Abstract

Global transition to green energy has increased the demand for advanced optimization and control strategies in islanded DC microgrids. Hybrid Energy Storage Systems (HESS) are integral to DC microgrids. This research aims to enhance battery efficiency, dynamics performance, and response times for such HESS using novel control and optimization strategies. This research proposes a novel HESS architecture that integrates Nickel-Metal Hydride (Ni-MH) batteries and Electric Double-Layer Capacitors (EDLCs) to mitigate poor voltage instability and rapid battery degradation, particularly under transient load fluctuations and intermittent photovoltaic generation that plague prevalent HESS configurations employing Lithium-ion (Li-ion) batteries and supercapacitors.

To compare the performance of the two HESS configurations Maximum Power Point Tracking (MPPT) with Incremental Conductance (INC) algorithm, a State of Charge (SOC) management system, and Discrete-time Proportional-Integral (PI) techniques for DC voltage stabilization are studied with MATLAB/Simulink tool. Results justify the proposed HESS scheme with better response times.

Simulation results were then utilized with metaheuristic optimization algorithms PSO (Particle Swarm Optimization), ABC (Artificial Bee Colony), and GWO (Grey Wolf Optimizer) to address voltage instability, minimize energy dissipation, and optimize energy storage utilization. Out of the three, GWO demonstrated superior performance and performed the best in terms of settling time, peak overshoot, and battery efficiency.

Furthermore, hybrid optimization approaches leverage the strengths of individual algorithms while compensating for their weaknesses, ensuring improved convergence speed and solution accuracy. a novel hybrid optimization approach, combining Particle Swarm Optimization–Artificial Bee Colony (PSO-ABC) and Artificial Bee Colony–Grey Wolf Optimization (ABC-GWO), was implemented to address the identified limitations. Among these, the ABC-GWO hybrid optimization strategy yielded the best results, effectively balancing voltage stability, energy conversion efficiency, and battery lifespan. These findings underscore the significant advantages of the proposed Ni-MH and EDLC-based HESS over the traditional Li-ion-based systems, with battery efficiency is 85.58%, a settling time is 0.016 sec and a peak overshoot is 4.72%, promising a more efficient and resilient solution for DC microgrids in terms of voltage stability and battery lifespan.