Optimal and Modular Configuration of Wind Integrated Hybrid Power Plants for Off-Grid Systems

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Wind Integrated Hybrid Power Plants

Definitions

General definition of hybrid power plants with renewables¹:

This is a power system, using one renewable and one conventional energy source OR more than one renewable with or without conventional energy sources, that works in ‘stand-alone’ or ‘grid-connected’ mode.

On-Grid Hybrid Power Plant

→ grid-integrated power plant unit

Off-Grid Hybrid Power Plant

→ consumer-directed stand-alone unit (isolated microgrid)

1. I. Lazarov, V. D., Notton, G., Zarkov, Z., Bochev, “Hybrid power systems with renewable energy sources types, structures, trends for research and development.” Int. Conf. ELMA, 2005
Agenda

• Introduction
  • Benefits and Types of Off-Grid Hybrid Power Plants

• Modular and Scalable System Topology

• Optimal Sizing Algorithm

• Assessment Studies
  • Impact of Resource Data Resolution

• Summary & Outlook
Background
Benefits of off-grid hybrid power plants

- CAPEX reduction to enable rural & island electrification
- OPEX reduction by substituting diesel power generation
- Sustainable & ecofriendly
- Increase system resiliency (as emergency power supply)
Types of Off-Grid Hybrid Power Plants

kW-scale vs. MW-scale

Renewable energy and hybrid systems for rural electrification:
Production → Distribution → Demand subsystem

kW-scale systems:
- Rural community with residential, small commercial and small industrial consumers
- Energy demand < 4000 kWh/day, Peak load < 500 kW, Installed total generation capacities < 1 MW
- Intermediate wind turbine size (10 – 250 kW)

MW-scale systems:
- E.g. remote energy-intensive industry (e.g. coal mining, pulp mill, cement kiln), remote military basis, islands
- Demand levels 5 – 100 MW up to 400 MW
- Large wind turbine size (2+ MW)

Ref.: DS-IEC TS 62257-9-2-2016
Optimal System Configuration

Siting, Sizing, Scheduling

- **Siting**: determining the general system topology (generic BoP)
  - Low voltage, medium voltage?
  - Interconnection of individual energy resources

- **Sizing**: determining the installed capacity
  - Power/Energy ratings of wind turbine, PV, battery, gensets etc.

- **Scheduling**: determining the generic system management strategies
  - When to charge/discharge the battery?
  - When to start up / shut down a genset?
  - When to curtail renewable power?
Modular and Scalable System Topology

Starting from kW-scale systems

Line length vs. Power infeed for $\Delta V = 6\%$:

- $25 \text{ mm}^2, S_{\text{line}} = 90 \text{ kVA}, P_{\text{loss}} = 1.53 \%$
- $35 \text{ mm}^2, S_{\text{line}} = 110 \text{ kVA}, P_{\text{loss}} = 2.15 \%$
- $50 \text{ mm}^2, S_{\text{line}} = 135 \text{ kVA}, P_{\text{loss}} = 2.89 \%$
- $70 \text{ mm}^2, S_{\text{line}} = 170 \text{ kVA}, P_{\text{loss}} = 4.12 \%$
- $95 \text{ mm}^2, S_{\text{line}} = 210 \text{ kVA}, P_{\text{loss}} = 5.68 \%$
- $120 \text{ mm}^2, S_{\text{line}} = 245 \text{ kVA}, P_{\text{loss}} = 6.84 \%$
- $150 \text{ mm}^2, S_{\text{line}} = 280 \text{ kVA}, P_{\text{loss}} = 8.19 \%$

→ Scalability impossible with LV connection!
Modular and Scalable System Topology

Proposed system topology

**Geographical constraints** (location of production subsystem)

- Wind Turbine Subsystem
- PV Subsystem
- Battery Energy Storage Subsystem
- Genset Subsystem

**Optimal System Configuration** (System topology & component sizing)

- Site parameters
- Energy Management Functions (minutes to hours)

**Additional electrical equipment**

- Switchgear, transformers
Optimal Sizing Algorithm

Simulation steps

1. Input: Annual load profile & resource data (wind speed & solar irradiation)
   - Hourly vs. Min. based data

2. Define reliability constraint
   - Power availability in % / year

3. Define search space for $X$ (min./max. subsystem ratings)
   
   $X = \begin{bmatrix} P_{WTG,\text{rat}} & P_{PV,\text{rat}} & E_{BEES,\text{rat}} & P_{GSx,\text{rat}} & S_{TR,\text{rat}} \end{bmatrix}$

   - E.g. battery converter and diesel genset(s) rating according to peak load
     - reduced search space
     - sufficient system reliability (100 %)

Energy Management Functions (minutes to hours)

Optimal System Configuration (System topology & component sizing)

End-consumer requirements

Renewable resource data

Load demand data

Financial & cost parameters

Additional electrical equipment

Site parameters
Optimal Sizing Algorithm

Simulation steps

4. Performing energy analysis for 1 exemplary year (Energy management)
   • Operational scheduling to ensure supply vs. demand balance
   • Power flow script (power losses and reactive power demand)

5. Extrapolating for project lifetime using economic parameters
   • CAPEX, OPEX, fuel costs, salvage value
   • Transformers, cables etc.

6. Enumeration based optimization algorithm
   • Min. Levelized Cost of Energy (LCOE)
   • High wind energy penetration in favour!
Assessment Studies

Impact of resource data resolution

• State-of-the-art method to apply hourly mean values of resource data (demand, wind speed, solar irradiation)

→ Is it sufficient considering the intra-hour power variations?

• Computed system configuration for $\Delta t = 1 \text{ h}$:

Load: 90 kW peak

60 kW

80 kW

160 kWh / 90 kW

3 x 30 kW

→ Next step: Energy management with $\Delta t = 1 \text{ min}$,

→ Power shortage due to power fluctuations and shut down genset!
Assessment Studies
Taking into account operational reserve

- Considered approach: Provide reserve power by battery!
- Default state-of-charge operating interval:
  $\rightarrow 20\% < \text{SOC} < 80\%$
- Increasing min. SOC limit based on statistical analysis of power fluctuations over 1 year
  $\rightarrow$ Exemplary result for this study case: $\text{SOC}_{\text{min}} = 44\%$

$\rightarrow$ Next step: Simulate system with updated $\text{SOC}_{\text{min}}$

$\rightarrow$ No power shortage due to committed diesel genset!
Summary

- System in scope: consumer-directed off-grid hybrid power plant integrating wind, PV, battery, gensets
- Modular and scalable system topology
- Optimal sizing algorithm, including:
  - Electrical infrastructure (extra cost, power losses)
  - Reactive power demand
  - Operational reserve (intra-hour power variations)
  - Customized models & operational strategies

→ Missing in benchmark tool (HOMER Energy)
Next Steps

PhD project: *Proof-of-concept of next generation Hybrid Power Plant Control*

**Power management functions (ms – s):**

- Voltage and frequency stability
- Active and reactive power sharing

→ Impact of power management strategies on optimal sizing!
Next Steps

PhD project: *Proof-of-concept of next generation Hybrid Power Plant Control*

**Power management functions (ms – s):**

- Voltage and frequency stability
- Active and reactive power sharing

→ Impact of power management strategies on optimal sizing!

**Energy management functions (min - h):**

→ Impact of demand & generation forecasting on optimal sizing!
Smart Energy Systems Laboratory at Aalborg University

PhD project: Proof-of-concept of next generation Hybrid Power Plant Control

Capturing Power/Energy System layer, Control layer & ICT layer

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