A Flexible Distributed Approach to Energy Management of an Isolated Microgrid

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Outline

- Introduction
- Isolated Microgrid Modeling
- Normal Form Game
- Simulation
- Conclusions

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- Introduction
  - Motivation
  - Concept Diagram
- Isolated Microgrid Modeling
- Normal Form Game
- Simulation Results
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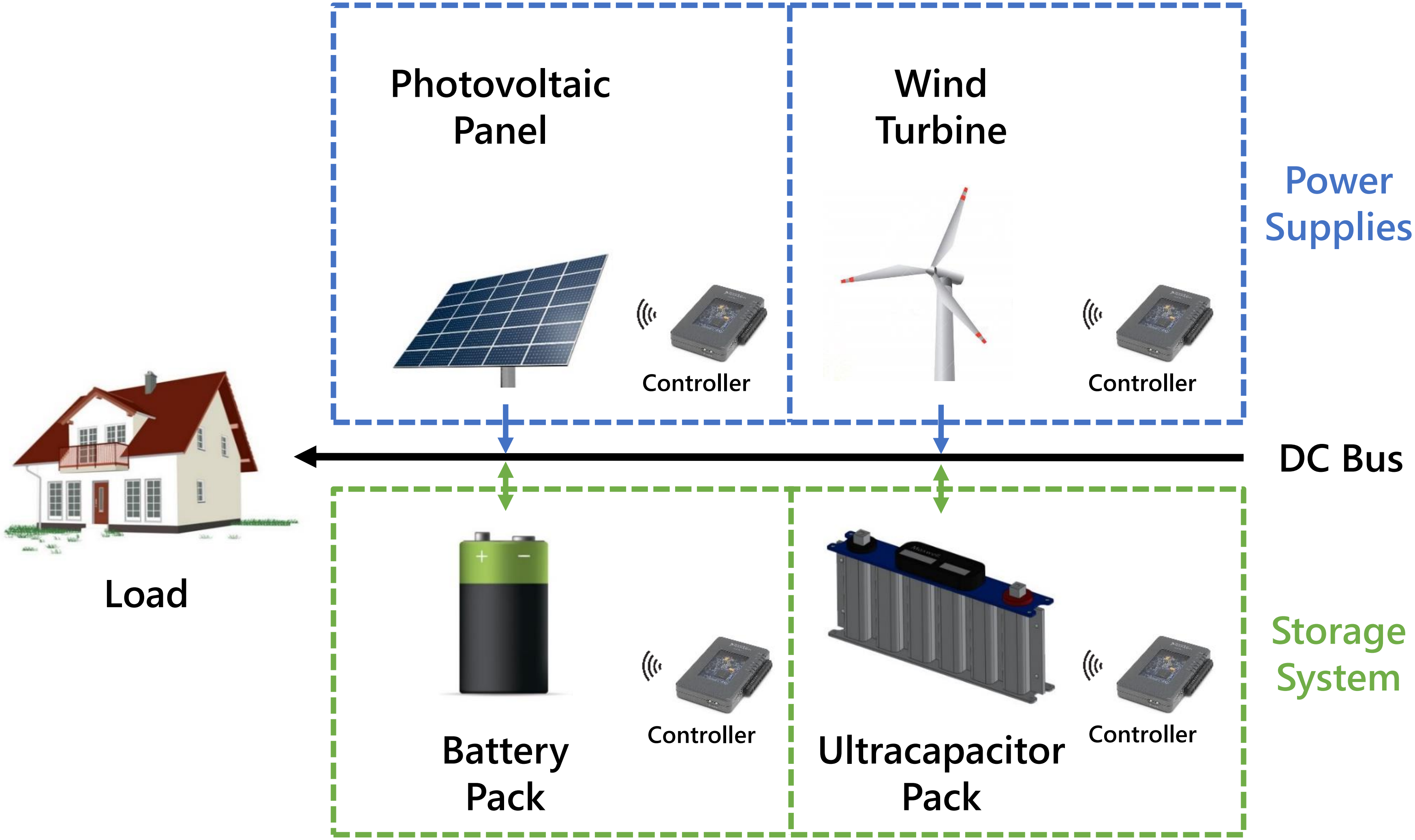
Motivation

- The isolated microgrids have wide applications such as in avionic, automotive, marine industries and remote rural areas.
- Challenges in a proper energy management approach
  - The existence of multiple energy sources
  - Uncertain weather conditions
  - Demand fluctuations

http://new.abb.com/grid/projects/kodiak-island-microgrid
http://www.euei-pdf.org/en/aeep/thematic-work-streams/sustainable-energy-southern-africa-forum-of-the-africa-eu-energy

Concept Diagram



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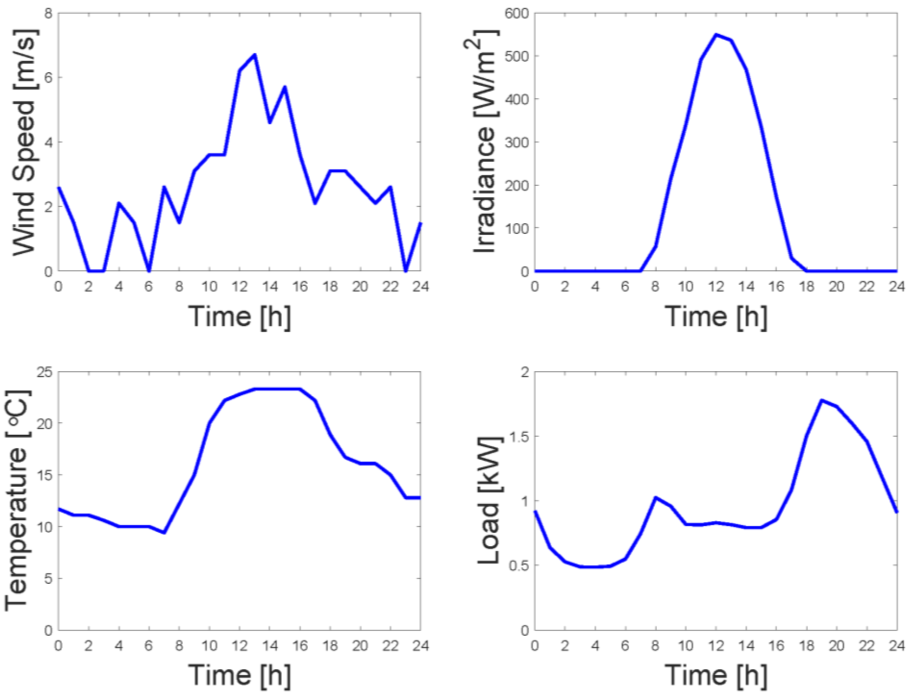
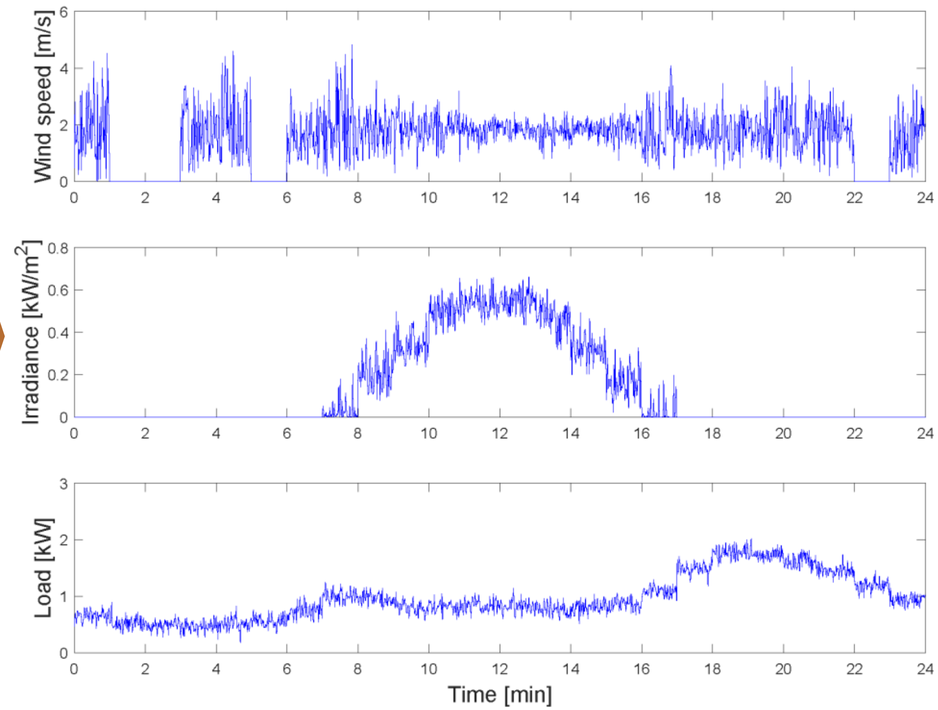
- Introduction
- Isolated Microgrid Modeling
  - Environment
  - Topology
  - Models of Devices
- Normal Form Game
- Simulation
- Conclusions

Environment

- Original Data
- Randomized Data



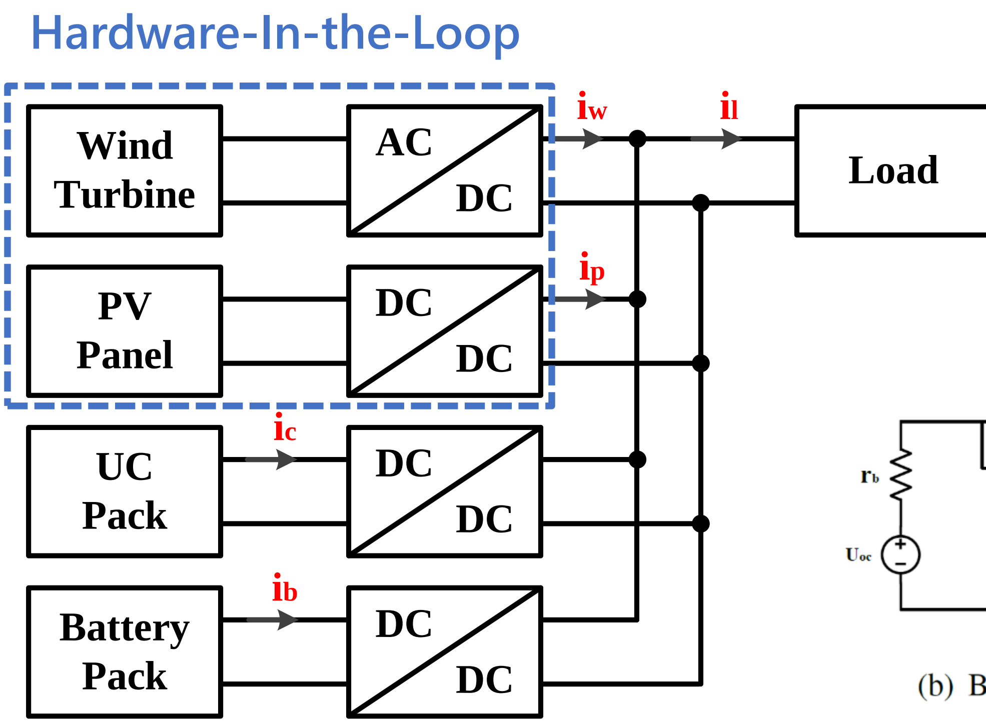


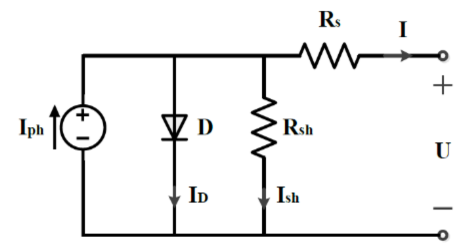
San Diego Lindbergh Field on Feb. 2nd

Ref.: Y. Li and E. Zio, "Uncertainty analysis of the adequacy assessment model of a distributed generation system," Renew. Energy, vol. 41, no. 2, pp. 235–244, 2012.

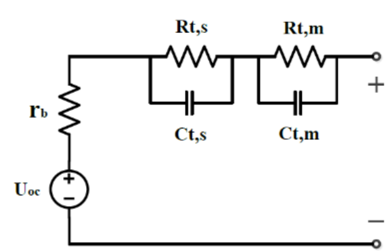
Topology in Simulation

- The PV panels and WTs are emulated by Hardware-In-the-Loop emulations, while the battery pack, UC pack and corresponding DC-DC converters are real devices.

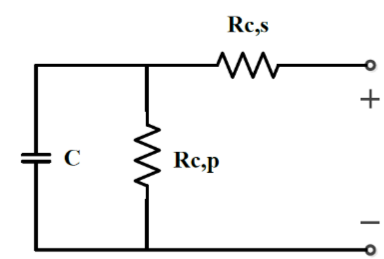




(a) Single PV cell.

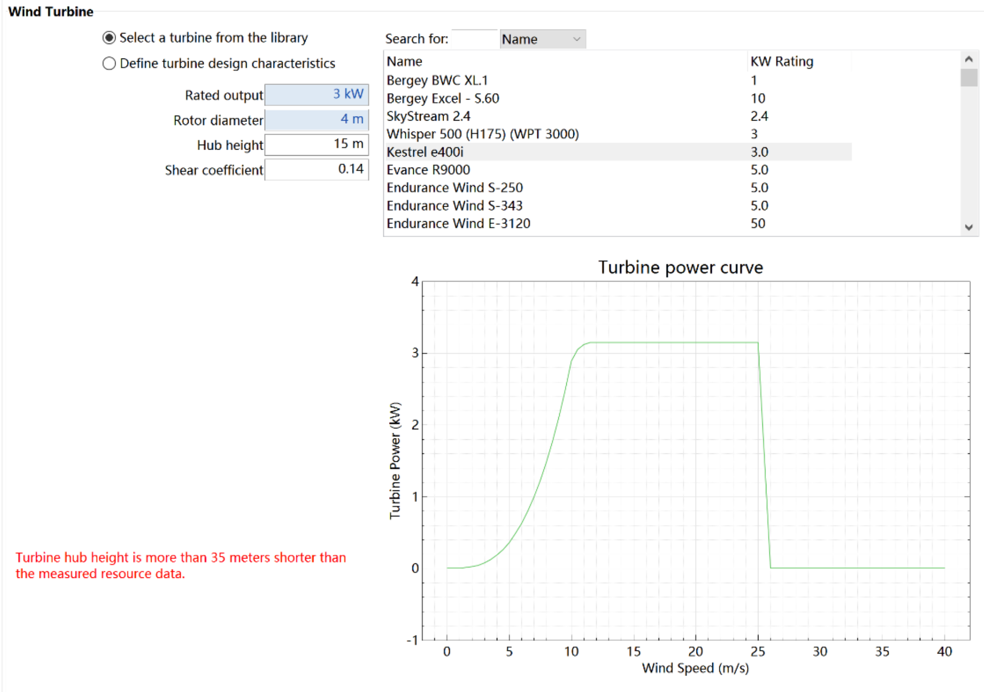


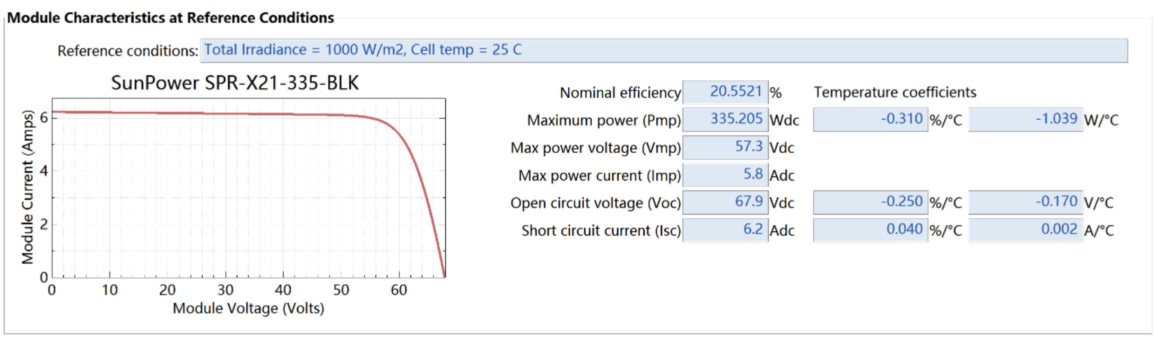
(b) Battery pack.



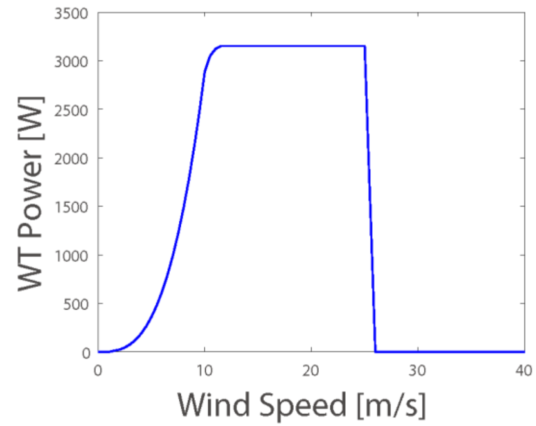
(c) UC pack.

Models of Devices

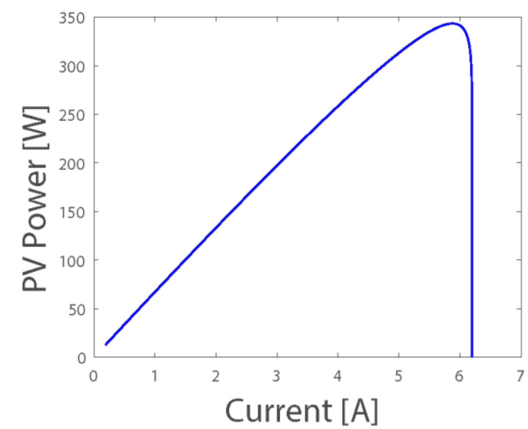




- Wind Turbine: Kestrel e400i



- PV Panel: SPR-X21-335-BLK



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  - Utility Functions
  - Nash Equilibrium
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Utility Functions

Utility functions quantify the degrees of preference across alternatives.

- WT and PV:
  - Maximize energy utilization ratio
- Battery Pack:
  - Extend cycle life
- UC Pack:
  - Maintain capability as an energy buffer

WT: $u_w = 1 - n_w(i_w - I_w^*)^2$

PV: $u_p = 1 - n_p(i_p - I_p^*)^2$

B: $u_{b1} = 1 - n_{b1}(i_b - \mu_{ib})^2$

$u_{b2} = 1 - n_{b2}(i_b - I_{blast})^2$

UC: $u_c = 1 - n_c(i_c - I_c^*)^2$

$$i_c = \frac{i_l - i_w - i_p - (1 - D_b)i_b}{1 - D_c}$$

WT: $u_{wc} = w_w u_w + w_{cw} u_c$

PV: $u_{pc} = w_p u_p + w_{cp} u_c$

B: $u_{bc} = w'_{b1} u_{b1} + w'_{b2} u_{b2} + w_{cb} u_c$

Nash Equilibrium

Best Response Functions:

$$\frac{\partial u_{wc}}{\partial i_w} = 0 \quad \frac{\partial u_{\text{pc}}}{\partial i_p} = 0 \quad \frac{\partial u_{\text{bc}}}{\partial i_b} = 0$$

$$i_w = k_w + k_{wp}\, i_p + k_{wb} i_b$$
$$i_p = k_p + k_{pw}\, i_w + k_{pb} i_b$$
$$i_b = k_b + k_{bw}\, i_w + k_{bp} i_p$$

$$k_p = \frac{2w_p n_p I_{\text{p}}^* + \frac{2w_{cp} n_c i_l}{(1-D_c)^2} - \frac{2w_{cp} n_c I_c^*}{1-D_c}}{2w_p n_p + \frac{2w_{cp} n_c}{(1-D_c)^2}}$$

$$k_{pw} = \frac{-\frac{2w_{cp} n_c}{(1-D_c)^2}}{2w_p n_p + \frac{2w_{cp} n_c}{(1-D_c)^2}}$$

$$k_{pb} = \frac{-\frac{2w_{cp} n_c (1-D_b)}{(1-D_c)^2}}{2w_p n_p + \frac{2w_{cp} n_c}{(1-D_c)^2}}$$

$$i_p = \frac{(1-k_{wb})\left(k_p + k_{pb} k_b\right) + \left(k_{pw} + k_{pb} k_{bw}\right)(k_w + k_{bw} k_b)}{\left(1-k_{pb} k_{bp}\right)(1-k_{wb} k_{bw}) - \left(k_{wp} + k_{wb} k_{bp}\right)\left(k_{pw} + k_{pb} k_{bw}\right)}$$

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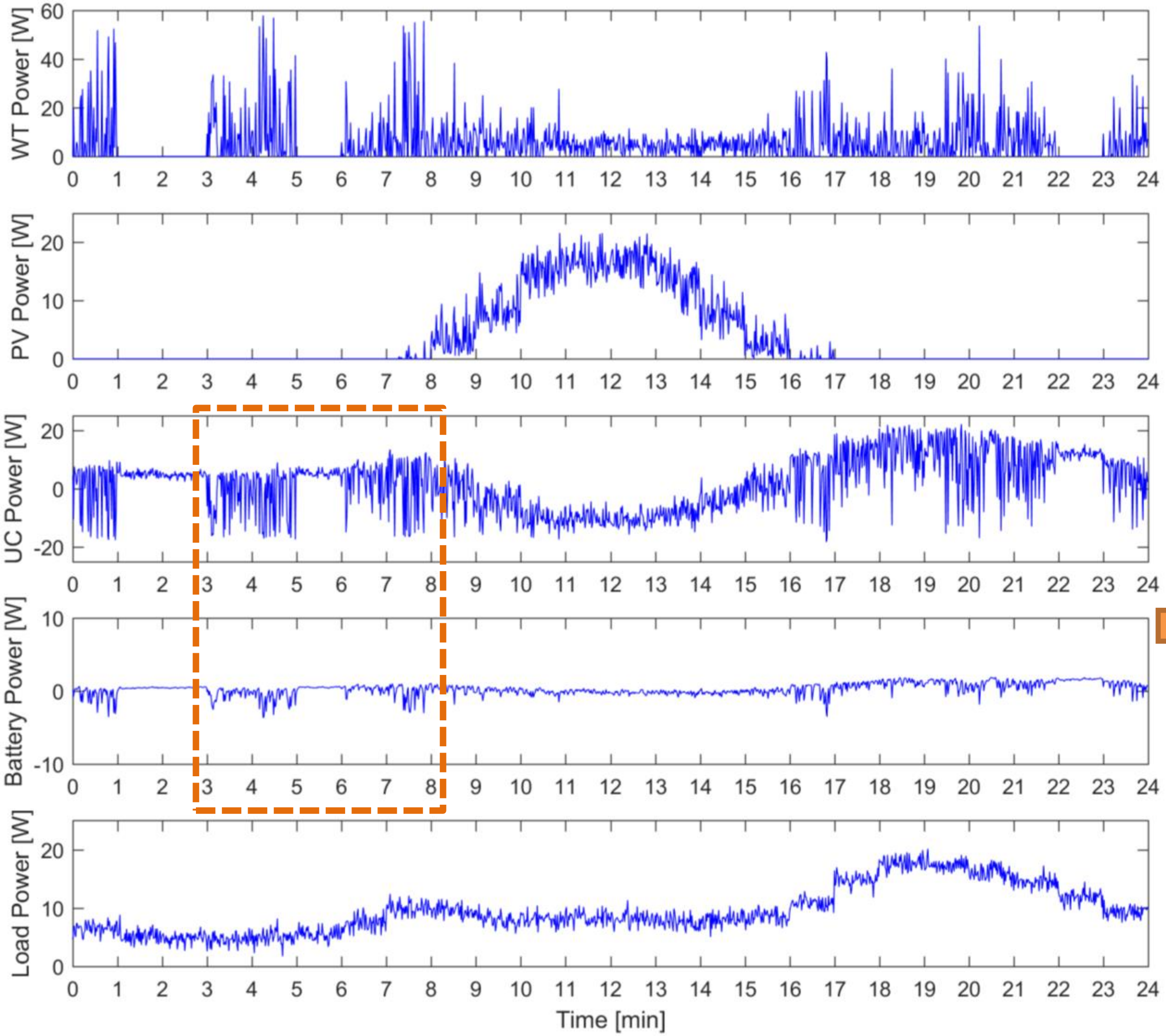
Simulation Results



Evaluation Criteria:

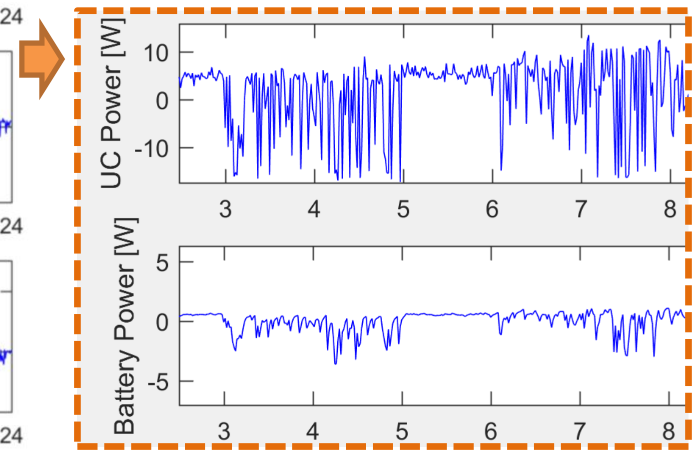
$$\eta_p = \frac{\sum i_p}{\sum I_p^*},$$

$$\eta_w = \frac{\sum i_w}{\sum I_w^*},$$

$$\mu_{ib} = \frac{1}{N}\sum i_b,$$

$$\sigma_{ib}^2 = \frac{1}{N}\sum (i_b - \mu_{ib})^2,$$

$$\mu_{Ec} = \frac{1}{N}\sum \left| \frac{1}{2}Cv_c^2 - \frac{1}{2}C(V_c^*)^2 \right|.$$



Comparative Study

- Supervisor Control

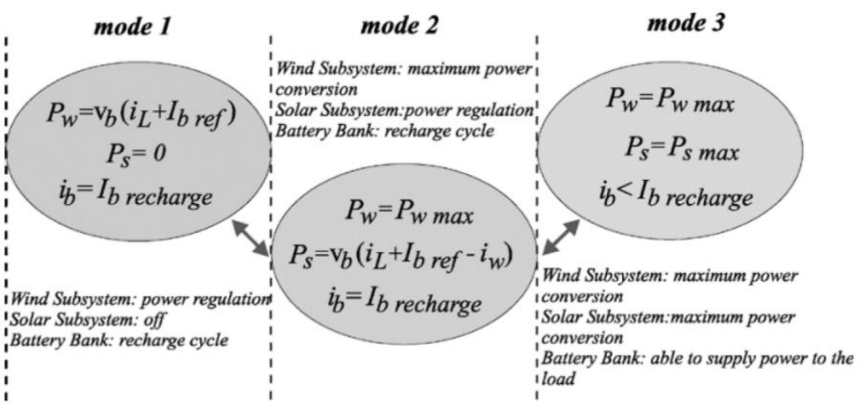
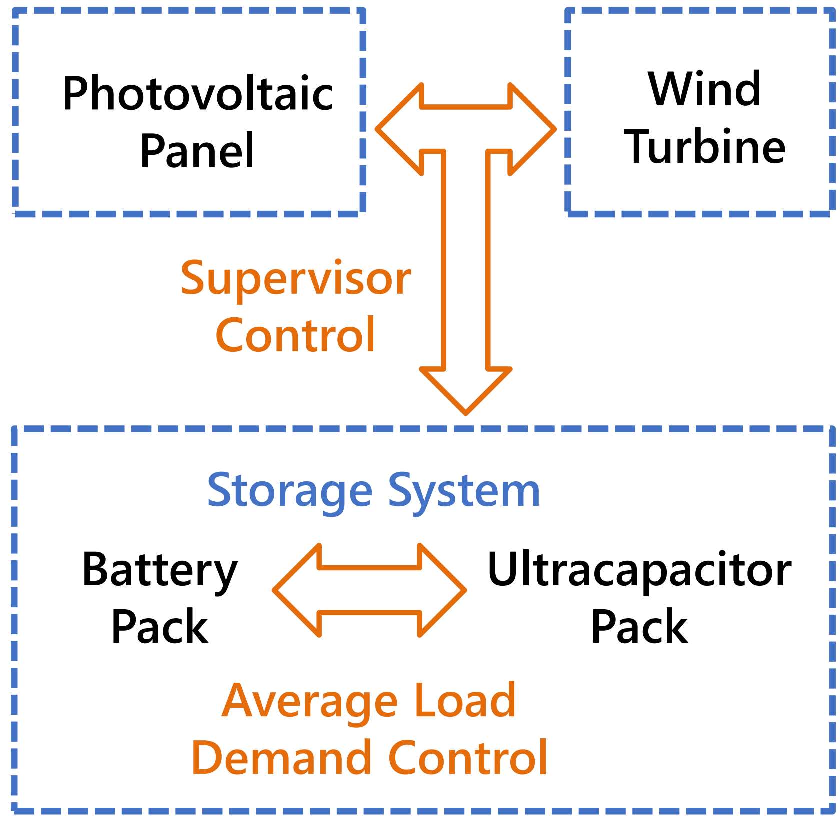


Fig. 2. Schematic description of the operation modes.

- Average Load Demand Control
  - Battery pack: Average of the load demand
  - UC pack: Dynamic part of the load demand



Ref.: F. Valenciaga and P. F. Puleston, "Supervisor control for a stand-alone hybrid generation system using wind and photovoltaic energy," IEEE Trans. On Energy Conversion, vol. 20, no. 2, pp. 398–405, 2005.

Results

- Case 1: Normal weather
- Case 2: Better weather
- Case 3: Worse weather

Case	Approach	η_p (%)	η_w (%)	μ_{ib} (A)	σ_{ib} (A^2)	μ_{Ec} (J)
1	Game theory based	99.23	91.66	0.04	0.06	251.59
	Rule based	100	100	0	0	337.98
2	Game theory based	98.99	92.12	0.06	0.06	187.42
	Rule based	76.08	100	0	0	334.59
3	Game theory based	99.75	92.46	0.13	0.07	136.16
	Rule based	100	100	0.3	0	332.62

Icons from http://www.flaticon.com/

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Conclusions

- A normal form game is defined and formulated to solve the energy management of an isolated microgrid.
- The existence of Nash equilibrium is proved.
- The randomized environment data is utilized and compressed to 24 minutes.
- The proposed distributed control approach has a comparable performance to the rule based approach.
- The proposed approach is more flexible with uncertainties in weather conditions.

Thank You

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