

INVESTIGATIONS ON GRID INTERACTIVE MICROGRIDS WITH DFIG BASED WIND-SOLAR PV GENERATION

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INDIAN INSTITUTE OF TECHNOLOGY DELHI**

JULY 2024

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**INVESTIGATIONS ON GRID INTERACTIVE MICROGRIDS
WITH DFIG BASED WIND-SOLAR PV GENERATION**

by

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Electrical Engineering Department

Submitted

in fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2024

CERTIFICATE

It is certified that the thesis entitled “**Investigations on Grid Interactive Microgrids with DFIG based Wind-Solar PV Generation,**” being submitted by **Mr. Puchalapalli Sambasivaiah** 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.

Dated: July 30, 2024

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ACKNOWLEDGEMENTS

I wish to express my deepest gratitude and indebtedness to **Prof. Bhim Singh** for providing me guidance and constant supervision to carry out the Ph.D. work. Working under him has been a wonderful experience, which has provided a deep insight to 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. G. Bhuvaneswari, Prof. B.K.Panigrahi, Prof. T. C. Kandpal, all SRC members for their valuable guidance and consistent support during my research work.

I wish to convey my sincere thanks to Prof. Bhim Singh, Prof. G. Bhuvaneswari, Prof. Sukumar Mishra, Prof. B. K. Panigrahi, Dr. Anandarup Das for their valuable inputs during my course work, which has made the foundation for my research work.

I am grateful to IIT Delhi for providing me the research facilities. I would wish to express my sincere gratitude to Prof. Bhim Singh, Prof. G. Bhuvaneswari and the Dr. A.K. Jain, as Prof. in-charge of PG Machine Lab, for providing me immense facilities to carry out experimental work. Thanks are due to Sh. Srichand, Sh. PuranSingh, Sh. Jagbir Singh, Sh. Amit Kumar, Sh. Jitendra of PG Machines Lab, UG Machines Lab and Power Electronics Lab., IIT Delhi for providing me the facilities and assistance during this work. I would like to thank all my seniors, Dr. Rajan Sonkar, Dr. Ikhlq Hussain, Dr. Aniket Anand, Dr. Nishant Kumar, Dr. Anshul Varshney, Dr. Saurabh Shukla, Dr. Nidhi Mishra, Dr. Geeta Pathak, Dr. Shailendra Kumar

Dwivedi, Dr. Anjeet Verma, Dr. Anjanee Kumar Mishra and Dr. Shreejith to motivate me in the starting of my research work. I would like to thank Dr. Souvik Das, Mr. Gurmeet, Mr. Amar, Mr. Priyabrat, Ms. Hina, Dr. Rohini Sharma, Dr. Farheen, Dr. Pavitra, Dr. Vivek, Ms. Sunaina Singh, Ms. Kripa, Dr. Jitendra Gupta, Mr. Gaurav Modi, Dr. Utkarsh and all other colleague for their valuable aid and cooperation. Moreover, I would like to thank Dr. Radha Khushwaha, Dr. Vandana Jain, Dr. Piyush Kant, Dr. Shatakshi Jha, Ms. Yashi Singh, Dr. Priyank Shah, Dr. VL Srinivas, Dr. Deepu Vijay M, Dr. Shadab Murshid, Dr. Tripurari Nath, Mr. Sudip Bhattacharyya, Ms. Nupur, Mr. Arayadip, Mr. Bilal, Mr. Munesh, Ms. Rashmi, Mr. Sandeep, Ms. Shalvi, Mr. Sharan, Mr. Shivam, Mr. Somnath, Dr. Tabish, Dr. Vineet, Mr. Utsav, Dr. Kashif, Dr. Shubhra, Mr. Rahul, Mr. Deepak, Mr. Saran, Mr. Rohit and all PG Machines lab group for their valuable support. I would also like to thank Mr. Satish and Mr. Yatindra, and all other Electrical Engineering Department office staff 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 Department of Science and Technology (DST), Govt. of India for funding this research work under the fund for improvement of S&T infrastructure in higher educational institutions (FIST: RP03195G), UKICERI (RP03391), J. C. Bose Fellowship (RP03128), and SERB National Science Chair (NSC) Fellowship.

My deepest love, appreciation and indebtedness go to my parents Mr. Puchalapalli Ramanaiah and Mrs. Padma for their ambitions, sacrifices and whole hearted support. I must appreciate my wife and my son Mrs. Niharika and Mr. Himanish Ram for giving me the invaluable support. Also, I must appreciate my sisters Mrs. Nagamani, Mrs. Nagabhushana and Mrs Naga Reddamma always behind me to provide the moral support for achieving this academic level. Also, I must appreciate my brother Mr. Pitchiah for giving me the invaluable support.

At last, 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 showered on me for strength, wisdom and determination to achieve in future.

Date: July 30, 2024.

Puchalapalli Sambasivaiah

ABSTRACT

This work deals with control and implementation of various microgrid configurations based on wind turbine driven DFIG (Doubly Fed Induction Generator) and solar PV (Photovoltaic) array to power the connected loads with enhanced power quality. It presents standalone DFIG based WPGS (Wind Power Generation System) with a new single input variable fuzzy logic controller (FLC). FLC is applied to both controls of rotor side converter (RSC) and load side converter (LSC) of DFIG to achieve acceptable performance in terms of wind peak power extraction and to regulate voltage and frequency at point of common coupling (PCC) irrespective of wind speeds and load change. Moreover, a battery energy storage (BES) is used at common DC link of RSC and LSC to support wind MPPT (Maximum Power Point Tracking) operation. In addition, the grid-interfaced wind turbine coupled DFIG without BES is investigated for feeding the wind power to the utility grid. Various controls such as adaptive RSC control along with GSC (Grid Side Converter) control, a dual layer least mean fourth (DL-LMF) based control scheme with reduced sensors, and an optimal RSC control, are presented. These controls are developed to achieve wind power extraction, and to regulate the DC link voltage along with power quality aspects such as harmonics elimination, unbalanced load balancing and reactive power compensation. Moreover, an optimal RSC control is proposed to achieve minimal losses in the wind driven DFIG system so that enhanced power is fed to the utility grid. This is done through sharing of reactive power of DFIG between RSC and GSC optimally. Moreover, this work presents grid-interfaced wind turbine driven DFIG with a BES, for which, a novel PLL based control is used to achieve regulated power flow through the grid irrespective of variable winds. Performance of PLL based control is analyzed at grid voltages with DC offset. This microgrid based on wind turbine driven DFIG and solar PV array with seamless transition between islanding and grid connected modes and vice versa, is presented.

Seamless transition controls are presented for both RSC and GSC of DFIG to achieve smooth transfer between standalone and grid connected modes. This work presents synchronizing control of wind turbine driven DFIG system with DG (Diesel Generator) set in an isolated microgrid (MG) involving the solar PV array and BES. Modified controls are presented for GSC to achieve minimal fuel operation of DG even at varying loads. Further, grid-interactive wind-solar-DG based MG with BES, is analyzed for enhancing the reliability of power supply. Modified controls are presented for smooth connection of grid/DG. Moreover, various proposed wind turbine driven DFIG and solar PV array based microgrid topologies and their control algorithms, are simulated and verified experimentally at different scenarios such as variable wind speeds, change in connected loads, both in on/off grid/DG modes.

सारांश

यह कार्य पवन टरबाइन चालित DFIG (डबल फ़ेड इंडक्शन जेनरेटर) और सौर पीवी (फोटोवोल्टिक) सारणी पर आधारित विभिन्न माइक्रोग्रिड विन्यासों के नियंत्रण और कार्यान्वयन से संबंधित है, ताकि बढ़ी हुई बिजली गुणवत्ता के साथ जुड़े भार को शक्ति प्रदान की जा सके। यह एक नए एकल इनपुट वेरिएबल फ़ज़ी लॉजिक कंट्रोलर (FLC) के साथ स्टैंडअलोन DFIG आधारित WPGS (पवन ऊर्जा उत्पादन प्रणाली) प्रस्तुत करता है। पवन पीक पावर निष्कर्षण के संदर्भ में स्वीकार्य प्रदर्शन प्राप्त करने और पवन गति और लोड परिवर्तन के बावजूद सामान्य युग्मन (PCC) के बिंदु पर वोल्टेज और आवृत्ति को विनियमित करने के लिए DFIG के रोटार साइड कनवर्टर (RSC) और लोड साइड कनवर्टर (LSC) दोनों नियंत्रणों पर FLC लागू किया जाता है। इसके अलावा, पवन MPPT (अधिकतम पावर पॉइंट ट्रैकिंग) विभिन्न नियंत्रण जैसे कि अनुकूली RSC नियंत्रण के साथ GSC (ग्रिड साइड कनवर्टर) नियंत्रण, कम सेंसर के साथ एक दोहरी परत कम से कम चौथा (DL-LMF) आधारित नियंत्रण योजना, और एक इष्टतम RSC नियंत्रण, प्रस्तुत किए गए हैं। ये नियंत्रण पवन ऊर्जा निष्कर्षण को प्राप्त करने और हार्मोनिक्स उन्मूलन, असंतुलित लोड संतुलन और प्रतिक्रियाशील शक्ति क्षतिपूर्ति जैसे बिजली गुणवत्ता पहलुओं के साथ डीसी लिंक वोल्टेज को विनियमित करने के लिए विकसित किए गए हैं। इसके अलावा, पवन चालित DFIG प्रणाली में न्यूनतम नुकसान को प्राप्त करने के लिए एक इष्टतम RSC नियंत्रण प्रस्तावित किया गया है ताकि बढ़ी हुई बिजली उपयोगिता ग्रिड को खिलाई जा सके। यह RSC और GSC के बीच DFIG की प्रतिक्रियाशील शक्ति को इष्टतम रूप से साझा करने के माध्यम से किया जाता है। इसके अलावा, यह कार्य ग्रिड-इंटरफ़ेस्ड पवन टरबाइन चालित DFIG को BES के साथ प्रस्तुत करता है, जिसके लिए, परिवर्तनशील हवाओं के बावजूद ग्रिड के माध्यम से विनियमित बिजली प्रवाह को प्राप्त करने के लिए एक उपन्यास PLL आधारित नियंत्रण का उपयोग किया जाता है। DC ऑफ़सेट के साथ ग्रिड वोल्टेज पर PLL आधारित नियंत्रण के प्रदर्शन का विश्लेषण किया जाता है। द्वीप और ग्रिड से जुड़े मोड और इसके विपरीत

के बीच निर्बाध संक्रमण के साथ पवन टरबाइन चालित DFIG और सौर PV सरणी पर आधारित यह माइक्रोग्रिड प्रस्तुत किया गया है। स्टैंडअलोन और ग्रिड से जुड़े मोड के बीच सुचारू हस्तांतरण को प्राप्त करने के लिए डीएफआईजी के आरएससी और जीएससी दोनों के लिए निर्बाध संक्रमण नियंत्रण प्रस्तुत किए गए हैं। यह कार्य सौर पीवी सरणी और बीईएस को शामिल करते हुए एक पृथक माइक्रोग्रिड (एमजी) में स्थापित डीजी (डीजल जेनरेटर) के साथ पवन टरबाइन संचालित डीएफआईजी प्रणाली के सिंक्रनाइज़ नियंत्रण को प्रस्तुत करता है। अलग-अलग भार पर भी डीजी के न्यूनतम ईंधन संचालन को प्राप्त करने के लिए जीएससी के लिए संशोधित नियंत्रण प्रस्तुत किए गए हैं। इसके अलावा, बिजली आपूर्ति की विश्वसनीयता बढ़ाने के लिए बीईएस के साथ ग्रिड-इंटरैक्टिव पवन-सौर-डीजी आधारित एमजी का विश्लेषण किया गया है। ग्रिड/डीजी के सुचारू कनेक्शन के लिए संशोधित नियंत्रण प्रस्तुत किए गए हैं।

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LIST OF ABBREVIATIONS

WPGS	Wind Power Generation System
BES	Battery Energy Storage
AC	Alternating Current
DC	Direct Current
DFIG	Doubly Fed Induction Generator
WECS	Wind Energy Convesion System
DSP	Digital Signal Processor
GSC	Grid Side Converter
LSC	Load Side Converter
RSC	Rotor Side Converter
MPPT	Maximum Power Point Tracking
MRAS	Model Reference Adaptive System
PCC	Point of Common Coupling
STS	Static Transfer Switch
THD	Total Harmonics Distortion
UPF	Unity Power factor
WRIM	Wound Rotor Induction Machine
VSC	Voltage Source Converter
PWM	Pulse Width Modulation
PIC	Proportional and Integral Controller

LIST OF SYMBOLS

i_{ra}, i_{rb}, i_{rc}	Three phase rotor currents(i_{rabc})
i_{sa}, i_{sb}, i_{sc}	Three phase stator currents (i_{sabc})
i_{La}, i_{Lb}, i_{Lc}	Three phase load currents (i_{Labc})
i_{ms}	Magnetizing current
i_{ga}, i_{gb}, i_{gc}	Three phase grid currents (i_{gabc})
i_{dr}^*	Direct axis rotor reference current
i_{qr}^*	Quadrature axis rotor reference current
i_{dr}	Direct axis rotor current
i_{qr}	Quadrature axis rotor current
P_g	Grid Active Power
P_L	Load Active Power
V_{dc}	DC Link voltage
V_w	Wind Speed in m/sec
λ	Tip Speed Ratio
β	Pitch Angle
C_p	Rotor Power Coefficient
η	Gear box ratio
L_m	Magnetizing inductance