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Aspects of relevance for utility scale wind-solar hybrid power plants

Work done as a part of Indo-Danish project “HYBRIDize” funded by Innovationsfonden Denmark
Some results are from EUDP Danish project “NetVind”
VRE based Hybrid Power Plant

- Utility-scale grid connected HPP are large power plants (hundreds of MW) operated to maximize profit from market while required to provide grid ancillary services similar to any large power plant.

Windlab and Vestas installed first utility-scale Kennedy Energy Park HPP in 2018 in Australia
43.2 MW of V136-3.6 MW WTs, 15 MW of PV and 2 MW/4 MWh Li-Ion battery storage
All managed by Vestas customised control system

Parc Cynog, UK
8.4 MW Wind and 5 MW solar PV

Press Information Bureau
Government of India
Ministry of New and Renewable Energy

MNRE issues National Wind-solar Hybrid Policy

INCREASE THE SYSTEM VALUE OF WIND POWER

Today’s wind turbines and wind farms are advanced electricity generation systems working in an increasingly integrated system that generates, stores, transmits and consumes energy. As described in the Megatrends, the build-out of the renewable energy capacity is moving towards technology-neutral tenders in which wind energy is competing head-to-head with other renewable technologies. Therefore, we are seeing companies moving towards delivering hybrid solutions consisting of e.g. wind, solar and storage facilities in order to best meet the demands for low cost, stable power generation and deliver reactive power and ancillary services.

The ability to fit into this new trend is a major innovation driver.
Hybrid Power Plant – Utility scale co-located grid connected

General Features:
- More than one generation sources involved
- All the assets are owned by same company so higher controllability
- Motivation is to reduce cost / maximize revenue from different energy markets
- Control of electrical load is not of concern for the power plant owner as compared to traditional Hybrid Power Systems
  - Sometime even provide near baseload generation
- Many stakeholders involved
Advantages/Values of HPP

- **Cost reduction and Revenue increase**
  - **Infrastructure**
    - Reduction in land cost
    - Optimal use of electrical infrastructure and other infrastructure (e.g. access roads) saves costs
  - **Project Development**
    - Joint permitting process reduces risks and costs
    - Shared resources reduce internal costs
    - Joint site development reduces costs for e.g. soil investigations & weather measurements
  - **Park Performance**
    - Less fluctuating production increases electrical infrastructure utilization
    - Storage increases flexibility and number of accessible markets (Energy market, ancillary services market)
    - Reduction of forecast error using storage

Grid emulation & advanced tests
- Emulation of future converter dominated power systems using CGI and / or synchronous condenser to emulate grid
- Development of new test methods / grid codes
- Validation of models

Uncertainties and forecast
- Variability for combined wind-solar-battery
- Market forecasts
- Hybrid power forecast
- Real time power simulation
- Assessment of flexibility & ancillary services

Energy Management System
- Optimal operation on markets: energy markets, ancillary service markets and capacity markets considering uncertainties, component lifetime

Sizing and siting
- Resource assessment
- Physical Design Optimization
- Choice of technologies
- Optimal sizing of components
- Hybridization of existing wind or solar plants

Electrical Design and Control
- Optimal electrical design – utilization of wind turbine DC links and inverter
- Use of electrical auxiliaries (supercapacitor, chopper, FACTS)
- Hybridization of existing wind or solar plants
- Hierarchical control / Distributed control
- Ancillary services
- Grid following vs. grid forming operation

Others
- Blackstart capability
- Wind turbine load and control, lifetime increase
- Wind farms wakes and control
- Grid interaction and stability
- Improvement/adaptation of solar/storage technologies for HPP
- Offshore applications
Sizing and siting: Power Simulation using CorRES

<table>
<thead>
<tr>
<th>Location</th>
<th>Wind Power CF [%]</th>
<th>Solar power CF [%]</th>
<th>Correlation</th>
</tr>
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<tbody>
<tr>
<td>Denmark (DK)</td>
<td>42</td>
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<tr>
<td>Sweden (SE)</td>
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<td>10</td>
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<td>France (FR)</td>
<td>32</td>
<td>16</td>
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</tr>
</tbody>
</table>

Sizing and siting: Increase in capacity factor

Total HPP Capacity = 500 MW, Evacuation Capacity = 500 MW

Total HPP Capacity = 1000 MW, Evacuation Capacity = 500 MW

DK: Total HPP Capacity = 1000 MW, Evacuation Capacity = 500 MW
Sizing and siting: Increased dispatchability and flexibility using storage

Wind Power=500MW, Solar Power=500MW, Evacuation Capacity=500
Electrical Design and Control


Electrical Design and Control

Electrical Design and Control

Electrical Design and Control

Challenges
- Control hierarchies
- Choose the ancillary services and regimes
- Sharing of responsibilities/flexibilities
- Uncertainties
- Dynamic interaction of controllers

Energy Management System – Example Case: Nordic market

Energy Management System – Example Case: Nordic market

Energy Management System – Example Case: Australian market

APPLY:
\[ u1(k+1), \]
\[ u2(k+1) \]

\[ \text{TI}(i-1) \quad \text{TI}(i) \quad \text{TI}(i+1) \quad \text{TI}(i+2) \quad \text{TI}(i+3) \quad \ldots \quad \text{TI}(I) \]

Real Prices

Update E(i-1)

Run MPC

SOC(i+1) Total NCC

OPTIMISE OVER N+1

\[ \text{TI}(k+1) \quad \text{TI}(k+2) \quad \text{TI}(k+3) \quad \ldots \quad \text{TI}(N) \quad \text{TI}(N+1) \]

P30 Forecast Horizon

\[ \mathbf{E}(\mathbf{p}) \]

Wind-Hybrid Research Facility

- Grid connected wind-hybrid power plant (wind / solar / storage)
- Open research controllers
- AC and DC power collection (grid connection)
- Controllable grid interface
- Connection to external information (weather forecasts, markets)
Wind turbines rebuilt

Plant controller references

Pitch Ref

WT measurements

Open research wind turbine controller

Converter controller

V27 rebuilt

WT (400 V AC)
Grid connection of HPP – AC power collection

- Two rebuilt (from type 1 to type 4) wind turbines
- AC connection of PV and storage
Extension with **controllable grid interface**

- **Back-to-back controllable converter**
- **Synchronous machine** (synchronous condenser – or generator/motor)
- **Low voltage (400 V)**

![Diagram](image)
HYBRIDize project

- 3 year Indo-Danish project
- Start date: 1st May 2019
- Funded by Innovationsfonden in Denmark and DST in India

Objective:
- minimize levelized cost of energy (LCOE) and levelized cost of storage (LCOS)
- maximize profit for HPP

Main Expected Outputs

- Weather based component sizing methodology (DTU)
- Electrical Infrastructure Design and Control (IIT, DTU)
- Assessment of grid code requirements for HPP (Suzlon)
- Development of Energy Storage Evaluator (HG-DK)
- HPP Forecasting System (DTU)
  - Benchmarking with state-of-art forecasting (Suzlon, NIWE)
- HPP supervisory control to maximize profit from market (DTU)
- Development and validation of controls at a small NIWE facility (NIWE, IIT, DTU)
Conclusion - Utility scale grid connected Hybrid Power Plant

• As a research field
  • Lots of scope
  • Budding field
  • Currently driven by industry

• As business case
  • General agreement on huge potential
  • Business case not well defined
Thank You
Reduction in variability