Dynamic Modelling of Wind-Solar-Storage Based Hybrid Power Plant

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Contents

• Relevance of Utility scale Hybrid Power Plant

• Research areas identified by Danish Hybrid Power Plant Forum

• Hybrid Power Plant topologies and control architecture

• Overview of Dynamic models of Hybrid Power Plant

• Discussions
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
3.6 MW Wind (2001)
4.95 MW PV (2016)

Kavithal, India 2018
50 MW Wind and 28.8 MW PV

Total HPP Cap = 380 MW
Wind = 120x2.5 = 300 MW (2020)
Solar = 50 MW (2021)
Battery = 30 MW, 120 MWh (2021)

https://windeurope.org/about-wind/database-for-wind-and-storage-colocated-projects/

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

# HPP: **Power-generating facility** that converts primary energy into electrical energy and which consists of more than one power-generating modules connected to a network at one connection point

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 research challenges

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1 WindEurope, “Renewable Hybrid Power Plants”, July 2019
2 K. Das et. al., "Enhanced Features of Wind-Based Hybrid Power Plants", 4th Hybrid Power Systems Workshop, 2019
Danish Wind Hybrid Power Plant Forum
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
AC Coupled HPP Topology

Advantage:
- Easy to implement
- Wind Park controller, PV park controller and BESS controller from different vendors can be readily used

Disadvantage:
- Suboptimal utilization of electrical infrastructure
Control Architecture in AC coupled HPP

**HPP control level**

- **TSO**
  - Control functions
  - Main controller
  - Dispatch function

**Subplants’ controllers**

- **WPP controller**
  - $P_{wpp\_ref}$

- **Solar PV plant controller**
  - $P_{pv\_ref}$

- **BESS controller**
  - $P_{bess\_ref}$

**Measurements in PCC**

- $P_{avail\_i}$
  - $i = \text{wpp, pv}$

- $\sum$ (total)
AC coupled HPP – Central control system

**Active power Control Functions**
1. ‘No power limitation’ control
2. Delta control
3. Balance control
4. Power rate limiter

**Main Controller**
- Control mode
- Control Functions Block
- Frequency Controller
  - Frequency measurement
  - P_pcc

**Dispatch**
- PWPOC block
  - PWPOC measurement
- PV block
  - PWPP_ref
  - PV_ref
- BESS block
  - PBESS_ref

**Dispatch block**
- PWPOC measurement
- PWPP_ref
- PV_ref
- PBESS_ref

**Diagram Elements**
- Pwpp_avail
- Pxv_avail
- Pref_in
- Ppcc
- SOC
PV model

BESS model

WECC Model

BESS Model from DIGSilent PowerFactory
Wind Turbine Dynamic Model for AC Coupled HPP
DC Coupled HPP Topology

Advantage:
- Better utilization of electrical infrastructure

Disadvantage:
- Nascent stage
- New control architecture and algorithms
HPP overall control system

System operators

HPP control level

Orders

PCC

Frequency & active power measurements

Power references

Available power

Hybrid units control level

Hybrid unit N control level

Hybrid unit 2 control level

Hybrid unit 1 control level

HPP overall control system
Hybrid unit control level

Dispatch principles:
1. BESS charging instead of curtailment
2. BESS operates in 10-90% SOC region
3. WT instead of PV system de-loading

Unit power reference

Hybrid unit dispatch

Assets dispatch signals

Hybrid unit controller

Sets up the assets power references

Assets available power

Hybrid unit

Assets power references

• Comprised of a WT, a PV system, and a BESS
• Contains their control systems
• Signals are converted into power

Unit available power

Allocates the reserve order among the assets

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DTU Wind Energy

18th Wind Integration Workshop
Hybrid unit control level

Hybrid Unit Controller

WT

PV

BESS

Hybrid Unit Dispatch

WTref

PVref

BESSref

Hybrid Unit

Inverter

DC bus

Signals

Power

pWT_meas

pPV_meas

pBESS_meas

pWT_ref

pPV_ref

pBESS_ref

pWT Disp

pPV Disp

pBESS Disp

pHU

pBU

pHU meas

pBU meas

Σ
Performance Analysis

- Wind: 60x2MW Type 4 WTs
- PV: 40 MW
- BESS: 10 MW/20MWh

- Zone A: MPT control
- Zone B: Battery charges during delta control
- Zone C: Wind curtailed during delta control (with ramp rate limitation)
- Zone D: Back to MPT control without ramp rate limitation
Ancillary Service – Frequency control

- Studied for the considered HPP in IEEE 12 bus system
Ancillary Service – Frequency control at DC coupled HPP

Support from individual Hybrid Unit (60 units in total)
Discussion

• Utility scale renewable based HPP is an evolving technology

• Dynamic modelling has new challenges
  • New possibilities of topologies
  • New control methods such as centralised vs distributed control
  • Ancillary service allocation among different assets
  • More control hierarchies
  • Advanced dispatch strategies for different assets
  • Controller interactions for different service provisions

• More research needs to be done
THANK YOU