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

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The intermittent nature of sustainable energy sources, coupled with unpredictable variations in load, significantly impacts microgrid planning and operation. Consequently, there is a need for storage systems with both high energy and power handling capacities to coexist in microgrids. Therefore, hybridization of Fuel Cell (FC) and battery storage system (BSS) combines the advantages of both systems (high power density of the battery and high energy density of fuel cell). To this end, this paper proposes a novel model for optimal sizing and management of hybrid Fuel cell and lithium battery system for microgrid applications considering a tradeoff between high power density and high efficiency of the lithium battery and the high energy density, and lifetime of fuel cell. Furthermore, the proposed approach considers the investment and operating costs of the hybrid system, the fuel cell state of the health, battery degradation cost and the dynamic efficiency of fuel cell. The problem is formulated as Mixed Integer Linear Programming (MILP) optimization problem and simulation results have demonstrated the effectiveness of the proposed approach.

## 1. Introduction and Problem Statement

Microgrids can be defined as a small-scale power system consisting of renewable and nonrenewable distributed generation, energy storage systems (ESS), and electrical loads, and it can operate in grid-connected mode or in islanded mode when the grid tie is absent [1]. The integration of renewable energy resources in microgrids has become one of the attractive solutions for increasing the penetration of renewable energy resources into power grids. Higher penetration of renewable energy is an environmentally friendly solution and decreases the cost of microgrid systems. Intermittent renewable sources are typically highly variable depending on weather conditions, thereby necessitating the use of highly efficient and rapid response backup system to store the excess renewable energy and redispatch that energy during deficit power periods [2]. Therefore, it is essential to have both short-term and long-term energy storage systems (ESSs) [3]. While batteries are low-cost and suitable for short-term storage due to their low energy density and self-discharge [3], they have a short cycle lifetime and are not ideal for extended runtimes (due to their low energy density) [4]. On the contrary, hydrogen Fuel Cells (FC) emerge as a promising option among various long-term energy storage technologies. Hydrogen is produced through electrolysis, stored in storage tanks, and re-electrified by fuel cells for meeting electric and contractual demands [4]. This choice is appealing due to its environmental friendliness, extended lifetime compared to lithium battery, and high energy density [3], [4] [5]. However, its low efficiency at low power levels [4], and high capital cost compared to battery technology are significant drawbacks. Therefore, there is a need for developing novel hybrid storage models that optimally combine the advantages of both technologies for microgrid applications, which is the primary motivation for this work.

The rapid degradation of fuel cells increases hydrogen consumption which reduces fuel cell efficiency [6]. Therefore, it becomes imperative to incorporate the change of the dynamic efficiency of fuel cell with respect to the change of its state-of-the-health (SOH) in the development of planning and energy management models for grid applications. It should be noted that SOH is defined as the ratio between the storage capacity at a specific charge/discharge cycle and its initial rated capacity [7]. It is a quality indicator of the level of degradation and remaining capacity of the storage [7]. In all the aforementioned studies, and to the best of the authors' knowledge, the short- and long-term optimal energy management of both the hydrogen storage and the battery that simultaneously considers fuel cell state-of-the-health (SOH) and its impact on the fuel cell dynamic efficiency (increased hydrogen consumption with degradation), battery degradation cost, microgrid operation cost and storage investment cost have not yet been adequately addressed in a comprehensive planning model. A model that considers all aforementioned aspects while combining the advantages of both components, mainly the high-power density of batteries and the high energy density of fuel cells is crucial for promoting hybrid fuel cell-battery storage for microgrid applications. The work in [3], has shed lights on the short- and long-term optimal energy management of hybrid storage. However, optimal sizing of the hybrid storage is not considered. The work in [4] proposed a model for sizing backup fuel-cell/battery hybrid system. However, no optimization problem is formulated, and the sizing is done using available online tools. Furthermore, the fuel cell SOH is not calculated and considered in the proposed method. In addition, the lifecycle is assumed and not calculated based on the system operation which affects the solution accuracy. The work in [6] considers the degradation of fuel cell efficiency. However, they propose an adaptive energy management model that focuses on improving the fuel economy of a degraded fuel cell hybrid electric vehicle and it is not a planning model for grid applications.

## 2. Original Contribution

To address the above-mentioned research gap, this paper proposes a comprehensive model that determines optimal size of hybrid fuel cell-battery storage system for microgrid applications considering a trade-off between the advantage of both technologies (high power density of batteries and the high energy density of fuel cell). Furthermore, battery degradation cost, fuel cell SOH and its impact on its dynamic efficiency are calculated and incorporated in the model development.

The contribution of this work lies in:

• Develop a novel comprehensive planning and energy management model for sizing hybrid fuel cell-battery storage system with an objective to minimize hybrid storage investment cost and microgrid operation cost.

• The model uniquely aims to combine the long-term storage feature of fuel cell and short-term storage feature of battery to achieve both short-term and long-term hybrid energy storage system, which is essential for meeting the uncertainty of renewable generation and extending fuel cell efficiency.

• Battery degradation cost and SOH of fuel cell are calculated and incorporated in the model development, which helps in improving the decision-making processes for hybrid storage planning and operation. Furthermore, the impact of the change of fuel cell SOH on its dynamic efficiency is considered in the model development. To the best of the author's knowledge, this work is the only work (planning optimization model) that can track the change of the dynamic efficiency of fuel cell with respect to the change of its SOH and incorporate it for a comprehensive hybrid storage planning model for microgrid applications.

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