CONTROL AND IMPLEMENTATION OF MICROGRIDS EMPLOYING RENEWABLE ENERGY SOURCES FOR EV CHARGING INFRASTRUCTURE

KRIPA TIWARI

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
HAUZ KHAS, NEW DELHI-110016, INDIA
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By

Kripa Tiwari

Department of Electrical Engineering

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CERTIFICATE

This is to certify that the thesis entitled, **"Control and Implementation of Microgrids Employing Renewable Energy Sources for EV charging Infrastructure"** being submitted by **Mrs. Kripa Tiwari** for the award of the degree of Doctor of Philosophy is a record of bona fide research work carried out by her in the Department of Electrical Engineering of Indian Institute of Technology Delhi.

Mrs. Kripa Tiwari 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 results obtained herein have not been submitted to any other University or Institute for the award of any degree.

Dated:
Place: New Delhi

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

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ABSTRACT

This thesis focuses on the design, modelling, control, and implementation of hybrid microgrid configurations—centred around both common AC and DC bus architectures The research investigates the operational characteristics and control challenges associated with both common AC bus and common DC bus-based microgrids. Particular emphasis is placed on developing robust control strategies for voltage regulation, unity power factor operation, power quality improvement, and seamless transition between grid-connected and islanded modes under dynamic conditions. Moreover, emphasis on robust control under non-ideal grid scenarios is also part of proper investigation. Interlinking converters and shared converter topologies are explored for their role in coordinating power exchange between AC and DC domains while ensuring operational performance and minimizing harmonic distortion.

Additionally, this work evaluates the integration of multiple solar arrays and energy storage systems in parallel configurations to meet the high-power demands of modern loads, such as fast-charging EV stations. The thesis proposes unified control frameworks that support synchronized grid interfacing, dynamic load management, and power sharing among renewable and conventional sources Comprehensive simulations and hardware-based validations are carried out under various operating scenarios, including grid disturbances, load transients, and source intermittencies. The findings demonstrate the effectiveness of the proposed configurations and control methods in ensuring reliable, flexible, and high-performance operation of hybrid microgrid systems.

सारांश

यह शोध कार्य सामान्य एसी और डीसी बस आधारित संरचनाओं के चारों ओर केंद्रित हाइब्रिड माइक्रोग्रिड विन्यासों के डिज़ाइन, मॉडलिंग, नियंत्रण और कार्यान्वयन पर केंद्रित है। इस शोध में सामान्य एसी बस और सामान्य डीसी बस पर आधारित माइक्रोग्रिड्स की परिचालन विशेषताओं और नियंत्रण संबंधी चुनौतियों का विश्लेषण किया गया है। विशेष रूप से वोल्टेज विनियमन, यूनिटी पावर फैक्टर संचालन, पावर क्वालिटी सुधार, और ग्रिड-संयुक्त व आइलैंडेड मोड्स के बीच निर्बाध संक्रमण के लिए मज़बूत नियंत्रण रणनीतियों के विकास पर ज़ोर दिया गया है। इसके साथ ही, गैर-आदर्श ग्रिड परिस्थितियों में मज़बूत नियंत्रण की आवश्यकता और उसका विश्लेषण भी इस कार्य का एक महत्वपूर्ण भाग है।

एसी और डीसी डोमेनों के बीच ऊर्जा विनिमय के समन्वयन में इंटरलिंकिंग कन्वर्टर्स और साझा कन्वर्टर टोपोलॉजी की भूमिका का भी गहन अध्ययन किया गया है, जिससे परिचालन प्रदर्शन सुनिश्चित हो और हार्मोनिक विकृति को न्यूनतम किया जा सके।

साथ ही, इस कार्य में कई सौर पैनलों और ऊर्जा भंडारण प्रणालियों को समांतर रूप में एकीकृत करने का मूल्यांकन किया गया है, ताकि तीव्र गति से चार्जिंग करने वाले ईवी स्टेशनों जैसी उच्च-शक्ति आवश्यकताओं को पूरा किया जा सके। यह शोध एकीकृत नियंत्रण ढांचे का प्रस्ताव करता है, जो ग्रिड के साथ समकालिक संपर्क, गतिशील लोड प्रबंधन, और नवीकरणीय व पारंपरिक स्रोतों के बीच ऊर्जा साझेदारी को सक्षम बनाते हैं।

विभिन्न परिचालन परिस्थितियों — जैसे ग्रिड व्यवधान, लोड ट्रांज़िएंट्स और स्रोत की अनियमितता — के तहत व्यापक सिमुलेशन और हार्डवेयर-आधारित परीक्षण किए गए हैं। निष्कर्षों से यह प्रमाणित होता है कि प्रस्तावित विन्यास और नियंत्रण विधियाँ हाइब्रिड माइक्रोग्रिड प्रणालियों के लिए विश्वसनीय, लचीले और उच्च-प्रदर्शन वाले संचालन को सुनिश्चित करती हैं

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LIST OF ABBREVIATIONS

DER	Distributed Energy Resources
DC	Direct Current
AC	Alternating Current
RES	Renewable Energy Sources
PV	Photovoltaic
SPV	Solar Photovoltaic
BES	Battery Energy Storage
PCC	Point of Common Coupling
MPPT	Maximum Power Point Tracking
VSC	Voltage Source Converter
GCM	Grid Connected Mode
SM	Standalone Mode
AM	Autonomous Mode
IM	Islanded Mode
STS	Static Transfer Switch
PI	Proportional Integral
PR	Proportional Resonant
ADC	Analog to digital Conversion
BDDC	Bidirectional DC DC converter
ILC	Interlinking Converter
PLL	Phase Locked Loop
FLL	Frequency Locked Loop
PQ	Power Quality
BLDCG	Brushless Direct Current Generator
SOGI	Second Order Generalized Integrator
WT	Wind Turbine
WECS	Wind Energy Conversion System
ZCD	Zero Crossing Dectector
RTS	Real Time Simulator
InC	Incremental Conductance
MG	Microgrid
DAC	Digital Analog Conversion
DIO	Digital Input output

LIST OF SYMBOLS

v_{ga}, v_{gb}, v_{gc}	Grid Voltages
i_{ga},i_{gb},i_{gc}	Grid Currents
i_{la},i_{lb},i_{lc}	Load Currents
v_{gab},v_{gbc}, v_{gca},	Grid Line Voltages
v_{gabp}, v_{gbcp}	Distorted Grid Line Voltgaes
v_{gabf}, v_{gbcf}	Filtered Grid Line Voltages
v_{pcca},v_{pccb},v_{pccc}	PCC Voltages
V_{pv}	PV Voltage
V_{w}	Wind Voltage
V_{h}	Pivo-hydro Voltage
I_{pv}	PV Current
I_{w}	Wind Current
I_{h}	Pico-hydro Current
i_{bes}	BES Current
V_{dc}	DC Link Voltage
V_{dcb}	DC link Voltage of Battery BDDC
V_{dcw}	DC link Voltage of Wind Boost
V_{dcpv}	DC link Voltage of PV Boost
V_{dch}	DC link Voltage of Pico-hydro Boost
P_{l}	Load Power
P_{g}	Grid Power
P_{pv}	PV Power
P_{h}	Pico-hydro Power
P_{w}	Wind Power
D_{boost}	Boost duty cycle
D_{buck}	Buck Duty cycle
L_{f}	Interfacing Inductors
f_{sw}	Switching Frequency
AH_{bes}	Ampere hour of Battery
V_{bes}	Battery Voltage
$S1$-$S6$	Switching Pulses
S_{bes}	BES Switching Pulses
S_{pv}	PV Boost Switching Pulses
S_{w}	Wind Boost Switching Pulses
S_{h}	Pico-hydro Boost Switching Pulses
U_{tpa}, U_{tpb}, U_{tpc}	In phase unit templates
U_{tqa}, U_{tqb}, U_{tqc}	Quadrature unit templates
θ_{g}	Grid angular frequency
θ_{l}	Load angular frequency
STS_{G}	Static Transfer switch pulses of Grid
STS_{PV}	Static Transfer switch pulses of PV

$Vter$	Terminal Voltage Amplitude
$i_{vsca},i_{vscb},i_{vscc}$	VSC Currents
C_{dc}	DC Link Capacitance