

CONTROL OF SMALL HYDRO-PV-WIND BASED HYBRID MICROGRIDS WITH SYNCHRONIZATION

SHALVI TYAGI



**DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
HAUZ KHAS, NEW DELHI-110016, INDIA
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CONTROL OF SMALL HYDRO-PV-WIND BASED HYBRID MICROGRIDS WITH SYNCHRONIZATION

by

SHALVI TYAGI

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
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CERTIFICATE

It is certified that the thesis entitled “**Control of Small Hydro-PV-Wind Based Hybrid Microgrids with Synchronization,**” being submitted by **Mrs. Shalvi Tyagi** 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 her under my supervision and guidance. The matter embodied in this thesis has not been submitted for award of any other degree or diploma.

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

Dated:

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ABSTRACT

This research work investigates different configurations of hydro-solar-wind based microgrids, aiming to offer a sustainable solution for decentralized power generation, especially in remote or off-grid areas and in grid connected areas. It focusses on developing control strategies for these inverter-based distributed energy resources, addressing on achieving synchronization of doubly fed induction generator-based wind energy conversion system with small hydro turbine driven permanent synchronous generator to enhance reliability of developed microgrid configurations. This is achieved by formulating a systematic methodology and devising control objectives for the rotor side converter and stator side converter of doubly fed induction generator-based wind energy conversion system. Additionally, to attain seamless transition between grid-connected and standalone modes and vice-versa, control objectives for the grid side converter are formulated in detail. Moreover, the synchronization is carried out using stator side static transfer switch (SSSTS) and grid side static transfer switch (GSSTS), respectively. Advanced control techniques for the grid side converter are also implemented to mitigate harmonics and unbalance currents due to single phase and three phase nonlinear loads. Besides, control scheme also facilitates the suppression of neutral current in the three phase four wire microgrid configuration. Furthermore, a sensorless scheme for the estimation of rotor speed and rotor position of doubly fed induction generator is devised based on notch filter thus, eliminating the use of sensor and reducing the cost. The effectiveness of developed hydro-PV-wind based microgrid configurations and their respective control methodologies is assessed through comprehensive simulations conducted on MATLAB/Simulink platform. Various simulation scenarios, encompassing steady state, transition mode and dynamic responses are analysed, with detailed simulated results provided for each system configuration. Furthermore, experimental validation of all developed microgrid

configurations is conducted using a laboratory prototype. The detailed test results are reported providing empirical evidence to complement the simulation findings.

सार

यह शोध कार्य हाइड्रो-सौर-पवन आधारित माइक्रोग्रिड के विभिन्न विन्यासों की जांच करता है, जिसका लक्ष्य विकेंद्रीकृत बिजली उत्पादन के लिए एक स्थायी समाधान प्रदान करना है, विशेष रूप से दूरस्थ या ऑफ-ग्रिड क्षेत्रों और ग्रिड से जुड़े क्षेत्रों में। यह इन इन्वर्टर-आधारित वितरित ऊर्जा संसाधनों के लिए नियंत्रण रणनीतियों को विकसित करने पर ध्यान केंद्रित करता है, विकसित माइक्रोग्रिड कॉन्फ़िगरेशन की विश्वसनीयता बढ़ाने के लिए छोटे हाइड्रो टरबाइन चालित स्थायी सिंक्रोनस जनरेटर के साथ डबल-फेड इंडक्शन जनरेटर-आधारित पवन ऊर्जा रूपांतरण प्रणाली के सिंक्रनाइज़ेशन को प्राप्त करने पर ध्यान केंद्रित करता है। यह एक व्यवस्थित कार्यप्रणाली तैयार करने और डबल-फेड इंडक्शन जनरेटर-आधारित पवन ऊर्जा रूपांतरण प्रणाली के रोटर साइड कनवर्टर और स्टेटर साइड कनवर्टर के लिए नियंत्रण उद्देश्यों को तैयार करने के द्वारा प्राप्त किया जाता है। इसके अतिरिक्त, ग्रिड-कनेक्टेड और स्टैंडअलोन मोड और इसके विपरीत के बीच निर्बाध संक्रमण प्राप्त करने के लिए, ग्रिड साइड कनवर्टर के लिए नियंत्रण उद्देश्यों को विस्तार से तैयार किया गया है। इसके अलावा, सिंक्रनाइज़ेशन क्रमशः स्टेटर साइड स्टैटिक ट्रांसफर स्विच (एसएसएसटीएस) और ग्रिड साइड स्टैटिक ट्रांसफर स्विच (जीएसएसटीएस) का उपयोग करके किया जाता है। एकल चरण और तीन चरण नॉनलाइनियर लोड के कारण हार्मोनिक्स और असंतुलित धाराओं को कम करने के लिए ग्रिड साइड कनवर्टर के लिए उन्नत नियंत्रण तकनीकों को भी लागू किया जाता है। इसके अलावा, नियंत्रण योजना तीन चरण चार तार माइक्रोग्रिड कॉन्फ़िगरेशन में तटस्थ धारा के दमन की सुविधा भी देती है। इसके अलावा, डबल फेड इंडक्शन जनरेटर की रोटर गति और रोटर स्थिति के आकलन के लिए एक सेंसर रहित योजना नॉच फिल्टर के आधार पर तैयार की गई है, जिससे सेंसर का उपयोग समाप्त हो जाएगा और लागत कम हो जाएगी।

विकसित हाइड्रो-पीवी-पवन आधारित माइक्रोग्रिड कॉन्फ़िगरेशन और उनके संबंधित नियंत्रण तरीकों की प्रभावशीलता का मूल्यांकन MATLAB/Simulink प्लेटफ़ॉर्म पर आयोजित व्यापक सिमुलेशन के माध्यम से किया जाता है। स्थिर स्थिति, संक्रमण मोड और गतिशील प्रतिक्रियाओं को शामिल करते हुए विभिन्न सिमुलेशन परिदृश्यों का विश्लेषण किया जाता है, प्रत्येक सिस्टम कॉन्फ़िगरेशन के लिए विस्तृत सिमुलेटेड परिणाम प्रदान किए जाते हैं। इसके अलावा, सभी विकसित माइक्रोग्रिड कॉन्फ़िगरेशन का प्रायोगिक सत्यापन एक प्रयोगशाला प्रोटोटाइप का उपयोग करके किया जाता है। विस्तृत परीक्षण परिणाम सिमुलेशन निष्कर्षों के पूरक के लिए अनुभवजन्य साक्ष्य प्रदान करते हुए बताए गए हैं

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LIST OF ABBREVIATIONS

AC	Alternating Current
AVR	Automatic Voltage Regulator
ADC	Analog Digital Conversion
ASOGI-FLL	Adaptive Second Order Generalized Integrator-Frequency Locked Loop
BTB	Back-to-Back
BES	Battery Energy Storage
BBC	Buck Boost Converter
BS-PLME	Block Sparse based Proportionate Least Mean M-Estimate
CPM	Constant Power Mode
DFIG	Doubly Fed Induction Generator
DC	Direct Current
DER	Distributed Energy Resources
DTC	Direct Torque Control
DPC	Direct Power Control
DIO	Digital Input/Output Pins
DG	Diesel Generator
DAC	Digital Analog Conversion
DSE	Distributed Sources of Energy
ELD	Enhanced Lyapunov's Demodulator
FOC	Field Oriented Control
FOGD	Fractional Order Gradient Descent
FRT	Fault Ride Through
GSC	Grid Side Converter
GCM	Grid Connected Mode
GFM	Grid Forming Converter
GSSTS	Grid Side Static Transfer Switch
GL-LAD	Generalized Logarithmic Least Absolute Difference

HCM	Hybrid AC/DC coupled microgrids
HTGS	Hydro Turbine Governing System
ILC	Interlinking Converter
InC	Incremental Conductance
IBR	Inverter Based Resources
IFO	Indirect Flux Mode
IPT	Inverse Park's Transform
LSC	Load Side Converter
LV	Low Voltage
MPPT	Maximum Power Point Tracking
MPE	Maximum Power Extraction
MRAS	Model Reference Adaptive System
MNF	Modified Notch Filter
PCC	Point of Common Coupling
PLL	Phase Locked Loop
PQ	Power Quality
PVC	Photovoltaic AC/DC Converter
PSS	Power System Stabilizer
PMSG	Permanent Magnet Synchronous Generator
RSC	Rotor Side Converter
RTS	Real Time Simulator
SPV	Solar Photovoltaic Array
SHP	Small Hydro Plants
SSC	Stator Side Converter
SG	Synchronous Generator
SOGI	Second Order Generalized Integrator
SM	Standalone Mode
SSSTS	Stator Side Static Transfer Switch

S&H	Sample & Hold
STF	Self-Tuning Filter
TLPN	Total Least Squares p-Norm
VSC	Voltage Source Converter
VFC	Voltage-Frequency Controller
VSID	Variable Speed Induction Motor Drive
VPM	Variable Power Mode
VSG	Virtual Synchronous Generator
WECS	Wind Energy Conversion System
WT	Wind Turbine
WRIG	Wound Rotor Induction Generator
ZCD	Zero Crossing Detector

LIST OF SYMBOLS

Ah_{BES}	Ah capacity of BES
$B1-B2$	Switching pulses for BBC
C_{DC1}, C_{DC2}	DC link capacitances
D_{boost}	Duty cycle of BBC during boost mode
D_{buck}	Duty cycle of BBC during buck mode
f_{swvfc}	Switching frequency of VFC
f_{swrsc}	Switching frequency of RSC
f_{swssc}	Switching frequency of SSC
f_{swBBC}	Switching pulses of BBC
g	Gear box ratio
i_{ga}, i_{gb}, i_{gc}	Grid currents
$i_{sha}, i_{shb}, i_{shc}$	Hydrogenerator currents
i_{sa}, i_{sb}, i_{sc}	Stator currents of DFIG
i_{ra}, i_{rb}, i_{rc}	Rotor currents of DFIG
i_{La}, i_{Lb}, i_{Lc}	Load currents
i_{Ln}	Load neutral current
i_{ca}, i_{cb}, i_{cc}	Voltage-frequency converter currents
i_{cn}	VFC neutral current
$i_{ilca}, i_{ileb}, i_{ilcc}$	Interlinking converter currents
$i_{pvca}, i_{pvcb}, i_{pvcc}$	PVC currents
i_{vn}	Capacitor bank terminal neutral current
I_{vfc}	Peak current flowing through VFC
I_b	Battery current
I_{rsc}	Peak current flowing through RSC
I_{ssc}	Peak current flowing through SSC
I_{ilc}	Peak current flowing through ILC
I_{gsc}	Peak current flowing through GSC

I_b	Battery current
I_{pv}	PV array current
L_{f1}, L_{f2}, L_{f3}	Inductance of interfacing inductors
P_t	Turbine power
P_s	Stator active power of DFIG
P_r	Rotor active power of DFIG
P_{bL}	Base load for microgrid
Q_s	Stator reactive power of DFIG
Q_r	Rotor reactive power of DFIG
RC	Ripple filter
$R1-R6$	Switching pulses for RSC
s_r	Rated slip
$S1-S6$	Switching pulses for VFC
$SP1-SP6$	Switching pulses for PVC
$S7-S13$	Switching pulses for SSC
t	Back up time of energy storage
$v_{gab}, v_{gbc}, v_{gca}$	Sensed grid line voltages
$v_{shab}, v_{shbc}, v_{shca}$	Sensed hydrogenerator voltages
$v_{sab}, v_{sbc}, v_{sca}$	Stator voltages of DFIG
V_{DC1}, V_{DC2}	DC link voltages
V_{shpk}	Amplitude of hydrogenerator voltage
V_{gpk}	Amplitude of grid voltage
V_{spk}	Amplitude of stator voltage of DFIG
V_{vfc}	Voltage rating of IGBT switch for VFC
V_{gsc}	Voltage rating of IGBT switch for GSC
V_{ssc}	Voltage rating of IGBT switch for SSC
V_{rsc}	Voltage rating of IGBT switch for RSC
V_{ilc}	Voltage rating of IGBT switch for ILC

V_{BES}	Battery voltage
V_{pv}	PV array voltage
W_{BES}	kWh capacity of BES
$x_{pa}^g, x_{pb}^g, x_{pc}^g$	In-phase grid unit templates
$x_{qa}^g, x_{qb}^g, x_{qc}^g$	Quadrature grid unit templates
$x_{pa}^{sh}, x_{pb}^{sh}, x_{pc}^{sh}$	In-phase hydrogenerator unit templates
$x_{qa}^{sh}, x_{qb}^{sh}, x_{qc}^{sh}$	Quadrature hydrogenerator unit templates
X_g	Grid side synchronizing signal
X_s	Stator side synchronizing signal
θ_g	Grid voltage phase angle
θ_{sh}	Hydro voltage phase angle
θ_s	Stator voltage phase angle
θ_{slip}	Slip angle of DFIG
ω_r	Rotor position of DFIG
λ_T	Optimal tip speed ratio