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Data-driven Design & Control of Low-Carbon Microgrids for Developing Communities

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Motivation

- Millions of people lack access to basic electricity, while a large majority of world population still relies on poor quality state electrification in the developing countries.
- This work proposes interface problem between the on- and off-grid solution for the last mile electrification.
- The grievous repercussions of the climate change are driving the urgent need to switch to renewable energy resources.
- It is easier to develop green energy infrastructure in developing countries than transforming existing energy nexus in developed countries.
- Towards the sustainable development goal 7 of the UN: to provide reliable universal energy access to all in a sustainable way.

Distributed generation: the way to last mile electrification

- *Advantages*:

1. Improvement in power quality for loads: big issue in developing countries.
2. Reduction in Transmission and Distribution losses.
3. Flatter feeder voltage profile possible.
4. Renewables can be added to the systems.

- *Challenges:*

1. Limiting fault currents.
2. Requirement of fast power control.
3. Need for rapid switching.
4. Costs are much higher than existing systems.

- *Design considerations:*

1. DG systems are new compared to conventional power systems & evolving rapidly.
2. Customization needed depending on temporal and spatial constraints.
3. Benchmarking DG merits versus conventional solutions.
4. For developing communities: costs should be lower than coal for a renewable system, for mass adoption.

Objective: design and control of green microgrid

Design

- Selection of renewable sources: local resources.
- Size of sources (PV): historical weather data.
- Selection of critical loads: community needs.
- Size of storage (battery): backup for critical loads.
- Power conditioning interface: design & selection.
- Microgrid size: number of prosumers.
- Flexibility in configuration to add/remove sources & loads over time.
- All design choices to meet economic & performance constraints.

Control

- Operation and scheduling of stochastic renewable generation.
- Source scheduling in presence/ absence of utility grid.
- Battery lifetime through charge/discharge cycle control.
- Load variation patterns over time & seasons.
- Use of actual data from developing nations to understand seasonal load patterns & source forecast.
- All control decisions to ensure maximum efficiency, high financial feasibility & low carbon release.

Methodology: considering real field constraints

• Low power quality leads to downtime in productivity & loss of time, resources with dissatisfaction of end users.

• Under lack of grid availability, grid tied PV systems cannot operate, leading to no power production.

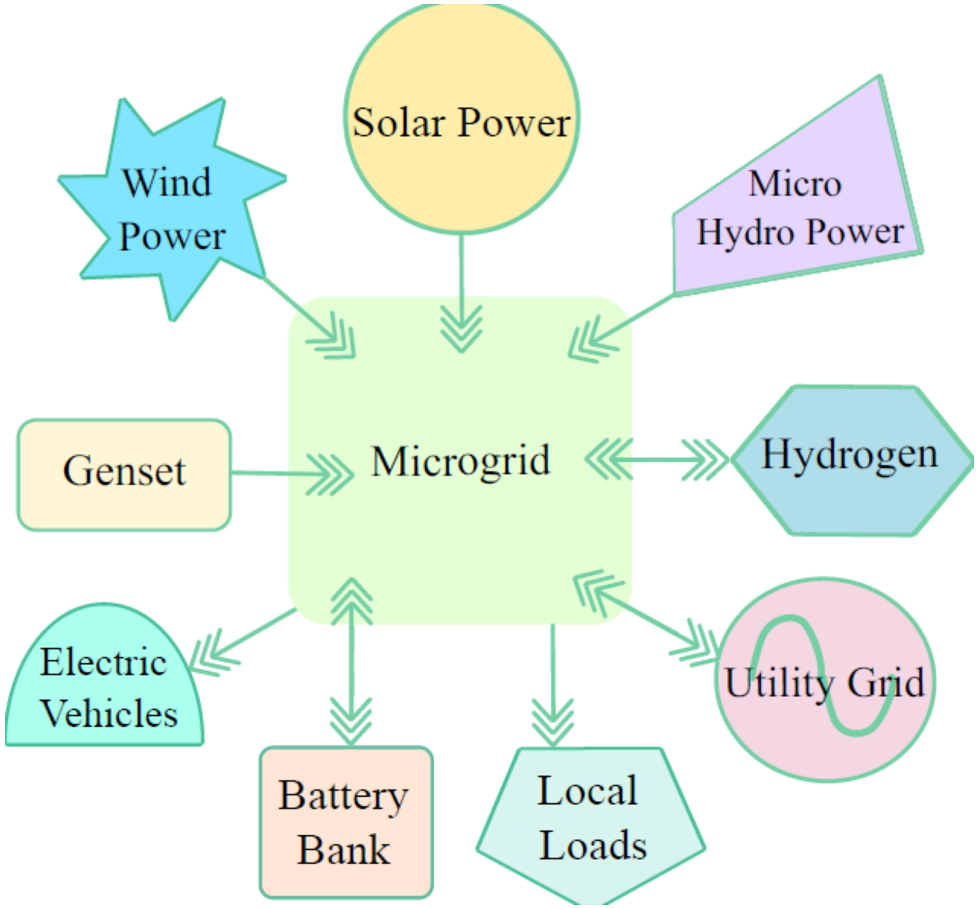
• To meet load demand during outage diesel gensets are used locally.

• Use of battery storage prevents the use of diesel gensets.

• Sun shines only during daytime, with number of hours varying around 12.

• Peak Capacity Factor = 0.45: with diffused nature of solar power, peak power is not produced throughout the day.

•On an average, peak power is produced for ~5 hours per day.



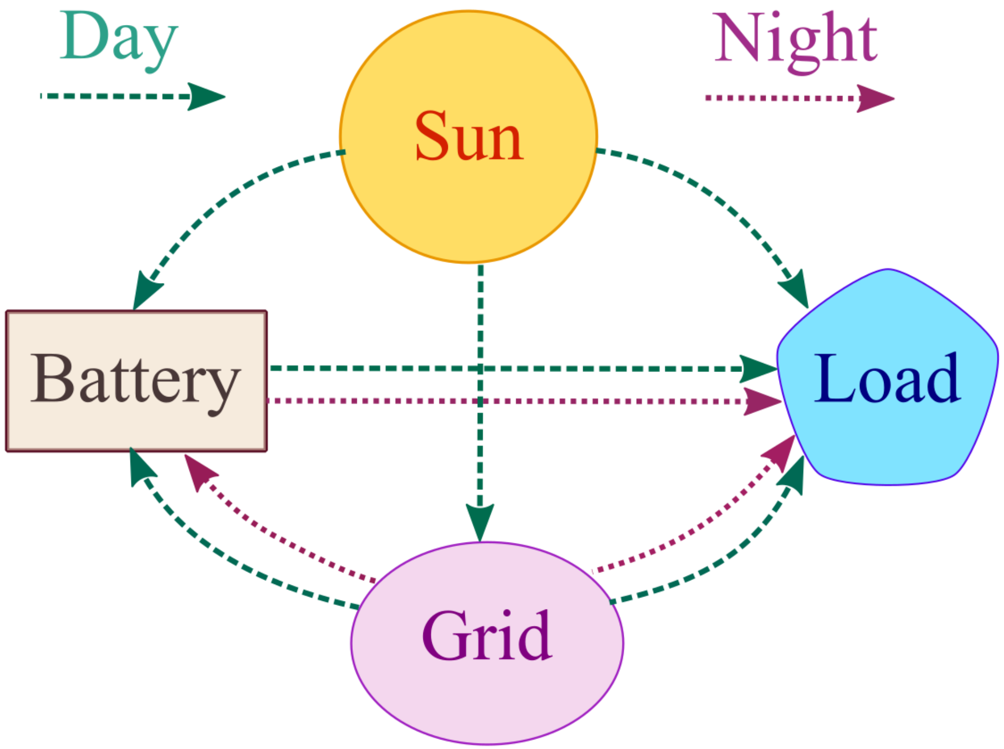
Case Study

Solar microgrid for a developing community:

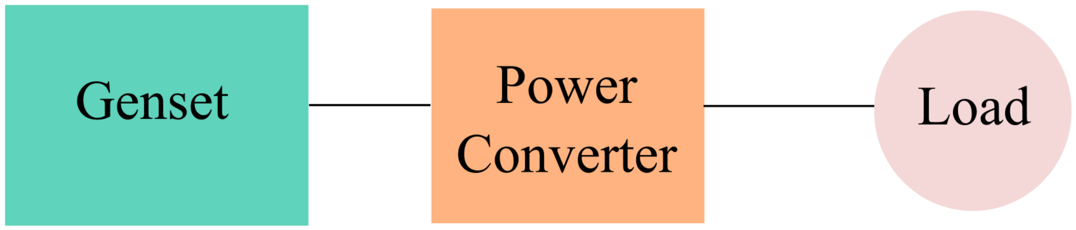
- determine minimum cost of energy without compromising the operating performance.

Scenarios considered for choosing optimum source selection:

- Critical local loads are varied from: 0.5 kW, 1kW, 2kW and 2.6kW.
- Battery is charged by the grid power.
- PV supplies power to load during the day and surplus power is fed to the grid.
- During night, grid supplies the load.
- During night-time grid outage, battery supplies the load till battery capacity saturates.
- Diesel cost of energy is Rs. 17/KWh.
- Grid energy cost of energy is Rs. 6/kWh.



Selection of power converter



$\eta \rightarrow$	88%	92%	95%
$C \rightarrow$	150	200	250 (\$/kW)

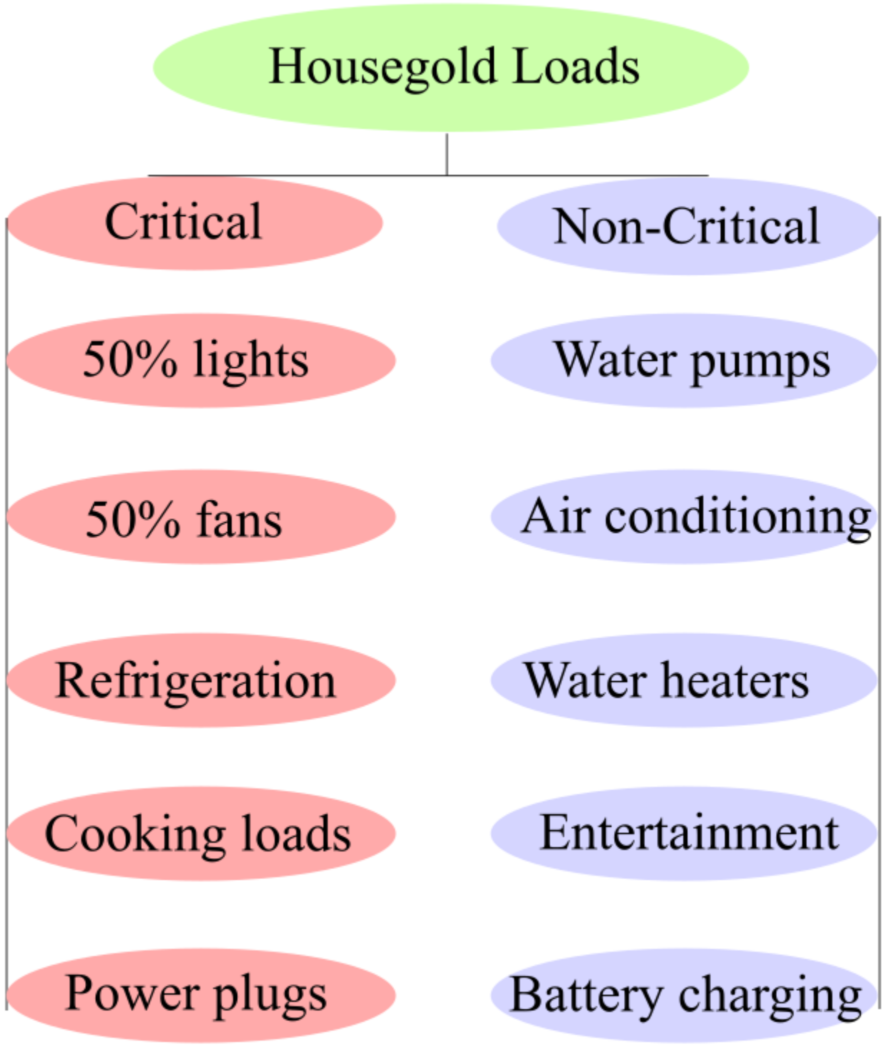
Properties of an ideal vs real power converter:

- Power loss : 0 — 95% efficiency
- Volume: 0 — 3-9 m3/MW
- Weight: 0 — 5 tons/MW
- Cost: 0 — 100,000 \$/MW

All the above trade-offs can be combined together to select the best power converter configuration for a given microgrid application

Selection of critical loads in a domestic set-up

- Increasing household income leads to more local loads and more critical loads.
- Difference in occupancy changes temporal variation of critical loads.
- Location impacts weather leading to heating/cooling load additions.
- Occupation of people in communities leads to varying load profiles.
- Seasonal variation further leads to addition/subtraction of local loads: agriculture.
- Upcoming technologies impact user load profile: electric vehicles.



Optimization with spatial and temporal constraints

Research objective:

- Minimize cost of battery management system (BMS)
- By scheduling household loads and microgrid sources
- Subject to: (1) grid availability, (2) solar forecast, (3) critical loads/user comfort.

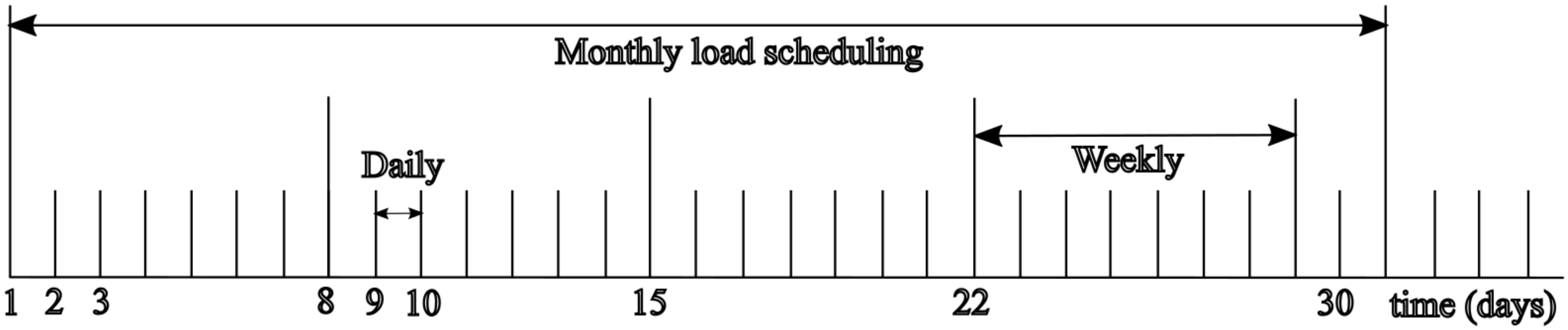
$$\min_{x} Cost_{BMS}$$

$$s.t. (1), (2), (3)$$

$$where\ x: battery\ cycling$$

Time-varying load scheduling:

- Day-ahead scheduling of loads: water pumping in low power demand time.
- Weekly load scheduling: laundry, house-cleaning, vehicle-maintenance, etc.
- Monthly load scheduling: depending on weather patterns, HVAC loads.



Cost of energy

COE is defined as the annual cost incurred per unit electrical energy produced.

Annual cost here includes:

- Total capital cost x annual interest rate : c1
- Annual operations and maintenance cost : c2
- Annual fuel cost : c3
- Negated annual secondary benefits : c4

Total energy produced is given by product of:

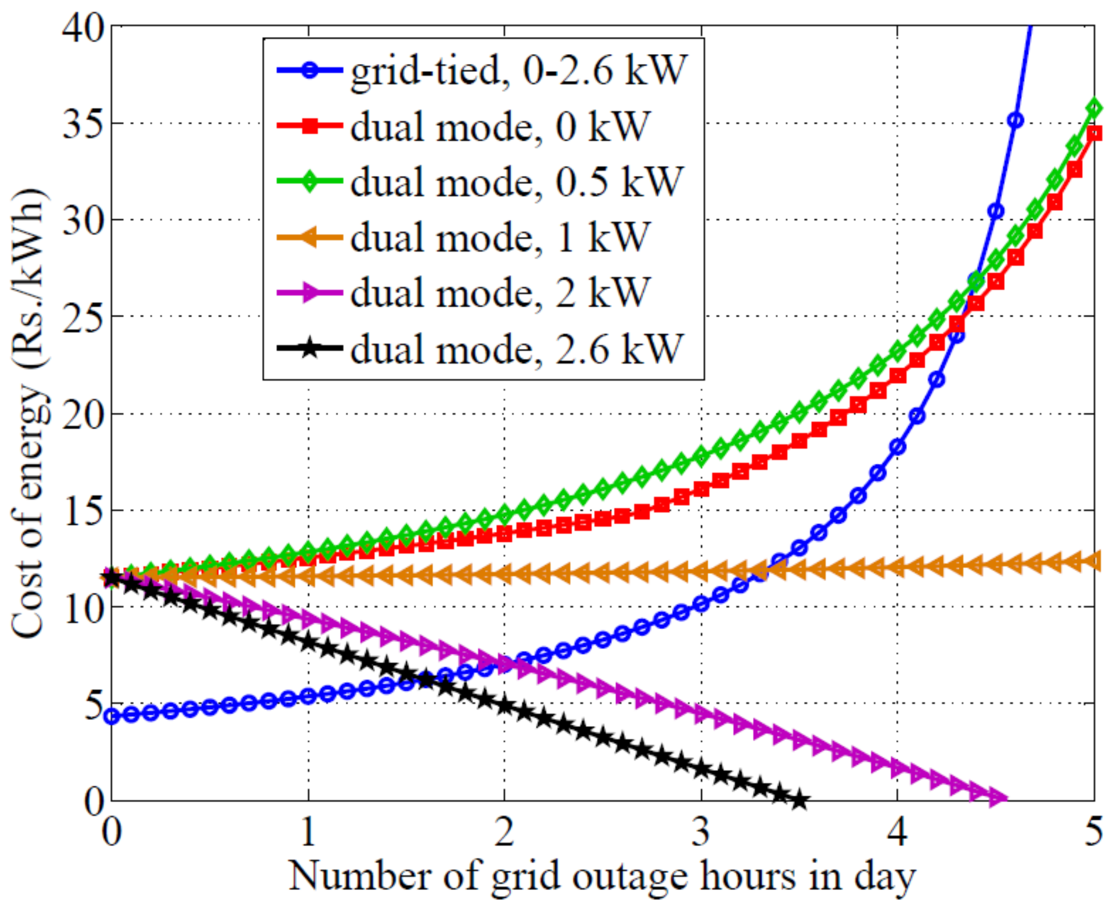
- Rated PV power PVr
- Time of operation in an year
- Efficiency of power converter

$$T = PVr \times hrs/day \times days/yr \times efficiency$$

$$AC = c1 + c2 + c3 - c4$$

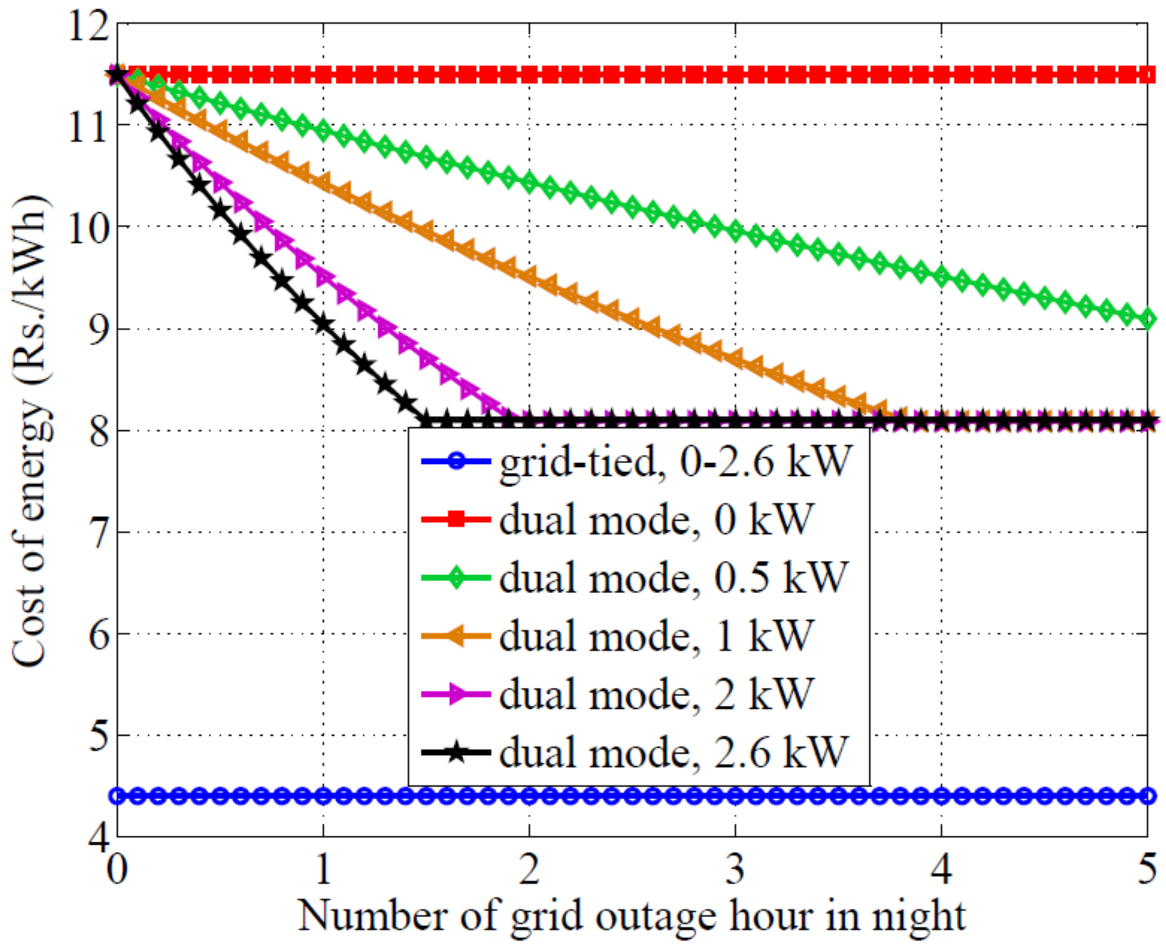
$$COE = AC/T$$

Results - day time outage



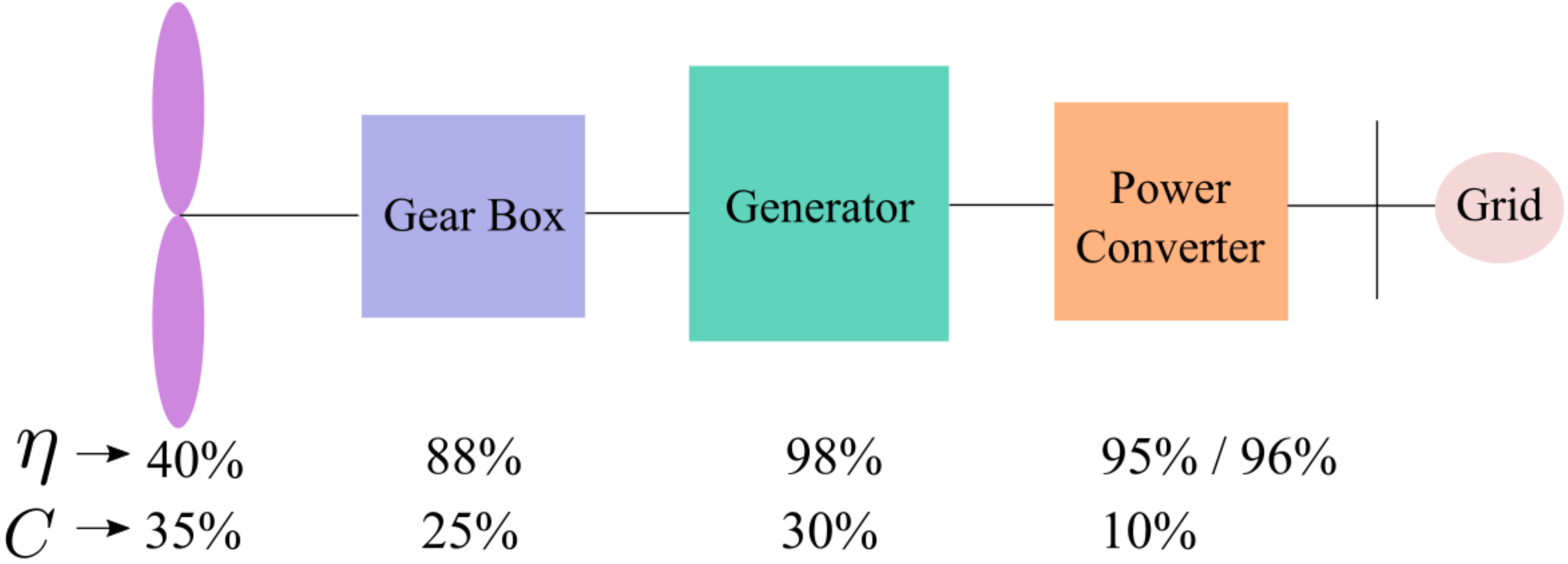
During day time grid outage, PV microgrids with storage are better with lower COE.

Results - night time outage



During night time grid outage, battery supplies critical loads till capacity saturation.

Application to Wind Power Generation



- Same analysis is applied for wind power based microgrid design for low cost and high efficiency optimization.
- Higher power converter efficiency increases overall efficiency more than increasing overall system cost.
- Smart power converter with variable speed drive helps capture more energy, helps reduce blade area, cut costs.

Conclusions:

• This case study can further be extended to redefine performance objective for developed countries considering load sensitivity to power quality.

• Present analysis considers varying critical load, which can be refined to consider predictable slow-varying load component based on historical data.

• Based on load patterns and solar power generation forecast, day ahead battery charging and discharging schedules can be prepared.

• Load deviations analysis can further enhance frequency stability in distributed generation while allowing less regulation on inverter side.

• Further enhancement of this study to include both centralized and distributed storage considering smart coordinated control can lead to quantifiable optimized performance.

• A tertiary level optimization depending on the: profiles of critical loads, state of charge of battery, solar power generation and grid availability; is the goal of this research.

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Thank You!

Please send your questions to authors @ bpallavi@mit.edu, ilic@mit.edu