DESIGN AND DEVELOPMENT OF SOLAR PV INTEGRATED LIGHT ELECTRIC VEHICLE USING SWITCHED RELUCTANCE MOTOR

GURMEET SINGH

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2025

DESIGN AND DEVELOPMENT OF SOLAR PV INTEGRATED LIGHT ELECTRIC VEHICLE USING SWITCHED RELUCTANCE MOTOR

by

GURMEET SINGH

DEPARTMENT OF ELECTRICAL ENGINEERING

Submitted

in fulfilment of the degree of doctor of philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2025

CERTIFICATE

It is certified that the thesis entitled "Design And Development of Solar PV Integrated Light Electric Vehicle Using Switched Reluctance Motor" being submitted by Mr. Gurmeet Singh for award of the degree of Doctor of Philosophy in the Department of Electrical Engineering, Indian Institute of Technology Delhi, is a record of the student work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

Date:

(Dr. Bhim Singh)
Professor
Electrical Engineering Department
Indian Institute of Technology Delhi
Hauz Khas, New Delhi-110016, India

ACKNOWLEDGEMENT

I wish to express my deepest gratitude and indebtedness to **Prof. Bhim Singh** for providing me guidance and constant supervision to carry out the PhD work. Working under him has been a wonderful experience, which has provided deep insight into the world of research. Determination, dedication, innovativeness, resourcefulness, and discipline of **Prof. Bhim Singh** have been the inspiration for me to complete this work. His consistent encouragement, continuous monitoring and commitments to excellence have always motivated me to improve my work and use the best of my capabilities. Due to his blessing, I have earned various experiences other than research, which will help me throughout my life.

My sincere thanks and deep gratitude are to **Prof. Sukumar Mishra**, **Prof. Anandarup Das**, and **Prof. Ashu Verma** all SRC members for their valuable guidance and consistent support during my research work.

I wish to convey my sincere thanks to **Prof. B. K. Panigrahi**, **Prof. Anandarup Das**, **Prof. Sukumar Mishra**, **Prof. T. C. Kandpal**, **Prof. G. Bhuvneshwari**, **Prof. M. Veerachary**, **Prof. Shubhendu Bhasin** and **Prof. Ramkrishan Maheshwari** for their valuable inputs during my coursework, which made the foundation for my research work. Moreover, my sincere thanks to **Prof. Bhim Singh** and **Prof. G. Bhuvneshwari** for their valuable support and guidance during collaborative work under my PhD work. I am grateful to **IIT Delhi** for providing me the funding and research facility. I wish to express my sincere thanks to **Prof. M. Veerachary**, Prof. in-charge PG Machines Lab, for providing research facility. A special thanks to Sh. Puran Singh and Sh. Jitendra of PG Machines Lab, IIT Delhi for providing me the facility and assistance during my PhD work.

I would like to offer my sincere thanks to Dr. Vasist Bist, Dr. Anshul Varshney, Dr. Shailendra Dwivedi, Dr. Anjeet Kumar, Dr. Seema, Dr. Radha Kushwaha, Dr. Shreejith Ravindran, Dr. Farheen Chisti, Dr. Shadab Murshid, and Dr. Anjanee Mishra, for their technical/non-technical

and informal support. I would like to thank Mr. Sudip Bhattacharyya, Mr. Sandeep Sahoo, Mr. Priyvrat Vats, Mr. Saran Chaurasiya, Mr. Shivam Yadav, Mr. Vipin Singh, Mr. Arjun Kumar, Mr. Sumit Kumar, Mr. Bishwajit Saha, Mr. Gaurav Kumar, Mr. Himanshu and other lab mates, colleagues, and juniors for their coordination with my PhD journey. I would also like to thank Mr. Satish Sah, Mr. Yatindra Tripathi, Mr. Narendra, Mr, Sandeep and all other electrical engineering department staff, and academic section for being supportive throughout. I am likewise thankful to those who have directly or indirectly helped me to finish my dissertation study. Moreover, I would like to thank the **Department of Science and Technology (DST), India**, and **IIT Delhi**, for funding this research work.

I would like to thank my father, **Mr. Guru Bachan Singh**, and mother, **Late. Ms. Kulwant Kaur**, for their dreams, blessings and constant encouragement.

Atlast, I am beholden to Almighty for their blessings to help me to raise my academic level to this stage. I pray for their benediction in my future endeavors. Their blessings may be showed on me for strength, wisdom, and determination to achieve in future.

Gurmeet Singh

Date:

Place:

ABSTRACT

This research focuses on the progression of sensorless control techniques for switching reluctance motor (SRM) drives to minimize supplementary costs associated with integrated motor drive units in electric vehicle application. The use of solar photovoltaic array to charge installed battery packs during daylight hours provides a significant benefit in extending the mileage of light electric vehicles (LEVs).

This research concentrates on the development of a sliding mode observer (SMO) for position sensorless management of switching reluctance motor (SRM) drives in solar and battery-powered light electric vehicles. Unlike look-up table-based methods, the SMO-based algorithm offers a direct and robust framework, obviating the necessity for pre-stored magnetic data. Alongside the utilization of SMO for position estimate, a two-phase excitation-based method is integrated into SRM control to guarantee unidirectional operation during starting. This method, however, encounters chattering, which is subsequently alleviated by the application of an adaptive gain sliding mode observer. The drive employs a sensorless method and sophisticated angle control for speed regulation of the SRM drive, thereby minimizing switching losses associated with the hysteresis controller. This research aims to develop a compact and economical motor technology by reducing the reliance on electrical sensors. The research introduces a modern reconstruction method for a three-phase 12/8 switched reluctance motor driven by an asymmetric bridge converter. This enhancement decreases sensor expenses while preserving vehicle driving performance. Moreover, the solar PV array for the continuous charging of the installed battery pack during both operational and non-operational hours enhances mileage and earnings while substantially decreasing vehicle operating costs. All generated configurations are modeled and simulated in the MATLAB/Simulink environment using the Simpower System toolbox to assess performance under diverse environmental conditions, and the system's operability is validated across initial, dynamic, and steady-state scenarios. Simulated results are verified by an experimental test prototype.

सारांश

यह शोध स्विच्ड रिलक्टेंस मोटर (SRM) ड्राइव्स के लिए सेंसर-रहित नियंत्रण तकनीकों के विकास पर केंद्रित है, जिसका उद्देश्य इलेक्ट्रिक वाहनों में प्रयुक्त एकीकृत मोटर ड्राइव यूनिट्स से संबंधित अतिरिक्त लागत को कम करना है। दिन के समय सौर फोटोवोल्टिक पैनलों की सहायता से बैटरी पैक को चार्ज करना, लाइट इलेक्ट्रिक वाहनों (LEVs) की माइलेज बढ़ाने में महत्वपूर्ण लाभ प्रदान करता है।

यह शोध सौर ऊर्जा और बैटरी चालित लाइट इलेक्ट्रिक वाहनों में SRM ड्राइव्स के सेंसर-रहित नियंत्रण हेतु स्लाइडिंग मोड ऑब्जर्वर (SMO) के विकास पर केंद्रित है। लुक-अप टेबल आधारित विधियों के विपरीत, SMO आधारित एल्गोरिदम एक प्रत्यक्ष और सुदृढ़ रूपरेखा प्रदान करता है, जिससे पूर्व-संग्रहीत मैग्नेटिक डेटा की आवश्यकता समाप्त हो जाती है। स्थिति अनुमान हेतु SMO के उपयोग के साथ, SRM नियंत्रण में एक द्वि-चरणीय उत्तेजन विधि को एकीकृत किया गया है, जो प्रारंभिक अवस्था में एकदिश संचालन सुनिश्चित करता है। हालांकि, यह विधि 'चैटरिंग' की समस्या से ग्रस्त होती है, जिसे अनुकूली गेन स्लाइडिंग मोड ऑब्जर्वर के प्रयोग से दूर किया गया है।

ड्राइव सेंसर-रहित तकनीक और परिष्कृत कोणीय नियंत्रण का उपयोग करता है, जिससे SRM ड्राइव की गति नियंत्रित होती है और हिस्टेरेसिस नियंत्रक से उत्पन्न स्विचिंग हानियाँ न्यूनतम होती हैं। इस शोध का उद्देश्य इलेक्ट्रिकल सेंसरों पर निर्भरता कम करके एक कॉम्पैक्ट और किफायती मोटर तकनीक विकसित करना है।

यह शोध एक तीन-चरणीय 12/8 SRM मोटर के लिए एक आधुनिक पुनर्निर्माण विधि प्रस्तुत करता है, जो असममित ब्रिज कन्वर्टर द्वारा संचालित होती है। यह नवाचार सेंसर लागत को कम करते हुए वाहन के प्रदर्शन को बनाए रखता है। इसके अतिरिक्त, कार्यशील और गैर-कार्यशील दोनों अवस्थाओं में स्थापित बैटरी पैक को निरंतर चार्ज करने हेतु सौर पीवी प्रणाली का उपयोग माइलेज और आय में वृद्धि करता है तथा वाहन के परिचालन खर्च में उल्लेखनीय कमी लाता है।

सभी विकसित विन्यासों का मॉडलिंग और सिमुलेशन MATLAB/Simulink वातावरण में Simpower System टूलबॉक्स का उपयोग करके किया गया है, ताकि विभिन्न पर्यावरणीय परिस्थितियों में प्रणाली के प्रदर्शन का मूल्यांकन किया जा सके। प्रणाली की कार्यक्षमता को प्रारंभिक, गतिशील और स्थिर अवस्था स्थितियों में सत्यापित किया गया है। सिमुलेशन परिणामों की पुष्टि एक प्रायोगिक परीक्षण प्रोटोटाइप द्वारा की गई है।

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

D, D_{PV}	Duty Cycle of BDDC Converter, Duty cycle of PV array Boost converter.
V_{in} , $V_{0,}$	Input and output voltages of BDDC converter.
L_{bd}, I_{Lbd}	Interfacing inductor of BDDC converter and current flowing through it.
f_{sw}	Switching frequency.
I_{MPP}, V_{MPP}, P_{MPP}	Curent, voltage and power of PV panel at MPP.
M_1,M_2, N_1, N_2	Input matrices in state space of BDDC converter.
C, R_{eqv}	Capacitance and equivalent resistance of BDDC converter.
R_m	Resistance of SRM winding.
ω, ω_{ref}, ω_m	Speed, reference and measured values of SRM speed.
Ψ, τ, i	Flux, torque and current of SRM.
V_{mpp}, i_{PV}, i_b	Voltage at MPP, Solar PV array current,, and battery current
θ_a, θ_m	Actaual and measured positon signals.
L_m, θ	SRM Winding Inductance and position signal of SRM.
θ_0, θ_{on}, θ_{off},	Starting, turn-on and turn-off commutating angles of SRM.
$\theta_{on\text{-}r}$, $\theta_{off\text{-}r}$	Turn-on and turn-off angles of SRM during regeneration.
M_{co}	Control to output transfer function of BDDC converter.
d	Duty cycle.
V_{bat}	Input battery voltage.
R_{load}, d_{load}, C_{load}, L_{load}	Resistance, duty, capacitance and inductance of load side.