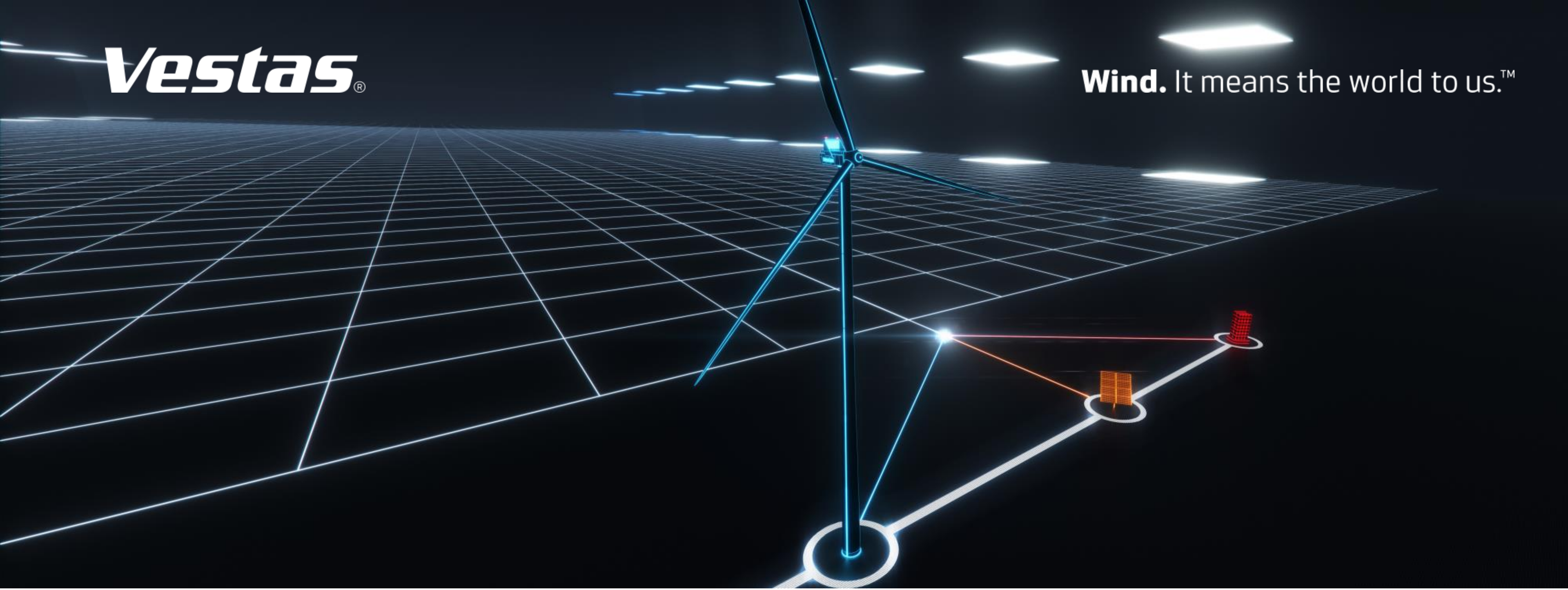

Public

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

Lennart Petersen, Industrial Ph.D. Fellow – Hybrid Solutions

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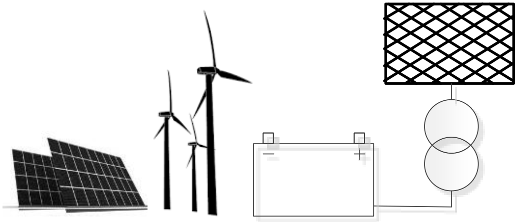
Wind Integrated Hybrid Power Plants

Definitions

General definition of hybrid power plants with renewables [1]:

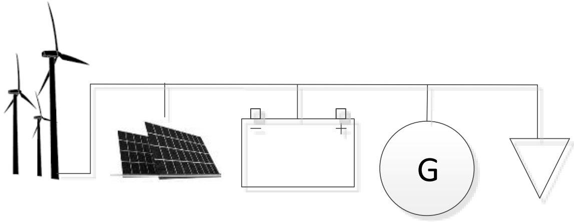
This is a power system, using one renewable and one conventional energy source OR more than one renewable with or without conventional energy sources, that works in 'stand-alone' or 'grid-connected' mode.

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

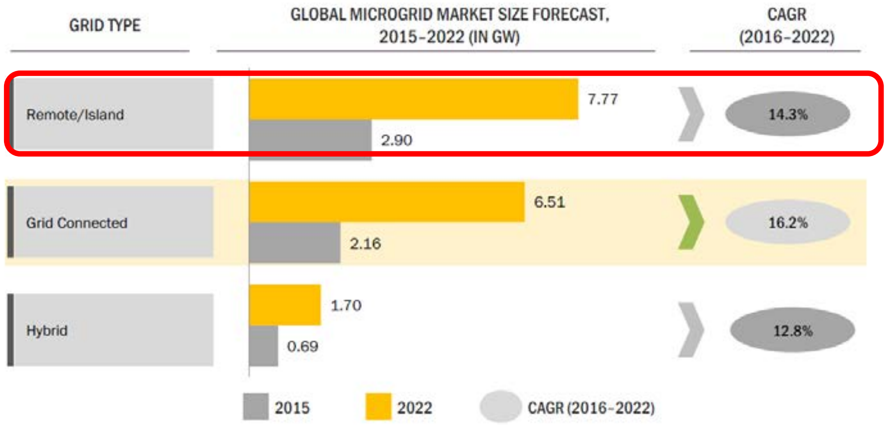
Agenda

- **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)



Rebuilding Puerto Rico's Power Grid: The Inside Story

Electricity may be fully restored this May—but the hard work of hurricane-proofing the grid remains

By Maria Gallucci

Photo: Erika P. Rodriguez

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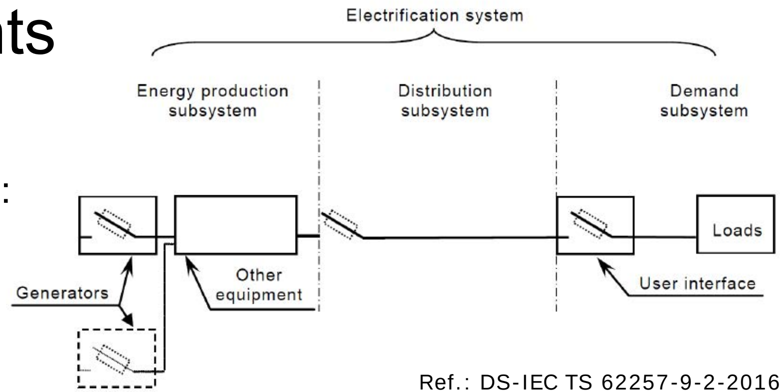
Types of Off-Grid Hybrid Power Plants

kW-scale vs. MW-scale



Ref.: DS-IEC TS 62257-9-2-2016

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)

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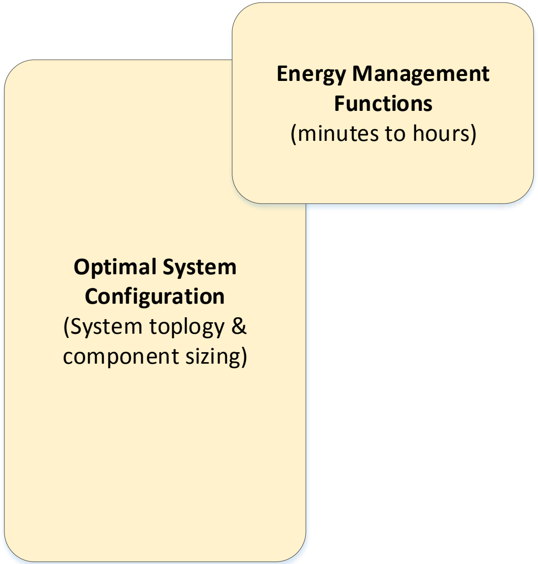
Optimal System Configuration

Siting, Sizing, Scheduling

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

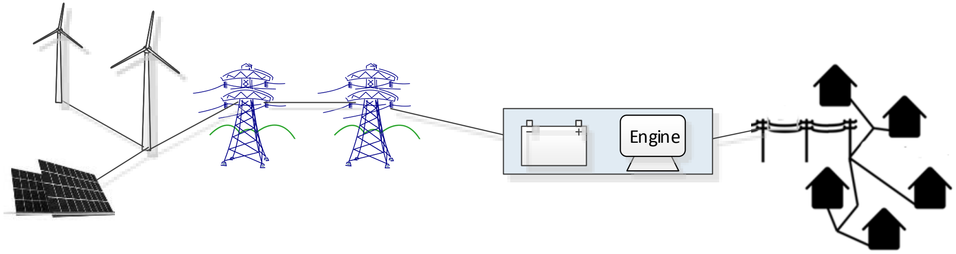
- **Sizing:** determining the installed capacity
  - Power/Energy ratings of wind turbine, PV, battery, gensets etc.

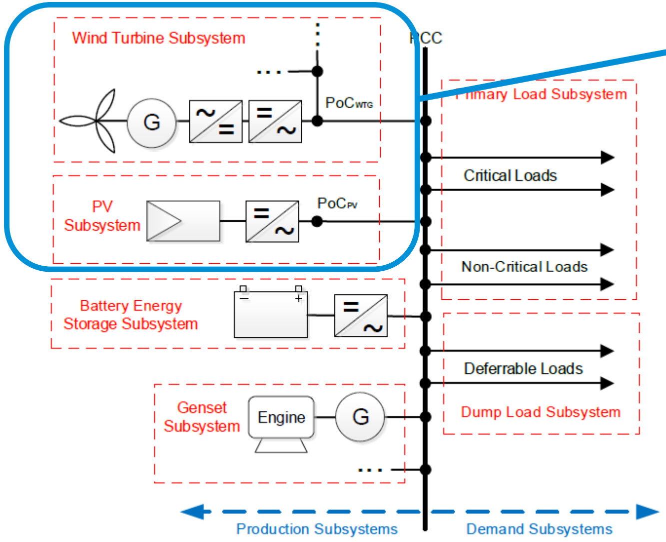
- **Scheduling:** determining the generic system management strategies
  - When to charge/discharge the battery?
  - When to start up / shut down a genset?
  - When to curtail renewable power?



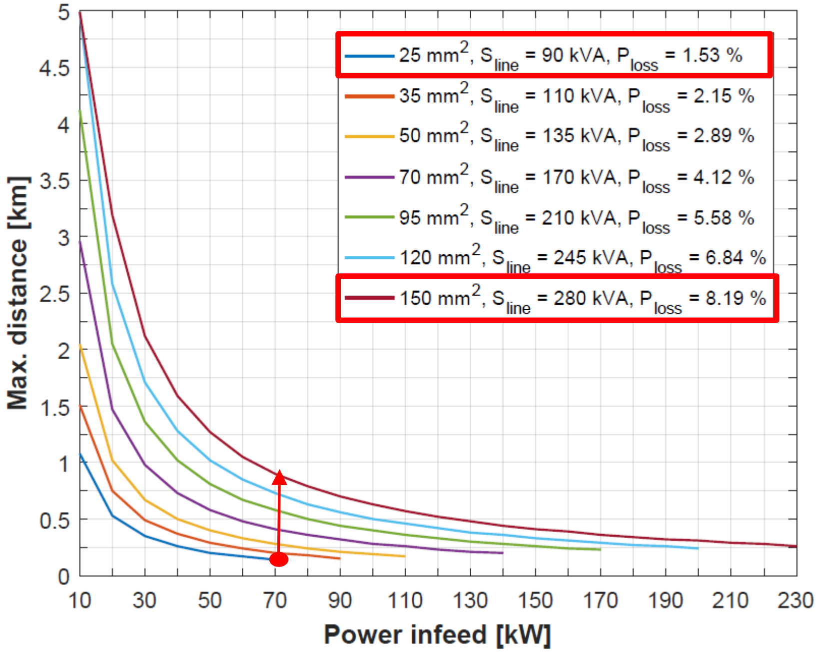
Modular and Scalable System Topology

Starting from kW-scale systems





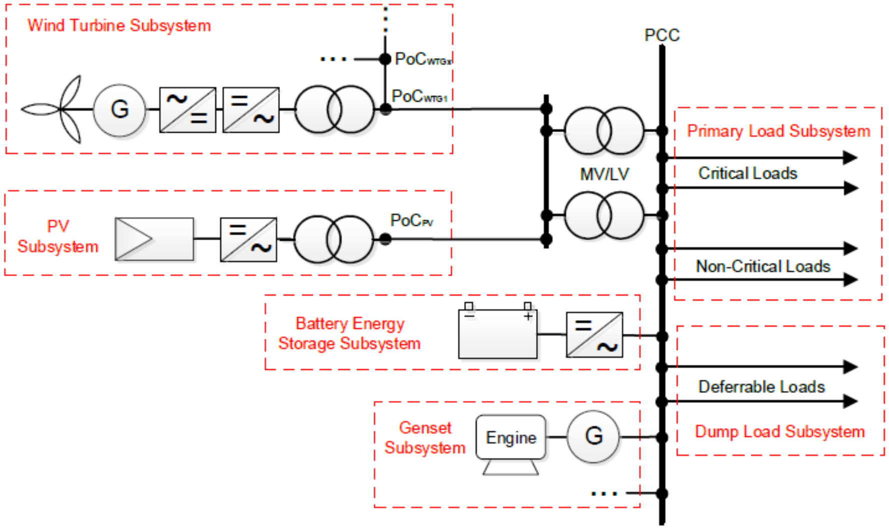
Line length vs. Power infeed for $\Delta V = 6\%$:



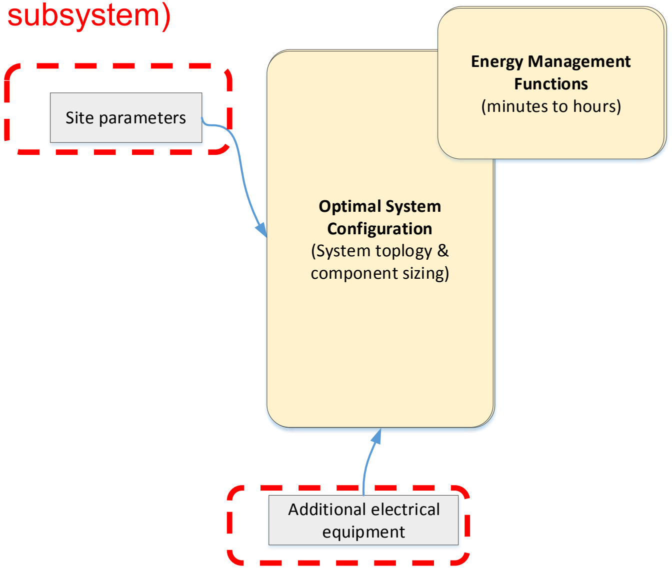
→ Scalability impossible with LV connection!

Modular and Scalable System Topology

Proposed system topology



Geographical constraints (location of production subsystem)



Switchgear, transformers

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Optimal Sizing Algorithm

Simulation steps

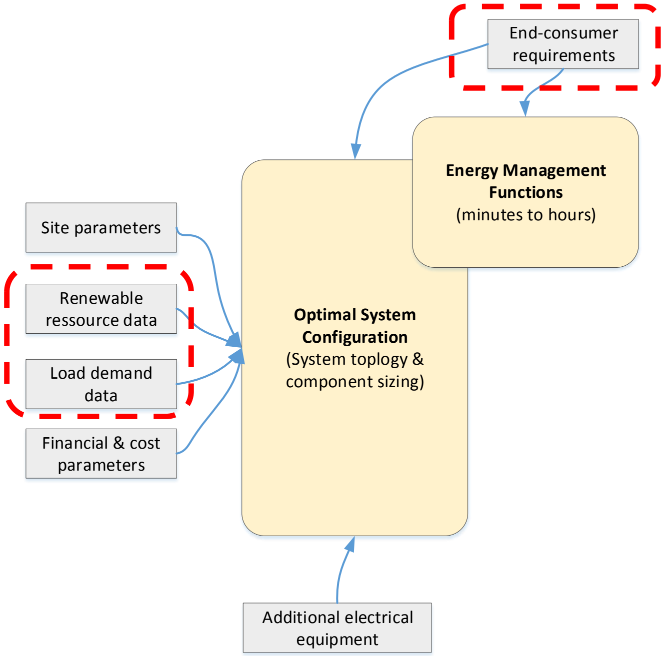
1. Input: Annual load profile & ressource data (wind speed & solar irradiation)
   - Hourly vs. Min. based data

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

3. Define search space for **X** (min./max. subsystem ratings)

$$\mathbf{X} = \begin{bmatrix} P_{WTG,rat} & P_{PV,rat} & E_{BESS,rat} & \\ P_{BESS-con,rat} & n_{GS} & P_{GSx,rat} & S_{TR,rat} \end{bmatrix}$$

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



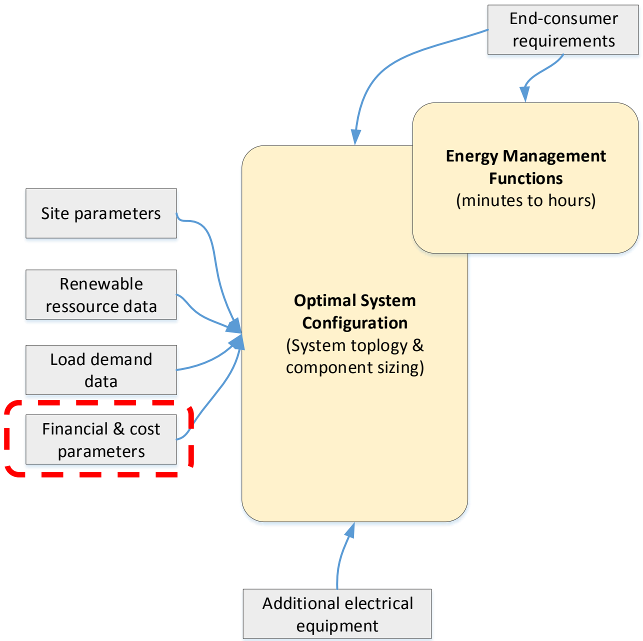
Optimal Sizing Algorithm

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 ressource data (demand, wind speed, solar irradiation)

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

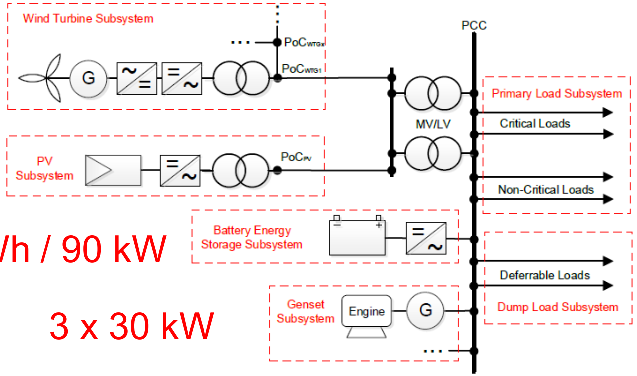
- Computed system configuration for $\Delta t = 1\ h$:

60 kW

80 kW

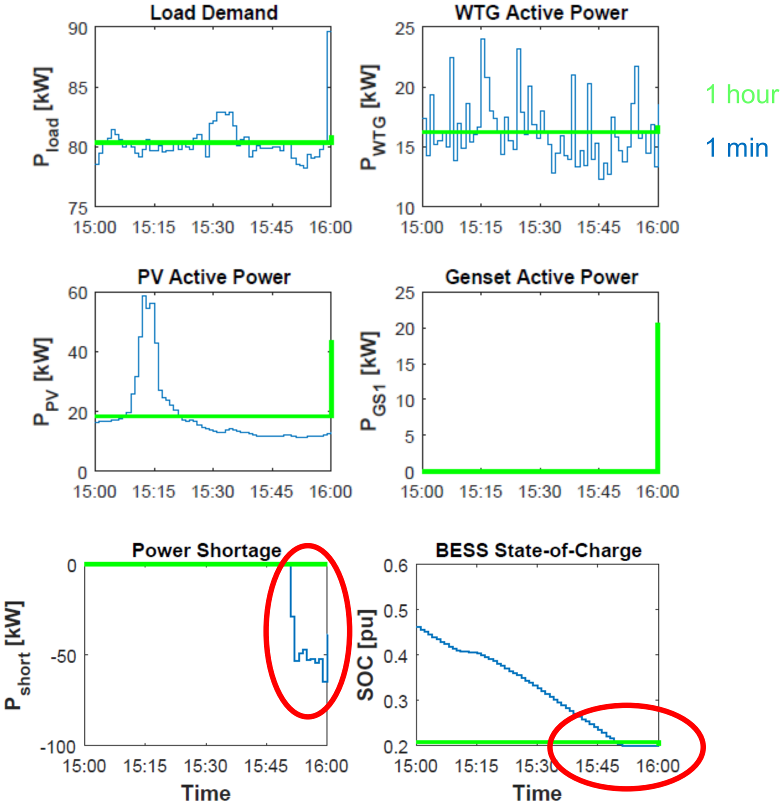
160 kWh / 90 kW

3 x 30 kW



Load:

90 kW peak



➔ Next step: Energy management with $\Delta t = 1\ min$,

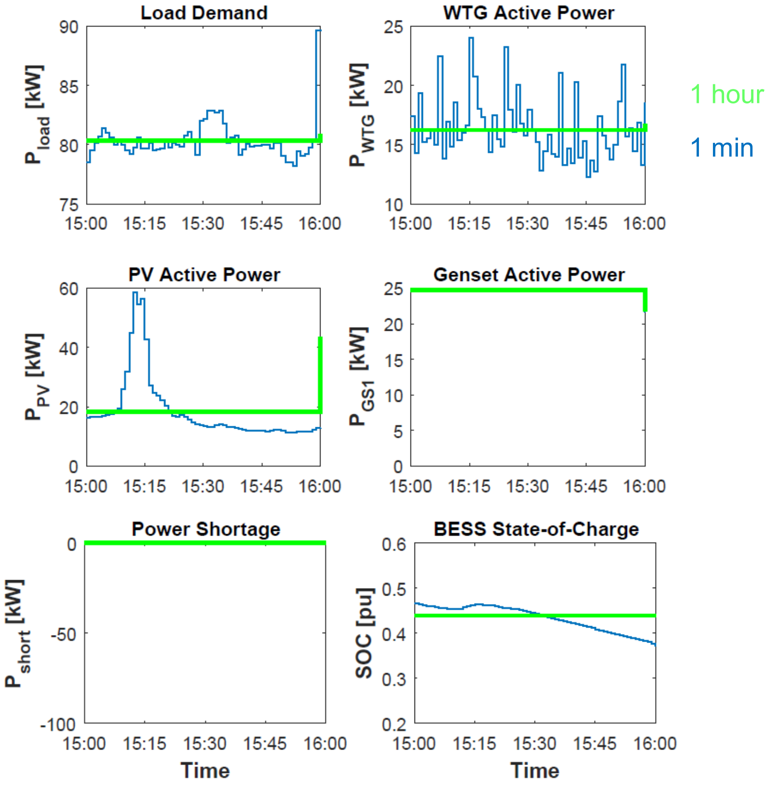
→ Power shortage due to power fluctuations and shut down genset!

Assessment Studies

Taking into account operational reserve

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

➔ Next step: Simulate system with updated SOC_{min}



→ No power shortage due to committed diesel genset!

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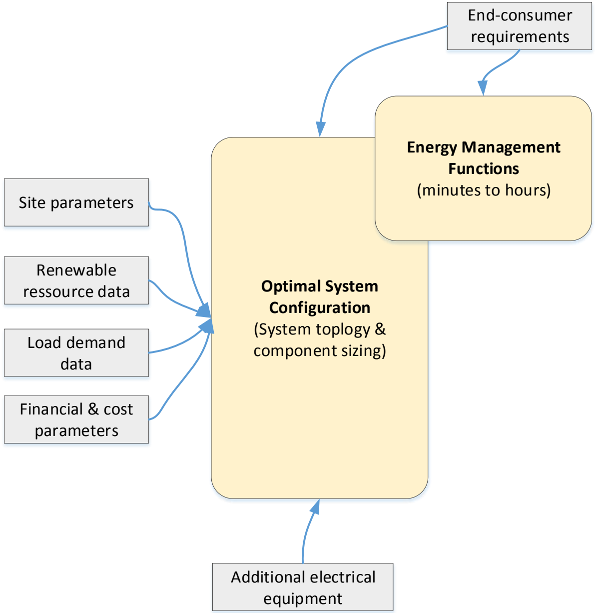
Summary

- 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)



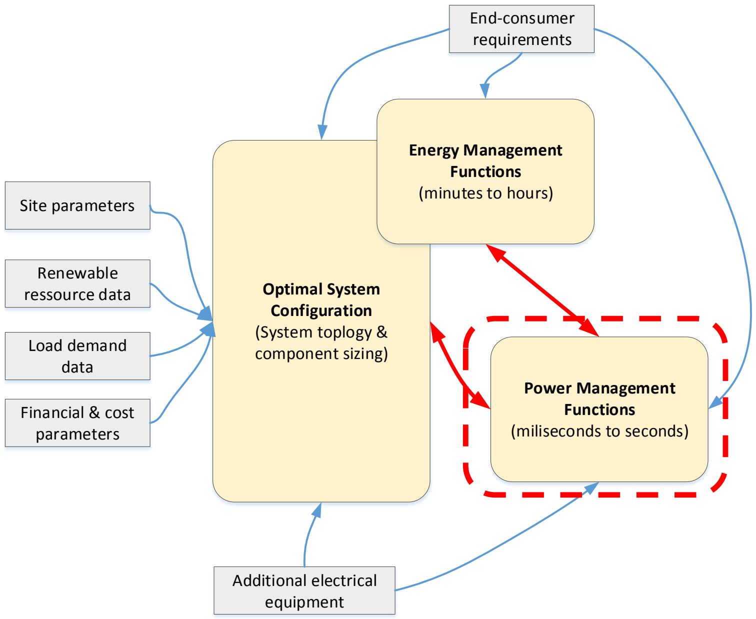
Next Steps

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*

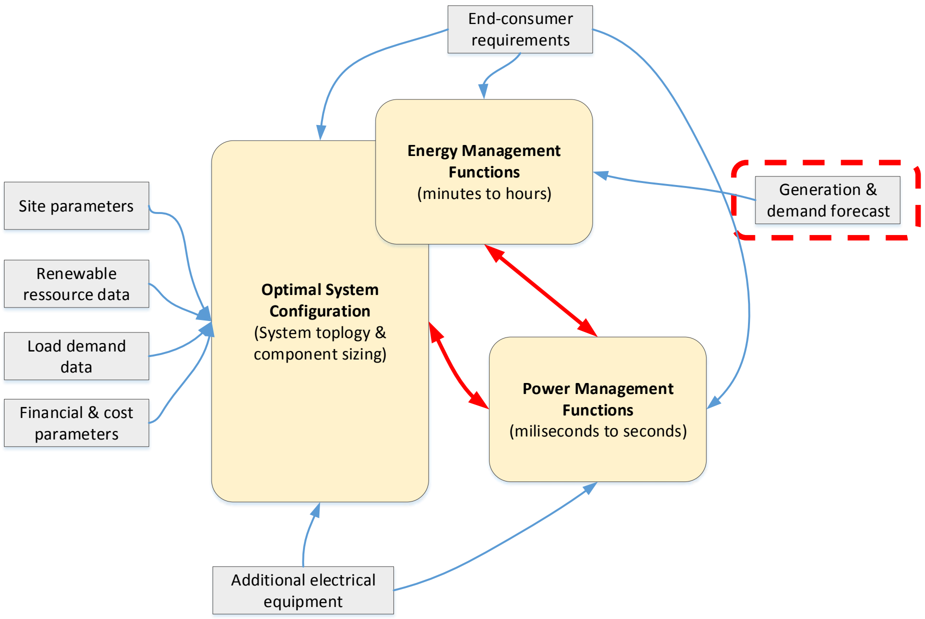
Power management functions (ms – s):

- 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!



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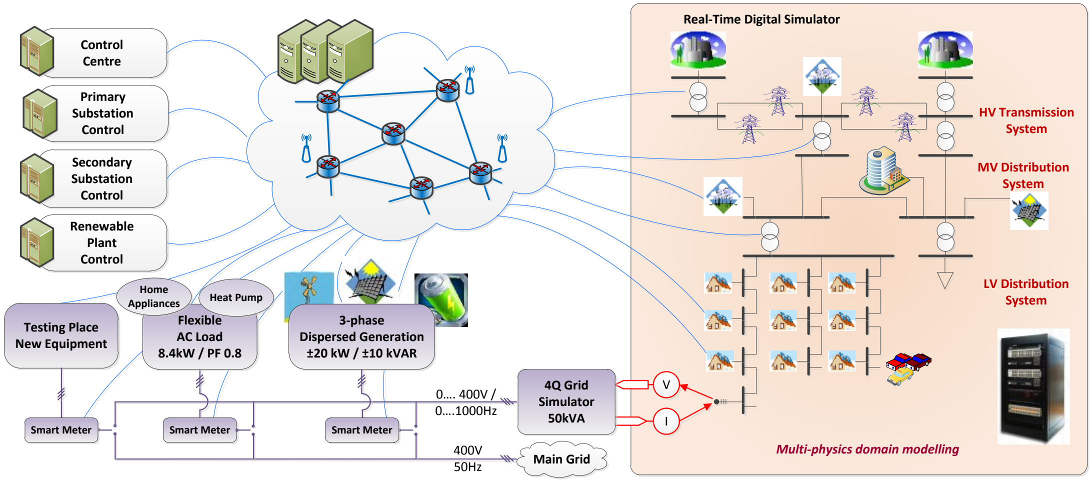
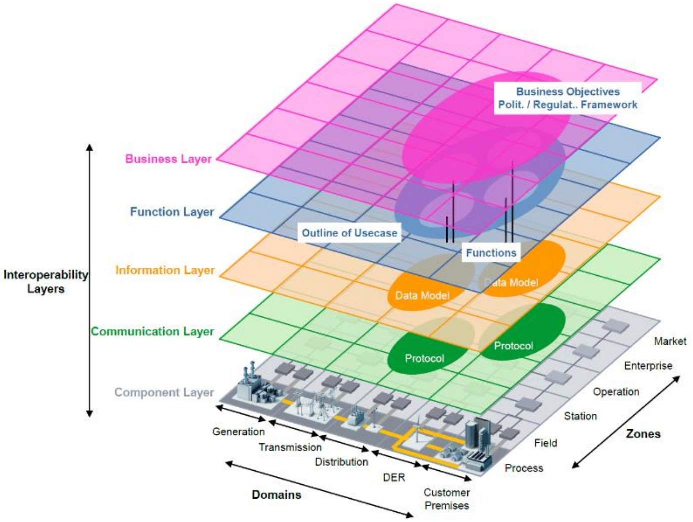
Smart Energy Systems Laboratory at Aalborg University

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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The authors acknowledge Innovation Fund Denmark for financial support through the Industrial PhD funding scheme.

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This work was carried out as part of the PhD project "Proof-of-Concept on Next Generation Hybrid Power Plant Control". The authors acknowledge Innovation Fund Denmark for financial support through the Industrial PhD funding scheme.