CONTROL AND IMPLEMENTATION OF SOLAR PV FED SENSORLESS PMSM DRIVE FOR ELECTRIC VEHICLES

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DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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CONTROL AND IMPLEMENTATION OF SOLAR PV FED SENSORLESS PMSM DRIVE FOR ELECTRIC VEHICLES

By

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Department of Electrical Engineering

Submitted

in fulfillment of the requirements of the degree of

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CERTIFICATE

This is to certify that the thesis entitled, **"Control and Implementation of Solar PV Fed Sensorless PMSM Drive for Electric Vehicles"** being submitted by **Mr. Sumit Kumar** for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him in the Department of Electrical Engineering of Indian Institute of Technology Delhi.

Mr. Sumit Kumar has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The matter embodied in this thesis has not been submitted for award of any other degree or diploma.

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ABSTRACT

This thesis presents the control and implementation of a solar photovoltaic (PV) fed, sensorless permanent magnet synchronous motor (PMSM) drive for EV applications, aimed at enhancing energy efficiency, system reliability, and operational flexibility. The research focuses on the development of advanced control strategies and observer-based techniques for eliminating mechanical position sensors, thereby improving system compactness, robustness, and cost-effectiveness. Both surface-mounted PMSM (SPMSM) based low-voltage and interior PMSM (IPMSM) based high-voltage electric vehicle configurations are proposed in this research work. These high-performance drives are integrated with solar PV array and operated under online Maximum Torque per Ampere (MTPA) control to ensure optimal efficiency while maintaining sensorless operation for enhanced system reliability and reduced hardware complexity. The sensorless control framework is developed using advanced estimation algorithms capable of accurately determining rotor position and speed across a wide range of operating conditions, including low-speed and transient states. A comprehensive energy management approach is also incorporated, enabling efficient coordination of the solar PV array, battery storage, and motor drive. Regenerative braking capability further enhances energy utilization, contributing to extended driving range and reduced battery dependency. Extensive simulation and experimental validation of the proposed system are carried out to assess its steady-

state, dynamic, and transient performance under real-world scenarios. The results confirm that the proposed control architecture offers a reliable, energy-efficient, and renewable-integrated drive system, making it a suitable solution for future electric mobility applications with enhanced performance and sustainability.

सारांश

यह शोध प्रबंध इलेक्ट्रिक वाहन अनुप्रयोगों के लिए सौर फोटोवोल्टिक (photovoltaic) से संचालित, सेंसर-रहित स्थायी चुंबक समकालिक मोटर ड्राइव (Permanent magnet motor drive) के नियंत्रण और कार्यान्वयन को प्रस्तुत करता है, जिसका उद्देश्य ऊर्जा दक्षता, प्रणाली की विश्वसनीयता और संचालनात्मक लचीलापन बढ़ाना है।

यह अनुसंधान उन्नत नियंत्रण रणनीतियों और ऑब्जर्वर-आधारित तकनीकों के विकास पर केंद्रित है, जिनके माध्यम से यांत्रिक स्थिति सेंसरों को समाप्त किया जाता है, जिससे प्रणाली की संकुचितता, मजबूती और लागत-प्रभावशीलता में सुधार होता है।

इस शोध कार्य में सतह-स्थापित आधारित निम्न-वोल्टेज तथा आंतरिक आधारित उच्च-वोल्टेज इलेक्ट्रिक वाहन विन्यास प्रस्तावित किए गए हैं। इन उच्च-प्रदर्शन ड्राइवों को सौर एरे के साथ एकीकृत किया गया है और इन्हें ऑनलाइन मैक्सिमम टॉर्क पर एम्पियर (maximum-torque per ampere) नियंत्रण के अंतर्गत संचालित किया जाता है, जिससे इष्टतम दक्षता सुनिश्चित होती है, साथ ही सेंसर-रहित संचालन द्वारा प्रणाली की विश्वसनीयता में वृद्धि और हार्डवेयर जटिलता में कमी आती है।

सेंसर-रहित नियंत्रण ढांचा उन्नत अनुमान (Estimation) एल्गोरिदम (Algorithm) का उपयोग करके विकसित किया गया है, जो विभिन्न परिचालन परिस्थितियों—जिनमें निम्न गति और संक्रमण अवस्थाएँ शामिल हैं—में रोटर (rotor) की स्थिति और गति का सटीक निर्धारण करने में सक्षम हैं।

इसके अतिरिक्त, एक व्यापक ऊर्जा प्रबंधन दृष्टिकोण भी सम्मिलित किया गया है, जो सौर एरे (Array), बैटरी भंडारण और मोटर ड्राइव के बीच कुशल समन्वय सुनिश्चित करता है। पुनर्योजी ब्रेकिंग (braking) क्षमता ऊर्जा उपयोग को और बढ़ाती है, जिससे ड्राइविंग रेंज (driving range) में वृद्धि और बैटरी (battery) पर निर्भरता में कमी आती है।

प्रस्तावित प्रणाली के स्थिर-अवस्था, गतिशील और संक्रमण प्रदर्शन का आकलन करने के लिए व्यापक सिमुलेशन (Simulation) और प्रायोगिक सत्यापन वास्तविक परिस्थितियों में किए गए हैं। परिणाम पुष्टि करते हैं कि प्रस्तावित नियंत्रण संरचना एक विश्वसनीय, ऊर्जा-कुशल और नवीकरणीय ऊर्जा-एकीकृत ड्राइव प्रणाली प्रदान करती है, जो भविष्य की इलेक्ट्रिक गतिशीलता अनुप्रयोगों के लिए उन्नत प्रदर्शन और स्थिरता के साथ एक उपयुक्त समाधान है।

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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
BDC	Bidirectional DC-DC Converter
DSP	Digital Signal Processor
DTC	Direct Torque Control
HV	High Voltage
ICE	Internal Combustion Engine
EMF	Electro Motive Force
FLL	Frequency Locked Loop
FOC	Field Oriented Control
IM	Induction Machine
IPMSM	Interior Permanent Magnet Synchronous Motor
LEV	Light Electric Vehicle
LPF	Low Pass Filter
LV	Low Voltage
MPPT	Maximum Power Point Tracking
NdFeB	Neodymium-Iron-Boron
PI	Proportional Integral
PLL	Phase Locked Loop

PMBDCM	Permanent Magnet Brushed DC Motor
PV	Solar Photovoltaic
P and O	Perturb and Observe
QPLL	Quadrature Phase Locked Loop
SASTSMO	Speed Adaptive Super Twisting Sliding Mode Observer
SMO	Sliding Mode Observer
SOC	State of Charge
SOGI	Second Order Generalized Integrator
SPMSM	Surface Mounted Permanent Magnet Synchronous Motor
SRF	Synchronous Reference Frame
SRM	Switched Reluctance Motor

LIST OF SYMBOLS

C	DC bus capacitor (F)
D	Duty cycle of boost converter
D_b	Duty ratio of BDC
$e_{\alpha,}\ e_{\beta}$	back-EMF components
f_{sw}	Switching frequency (Hz)
Fs	Sampling frequency (kHz)
I_b	Battery current (A)
$i_{\alpha};i_{\beta}$	Actual motor phase currents in α-β domain (A)
$i_a;\ i_b;\ i_c$	Motor three phase currents (A)
$i_d;\ i_q$	Actual motor phase currents in d-q domain (A)
I_{pv}	PV array current (A)
I_{DC}	DC link current
T_{ref}	Reference PMSM torque
T_L	Load torque
$v_{\alpha},\ v_{\beta}$	αβ-axes PMSM voltages
V_{DC}	DC link voltage
$v_{\alpha},\ v_{\beta}$	αβ-axes PMSM voltages
θ_{ref}	Reference rotor position (rad)
θ_{est}	Estimated rotor position (rad)
θ_{error}	Error between estimated rotor position and reference position (rad)

ω_{ref}	Reference speed (rad/s)
ω_{est}	Estimated speed (rad/s)
ψ_{PM}	Permanent magnet flux linkage (V.s)