



Synopsis of the thesis entitled

Control and Optimization of Hybrid Energy Storage System in Microgrid

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by

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Introduction

Rapid variations in source power and load demand for isolated DC microgrids affect the DC link voltage [1]. A SOC-based power management technique for coordinated control of an isolated DC microgrid maintains almost constant DC link voltage with variation on the source side [2] and load side [3]. Therefore, the battery should be capable of absorbing transients and maintaining DC link voltage for a longer period. If SOC of the battery crosses the safety limits, the controller stops charging and discharging, leading to a deterioration of working capacity of the battery. In this situation, regulating DC link voltage using a single storage device becomes highly difficult and leads to peak overshoot, high settling time, and lower state-of-charge (SOC) [4]. A single Energy Storage (ES) may not be relied on to provide adequate power dynamics to compensate for the voltage fluctuation [5][6].

Problem Statement:

During rapid load variations in DC microgrids, voltage fluctuations significantly challenge voltage stability and reliability [7]. Traditional Hybrid Energy Storage Systems (HESS), which combine lithium-ion (Li-ion) batteries with Li-ion supercapacitors, have been employed to mitigate these issues, however, they suffer from several limitations, including slow response times, inconsistent voltage regulation, and accelerated battery degradation caused by frequent charging and high discharge rates.[8][9]. Although Li-ion batteries have a high energy density for long-term storage, they are not designed to withstand abrupt changes in load power [10]. Conversely, Li-ion supercapacitors, while faster than batteries, still struggle with limited power density and a shorter cycle life.

A novel HESS configuration combining Nickel-Metal Hybrid (Ni-MH) batteries with Electric Double-Layer Capacitors (EDLC) supercapacitors is proposed in this research as an innovative approach to overcome the above limitations.

Research Objectives

The objectives and scopes of the research work are as follows:

- To minimize response time of HESS.
- To minimize voltage fluctuations in the DC bus system.
- To improve battery efficiency.
- To minimize discharging period of battery.

The work described in the thesis includes:

A DC microgrid is designed to simulate voltage variations caused by load variations or transient events. Efficient methodologies are proposed to manage the power and State of Charge (SOC) of the energy storage system in the DC system. Logic-based control for SOC management through higher and lower limits based on a seamless transition to the load. Hysteresis control strategies for reducing voltage fluctuation in the DC bus system as well as improving the response time of the energy storage devices.

PI controller stabilizes the DC microgrid system during fluctuating load demands. Results show the maximum power output from the MPPT controller with discrete PI control strategies. Renewable Energy Source data are generated from a 15kw PV panel demonstrator. For detailed analysis, this is further divided into different cases.

In Case 1, the battery and supercapacitor would not be charged or discharged, and the PV supplies the load power at the maximum power output when the DC bus voltage is near the ideal value.

In Case 2, load power is larger than the PV maximum output power, but still within the maximum power from the PV and battery can supply in combination. So, the MPPT control loop would be enabled to utilize most of the solar energy under specific irradiance and temperature conditions. In the meantime, the battery would be operated in discharging mode to supply a part of the load power and maintain the DC bus voltage. Results show that the response time of 0.3 sec with a 17.72% overshoot in DC bus voltage.

In Case 3, during the sudden variation in load demand, the supercapacitor supplies the deficit power for a short duration until the battery can be regulated. Results show that the use of a Hybrid energy storage system in this case minimizes the response time to 0.1 sec with a 6.51 % overshoot in DC bus voltage.

In case 4, the battery and supercapacitor would not be fully discharged, and the PV supplies minimum power. In this type of situation, the fuel cell works as a standby option.

Now, an optimization model is developed to minimize power discharge from the battery as well as minimize the voltage fluctuations in the DC bus using the data from the simulation results and evaluated with parameters such as overshoot and settling time.

Optimization results show that PSO (Particle Swarm Optimization) minimizes the overshoot to 13% with a settling time of 0.3 seconds and discharge power from the battery is 7156.72W with an efficiency of 75%. ABC (Artificial Bee Colony) minimizes the overshoot to 8.95% with a settling time of 0.4 seconds and the discharge power from a battery is 7156.72W with an efficiency of 72% and GWO (Grey Wolf Optimization) reduces 6.5% overshoot and 0.2 seconds settling time and discharge power from the battery is 5327.19 W with an efficiency of 81%. Thus, GWO emerges as the superior algorithm for combined minimization of overshoot and settling time while ensuring good steady-state and dynamic responses of the system.

Two novel hybrid optimization models with PSO-ABC and ABC-GWO are developed to minimize voltage fluctuations and improve battery efficiency. For hybrid optimization, the maximum iterations were set to 50 and 100 respectively. Analysis shows that PSO-ABC reduces the overshoot to 7% with a settling time of 0.1 second and discharge power from the battery 5984.16 W with an efficiency of 78% as well as ABC-GWO reduces the overshoot to 4.72% with a settling time of 0.2 second and discharge power from the battery 4314.63W with an efficiency of 85.5%.

Therefore, DC bus voltage is maintained and the response time of the hybrid energy storage system is improved, increasing overall system stability and reliability. Optimization methods such as particle swarm optimization, artificial bee colony optimization, and grey wolf optimization are used to maximize battery efficiency and minimize power discharge from battery periods. PSO-ABC and GWO-ABC are hybrid optimization techniques that extend battery lifespan and reduce voltage fluctuation.

A brief description of the research work reported in the thesis is given below:

Chapter 1: Introduction

This chapter describes the brief history and overview of the research problem. It also introduces the objectives of the research work and the scope of the improvement in existing methods.

Chapter 2: State of Art

This chapter covers a literature assessment of DC microgrid control under various scenarios.

Chapter 3: Modeling and Design of DC Microgrid with HESS

This chapter presents the design and modeling of a DC microgrid integrated with a Hybrid Energy Storage System (HESS). It includes the architecture and dynamic models of batteries and supercapacitors

Chapter 4: Simulation and Control of Novel HESS Configuration

This chapter covers the simulation of a new HESS configuration and its control strategies. Various methods are used to manage energy flow under dynamic operating conditions.

Chapter 5: Metaheuristic Controller Optimization for HESS

This chapter applies metaheuristic algorithms like PSO, ABC, and GWO to optimize HESS controllers. It aims to enhance system response, stability, and energy efficiency.

Chapter 6: Hybrid Optimized Controller for HESS

This chapter develops a hybrid control approach combining optimization and control strategies. Simulation results show improved performance over conventional methods.

Chapter 7: Conclusion and Future Scope

Concludes with the remarks regarding proposed solutions and their applicability under various situations. Future work in the area is also suggested.

The thesis ends with a complete bibliography and list of my publications.

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LIST OF PUBLICATIONS

International peer-reviewed journals

1. Kinjal R. Patel, Jagrut J. Gadit “Power Management and Control of Hybrid Energy Storage System in A Standalone DC Microgrid” Journal of Alternate Energy Sources & Technologies,2024; 14(3): 41–52p.DOI: 10.37591/Jo aest, ISSN: 2230-7982
2. Kinjal R. Patel, Ruchi M. Sadhu, Jagrut J. Gadit, “Energy management using hybrid energy storage system in DC microgrid: A Review” Trends in Electrical Engineering, April 10, 2024; 14(1): 37–43p.

International conferences

1. Kinjal R. Patel, Jagrut J. Gadit “Power management and Control of Hybrid Energy storage system in a Standalone DC Microgrid” International Multidisciplinary Conference on Emerging Trends in Sustainable Development, Mahuva,15th February 2024, Awarded as “BEST RESEARCH PAPER” ISBN: 978-81-952901-7-8
2. Kinjal Patel, Dr. Jagrut J. Gadit “A novel approach for power management Strategies on Hybrid Energy Storage Systems in DC Microgrid "National Conference IETE NTPC PRECCON-2024 on Recent Trends in engineering and technology, Loni, MH-India, April 1st and 2nd,2024
Book Name: [A Hybrid Mode: National Conference on IETE-National Technical Contest-2024 on “Recent Trends in engineering and technology”](#) ISBN: 978-93-340-3017-4
3. Kinjal R. Patel, Jagrut J. Gadit, “Modelling and simulation of a Hybrid Energy Storage System for DC Microgrid” International Conference on Paradigms of Communication, Computing and Data Analytics: PCCDA 2024, April 21st,2024
Book Name: [Algorithms for Intelligent Systems](#), Springer Book series
ISBN: 2524-7573, Published in *Web of Science*
4. Kinjal R. Patel, Ruchi M. Sadhu, Jagrut J. Gadit, Energy management using hybrid energy storage system in DC microgrid: A Review. Trends in Electrical Engineering, First International Multidisciplinary Conference on Emerging Trends in Sustainable Development (IMCETSD), 15th and 16th February 2024. ISBN: 978-81-952901-7-8

Communicated papers in international journals (under review)

1. Kinjal Patel and Jagrut J. Gadit “Design of DC microgrid using a Composite Energy Storage System Involving Battery -Supercapacitor based energy management system”, Journal of Electrical Systems (JES), -- Scopus Indexed
2. Kinjal Patel and Jagrut J. Gadit “A Battery based Energy Management System for DC microgrids Battery -Supercapacitor based energy management system”, Journal of Engineering Research (JER), --Scopus Indexed
3. Kinjal Patel and Jagrut J. Gadit “Power Control and Optimization in DC Microgrids: A Harmonious and Effective Approach”, 5th International Conference on Advanced Engineering Optimization Through Intelligent Techniques (AEOTIT), 28-30 November 2024, SURAT. --Scopus Indexed

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Endorsement of Supervisor; Synopsis is approved by me

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