

Abstract

This dissertation investigates optimal power flow (OPF) and energy management solutions for modern power grids integrating renewable energy sources and energy storage systems (ESS). It reviews traditional OPF algorithms and the necessary adaptations to accommodate distributed energy resources (DERs) and ESS. The growing importance of ESS integration in power systems is highlighted, as ESS can provide power support, voltage stability, and economic benefits. The report presents deterministic and non-deterministic optimization algorithms proposed for solving OPF and energy management problems in power systems with DERs and ESS.

An optimal energy management solution is proposed for grid-connected ESS, utilizing real-time energy prices and load forecasts. A graph search-based approach utilizing quadratic programming is implemented to minimize costs over a 24-hour horizon, considering energy prices, ESS state of charge, and load demand. The A* algorithm schedules day-ahead ESS operations with the leastcost dispatch. Several case studies are also conducted to ensure the solution's optimal response, including different step sizes, capacity, state of charge, etc. Additionally, to demonstrate its effectiveness,

it is also compared with other meta-heuristic methods like particle swarm optimization and genetic algorithms. The solution is implemented on a modified IEEE 123-bus distribution network with ESS, photovoltaics (PV), and dynamic loads, and validated through a Controller-Hardware-in-the-Loop test bed using a Digital Real-Time Simulator.

Furthermore, the report addresses the challenges of co-optimizing integrated transmission and distribution networks with ESS and PV. A hierarchical co-optimization framework, Q-learning based Analytical Target Cascading (ATC-Q), is proposed for solving combined Transmission and Distribution OPF (T&D OPF). The algorithm decouples time-domain constraints, formulating an optimal ESS queue based on current states and forecasts. ATC decomposes the two-stage stochastic

T&D OPF into a master problem and subproblem. The performance of the proposed method is evaluated by comparing different case studies, such as integrating multiple distribution units and using different price structures. The approach is validated on a modified IEEE 39-bus transmission network integrated with a 34-bus distribution system, incorporating PV, ESS, and dynamic loads.

Comprehensive case studies demonstrate reduced operational costs, optimal ESS scheduling, and enhanced network operation. The research also performed the security-constrained analysis of integrated transmission and distribution networks, utilizing a modified IEEE 14-bus transmission system interconnected with a 4-bus distribution network. By evaluating algorithm performance under various contingencies, like bus outages and generator failures, it offers a robust framework for managing increasingly complex modern power systems with improved resilience and economic performance.

Moreover, the proposed algorithm is validated using a digital real-time simulator setup. The algorithm is implemented in Python/Matlab on an external computer serving as the controller with IEEE 1815 DNP3 communication protocol. In both offline and real-time simulations, similar results were obtained, confirming that the proposed algorithm is cost-effective and suitable for real-time applications.