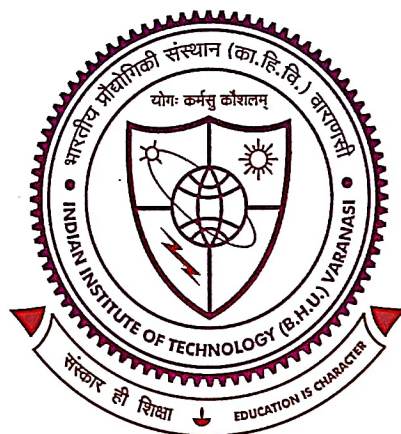


Material Development for Electro-Catalysis and System-Level Integration for Future Hybrid Energy Systems



Thesis submitted in partial fulfillment for the
Award of Degree

Doctor of Philosophy

By

Modalavalasa Udaya Bhaskara Rao

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
INDIA


Roll No. 20081507

Year 2025

CERTIFICATE

It is certified that the work contained in the thesis titled '**Material Development for Electro-Catalysis and System-Level Integration for Future Hybrid Energy Systems**' by **Modalavalasa Udaya Bhaskara Rao** has been carried out under my supervision and this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of comprehensive examination, Candidacy and SOTA for the award of Ph.D. Degree.



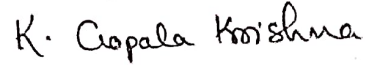
Prof. R. K. Saket

(Supervisor)

Department of Electrical Engineering
Indian Institute of Technology(BHU),
Varanasi- 221005 (UP), India

आचार्य / PROFESSOR

विद्युतीय अभियांत्रिकी विभाग/Department of Electrical Engineering
भारतीय प्रौद्योगिकी संस्थान/Indian Institute of Technology
(काशी हिन्दू विश्वविद्यालय)/(Banaras Hindu University)
Varanasi, U.P. (INDIA)



Dr. K. Gopala Krishna

(Co-Supervisor)

Chief Scientist,
CSIR-National Metallurgical Laboratory,
Jamshedpur, Jharkhand, India

DECLARATION BY THE CANDIDATE

I, 'Modalavalasa Udaya Bhaskara Rao, certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of 'Professor R.K. Saket' from Decemeber 2020 to August 2025, at the 'Department of Electrical Engineering', Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research worker wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, thesis, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date: 14/08/2025

Place: Varanasi

M. Udaya Bhaskara Rao
(Modalavalasa Udaya Bhaskara Rao)

CERTIFICATE BY THE SUPERVISOR

It is certified that the above statement made by the student is correct to the best of my/our knowledge.

R. K. Saket
08/10/2025

Prof. R. K. Saket
(Supervisor)

Department of Electrical Engineering
Indian Institute of Technology(BHU)
Varanasi-221005 (UP), India

R. K. Saket
8/10/25

Signature of Head of Department
आचार्य व दिनांक
विद्युतीय अभियांत्रिकी विभाग / Department of Electrical Engineering
भारतीय प्रौद्योगिकी संस्थान / Indian Institute of Technology
(काशी हिन्दू विश्वविद्यालय) / (Banaras Hindu University)
Varanasi, U.P. (INDIA)

COPYRIGHT TRANSFER CERTIFICATE

Title of the Thesis: "Material Development for Electro-Catalysis and System-Level Integration for Future Hybrid Energy Systems".

Name of the Student: **Modalavalasa Udaya Bhaskara Rao.**

COPYRIGHT TRANSFER

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University), Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the Doctor of Philosophy.

Date: 14/08/2025

Place: Varanasi

M. Udaya Bhaskara Rao
(Modalavalasa Udaya Bhaskara Rao)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the institute's copyright notice are indicated.

ACKNOWLEDGEMENTS

With great pleasure, I would like to convey my sincere gratitude to my supervisor **Prof. R. K. Saket**, Department of Electrical Engineering, Indian Institute of Technology (BHU), Varanasi (UP), India, for being my parent during research work and providing me invaluable guidance, scientific supervision, feedback, motivation and countless constructive discussions for improving the quality of my work. I have earned many professional skills, numerous moral and ethical values from him. I pray to God to carry all those values throughout my life.

Besides my supervisor, I am highly thankful to my Co- Supervisor **Dr. Gopala Krishna** for constantly encouraging and guiding me throughout the tough times. I am fortunate to have RPEC members viz., **Prof. R.K. Srivastava**, Department of Electrical Engineering, IIT (BHU) and **Prof. M.K. Meshram**, Department of Electronics Engineering, IIT (BHU) for their insightful comments and encouragement.

I extend my heartfelt gratitude to the Head of the Department, **Prof. R.K. Singh**, and all the faculty members of the Electrical Engineering Department, IIT (BHU) Varanasi, for their guidance. I would like to express my special thanks to **Prof. Ranjit Mahanty**, **Dr. Sandip Ghosh**, **Dr. V.N. Lal**, **Dr. J.C. Pandey** and **Ms. Sobhita Mehar**, **Dr. Zaheer Mohd Khan Yusufzai** for the valuable knowledge and subject concepts they imparted, which played a significant role in shaping my research work.

I am truly indebted to **Dr. Sandip Ghosh Chowdhury**, Director, CSIR–National Metallurgical Laboratory, and **Dr. Indranil Chattoraj**, Former Director, CSIR–NML, for providing the research facilities and financial support that enabled the successful completion of my work. I also extend my heartfelt thanks to **Dr. Prem Kumar Murugayan** and **Dr. Animesh Jana** for their generous support, invaluable knowledge sharing, and unconditional access to research facilities. My gratitude is further due to **Dr. Dhanunjaya Rao Mudila**, **Dr. Shailendra Kr. Jha** for their constant guidance and help to understand key concepts.

I am deeply grateful to the staff members of the CSIR-NML Engineering Division for their unwavering support. My special thanks go to **Mr. Sanjay Kumar**, **Mr. B.M.S. Rao**,

Mr. Pothal, Mr. Raushan Kumar, Mr. Amit, Mr. Ansari, Dr. Niami Haldar, Ms. Y. Usha, Mr. Roshan Kumar, Mr. Pankaj, Mr. Manoj, Mr. Purthi, Mr. Dilip, Dr. P. Pal, Mr. Shalendra Kumar, Mr. R. R. Srivastava, Dr. Rachit Ghosh, Mr. Chakraborty, and Mr. Prakash for their tireless assistance. I am especially indebted to my past senior colleagues in the division Dr. Rajneesh Kumar Gupta, Mr. I. B. Mishra, and Mr. P. K. Dhawan and my dear seniors of UBC Convent for their constant encouragement and valuable guidance.

I am also deeply grateful to colleagues from CSIR-NML- Dr. Biraj Kumar, Dr. Snehashish, Dr. Ganesh, Mr. Ramesh, Dr. Saurav, Dr. Rajini Kant, Dr. Ashok, Dr. Madan, Dr. Krishna Kumar, Dr. Kuldeep S. Gour, Dr. Ammasi, Mr. Sudhakar, Dr. Sudhakar, Mr. Seshagiri and Mr. Lalit for their generous support in providing research facilities, as well as for their wisdom, guidance, and encouragement.

A very special gratitude goes to my besties Mr. K. Bhaskar Rao, Mr. S. Togula Reddy who always inspires me with their thoughts and deeds, with special appreciation for Dr. Saumya, Ms. Smriti Singh, Ms. Jyoti Maurya, Ms. Anchal Verma, Ms. Anchal Singh S. Vardhan, Mr. Harsh Srivastav, and Dr. Abhishek, Mr. Vamsi Krishna for their unwavering support and companionship.

Last but certainly not least, I express my deepest gratitude to my mother, my wife, brother, sister, kids, In-laws and all other family members for their unwavering support and encouragement in pursuing my passions. They have been my constant source of motivation through every success and setback, and their faith in me has always been the foremost driving force behind my efforts. No words can truly convey the depth of my indebtedness to them, and I pray that their blessings remain with me always. Finally, I extend my heartfelt thanks to the unseen divine power for blessing me with the inner strength, clarity, and determination that guided me throughout this academic journey.

Date: 14/08/2025

M. Udaya Bhaskara Rao
Modalavalasa. Udaya Bhaskara Rao