"CONTROL AND OPTIMIZATION OF HYBRID ENERGY STORAGE SYSTEM IN MICROGRID"

A thesis submitted for the award of
the Degree of

Doctor of Philosophy

in

Electrical Engineering

By

PATEL KINJAL RAMESHBHAI

(FOTE/1098)

Under the guidance of

Dr. JAGRUT J. GADIT

DEPARTMENT OF ELECTRICAL ENGINEERING
FACULTY OF TECHNOLOGY AND ENGINEERING
THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA, VADODARA

February 2025

DEPARTMENT OF ELECTRICAL ENGINEERING
Faculty of Technology and Engineering,
The Maharaja Sayajirao University of Baroda,
Kalabhavan Vadodara-390001, Gujarat, India

Date: 08/02/2025

CERTIFICATE

This is to certify that the Ph. D. thesis entitled **"Control and Optimization of Hybrid Energy Storage System in Microgrid"** submitted by **Ms. Kinjal R. Patel**, (Registration No. **FOTE/1098**, dated **21/02/2022**) as part of the fulfilment of requirements for the award of the degree of DOCTOR OF PHILOSOPHY in Electrical Engineering, represents the work carried out in the Department of Electrical Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. The content presented in this Ph. D. thesis incorporates the original findings of independent research work carried out by the candidate herself. The content of this thesis has not been submitted elsewhere for the award of any degree.

10/2/2025

GUIDE

Dr. Jagrut Gadit

Associate Professor
Department of Electrical Engineering
Faculty of Technology & Engineering
The Maharaja Sayajirao University of Baroda

Sorum Kotia

HEAD

Dr. Sorum Kotia

Department of Electrical Engineering
Faculty of Technology & Engineering
The Maharaja Sayajirao University of Baroda

DEAN 10/2 10/2

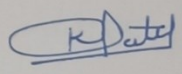
Faculty of Technology & Engineering
The Maharaja Sayajirao University of Baroda
Vadodara-390001

Declaration

I, Kinjal R. Patel, hereby declare that the work presented in this thesis, entitled **"Control and Optimization of Hybrid Energy Storage System in Microgrid"** submitted in partial fulfillment of the requirements for the award of the degree of ***Doctor of Philosophy*** in the Department of Electrical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, Vadodara, is original and has been conducted and presented in adherence to academic integrity and ethical standards.

I confirm that this work has not been previously submitted for any academic qualification, nor has it served as the basis for awarding any degree or diploma to me or any other individual at this or any other university or institution.

Any exclusion, that might have occurred by oversight or error, is regretted.



Kinjal R. Patel

February 2025

Dedicated

To my Maternal **G**randparents, **M**om, and **D**ad, for their unwavering love, support, and guidance. This achievement is a reflection of your endless encouragement.

Acknowledgment

The fulfillment of completing my Ph.D. thesis would be incomplete without acknowledging those who have been pivotal to this journey. With immense gratitude, I express my sincere appreciation to everyone who has offered invaluable guidance, unconditional support, and constant encouragement along the way.

First and foremost, I owe this achievement to the grace and blessings of GOD, whose strength has been my unwavering foundation throughout this work.

I extend my heartfelt gratitude to Dr. Jagrut Gadit, whose enduring support, mentorship, and motivation have been instrumental in shaping my research. His guidance, insight, and patience have been a continuous source of inspiration, and I am deeply indebted to him for his invaluable contributions.

I am sincerely grateful to Dr. Sorum Kotia, Head of the Department of Electrical Engineering, Faculty of Technology and Engineering, Vadodara, for her assistance when required. I am truly grateful to Prof. Dhanesh Patel, the Dean of the Faculty of Technology and Engineering, Vadodara, for creating a supportive research environment and offering all the necessary assistance throughout my research work. I owe my gratitude to Dr. Pramod S. Modi, and the other committee members for their valuable suggestions and steadfast support throughout my research journey.

I sincerely appreciate Dr. Nehal G. Chitaliya and Dr. Ashish Patel for their continuous moral support and encouragement throughout my research work. I am truly grateful to my confidant for his constant encouragement and support. His belief in me, even from a distance, has been a powerful source of inspiration and strength throughout this journey.

I am deeply grateful to my Grandparents for their blessings, without which this research would not have been possible. I also wish to express my heartfelt thanks to my mother, Kaushika Ben, and my father, Rameshbhai whose endless love, sacrifices, and unwavering support have been my strength and motivation throughout this journey. Their belief in me has made this achievement possible. Equally, I am thankful to my sister, Riya, and my brother, Meet, for their continuous encouragement, understanding, and motivation, all of which have been crucial in making this accomplishment a reality.

I am deeply appreciative of my maternal family, Mr. Rakesh Patel and Mr. Nirav Patel, for their constant love, support, and belief in me. Their abiding presence has been a tremendous source of strength. I am truly grateful to Ms. Hansaben M. Patel for their invaluable contributions in my journey..

I sincerely thank all who have contributed, both directly and indirectly played significant role during my research work.

Kinjal Patel

List of Figures

List of Tables

List of Abbreviations

PV	Photovoltaic
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
INC	Incremental Conductance
PSO	Particle Swarm Optimization
GWO	Grey Wolf Optimization
ABC	Artificial Bee Colony
MATLAB	Matrix Laboratory
DCMG	Direct Current Microgrid
HESS	Hybrid Energy Storage System
SOC	State of Charge
ELDC	Electrochemical Double Layer Capacitor
ESS	Energy Storage System
RES	Renewable Energy Sources
PWM	Pulse-Width Modulation
PI	Proportional-Integral
PID	Proportional Integral Derivative