Design of Converter Configurations and Control Structures for Hybrid Energy Storage Interfaced Renewable Microgrid

A THESIS

submitted by

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for the award of the degree

of

DOCTOR OF PHILOSOPHY

SCHOOL OF COMPUTING AND ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY MANDI

JANUARY 2021

To My Family and Well-wishers

THESIS CERTIFICATE

This is to certify that the thesis entitled **"Design of Converter Configurations and Control Structures for Hybrid Energy Storage Interfaced Renewable Microgrid"** submitted by **Ravada Bhaskara Rao** to the Indian Institute of Technology, Mandi for the award of the degree of Doctor of Philosophy is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Place: Mandi
Date: 08.01.2021

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DECLARATION BY RESEARCH SCHOLAR

I hereby declare that the entire work embodied in this thesis is the result of investigations carried out by me in the School of Computing and Electrical Engineering, Indian Institute of Technology Mandi, under the supervision of Dr. Narsa Reddy Tummuru, and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgments have been made wherever the work described is based on finding of other investigators.

IIT Mandi, Kamand

Date: 08/01/2021

Signature

(RAVADA BHASKARA RAO)

ACKNOWLEDGEMENTS

I take this opportunity to acknowledge my heartfelt gratitude to all those people who directly or indirectly helped me to carry out this research work successfully.

I am heartily thankful to my supervisor, Dr. Narsa Reddy Tummuru, whose encouragement, guidance and support through out my research work enabled me to develop an understanding of the subject. I appreciate his sincere help in terms of contributions of time, ideas so as to make my Ph.D. experience stimulating and productive. The joy and enthusiasm that he has for his research was contagious and motivational for me, even during tough times in the Ph.D. pursuit. I express my gratitude for his willingness to help and timely advices on issues, even beyond the scope of doctoral studies.

I am very much thankful to Prof. Ramesh Oruganti for his encouragement. His nature of asking questions has always helped me to progress in the right direction. He was always there to give suggestions and hold discussions on my research work.

I would like to acknowledge the financial, academic and technical support of the Indian Institute of Technology Mandi for this research. I am thankfully to Dr. Bharat Singh Rajpurohit and Dr. Samar Agnihotri., Chair persons of the school during the course of my study. I am sincerely grateful to Dr. Tushar Jain, Dr. Himanshu Misra, Dr. Ankush Bag, and Dr. Rik Rani Koner, for assessing the work and giving invaluable suggestions as members of Doctoral committee.

The members of our research group have contributed immensely to my personal and professional time during my stay in the institute. The group has been a source of friendships as well as good advice and collaboration. I especially thank Dr. Adil Usman, Dr. Rajesh Pindoriya and Mr. Neelesh for their valuable advices during my course of research and personal life. I am extremely thankful to the supported extended by the friends Mr. Ravi Teja, Mr. Bala Naga Lingaiah, Mr. Sachin, Mr. Ritwik, Mr. Bharat, Ms. Akansha during the course of my stay in the research laboratory. Thanks are also due to Mr. Ashok Mr. Rajineesh, Mr. Gaurav, Mr. Manoj , Mr. Ranjit, Mr. Trivendar, Mr. Nagraju, Mr. Chanakya, Mr. Madhu, Mr. Eswar, Mr.pramodh and Ms.

jeevita who have given me company and moral support in the campus and made the residence as a pleasant experience.

I would like to express gratitude to the services being offered by Mr. Arun Kumar, Mr. Tharun, Ms. Tharuna Kumari staff of laboratory and , Ms. Rakhi office staff of School of Computing and Electrical Engineering.

Last but not the least I would like to thank my family, my parents who educated me, for always believing in my capabilities and for encouraging me to pursue my dreams. Especially my mother, for unconditional support and encouragement, for listening to all my problems and frustrations very patiently and for always being there for me during good and bad times. I thank my cousins, for their loving care and support all these years and my brothers, for motivating me to carry out research and for cultivating a challenging nature in me ever since my childhood. Without them I would not be in the position, where I am today.

Ravada Bhaskara rao

ABSTRACT

KEYWORDS: Battery, FCS-MPC, HESS, IDA-PBC, Multi-port converter, Power management scheme, PV, Supercapacitor, and Wind power.

The intensive demand for hybridization of energy storage devices and renewable power sources such as PV/wind, battery/supercapacitors, necessitate significant research on interfacing converters configurations, control structures, and power sharing schemes. Appreciable research has been done and reported in the literature regarding the interfacing configurations and control structures. The interfacing configurations reported consists a dedicated converter for each source, leads to complexity in the control structure, lower utilization, higher cost, and less efficiency. Hence, several multi-input converter configurations that can address the above-mentioned issues are reported in literature. However, these are not capable of interfacing hybrid energy storage. The control structure reported consists a multiple numbers of PI controllers which makes designing/tuning of all the controllers complicated. Moreover, hybrid energy storage non-linearity cannot be handled. Therefore, a research urgency in developing a novel multi-source converter configurations and non-linear control structures is spotted. Hence, this work concerns, the electrical design of efficient converter configurations and effective control structure for the synergy of PV, wind, battery, and supercapacitor.

Anent the design of interfacing converter configurations, a novel isolated and non-isolated multi-source DC-DC converter configurations for the synergy of PV, Wind, battery, and supercapacitor is proposed and validated experimentally. The comprehensive design, modeling, and analysis of the proposed configurations are carried out. Make use of the proposed DC-DC converter configurations, a grid-interactive microgrid system consisting of Photovoltaic (PV), wind, and Hybrid Energy Storage (HES) is developed. The controller is designed along with a power-sharing scheme to operate the system under various operating modes such as (i) Grid-connected and Islanded modes, (ii) state of charge of battery less than or greater than specified limits, (iii) Operating renewable sources (PV and wind) at maximum power point and charging/discharging of energy

storage based on power availability.

Focusing on the control structure, a conventional PI-based control structure is designed and implemented for a stand-alone DC renewable microgrid. It is observed that conventional PI-based linear controllers are designed around a single operating point. However, due to self-discharge or frequent discharge during operation, supercapacitor voltage can reach the lowest value which adversely affects controller performance, even makes the system unstable. Therefore, a robust non-linear controller (Interconnection Damping Assessment-Passivity Based Controller), is implemented as an outer loop controller to regulate DC-link and supercapacitor voltages. A Finite Control Set-Model Predictive Control is implemented as inner current controllers. In addition, the sizing of the HES unit and lifetime analysis on the battery is performed.

The key contributions of this research are: (1) The proposed converter configuration has: (i) Low component count, (ii) Inherent voltage boosting, (iii) Inherent voltage regulation of supercapacitor and inherent power-sharing among battery and supercapacitor (iv) Simple control structure with a reduced number of sensors and (v) Galvanic isolation and high voltage gain capability. (2) The proposed control structure combining IDA-PBC and FCS-MPC tackles system non-linearity and the requirement of extra controller for supercapacitor voltage regulation with a conventional PI-based control structure was circumvented.

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