DEVELOPMENT OF POSITION SENSORLESS SWITCHED RELUCTANCE MOTOR DRIVES FOR SOLAR WATER PUMPING

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DEVELOPMENT OF POSITION SENSORLESS SWITCHED RELUCTANCE MOTOR DRIVES FOR SOLAR WATER PUMPING

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CERTIFICATE

It is certified that the thesis entitled "**Development of Position Sensorless Switched Reluctance Motor Drives for Solar Water Pumping**," being submitted by **Mr. Yalavarthi Amarnath** 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 award of any other degree or diploma.

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ABSTRACT

The utilization of solar photovoltaic (PV) energy in water pumping is conservative particularly in isolated regions where the cost of transmission of power is either impractical or exorbitant. In this work, the research is inclined towards the development of sensorless control techniques for switched reluctance motor (SRM) drives for solar photovoltaic (SPV) fed water pumping systems. Even though permanent magnet (PM) motors are considered as the best for water pumping, the use of PMs makes the overall system expensive. Besides these, SRM comes in simple geometrical steel structure involving neither magnets nor rotor windings, with performance in comparable with the PM motors. Moreover, SRMs require zero maintenance as they do not employ brushes and are highly suitable for harsh environments. This finds the motivation to the researchers to aim for a low-cost high-performance drive using SRMs.

Even though the SRMs come with numerous advantages, the major pull back of the drive is the necessity of its shaft position sensing equipment. The cost of these sensors accounts for major share of the cost of the drive. Moreover, mechanical sensors are highly sensitive to motor shaft vibrations and their use is unadvisable in case of operations in dust and dirt conditions especially for submersible pumps. Therefore, an elimination of these mechanical sensors improves both reliability and affordability. Moreover, there is no considerable research in the literature for sensorless controlled SRM driven solar pump. Therefore, this work focuses on the development of mechanical sensor-free SRM drives to provide cost-effective and reliable solution.

Initially, this work aims at the development of sliding mode observer (SMO) based position sensorless control for SRM drive for PV-battery standalone submersible pumps. Unlike look-up table-based methods, SMO-based algorithm offers simple and robust architecture and does not require any pre-stored magnetic data. Besides implementing SMO for position estimation, a two-

phase excitation-based algorithm is integrated to SRM control to guarantee the unidirectional operation during starting. However, this technique suffers from chattering and to eliminate which, later, an adaptive gain super twisting sliding mode observer (AGST-SMO) is implemented. Furthermore, this work presents a neural network approach for the development of position sensorless switched reluctance (SR) drive. In neural network, a real-time magnetic data is mapped through supervised training by using back propagation (BP) learning algorithm. Besides using a sensorless scheme, the drive uses an advance angle control for the speed control of SR drive which eliminates the switching losses induced by the hysteresis controller. Further, the works aims at developing a compact and economical drive by reducing the electrical sensor usage. The research proposes a current reconstruction strategy for a four phase 8/6 SRM driven by a split-DC (SDC) converter. This development drops the current sensors count by three, without sacrificing the drive performance. Moreover, the proposed method is validated for sensorless control by developing a starting scheme. Apart from the above advantages, the proposed method demands no extra hardware requirements and involves less computations.

The dependency on solar potential results PV array an unreliable source for water pumping application. In bad climatic conditions, even though MPPT is employed, the system is underutilized since the pump is not operated at its full capacity and even leads to complete shutdown during nights. This problem is resolved by adding an auxiliary source in the form of a battery storage or through grid interaction. All these developed configurations are modeled and simulated in MATLAB/Simulink environment by using Simpower system toolbox to study the performance during various environmental conditions and the operability of the system is justified during starting, dynamic and steady state conditions. Simulated results are validated using a developed prototype in the laboratory.

सार

जल पंपिंग में सौर फोटोवोल्टिक (PV) ऊर्जा का उपयोग रूढ़िवादी है, विशेष रूप से पृथक क्षेत्रों में जहां बिजली के संचरण की लागत या तो अव्यावहारिक या अत्यधिक है। इस कार्य में अनुसंधान का झुकाव सौर फोटोवोल्टिक (SPV) पोषित जल पंपिंग प्रणालियों के लिए स्विच्ड रिलक्टेंस मोटर (SRM) ड्राइव के लिए सेंसर रहित नियंत्रण तकनीकों के विकास की ओर है। भले ही स्थायी चुंबक (PM) मोटर्स को पानी पंपिंग के लिए सबसे अच्छा माना जाता है, पीएम का उपयोग समग्र प्रणाली को महंगा बनाता है। इनके अलावा, SRM सरल ज्यामितीय स्टील संरचना में आता है जिसमें न तो मैग्नेट और न ही रोटर वाइंडिंग्स शामिल हैं, जिसका प्रदर्शन पीएम मोटर्स के बराबर है। इसके अलावा, SRM को शून्य रखरखाव की आवश्यकता होती है क्योंकि वे ब्रश का उपयोग नहीं करते हैं और कठोर वातावरण के लिए अत्यधिक उपयुक्त हैं। इससे शोधकर्ताओं को SRM का उपयोग करके कम लागत वाली उच्च-प्रदर्शन वाली ड्राइव का लक्ष्य रखने की प्रेरणा मिलती है।

हालांकि एसआरएम कई फायदों के साथ आते हैं, ड्राइव का मुख्य आकर्षण इसके शाफ्ट स्थिति संवेदन उपकरण की आवश्यकता है। इन सेंसरों की लागत ड्राइव की लागत का बड़ा हिस्सा है। इसके अलावा, मैकेनिकल सेंसर मोटर शाफ्ट कंपन के प्रति अत्यधिक संवेदनशील होते हैं और विशेष रूप से सबमर्सिबल पंपों के लिए धूल और गंदगी की स्थिति में संचालन के मामले में उनका उपयोग अनुचित है। इसलिए, इन यांत्रिक सेंसरों के उन्मूलन से विश्वसनीयता और सामर्थ्य दोनों में सुधार होता है। इसके अलावा, सेंसर रहित नियंत्रित एसआरएम संचालित सौर पंप के लिए साहित्य में कोई महत्वपूर्ण शोध नहीं है। इसलिए, यह कार्य लागत प्रभावी और विश्वसनीय समाधान प्रदान करने के लिए मैकेनिकल सेंसर-मुक्त एसआरएम ड्राइव के विकास पर केंद्रित है।

प्रारंभ में, इस कार्य का उद्देश्य पीवी-बैटरी स्टैंडअलोन सबमर्सिबल पंपों के लिए एसआरएम ड्राइव के लिए स्लाइडिंग मोड ऑब्जर्वर (SMO) आधारित स्थिति सेंसर रहित नियंत्रण का विकास करना है। लुक-अप टेबल-आधारित तरीकों के विपरीत, एसएमओ-आधारित एल्गोरिदम सरल और मजबूत वास्तुकला प्रदान करता है और इसके लिए किसी पूर्व-संग्रहीत चुंबकीय डेटा की आवश्यकता नहीं होती है। स्थिति अनुमान के लिए एसएमओ को लागू करने के अलावा, शुरुआत के दौरान यूनिडायरेक्शनल ऑपरेशन की गारंटी के लिए एसआरएम नियंत्रण में दो-चरण उत्तेजना-आधारित एल्गोरिदम एकीकृत किया गया है। हालाँकि, यह तकनीक बकबक से ग्रस्त है और जिसे खत्म करने के लिए, बाद में, एक अनुकूली लाभ सुपर ट्विस्टिंग स्लाइडिंग मोड

ऑब्जर्वर (AGST-SMO) लागू किया जाता है। इसके अलावा, यह कार्य स्थिति सेंसर रहित स्विच्ड अनिच्छा (SR) ड्राइव के विकास के लिए एक तंत्रिका नेटवर्क दृष्टिकोण प्रस्तुत करता है। तंत्रिका नेटवर्क में, वास्तविक समय के चुंबकीय डेटा को बैक प्रोपेगेशन (BP) लर्निंग एल्गोरिदम का उपयोग करके पर्यवेक्षित प्रशिक्षण के माध्यम से मैप किया जाता है। सेंसर रहित योजना का उपयोग करने के अलावा, ड्राइव एसआर ड्राइव की गति नियंत्रण के लिए एक अग्रिम कोण नियंत्रण का उपयोग करता है जो हिस्टैरिसीस नियंत्रक द्वारा प्रेरित स्विचिंग नुकसान को समाप्त करता है। इसके अलावा, इस कार्य का उद्देश्य विद्युत सेंसर के उपयोग को कम करके एक कॉम्पैक्ट और किफायती ड्राइव विकसित करना है। शोध एक स्प्लिट-डीसी (SDC) कनवर्टर द्वारा संचालित चार चरण 8/6 एसआरएम के लिए एक वर्तमान पुनर्निर्माण रणनीति का प्रस्ताव करता है। यह विकास ड्राइव प्रदर्शन से समझौता किए बिना, वर्तमान सेंसरों की संख्या को तीन तक कम कर देता है। इसके अलावा, प्रस्तावित विधि को एक प्रारंभिक योजना विकसित करके सेंसर रहित नियंत्रण के लिए मान्य किया गया है। उपरोक्त लाभों के अलावा, प्रस्तावित विधि में किसी अतिरिक्त हार्डवेयर आवश्यकता की आवश्यकता नहीं है और इसमें कम गणनाएँ शामिल हैं।

सौर संभावित परिणामों पर निर्भरता पीवी सरणी जल पंपिंग अनुप्रयोग के लिए एक अविश्वसनीय स्रोत है। खराब जलवायु परिस्थितियों में, एमपीपीटी कार्यरत होने के बावजूद, सिस्टम का कम उपयोग किया जाता है क्योंकि पंप अपनी पूरी क्षमता पर संचालित नहीं होता है और यहां तक कि रात के दौरान पूरी तरह से बंद हो जाता है। बैटरी भंडारण के रूप में या ग्रिड इंटरैक्शन के माध्यम से एक सहायक स्रोत जोड़कर इस समस्या का समाधान किया जाता है। इन सभी विकसित कॉन्फ़िगरेशन को विभिन्न पर्यावरणीय परिस्थितियों के दौरान प्रदर्शन का अध्ययन करने के लिए सिंपॉवर सिस्टम टूलबॉक्स का उपयोग करके MATLAB/Simulink वातावरण में मॉडल और सिम्युलेटेड किया गया है और सिस्टम की संचालन क्षमता को शुरुआती, गतिशील और स्थिर स्थिति स्थितियों के दौरान उचित ठहराया गया है। प्रयोगशाला में विकसित प्रोटोटाइप का उपयोग करके सिम्युलेटेड परिणामों को मान्य किया जाता है।

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LIST OF ABBREVATIONS

AC	Alternating Current
AAC	Advance Angle Control
ADC	Analog to Digital Converter
Ah	Ampere Hour
ANN	Artificial Neural Network
BDDC	Bidirectional DC-DC Converter
BES	Battery Energy Storage
BLDC	Brushless DC Motor
CCM	Continuous Conduction Mode
CCC	Current Chopping Control
CPU	Central Processing Unit
DAC	Digital to Analog Converter
DC	Direct Current
DSP	Digital Signal Processor
EMI	Electromagnetic Interference
FFT	Fast Fourier transformation
FLL	Frequency Locked Loop
HCC	Hysteresis Current Control
IC	Integrated Circuits
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Integrated Gate Bipolar Transistor
ILST	Improved Linear Sinusoidal Tracer
IM	Induction Motor
InC	Incremental Conductance
LMBP	Levenberg-Marquardt Back-Propagation
LPF	Low Pass Filter
LUT	Look-Up Table
MHRD	Ministry of Human Resource Development

MNRE	Ministry of New & Renewable Energy
MPC	Mid-Point Converter
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
Op-Amp	Operational Amplifier
P & O	Perturbation and Observation
PCC	Point of Common Coupling
PFC	Power Factor Correction
PI	Proportional- Integrator
PMSM	Permanent Magnet Synchronous Motor
PQ	Power Quality
PV	Photovoltaic
PWM	Pulse Width Modulation
RMS	Root Mean Square
SDC	Split-DC Converter
SEPIC	SEPIC Single Ended Primary Inductor Converter
SMO	Sliding Mode Observer
SPM	Single Pulse Mode
SRM	Switched Reluctance Motor
STA	Super Twisting Algorithm
STC	Standard Test Condition
SyRM	Synchronous Reluctance Motor
THD	Total Harmonic Distortion
TLBC	Three Level Boost Converter
VSC	Voltage Source Converter
VSI	Voltage Source Inverter

LIST OF SYMBOLS

C_{DC1}, C_{DC2}	Split DC link capacitors of mid-point converter (μF)
C_f	Capacitor of the R-C ripple filter (μF)
D_a, D_b, D_c, D_d	Freewheeling diodes of mid-point converter
D	Duty Ratio of DC stage converter
G	PV array irradiance level (W/m2)
I_{dc}	Loss component of current of DC link
i_L	Currents flowing through the loads at PCC inductors (A)
I_{mpp}, V_{mpp}, P_{mpp}	Solar PV array current (A), voltage (V) and power (W) at MPP
I_{PV}, V_{PV}, P_{PV}	Solar PV array current (A), voltage (V) and power (W)
i_g	Utility grid current (A)
i_g*	Reference utility grid current (A)
I_1, I_2, I_3, I_4	Winding currents of SRM (A)
J	Moment of inertia of the SRM (kg.cm2)
L_f	Interfacing inductor (mH)
Lu, La	Unaligned and Aligned inductance of SRM (mH)
N	Instantaneous speed of SRM-pump (rpm)
Ns, Np	Numbers of PV modules connected in series and parallel
Ns , Nr	Number of stator and rotor poles
T_e	Electro-magnetic torque (Nm)
R_f	Resistance of the R-C ripple filter
S_1, S_2, S_3, S_4	Switches of DC-DC converter
S_{A1}, S_{A2}, S_{B1}, S_{B2}, S_{C1}, S_{C2},	Switches of grid-interfaced converter
$T1$, $T2$, $T3$, $T4$	Commutation signals of mid-point converter switches
Ts	Sampling rate
V_{DC1}, V_{DC2}	Voltage across split DC link capacitors (V)
V_{DC}	Net DC link voltage (V)
v_g	Utility grid voltage (V)
ΔD	Perturbation in the duty ratio of MPP
θ_{ON}, θ_{OFF}	Turn on and off angles (º)

α	Dwell angle of SRM (º)
βs, βr	Stator and rotor pole pitches (º)
ω_s	Line frequency of the utility grid (rad/sec.)
ψ_1, ψ_2, ψ_3, ψ_4	Magnetic flux across SRM windings (Wb/m2)