Iron-Sodium Batteries for Emissions-Free Backup and Load-Leveling at AI Data Centers

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***Abstract* — An emission-free, economic and flexible backup generator alternative with iron-sodium batteries reduces capital and operations expenditures through increased asset utilization from load leveling. The transition to 800 VDC architectures adds potential to smooth highly dynamic Artificial Intelligence (AI) workloads via DC/DC converters. Methods used include battery testing, economic analysis, and power system modelling.**

Keywords* — *iron-sodium battery, AI, load smoothing, data centers, resilience, backup power, battery energy storage systems

I. INTRODUCTION

Low-cost, long duration energy storage (LDES), enabled by iron-sodium batteries at ~$1000/kW for 24 hour duration installed capital expenditure, can replace diesel generators used in traditional data centers. Rising rack power densities drive a shift toward 800 VDC [1], and additional value is unlocked when the powertrain is simplified by consolidating traditionally separate functions [diesel gensets, short-duration battery storage, and uninterruptible power supply (UPS)] into a battery energy storage system (BESS), as shown in Fig 1. The iron-sodium BESS addresses three distinct time-scales:

- Backup alternative: fast responding >24 hour discharge.
- Peak shaving: 4-8 hour duration discharge flattens loads.
- Load smoothing: Sub-second response to AI load spikes.

The iron-sodium chemistry offers the unique set of characteristics that enables a simplification of the data center powertrain, while delivering the aforementioned functions. Iron-sodium's high round trip efficiency (>85%) coupled with low-cost active materials enables this uniquely affordable approach, capable of carrying highly variable loads, daily cycling, and long duration energy storage. The iron-sodium transition has the potential to disrupt the current cost model, aiming for a total system expenditure with 50% to 75% reduction compared to traditional diesel-backed architectures.

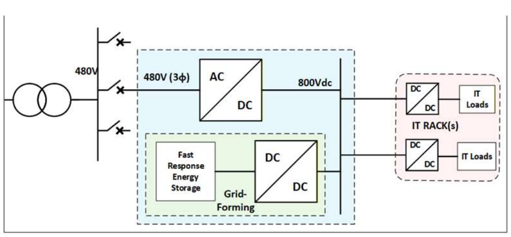

Fig. 1 A sample single line diagram of a DC microgrid.

II. BACKUP POWER

High reliability and availability requirements for data centers have traditionally been addressed using a combination of diesel generators and UPS bridging power. However, diesel generators are difficult to permit, polluting and noisy, require regular maintenance and suffer from complex fuel logistics [2, 3]. Iron-sodium BESS provides lower cost partial or total replacement for diesel generators up to 24-hour duration, as demonstrated in the capital expenditure (CAPEX) cost curve in Fig 2.

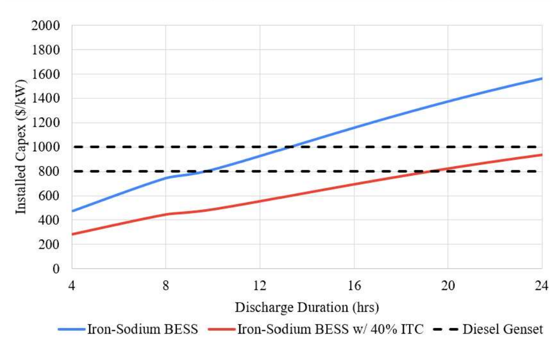

Fig. 2 Figure comparing the fully installed CAPEX-duration relationship of diesel genset [4] and iron-sodium BESS

Furthermore, when architected as an 800 VDC data center, the traditional rack adjacent UPS systems can be replaced with seamless, instantaneous response and simplified integration. This approach was modelled in PSCAD using a constant-power, fluctuating AI workload with a 1.07 MW peak and 0.8 MW average load. In the simulation, a 1.2 MW iron-sodium battery sized for 24 hours of backup power is able to successfully stabilize the DC bus during the grid interruption (Fig. 3), without the presence of a rack adjacent or centralized UPS.

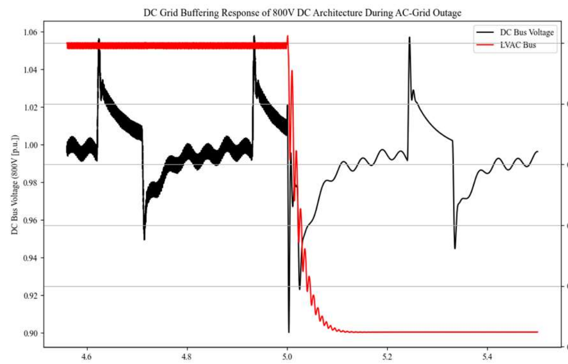

Fig. 3 UPS functionality provided by the grid-forming iron-sodium battery system after an AC grid outage, at 5 seconds.

III. Peak Shaving

Iron-sodium BESS is able to charge and discharge dynamically to level hourly and sub-hourly load fluctuations, which can maximize utilization of interconnection or on-site generation. In the exemplary powertrain, the iron-sodium BESS can be used in diurnal durations for load levelling without substantial losses. Depending on data center load factor, this functionality could unlock 20-50% higher interconnect or generation asset utilization. This reduction results in cost savings and potentially decreases time-to-power for utility service upgrades.

IV. Smoothing Sub-Second AI Workloads

An emerging challenge with AI focus data centers is synchronous GPU loads when running AI workloads. These large fluctuations in power threaten grid stability and extend interconnect study times. With an iron-sodium BESS sized for back-up duration, such loads can be easily buffered without meaningfully affecting back-up capability.

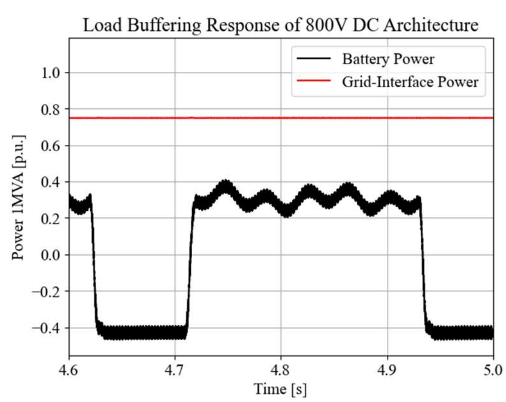

Fig. 4 A representative fluctuating AI load smoothed by iron-sodium batteries modelled in PSCAD.

To validate this, a representative AI workload with power fluctuations of up to 3A/us was simulated in the exemplary powertrain as shown in Fig. 1 [5]. The results of the simulation as shown in Fig. 4 show the grid interface load remaining stable while the BESS and coupled DC-DC converters buffer the power fluctuations by micro-cycling the BESS.

Most battery technologies experience accelerated degradation when subjected to highly dynamic load profiles. Traditional UPS systems need replacement much more often under these conditions, resulting in higher CAPEX and frequent maintenance. These rapid fluctuations in power place high stress and continuous capacity throughput on the batteries, leading to a reduction in overall performance.

To evaluate the iron-sodium battery degradation impacts to these demanding conditions, cell level cycling was conducted. The cell was subjected to a dynamic duty cycle consisting of a 0.5-second charge immediately followed by a 0.5-second discharge at 50% of state of charge. The charge and discharge powers were set at 130% of the nominal rate. After every ~2,500Ah micro cycling throughput the capacity of the cell was tested to evaluate capacity degradation. This rigorous micro-cycling validation confirms iron-sodium's capacity for sub-second load leveling, providing a solution to suppress GPU-induced transients and stabilize the grid interface.

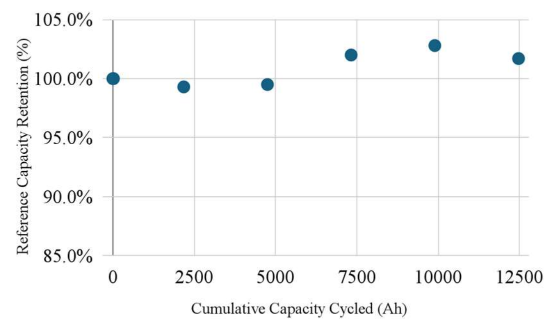

Fig. 5 Iron-sodium cell retaining capacity throughout cycles

V. Conclusion

Iron-sodium batteries are demonstrated as an emission free, low-cost, and flexible alternative to diesel generators in traditional data center architectures. By adopting 800 VDC microgrid architectures, data center developers will unlock access to a simplified and streamlined powertrain that will reduce time-to-power; result in savings in CAPEX, O&M, and electricity costs; and offer opportunities to participate actively in revenue generating electricity markets.

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