Microgrid Layout Design for Cost Minimization in Conventional Diesel Backup Systems

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Diesel Generators (DGs) are commonly used in developing countries as backup power sources to overcome the problem of inadequate grid connectivity and frequent outages. However, power from DGs is highly expensive and environmentally harmful. Obviously, systems based on solar generation and batteries offer a good opportunity to offset this high DG cost.

A systematic Layout design of a hybrid microgrid is investigated in this work aiming at simultaneously integrating the energy management and the capacity of each component of the system. This work proposes an optimization framework targeted to reduce the running costs associated with the grid and DG, in the presence of outages, and the overall costs of installing new resources such as PVs and batteries.

[Opportunities and Challenges]

- ▶ Green Energy Resources has almost no running cost beside its cleanness.
- ▶ Offering an affordable power supply can assist weak utility systems (inadequate grid infrastructure or/and frequent interruption of the grid).
- ▶ Conventional backup systems depend mainly on diesel fuel [**POLLUTION**]
- ▶ DGs are greedy consumer of fuel [**High running cost *BUT* Low investment**]
- ▶ Sizing a system based on elementary statistics leads to **OVERSIZING > HIGH COST**
- ▶ Hybrid generation compromises between cost and cleanness [**PV-BESS-Diesel**]

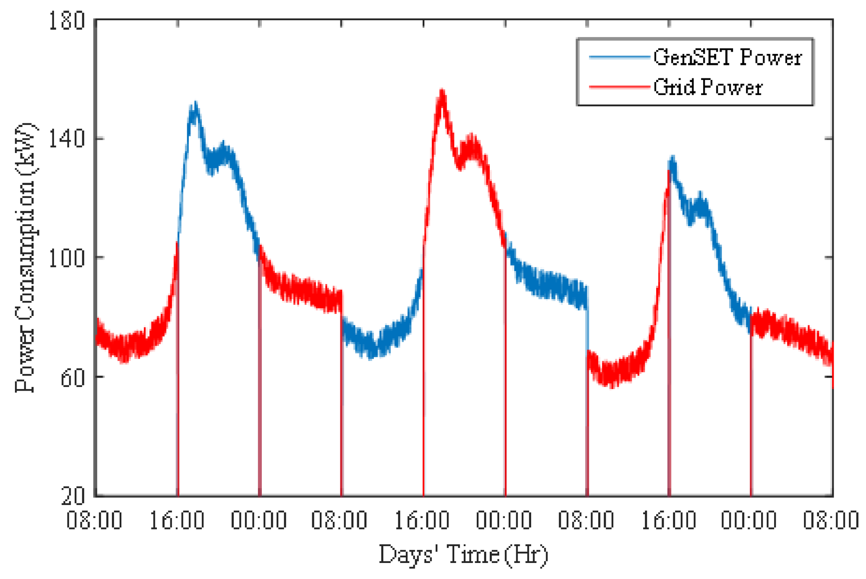

Fig. 1 Diesel operation during power outage (8 Hours ON/OFF).

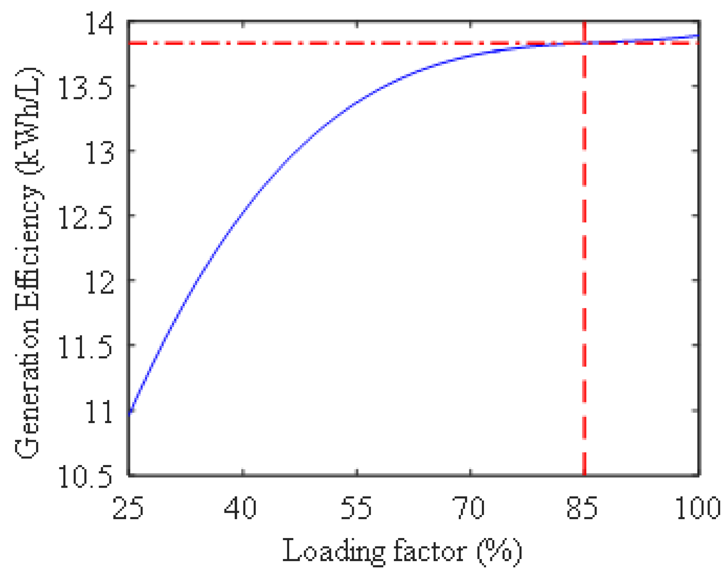

Fig. 2 Efficiency characteristics of a 200kVA diesel generator.

[Microgrid Model]

- ▶ The system is assumed supplying the essential/critical load of a facility, (i.e. the loads of high priority are ranked as critical).
- ▶ ***Legacy (current) system*** Diesel generator and the utility grid.
- ▶ ***New (additional) system***: PV Array, Battery Energy Storage System (BESS), Bi-directional power inverter and the Energy Management System (EMS).

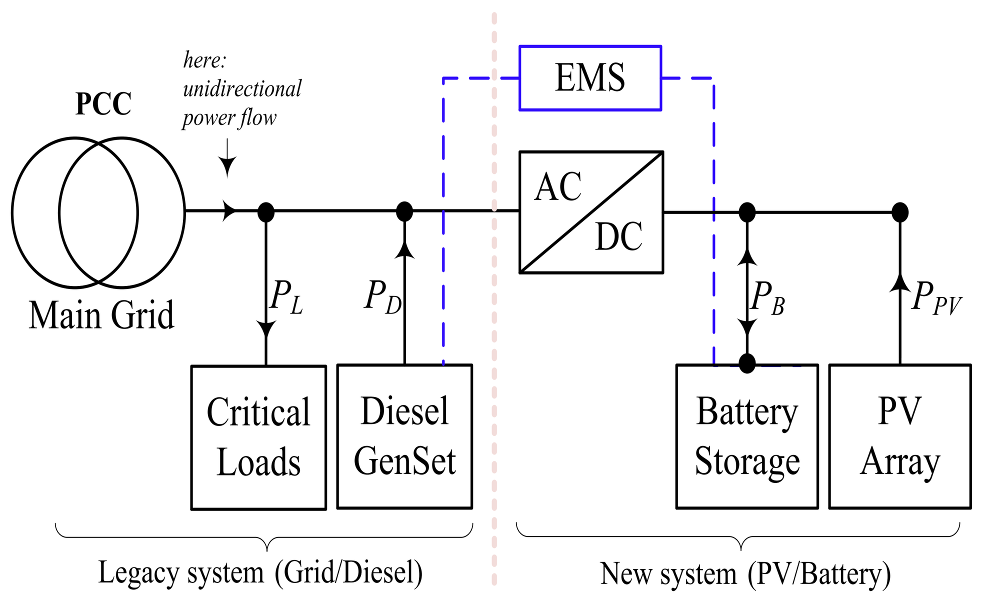

Fig. 3 Proposed Microgrid System including the legacy backup system.

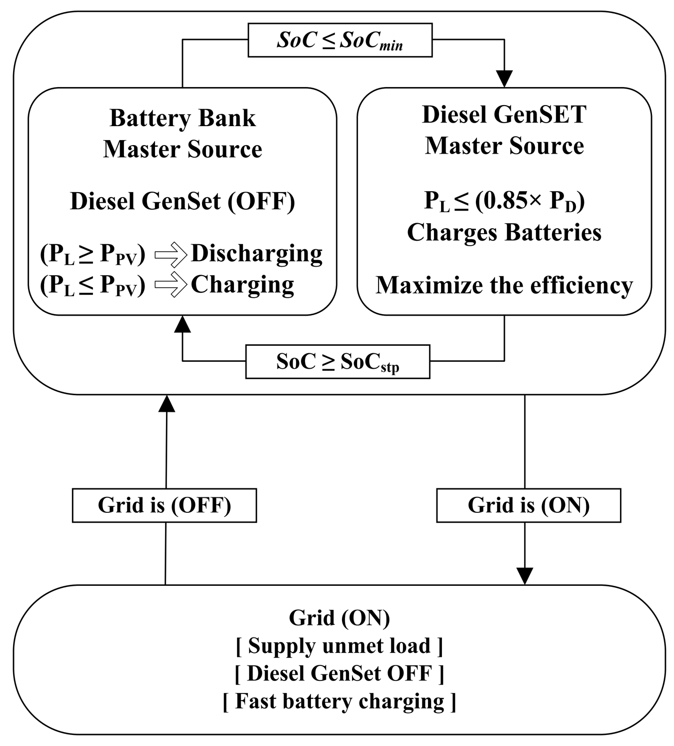

Fig. 4 Rule-Based Energy Management System

[Optimization Framework]

Cost Function

$$C_T = N_{PV} C_{PV} + N_B C_{Bat} + P_{DG}^{Best} C_{DG} + C_f F_c + C_g E_g$$

Investment cost (PV Array & Battery) — **Running cost** (Fuel cost + Grid purchase)

Fitness Function

$$\Pi := C_T + \left(w \sum_{1\,year} P_{Loss} \Delta \right)$$

Total cost + penalty due to unutilized RES energy

Applied technique: Genetic Algorithms

GA vs. Brute force (direct or simplex search)

Search space: All possible solutions × 1 year simulation $(N_{PV}, N_B, DG, N_{soc}, N_{soc}) \times (6 \times 8760)$

1. **Inputs:** Weather data, load profile and grid powering states.
2. **Candidate of decision variables:** $\mathbf{C} := (N_{PV}, N_B, DG, SoC_{min}, SoC_{stp})$
3. **Initialization:** randomly seeded possible solutions.
4. **Main Control Strategy:** Is candidate **C** appropriate for energy management scheme? If yes, evaluate the penalty function. Otherwise, exclude **C**.
5. **Selection:** Select the best candidate solution among the present generation before step in the next generation.
6. **Crossover and mutation:** The new possible candidate solution is generated from the parents which survived.
7. **Apply the main control strategy again (STEP 4)**
8. **Termination:** after exceeding the time budget or generation limit or satisfying the minimum criteria.
9. **Output:** the values correspond to the best/final solution.

$$UF = \frac{Net\ energy\ supplied\ by\ RES}{Total\ RES\ production} \times 100\% \qquad PL = \frac{Net\ energy\ supplied\ by\ RES}{Total\ energy\ demand} \times 100\%$$

[Case Study]

- ▶ Al-Shifa' Hospital is the largest healthcare facility in Gaza-city.
- ▶ The region faces a frequent power outages in a daily basis.
- ▶ Prolonged grid blackouts are scheduled across Gaza per day (16 - 20 Hrs) [2].
- ▶ A part of the essential load with the same characteristics is considered.

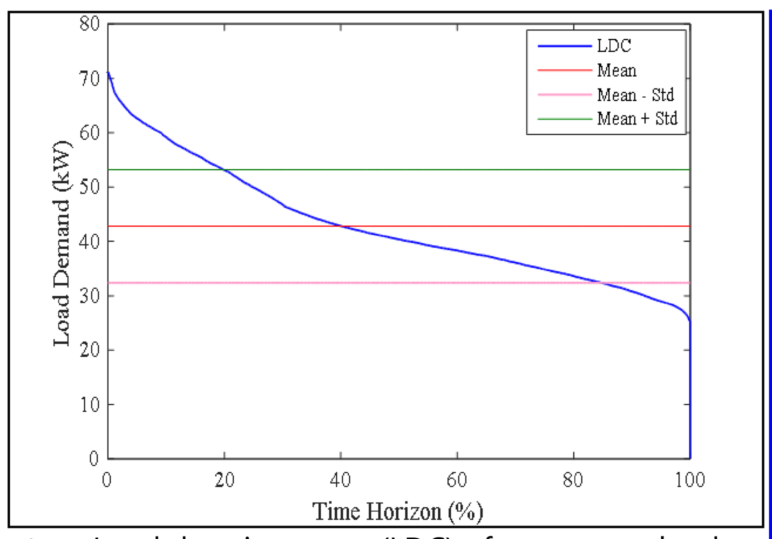

Fig. 5 Load duration curve (LDC) of a one-year load.

Peak load: **71.2** kW
Base load: **25.3** kW
Mean consumption: **42.8** kW
Standard deviation: **10.4** kW

Elementary Components

PV module: ***250 W_p***, Unit Cost => 1.9 \$ / W_p
Annual capital = [1.9 (\$/W_p) × 250 (W_p)] / 20 (yr) = 24 (\$/yr)

Battery: Trojan battery model IND17-6V: ***5.5 kWh***
2200 cycles at 40% SoC with nominal price is 1400 \$.
Annual capital = 1430 (\$) × [365 (cycles/yr) / 2200 (cycles)] = 237 (\$/yr)

[Simulation Results]

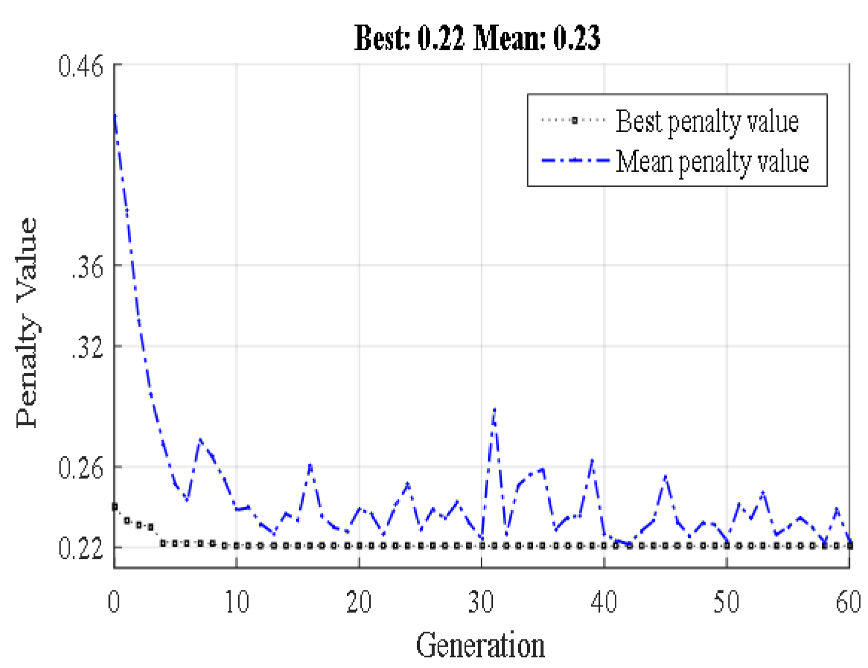

Fig. 6 Convergence of penalty function over GA generations

Fitness function is converged to a final value 0.22

This value expresses mainly the levelized cost of energy (LCoE) per kWh and the inherent increasing due to the non-utilized PV energy.

Optimized Microgrid Components

Number of storage units	140 units
Number of PV panels	922 panels
Rated power of the diesel generator	100 kW
Minimum allowable state of charge	40 %
Stop charging threshold from GenSet	89 %

Purchased Energy and Fuel Savings

Parameter	Diesel & Grid	Hybrid Microgrid
Purchased energy from grid (MWh)	124,98	116,12
Gross purchasing from grid ($\$ \times 10^3$)	22,45	20,90
Total fuel consumption ($L \times 10^3$)	80,98	3,31
Operation Hours (Hr)	5840	153
Total fuel costs ($\$ \times 10^3$)	149,8	6,12

[Net Savings and Conclusion]

- ▶ The annual payments of installation and replacement count ***75×10^3 US-\$***
- ▶ The long-term annual savings will be ***145×10^3 US-\$***
- ▶ Means that the net annual saving will be **70×10^3 US-\$**, that is: approx. ***half the fuel cost in the old configuration*** ≈ 149,8×10^3 US-\$
- ▶ In old configuration, diesel operates 2/3 year ≈ 5840 Hrs
- ▶ With the microgrid, diesel operates ≈ 153 Hrs

Annual produced and utilized energy (MWh)

Annual Energy (MWh)	Diesel & Grid	Hybrid Microgrid
Gross purchased energy from grid	124,98	116,12
Net load supplied from grid	124,98	96,87
Gross produced energy from diesel	249,9	11,50
Net load supplied from diesel	249,9	10,225
Total produced energy from PV	–	**404,16**
Net load supplied from PV	–	**267,78**
Total energy of the load	**374,88**	

Net Energy Sharing (PL)

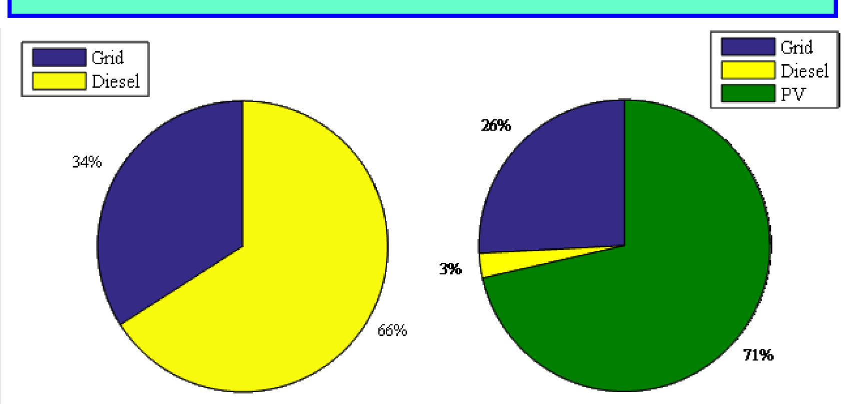

Fig. 7 Net share of each power source
(a) Legacy backup system (b) Hybrid Microgrid system

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