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Optimal Planning of Hybrid Fuel Cell-Battery System for Microgrid Applications

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Abstract:

Developing hybrid fuel cell-battery (HFB) storage for electric power grid applications brings multifaceted benefits. Firstly, it offers enhanced flexibility and reliability to the grid by combining the strengths of both technologies. Fuel cells (FC) provide consistent, long-duration power generation, and batteries excel at short-duration energy needs. The synergy between FC and batteries presents a promising pathway towards a more efficient, resilient, and eco-friendly grid infrastructure. This research proposes a novel model for optimal sizing and energy management of HFB systems for microgrid applications. Furthermore, the proposed approach considers the investment and operating costs of the hybrid system, the state-of-health (SoH) and dynamic efficiency of FC, as well as battery degradation costs. Simulation results have demonstrated the effectiveness of the proposed approach.

Introduction:

Microgrid is a small-scale grid powered consists of renewable energy sources (RES) such as solar and wind, etc., dispatchable generating units (DGs), and energy storage systems (ESS). The hybrid fuel cell-battery energy storage for microgrid application combines the advantages of both technologies as:

Fuel Cell (FC)
- Low Power Density
- High Energy Density
- Greater Lifetime
- Less Maintenance Required

Battery (Lithium-Ion)
- High Power Density
- Low Energy Density
- Less Lifetime
- Maintenance Required

Short and long storage → HSS → Minimum Investment Cost → Sizing and management optimization problem

Methodology:

Minimized the Annual Microgrid Expansion Cost Function

$$MinTC = MG_{oc} + Bt_{FOpC} + Bt_{Inv.c} + FC_{Inv.c}$$

Microgrid Operation Cost:

$$MG_{oc} = \left(\sum_{i=1}^{G}\sum_{j=1}^{t} F_G\, P_{ist}^{g}\, UC_{ist} + SU_i\, Sup_{ist} + SD_i\, Sdn_{ist}\right) + \sum_{j=1}^{t} Mpz\, |P_{st}^{cur}| + BtC_{voc}|P_{st}^{Bat}| + FcC_t\, |P_t^{FC}| + C_{dr}\, Cl_{st}$$

Investment Cost of Battery, Fuel Cell and Power Balance Equation:

$$Bt_{inv.c} = C_{p.B}\, P_B^{rated} + C_{e.B}\, E_B^{rated} \qquad FC_{inv.c} = C_{p.FC}\, P_{FC}^{r} + C_{e.FC}\, E_{FC}^{r}$$

$$\sum_{i}^{G} P_{ist}^{g} + P_{st}^{Bat} + P_{st}^{FC} + P_{st}^{Cur} = Nl_{st}\ \forall i \in G, \forall t$$

Islanded Mode

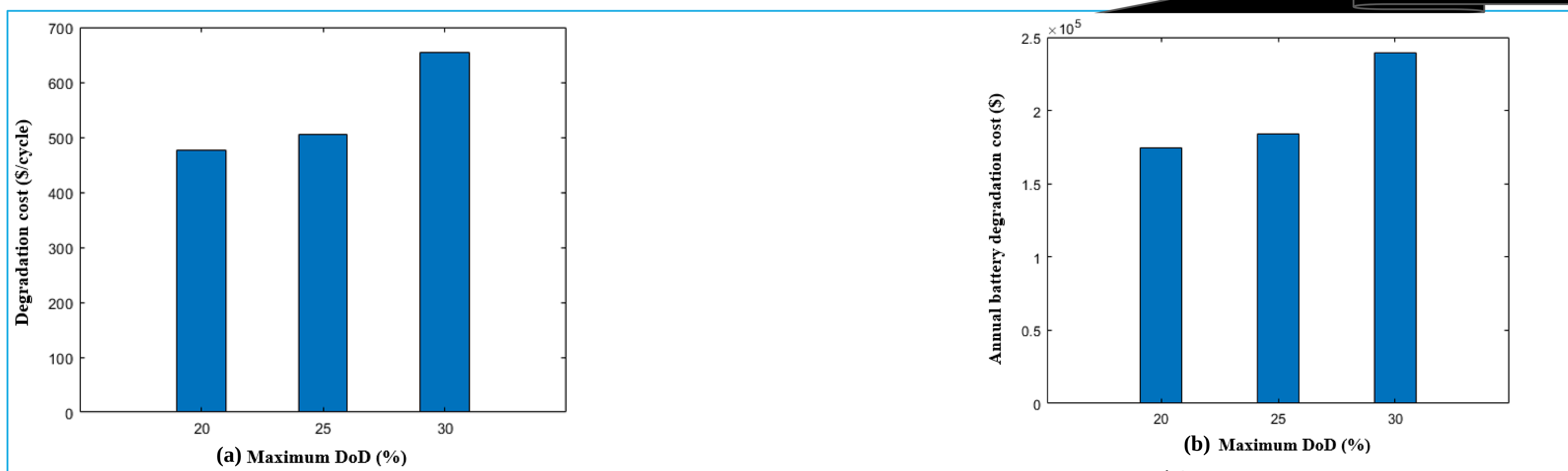

Fig 3. The change of battery degradation cost with respect to change in adopted maximum DoD (a) $/cycle, (b) annual degradation cost

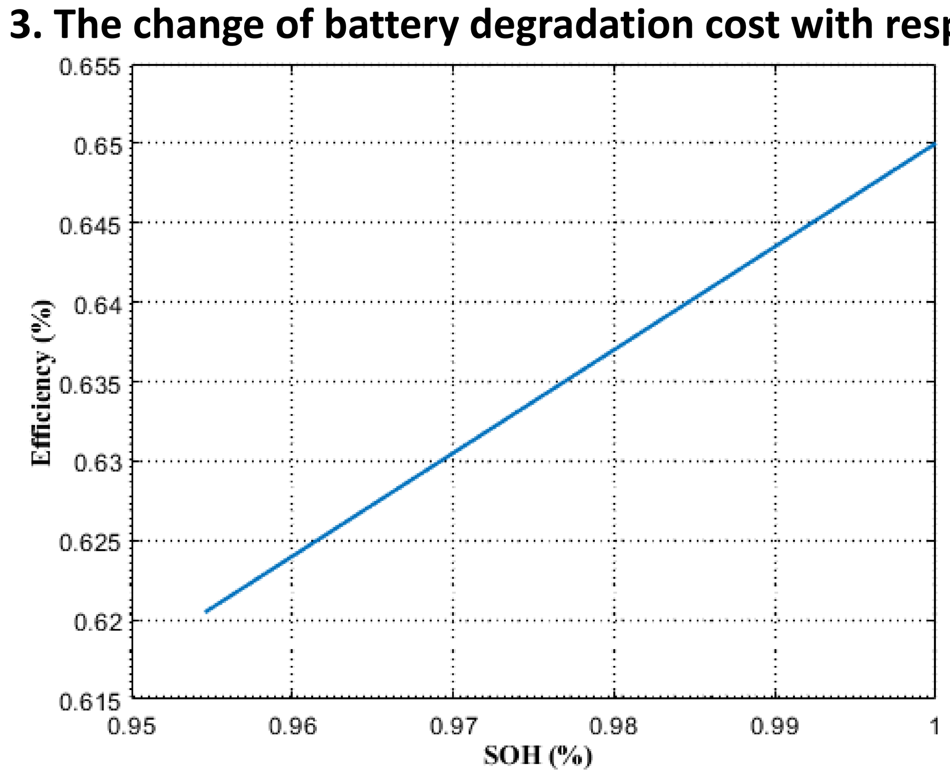

Fig 4. The change of the FC efficiency with respect to the change of its SOH

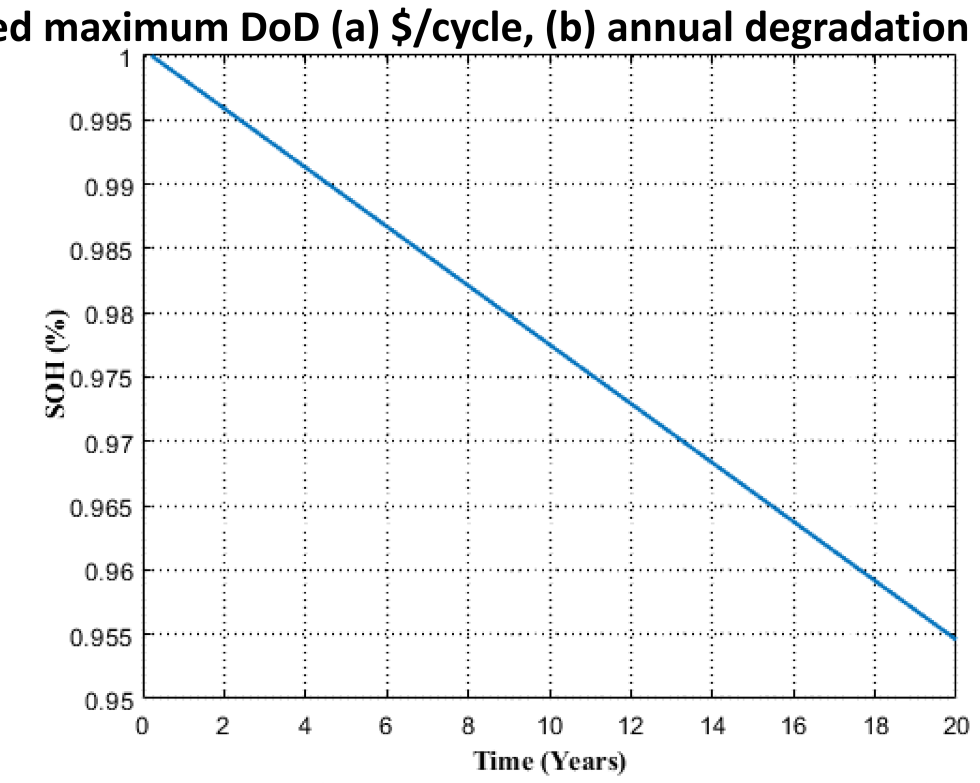

Fig 5. Evolution of Fuel Cell SoH over the project lifetime.

Table 1. Obtained optimal results

Technology	Energy Rating	Power Rating	Total MG Annual Cost
Lithium-Ion BT	8.40 (MWh)	2.231 (MW)	$2,334,907
FC	4.2875 (MWh)	1.0936 (MW)	$2,334,907

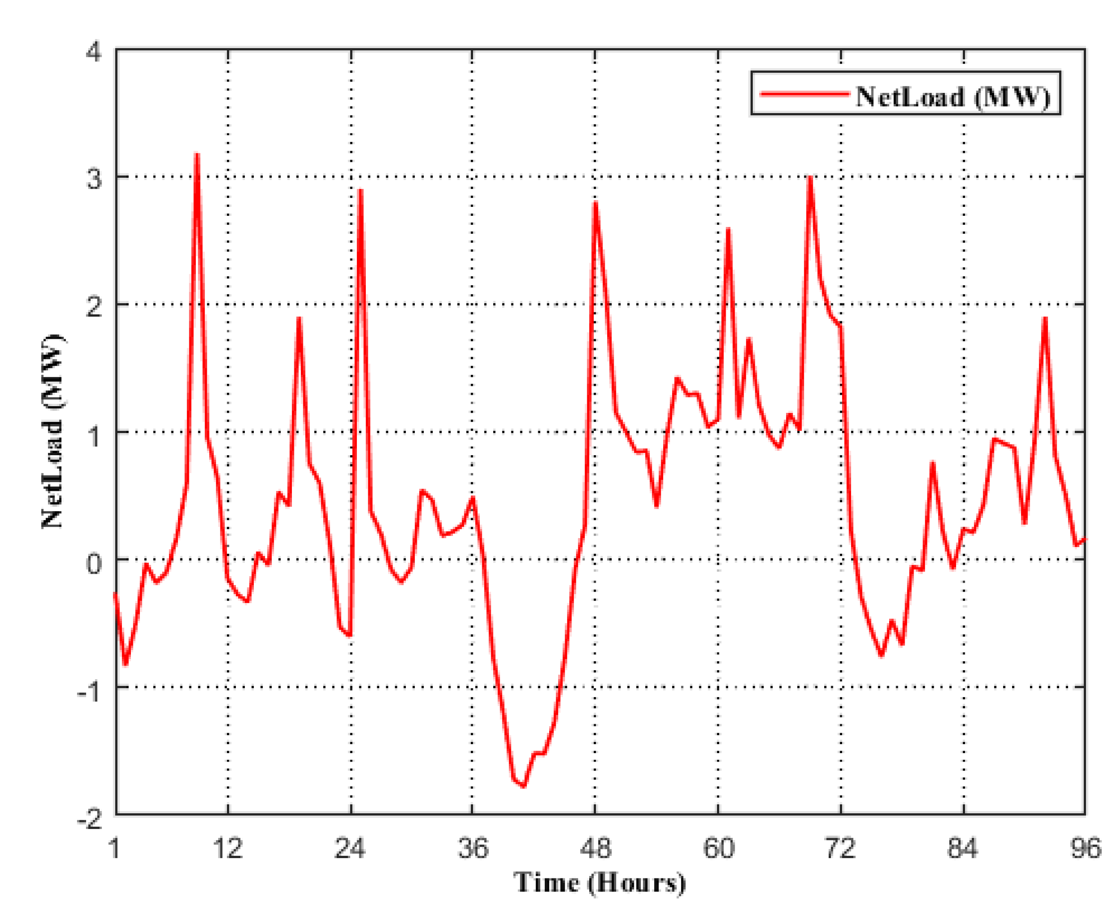

Fig 1. Netload profile

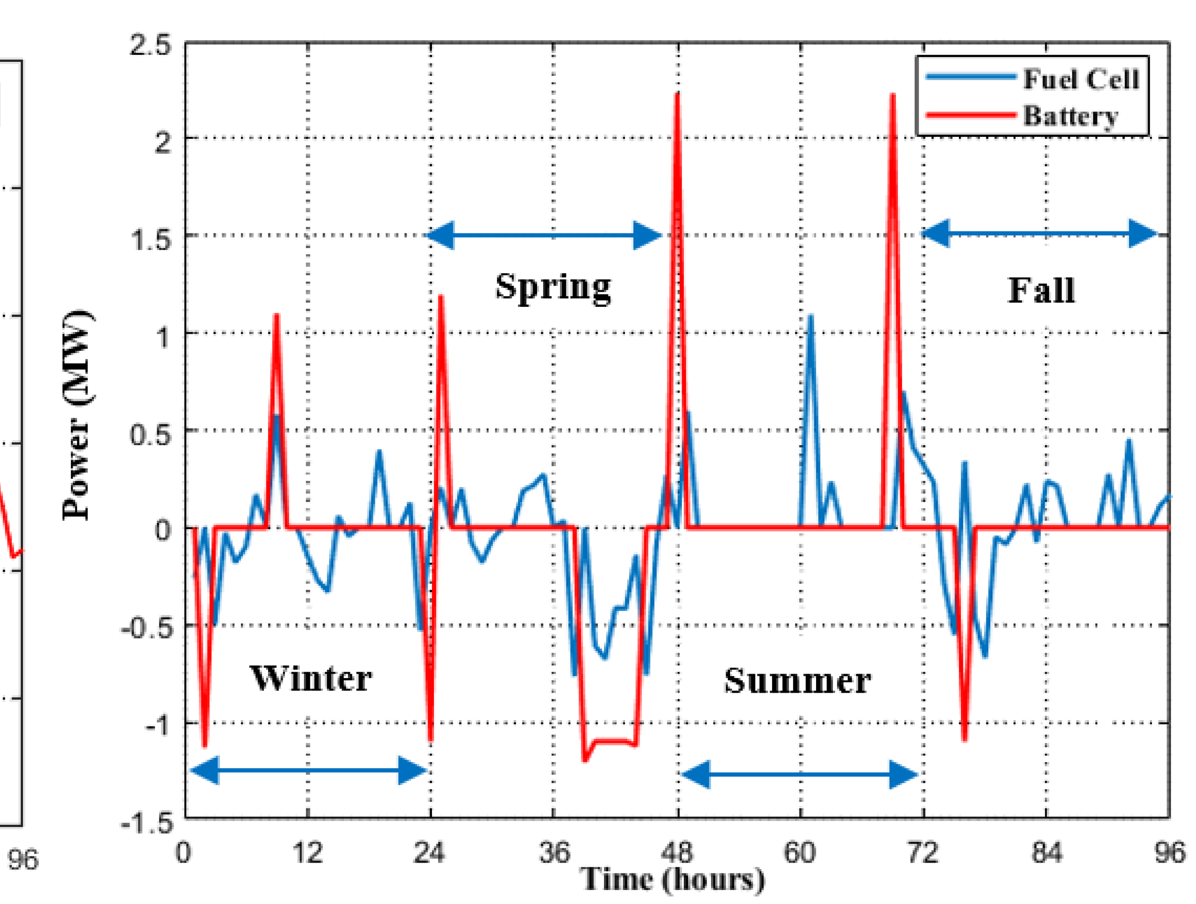

Fig 2. Hourly FC and battery power for representative 4 typical days.

Discussion:

- The optimal size of the hybrid system is found to be (2.231 MW, 8.40 MWh) for BSS and (1.0936 MW, 4.2875 MWh) for FC. The total annual microgrid expansion cost is $2,334,907.
- It was found that the model has successfully tracked the SOH of FC and it did not fall beyond the threshold value .The optimal management of FC has maintained a high energy efficiency over entire project lifetime, where the efficiency has dropped only 3% from 65% to 62% at the end of project lifetime. .
- The battery has performed 365 cycles/year which is within the maximum limit of 385 cycles/year at 30% maximum DoD. Furthermore, the model calculated the battery degradation cost per performed cycle using (32), which is found to be 655.044 $/cycle. Thus, the total annual degradation cost of the battery is found to be $329,090.

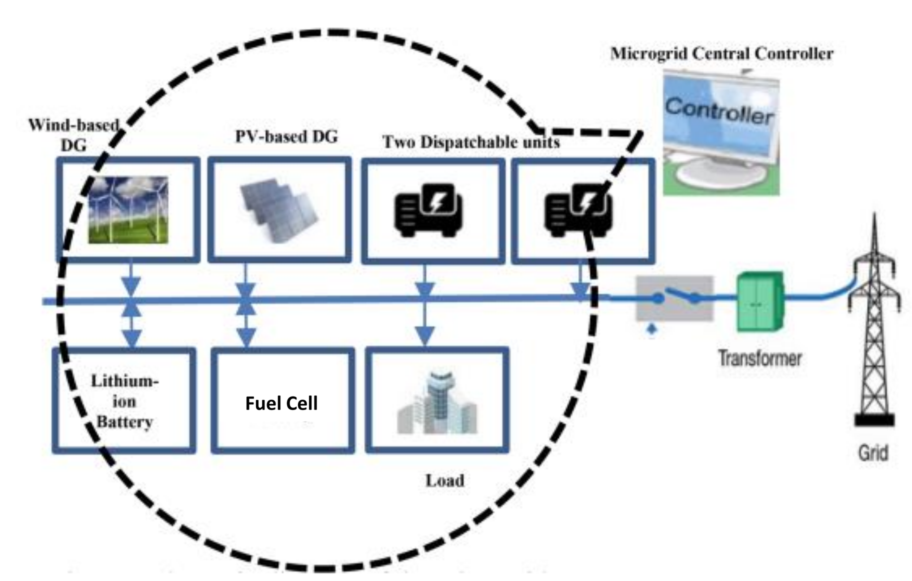

Fig 6. Microgrid Configuration
Source: https://building-microgrid.lbl.gov/about-microgrids

Conclusion:

- In this work we proposed a novel MILP model for optimal sizing and energy management of hybrid Fuel cell-lithium battery system for microgrid applications with an objective to minimize annual microgrid expansion cost.
- The simulation results have shown that the proposed model has effectively addressed both short and long-term storage requirements by combining the high energy density feature of FC and high-power density of battery technology.
- It was observed that the innovative idea of dispatching FC for small power periods has sustained and improved fuel cell efficiency over project lifetime. This advocates that understanding the mechanisms behind degradation and developing strategies to mitigate its effects are crucial for sustaining and improving fuel cell efficiency.