TECHNO-ECONOMIC OPTIMIZATION OF A HYBRID MINI-GRID USING A ONE-MINUTE TIME STEP APPROACH

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Motivation and Purpose

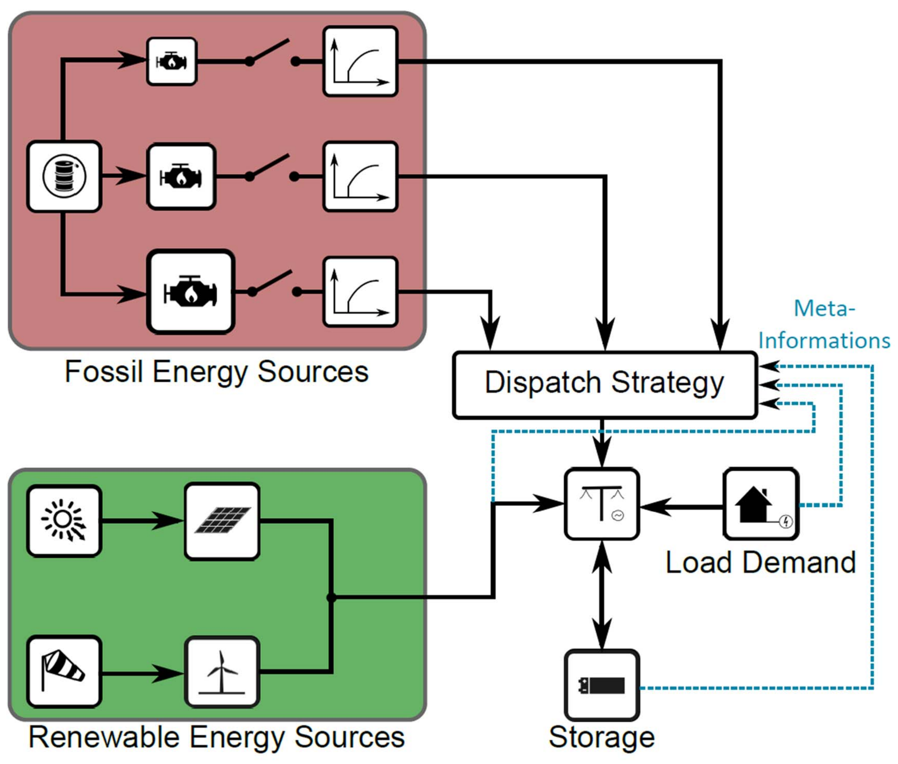
- Hybridization of diesel based mini-grids can reduce both costs and emissions.
- For successful integration proper simulation and optimization of technological and economic aspects are essential.
- Considering fast fluctuating renewable energies and stability criteria complex simulation tools are required.

⇒ Development, validation and application of one-minute simulation tool of hybrid mini-grids.

⇒ Including detailed genset, battery and system operation and stability models.

Simulation Model, Features and Input Parameters

▶ Figure 1: Components, resources and power flows of a hybrid mini-grid.



Diesel Genset: Different engine capacities, minimal loading, partial loading efficiencies, minimal runtime, and starting costs. Optimized diesel dispatch for any occuring residual load.

Battery: Power-related efficiency, dynamic lifetime (cycles, Rainflow-Model), able to provide spinning reserve.

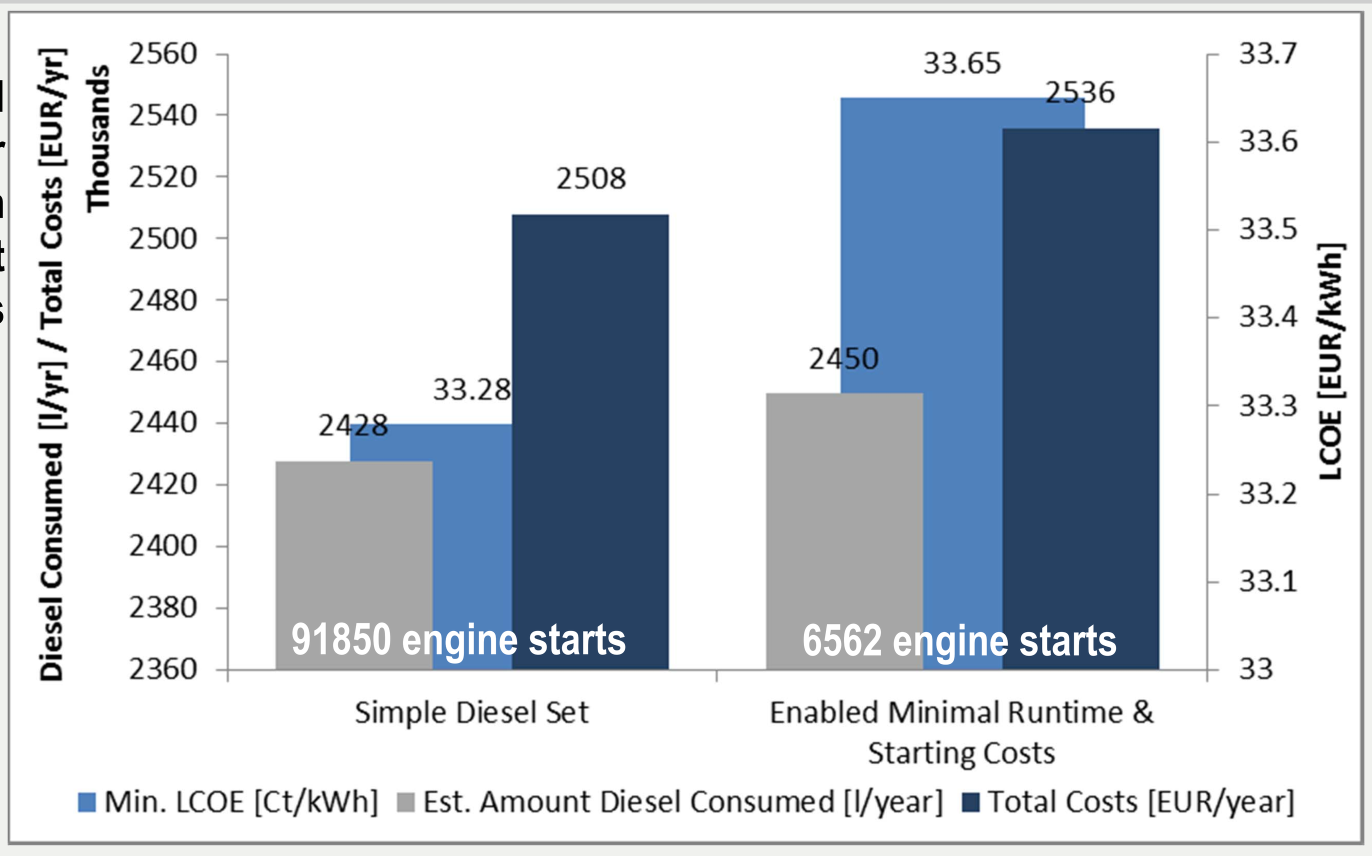
Operation Strategy: Battery and diesel genset can communicate.

Spinning Reserve: Realistic implementation of the diesel gensets' spinning reserve. Stability criteria have to be fulfilled at each time step.

Input Parameter: Project lifetime: 20yr, WACC: 11%, Load demand (Mean: 900kW, Peak: 1600kW), Capex (Diesel: 0€, PV: 1800€/kWp, Wind: 2000€/kW, Battery: 400€/kWh), Opex (Diesel: 350€/kW, PV+Wind: 3% of Capex/yr, Battery: 1,5% of Capex/yr), Battery Data (C-Rate: 1/6, Cycles @ 80% DOD: 5500).

Results: Diesel-Only System

Figure 2: ▶ Costs and diesel consumption for diesel-only system with and without minimal runtimes and starting costs.



No minimal runtime criteria lead to frequent on- and off-switching of diesel gensets.

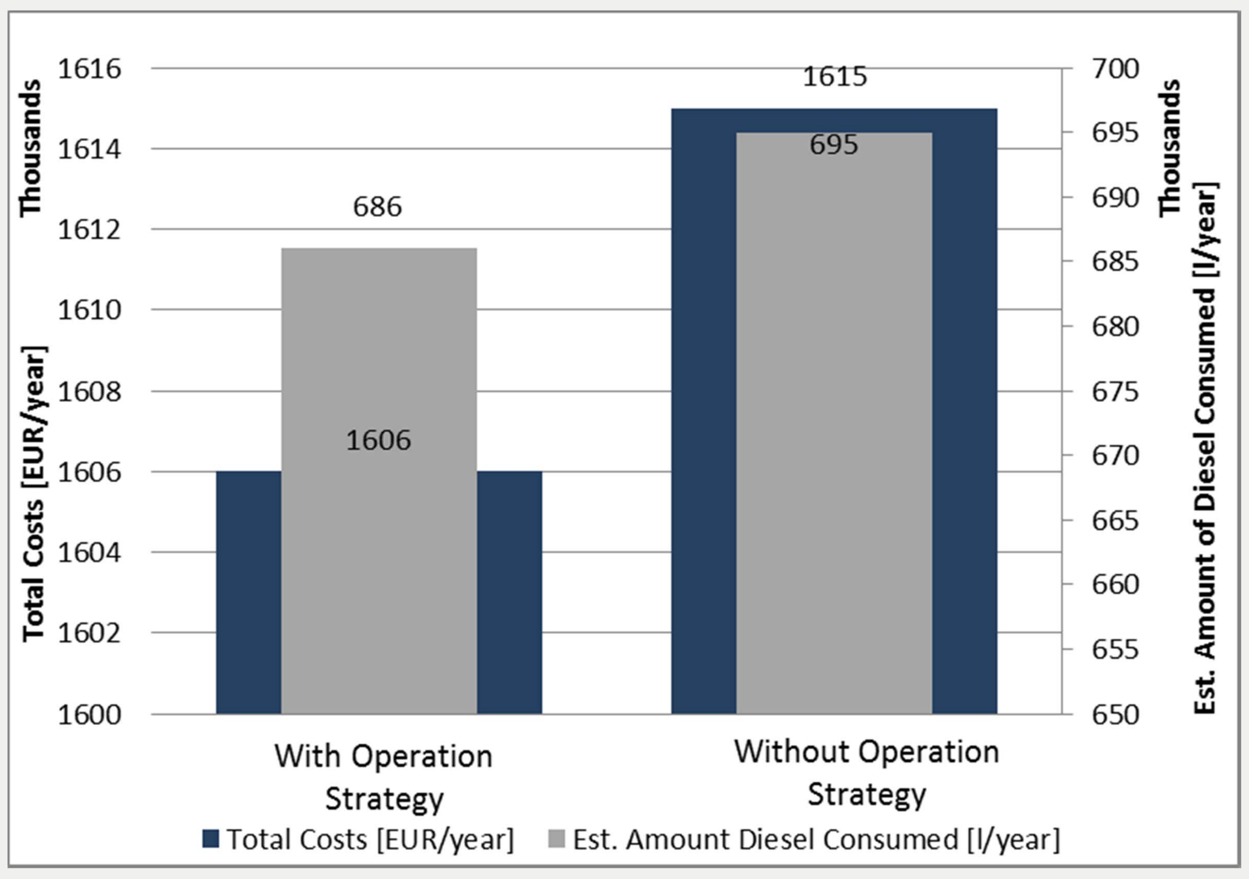
⇒ Engine starts are reduced by minimal runtimes, diesel consumption slightly increases.

Diesel starts cause additional costs due to maintenance efforts.

⇒ Additional costs for each start are implemented and increase total costs.

Results: Operation Strategy

Figure 3: ▶ Resulting costs and diesel consumption for the energy system with integrated renewables with and without an operation strategy.



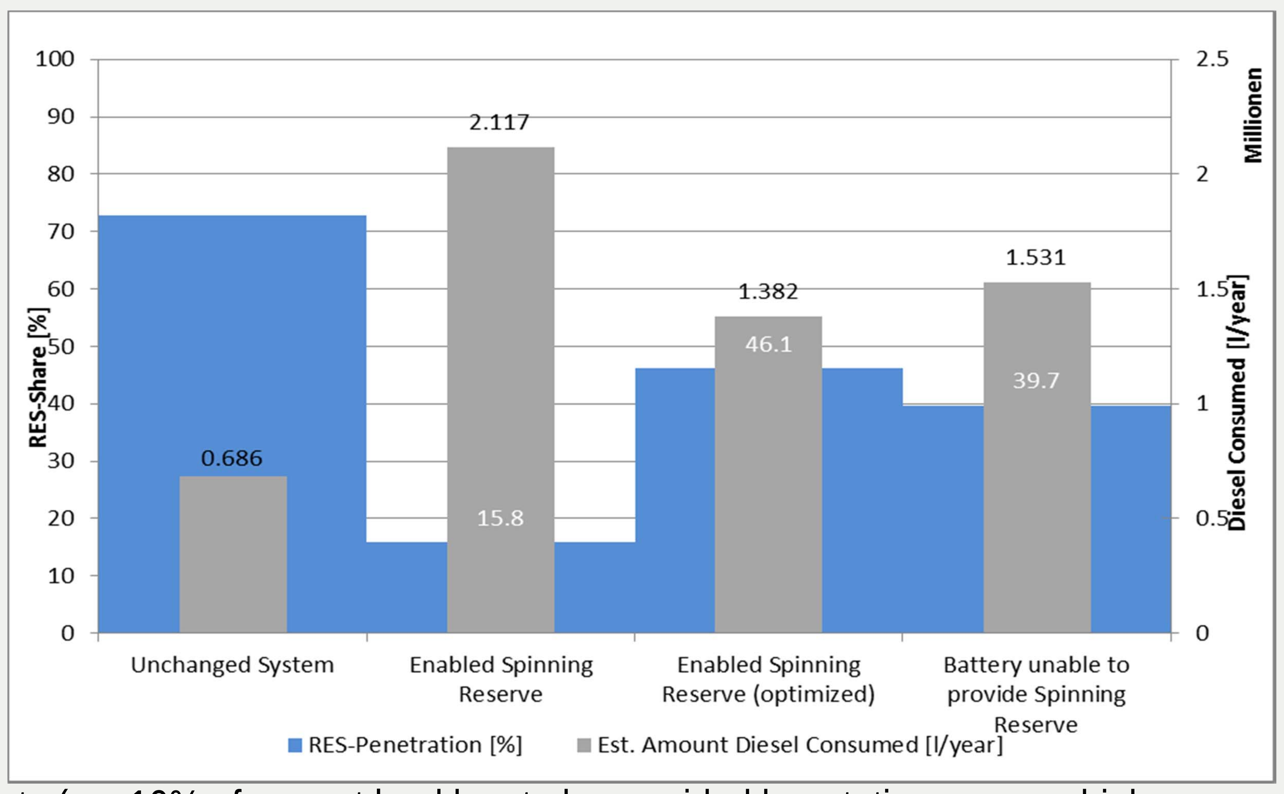
Simple operation strategies do not allow storage of diesel power generated excess energy

⇒ New dispatch enables communication between battery and diesel genset, which saves diesel fuel.

⇒ The higher the share of renewables the higher is the importance of such dispatch strategies.

Results: Spinning Reserve

Figure 4: ▶ Penetration of renewables and related diesel consumption considering spinning reserve. On the right side, battery is unable to provide spinning reserve.



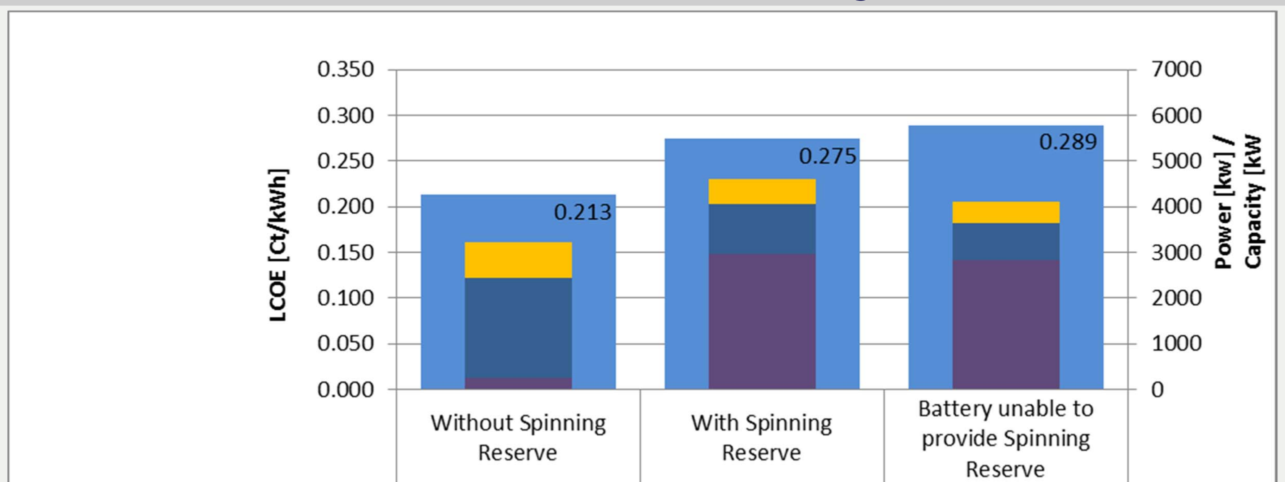
Spinning reserve constraints (eg. 10% of current load has to be provided by rotating mass or high power batteries) have to be included to ensure system stability.

⇒ Spinning reserve increases diesel consumption, as diesel engines have to run even in times of high renewable penetration.

⇒ Optimized system configurations are adopted due to spinning reserve criteria (cf. Fig. 5)

Results: Value of the Battery

Figure 5: ▶ Optimal dimensions of the hybrid system and resulting LCOE without and with spinning reserve and the battery unable to provide spinning reserve.



	Without Spinning Reserve	With Spinning Reserve	Battery unable to provide Spinning Reserve
LCOE [Ct/kWh]	0.213	0.275	0.289
PV Installed Power [kW]	776	528	474
Wind Installed Power [kW]	2200	1100	825
Battery Installed Capacity [kWh]	246	2967	2825

High power batteries are able to store excess energy AND provide stability services.

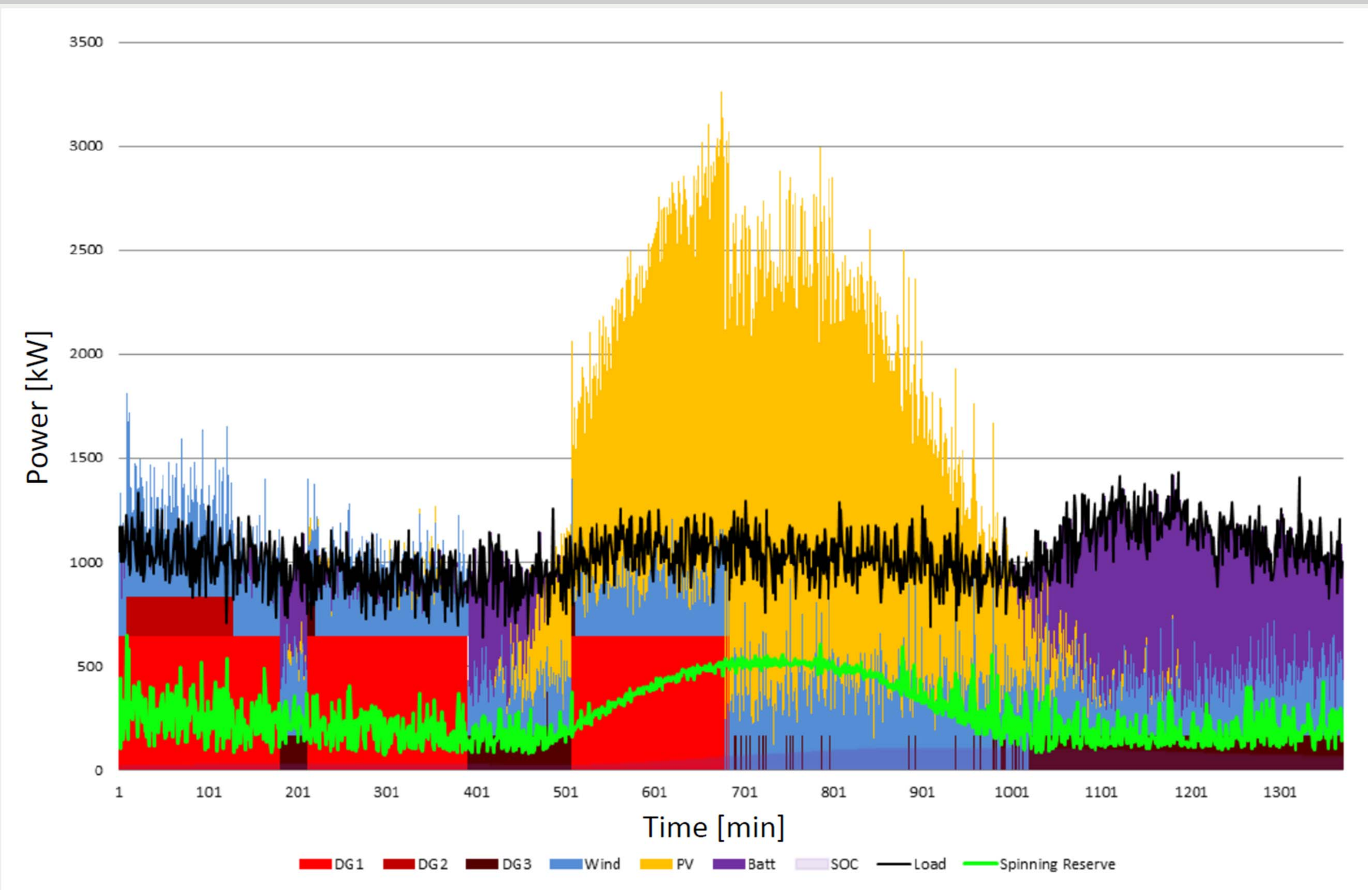
⇒ Battery capacities are dramatically increased when spinning reserve is required as it is more cost effective than running diesel gensets.

⇒ If the battery is unable to provide spinning reserve, less renewables are installed and the overall diesel consumption increases (cf. Fig. 4).

Example: Power Flows

Figure 6: ▶ Power flow example of one day. The load demand is supplied by a diesel genset, containing three diesel engines (small, medium, large), renewables and a battery. Stability criteria of spinning reserve has to be fulfilled at every minute. Battery is enabled to provide spinning reserve.

DG: Diesel genset
Wind: Wind power
PV: Solar power
Batt: Battery discharge power
SOC: State of charge of battery



Conclusion

- A one-minute time step simulation tool for hybrid mini-grids (including diesel, PV, wind and battery) is developed in Matlab.
- The new tool enables are more detailed and realistic simulation of hybrid mini-grids.
  - Simple diesel models underestimate the diesel consumption.
  - Neglecting the spinning reserve leads to high overestimation of the performance of hybrid systems.
  - Additional values of batteries can be simulated and tested within the new developed simulation tool.
- Implementation of renewables into diesel systems is technologically and economically viable.

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