CONTROL OF SWITCHED RELUCTANCE MOTOR DRIVE FOR LIGHT ELECTRIC VEHICLES WITH SOLAR PHOTOVOLTAIC INTEGRATION

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by

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CERTIFICATE

It is certified that the thesis entitled "Control of Switched Reluctance Motor Drive for Light Electric Vehicles with Solar Photovoltaic Integration" being submitted by Mr. Arjun Kumar 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.

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ABSTRACT

This thesis deals with the development of advanced control strategies, regenerative braking schemes, and renewable energy integration, as rooftop for SRM drives in LEV applications. A three-phase, 12/8, 48 V, 28 A, 2700 rpm SRM is used as a candidate machine. Various converter topologies, modified boost, Zeta, Cuk, and SEPIC, are developed for solar photovoltaic (PV) integration, and maximum power point tracking (MPPT) algorithms such as incremental conductance and variable step-size perturb & observe are implemented to maximize energy harvesting efficiency. Advanced control techniques, including modified direct instantaneous torque control (DITC), model predictive control (MPC), and torque sharing functions (TSF), are proposed to achieve torque ripple reduction, smooth motoring operation, and efficient regenerative braking. Furthermore, sensorless rotor position estimation techniques based on flux polynomials, pulse injection, and inductance calibration are investigated to eliminate mechanical sensors, thereby improving system reliability and reducing cost. Simulation and experimental validations are carried out using MATLAB/Simulink and a real-time dSPACE DS-1103 controller platform. The results are verified that proposed methods have effectively minimized torque ripple, enhanced efficiency under rated conditions, and have provided reliable regenerative energy recovery during stop-and-go driving scenarios. An integration of solar PV array has further extended the vehicle operating range, while optimized battery sizing demonstrated that overall storage requirements are reduced without compromising performance. The findings of this thesis confirm that SRM drives, when supported with advanced control strategies and renewable energy integration, represent a technically viable, economically competitive, and environmentally sustainable propulsion solution for light electric vehicles. The developed methodologies and experimental validations lay a strong foundation for future commercialization of SRM-based electric mobility platforms.

सारांश

यह थीसिस LEV (लाइट इलेक्ट्रिक वाहन) अनुप्रयोगों में SRM ड्राइव के लिए उन्नत नियंत्रण रणनीतियों, रीजेनरेटिव ब्रेकिंग योजनाओं और नवीकरणीय ऊर्जा एकीकरण के विकास से संबंधित है। एक तीन-चरण वाला, 12/8, 48 V, 28 A, 2700 rpm SRM मशीन को एक उम्मीदवार मशीन के रूप में उपयोग किया गया है। सौर फोटोवोल्टिक (PV) एकीकरण के लिए विभिन्न कनवर्टर टोपोलॉजी–जैसे संशोधित बूस्ट, Zeta, Cuk और SEPIC—विकसित की गई हैं; साथ ही, ऊर्जा संचयन दक्षता को अधिकतम करने के लिए अधिकतम पावर पॉइंट ट्रैकिंग (MPPT) एल्गोरिदम–जैसे इंक्रीमेंटल कंडक्टेंस और वेरिएबल स्टेप-साइज़ पर्टर्ब एंड ऑब्ज़र्व–को लागू किया गया है। टॉर्क रिपल (torque ripple) को कम करने, सुचारू मोटरिंग संचालन और कुशल रीजेनरेटिव ब्रेकिंग प्राप्त करने के लिए उन्नत नियंत्रण तकनीकों–जिनमें संशोधित डायरेक्ट इंस्टेंटेनियस टॉर्क कंट्रोल (DITC), मॉडल प्रेडिक्टिव कंट्रोल (MPC) और टॉर्क शेयरिंग फ़ंक्शन (TSF) शामिल हैं–का प्रस्ताव दिया गया है। इसके अलावा, यांत्रिक सेंसरों को हटाने के लिए फ्लक्स बहुपद, पल्स इंजेक्शन और इंडक्टेंस कैलिब्रेशन पर आधारित सेंसर-रहित रोटर स्थिति अनुमान तकनीकों की जांच की गई है, जिससे सिस्टम की विश्वसनीयता में सुधार होता है और लागत कम होती है। MATLAB/Simulink और एक रीयल-टाइम dSPACE DS-1103 कंट्रोलर प्लेटफ़ॉर्म का उपयोग करके सिमुलेशन और प्रायोगिक सत्यापन किए गए हैं। परिणामों से यह सत्यापित होता है कि प्रस्तावित विधियों ने टॉर्क रिपल को प्रभावी ढंग से कम किया है, रेटेड स्थितियों के तहत दक्षता बढ़ाई है, और 'स्टॉप-एंड-गो' ड्राइविंग परिदृश्यों के दौरान विश्वसनीय रीजेनेरेटिव ऊर्जा पुनर्प्राप्ति प्रदान की है। सौर PV सरणी के एकीकरण ने वाहन की परिचालन सीमा को और विस्तृत किया है, जबकि अनुकूलित बैटरी साइज़िंग ने यह प्रदर्शित किया है कि प्रदर्शन से समझौता किए बिना समग्र भंडारण आवश्यकताओं को कम किया जा सकता है। इस थीसिस के निष्कर्ष इस बात की पुष्टि करते हैं कि SRM ड्राइव–जब उन्नत नियंत्रण रणनीतियों और नवीकरणीय ऊर्जा एकीकरण द्वारा समर्थित होते हैं–तो वे हल्के इलेक्ट्रिक वाहनों के लिए एक तकनीकी रूप से व्यवहार्य, आर्थिक रूप से प्रतिस्पर्धी और पर्यावरणीय रूप से टिकाऊ प्रणोदन समाधान प्रस्तुत करते हैं। विकसित कार्यप्रणालियाँ और प्रायोगिक सत्यापन SRM-आधारित इलेक्ट्रिक मोबिलिटी प्लेटफ़ॉर्म के भविष्य के व्यावसायीकरण के लिए एक मजबूत नींव रखते हैं।

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LIST OF ABBREVIATIONS

EV	Electric Vehicle
LEV	Light Electric Vehicle
PV	Photovoltaics
DC	Direct Current
IM	Induction Motor
PMSM	Permanent Magnet Synchronous Motor
BLDCM	Brushless DC Motor
SyRM	Synchronous Reluctance Motor
SRM	Switched Reluctance Motor
DTC	Direct Torque Control
MPC	Model Predictive Control
DITC	Direct Instantaneous Torque Control
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
EMS	Energy Management Systems
P&O	Perturb and Observe
TSF	Torque Sharing Function
FOC	Field Oriented Control
ADC	Analog to Digital Conversion
DAC	Digital to Analog Conversion
ASHB	Asymmetrical Half Bridge Converter

LIST OF SYMBOLS

D, T_s	duty cycle of converter and sample time
V_{MPP}, I_{MPP}, P_{MPP}	MPP Voltage, current and power
γ, λ, F	Flux linkage
ω, J, B	Motor angular speed, moment of inertia of the motor drive system and viscous friction coefficient,
I_b, , I_{ph}	Battery current, phase current
V_{DC}, V_b, v_{ph}, v_s, v_D,	DC-link voltage, battery volrtage, phase voltage, switch voltage and diode voltage
T_e, T_{ph}, T_L and T^*	Total torque, phase torque, load torque and reference torque
r, L	Phase resistance and phase inductance
N^*, T^*, N, N_{est}, θ, θ_{est},	Reference speed, reference torque, rotor speed in rpm, estimated speed, rotor actual position and estimated speed
$\theta_{on,}$, θ_{off}, ξ	Turn on, turn off and stroke angle
S_x, S_{xk}	Sector; switching state
ΔT, T_r	Incremental torque and torque ripple