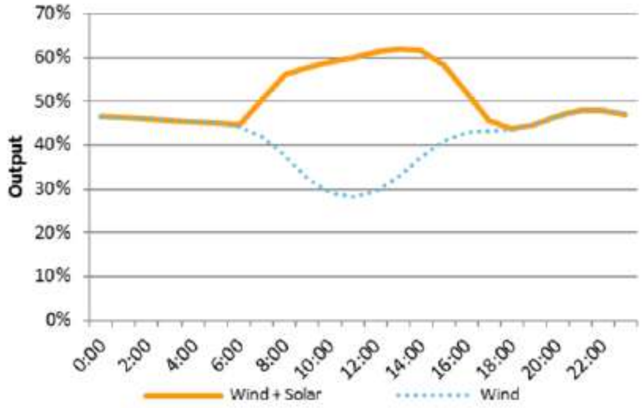
Why complementary feature analysis is important?

- 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

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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).

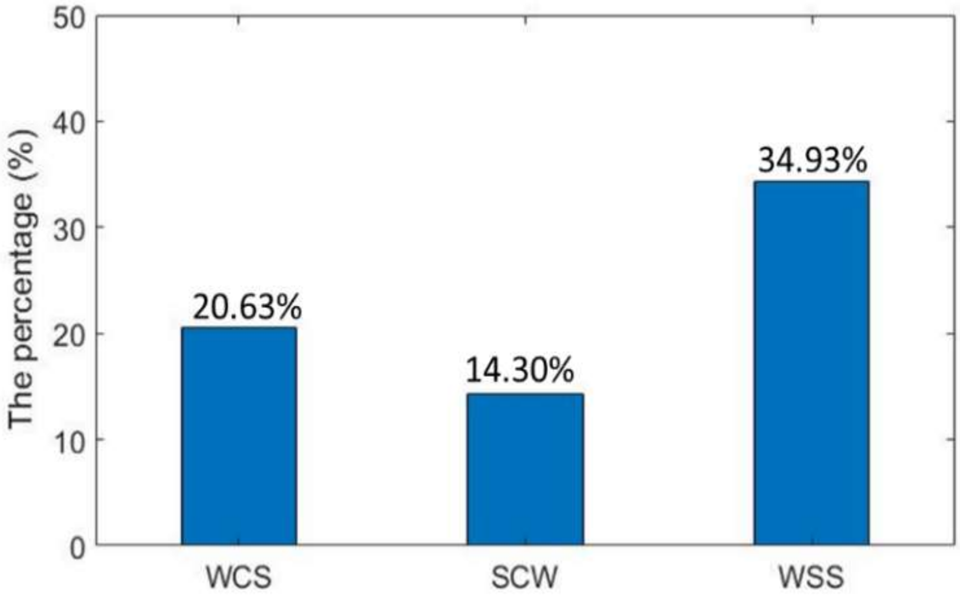
$$WCS(\%) = \frac{Number\ of\ hours\ (WPD > 240Wm^{-2}\ AND\ GHI \leq 170Wm^{-2})}{Total\ number\ of\ hours} \times 100\%$$

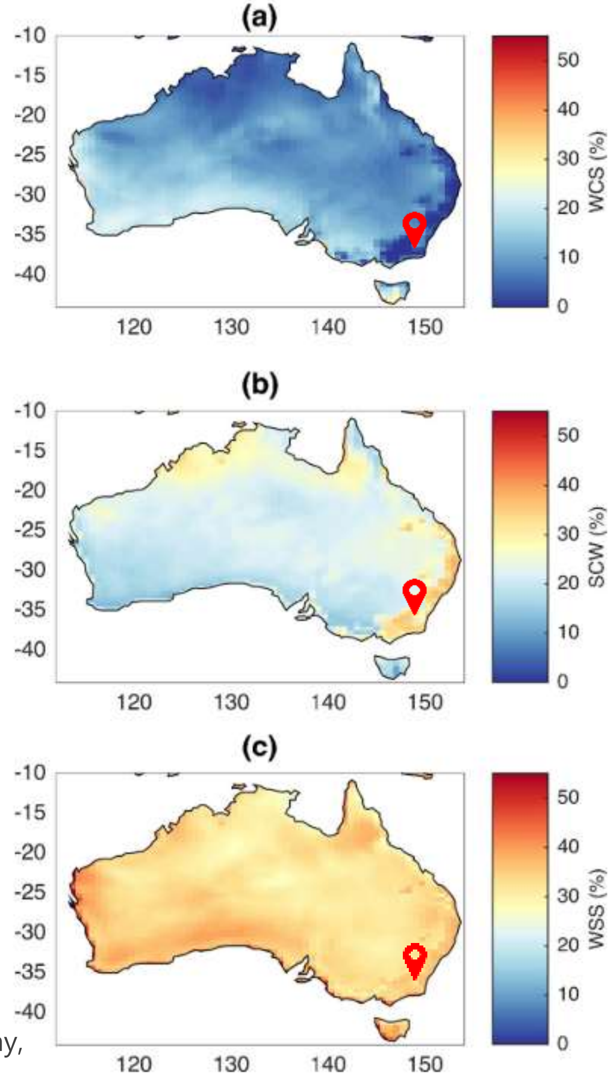
$$SCW(\%) = \frac{Number\ of\ hours\ (WPD \leq 240Wm^{-2}\ AND\ GHI > 170Wm^{-2})}{Total\ number\ of\ hours} \times 100\%$$

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

[1] Prasad, Abhnil A., Taylor, Robert A. and Kay, Merlinde, Assessment of solar and wind resource synergy in Australia, Applied Energy

Complementary Feature Investigation on Synergy





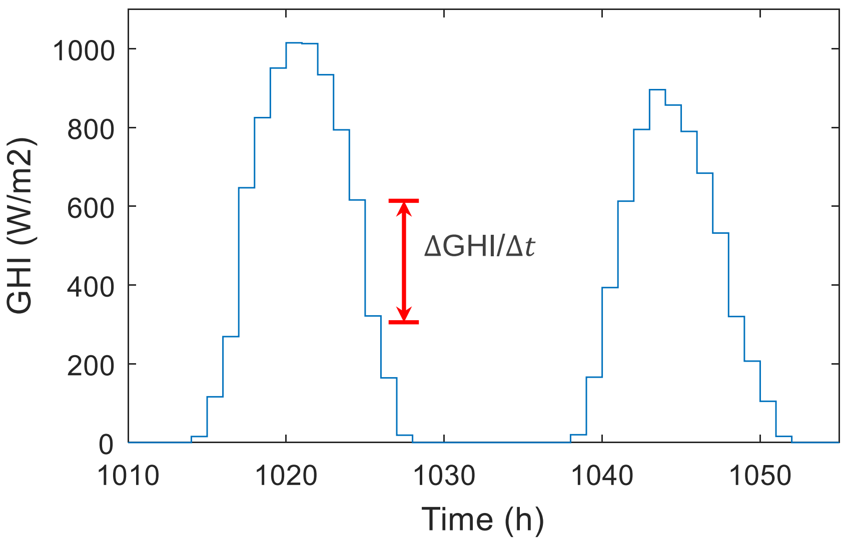
The right figure on the right hand side is from Prasad, Abhnil A., Taylor, Robert A. and Kay, Merlinde, Assessment of solar and wind resource synergy in Australia, Applied Energy

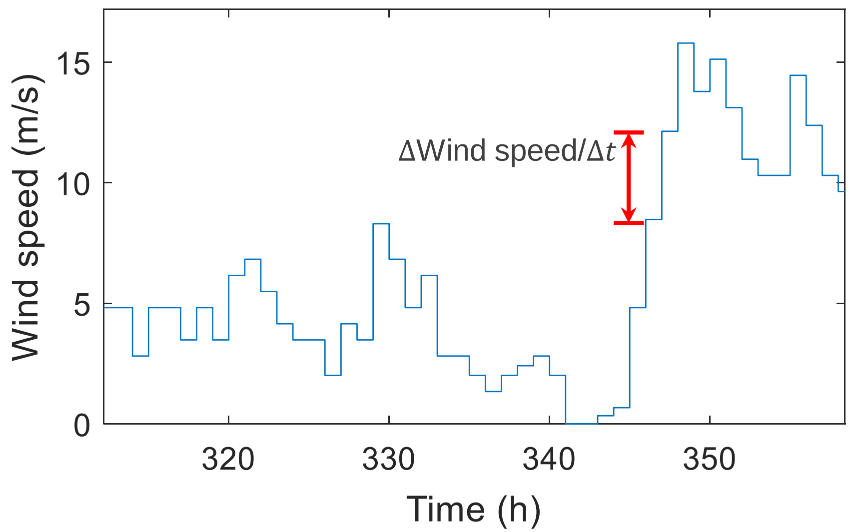
Complementary Feature Investigation from Ramp Rates

$$Ramp\ Rate\ of\ GHI = \Delta GHI(kWm^{-2})/\Delta t\ (h)$$

$$Ramp\ Rate\ of\ Wind\ Speed = \Delta\ Wind\ Speed\ (ms^{-1})/\Delta t\ (h)$$

ΔGHI/Δt





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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)

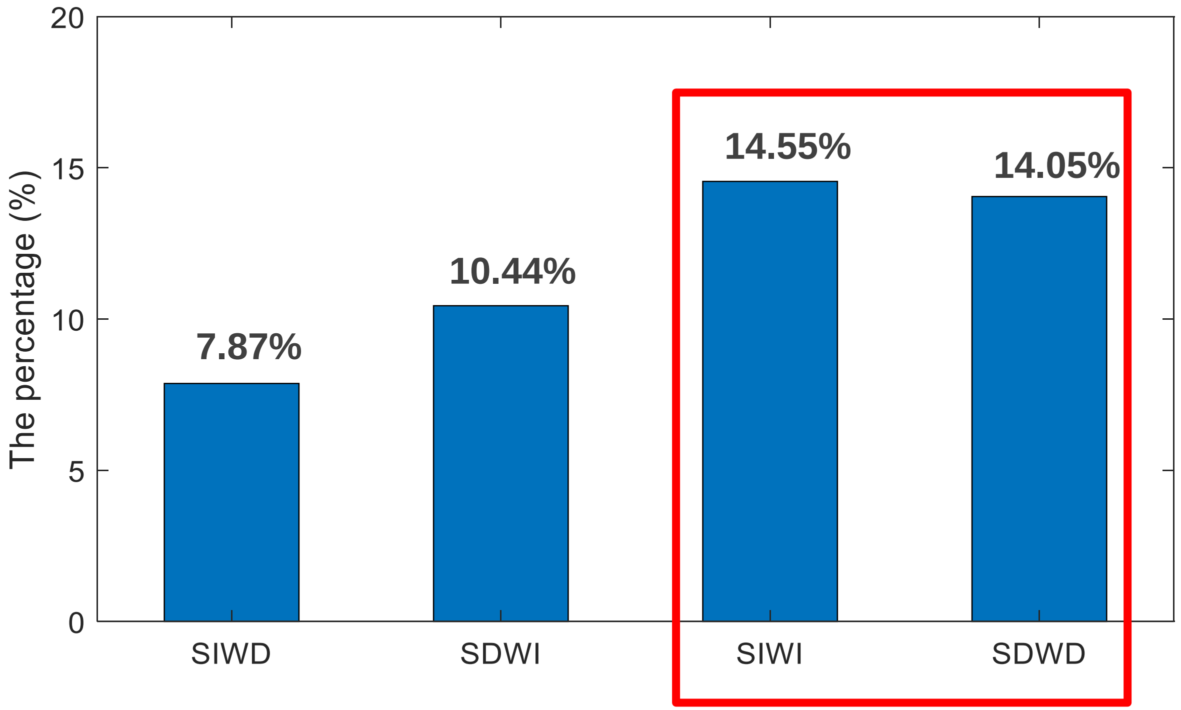
$$SIWD(\%) = \frac{Number\ of\ hours\ (\Delta GHI > 0\ AND\ \Delta WS < 0)}{Total\ number\ of\ hours} \times 100\%$$

$$SDWI(\%) = \frac{Number\ of\ hours\ (\Delta GHI < 0\ AND\ \Delta WS > 0)}{Total\ number\ of\ hours} \times 100\%$$

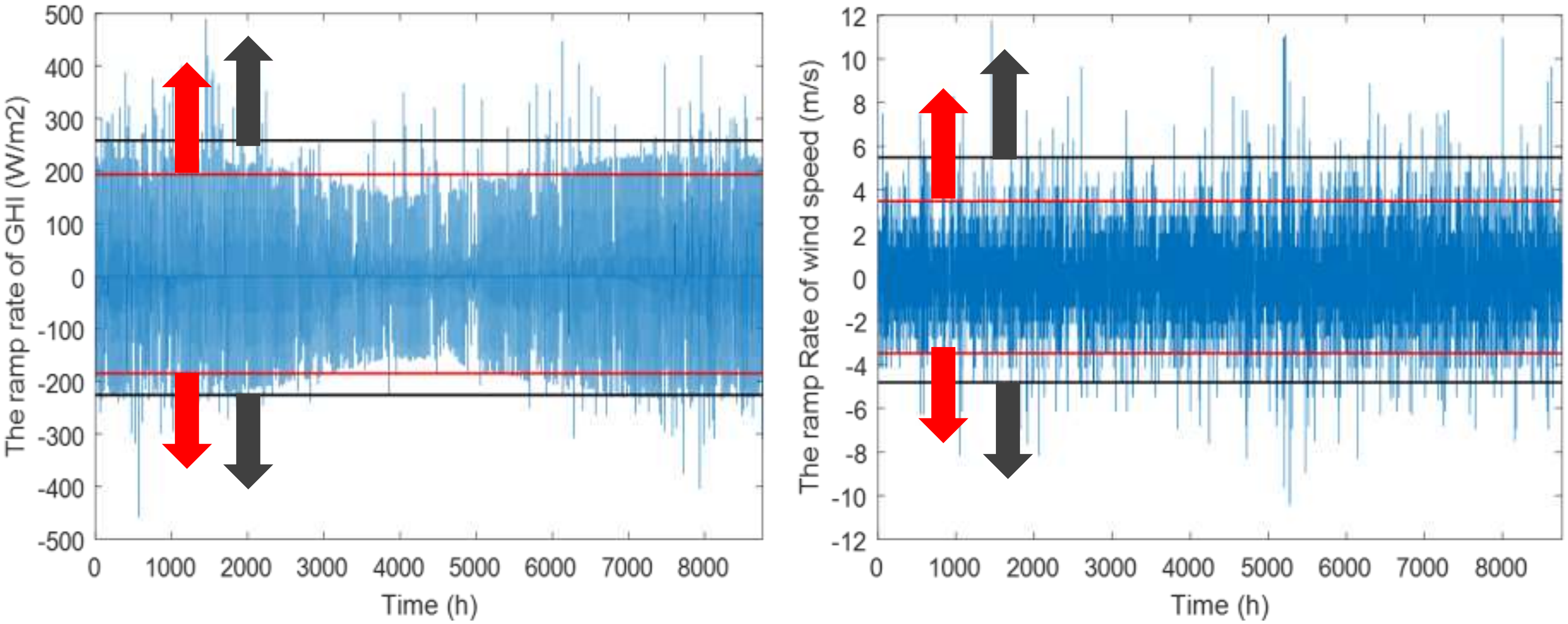
$$SIWI(\%) = \frac{Number\ of\ hours\ (\Delta GHI > 0\ AND\ \Delta WS > 0)}{Total\ number\ of\ hours} \times 100\%$$

$$SDWD(\%) = \frac{Number\ of\ hours\ (\Delta GHI < 0\ AND\ \Delta WS < 0)}{Total\ number\ of\ hours} \times 100\%$$

Complementary Feature Investigation from Ramp Rates



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

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

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

Ramp Rate GHI	(+1%)	(+1%)	(-1%)	(-1%)
Ramp Rate Wind Speed	(+1%)	(-1%)	(+1%)	(-1%)
Total	9	1	6	11
2001	1	0	0	0
2002	0	0	0	0
2003	2	0	0	1
2004	0	0	0	1
2005	1	0	0	2
2006	1	0	1	1
2007	2	1	2	1
2008	2	0	0	2
2009	0	0	2	2
2010	0	0	1	1

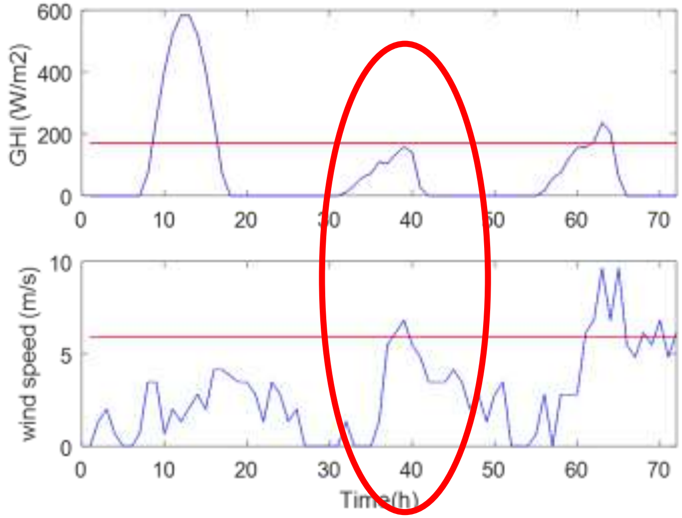
Complementary Feature Investigation from Prolonged Lulls

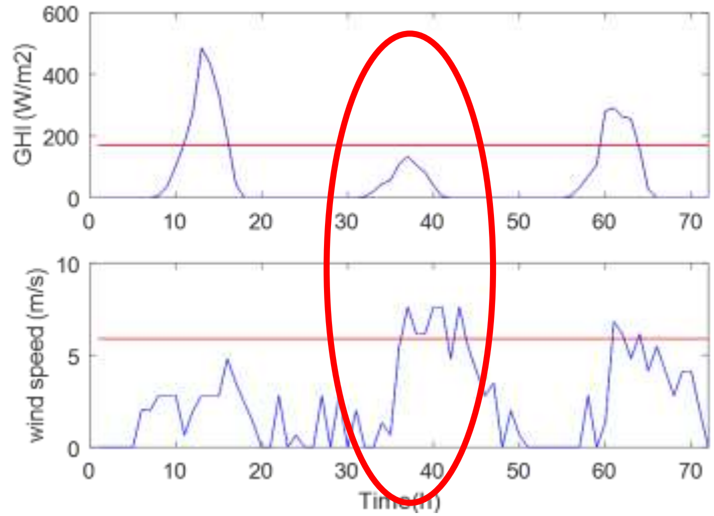
- **Solar prolonged lulls**
  with the GHI < 170 kW/m^2 for
  more than 24 hours
- **Wind prolonged lulls**
  with the wind power density <
  240 kW/m^2 for more than 24
  hours

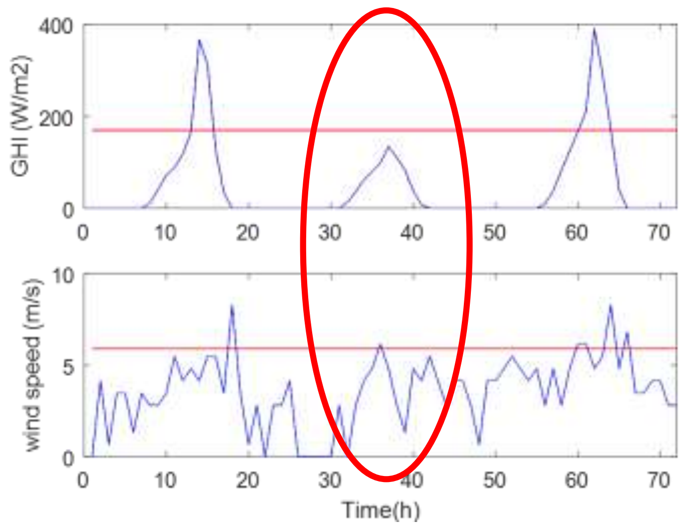
The frequency that more than 24 consecutive lull hours occurred

more than 24-hour consecutive lull happened	Solar	Wind
2001	3	28
2002	1	23
2003	4	21
2004	0	16
2005	2	19
2006	4	25
2007	2	23
2008	0	20
2009	0	16
2010	2	31

Complementary Feature Investigation from Prolonged Lulls



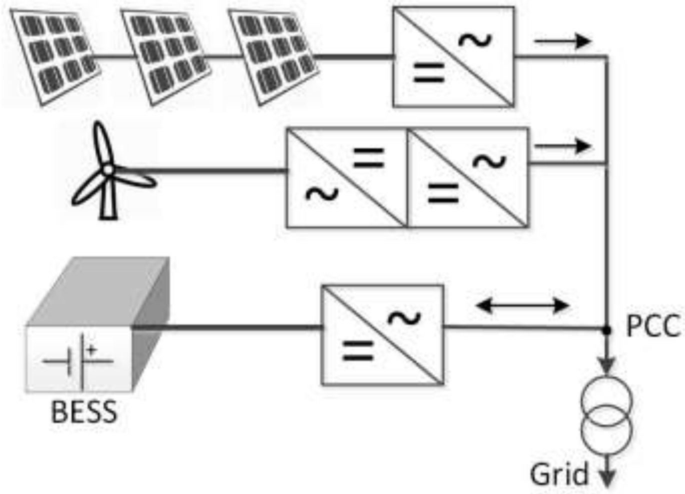




- Three scenarios that solar is experiencing prolonged lulls in 2001
- All of the cases that wind is not experiencing the prolonged lulls, with the third scenario that wind just reach the boundary

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!