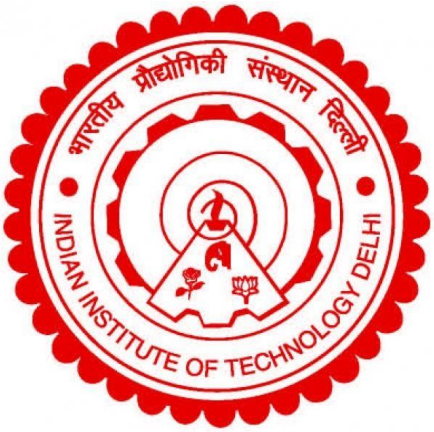
CONTROL OF UNIFIED POWER QUALITY CONDITIONER FOR GRID CONNECTED AND STANDALONE RENEWABLE ENERGY INTERFACED AC SYSTEM

SANJENBAM CHANDRAKALA DEVI



Department of Electrical Engineering
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Control of Unified Power Quality Conditioner for Grid Connected and Standalone Renewable Energy Interfaced AC Systems

by

Sanjenbam Chandrakala Devi

Department of Electrical Engineering

Submitted

In fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

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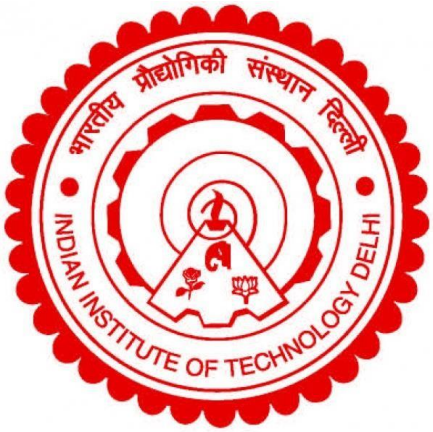

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CERTIFICATE

It is certified that the thesis entitled "**Control of Unified Power Quality Conditioner for Grid Connected and Standalone Renewable Energy Interfaced AC Systems**," being submitted by **Ms. Sanjenbam Chandrakala Devi** 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 supervisionand guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

Dated: 20/02/2025

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ABSTRACT

This thesis presents an advanced control strategies for a unified power quality conditioner (UPQC) renewable energy-based AC systems, addressing both grid-connected and standalone operational modes. As renewable energy sources (RES) become increasingly integrated into modern power systems, maintaining power quality remains a critical challenge due to their intermittent nature. The increasing integration of renewable energy sources, such as solar photovoltaic (PV) array systems and hydro power generations, into electrical grids poses significant challenges related to power quality (PQ). The UPQC, a combination of series and shunt compensators, offers an effective solution to mitigate power quality issues such as voltage sags, harmonics, and reactive power imbalances. In grid-connected mode, the UPQC is designed to enhance power quality by compensating for grid voltages disturbances and ensuring smooth integration of RES. In standalone mode, it ensures the stability and reliability of the microgrid by maintaining voltage and frequency stability, even under variable load conditions. This research work aims to address the capability of voltage and current qualities improvement through an adaptive control algorithm, which dynamically controls the operation of the UPQC.

The control strategies integrate advanced techniques such as enhanced second-order generalized integrator (ESOGI) control method for a grid-integrated UPQC with a solar PV system. This approach eliminates the need for voltage sensors on the grid side, effectively mitigating DC offsets and estimating fundamental elements to compute reference signals. A double-stage solar PV array integrated UPQC is developed for a three-phase three wire and four-wire distribution networks. The system effectively addresses multiple PQ issues, including neutral current and harmonics, through two four-leg voltage source inverters connected via a common DC bus. Performance analysis confirms the system's capability to maintain high PQ levels under diverse operational conditions.

The thesis also investigates the applications of a damped ratio adaptive second order generalized integrator (DRASOGI) control and model predictive control (MPC) method in standalone systems driven by pico-hydro turbines to enhance the performance of the UPQC. The proposed system is validated through extensive simulation and experimental studies, demonstrating its effectiveness in improving power quality and system stability in both grid-connected and standalone modes. Experimental validation through hardware prototypes further confirms the system's ability to follow the IEEE-519, IEEE-1159, IEC 61727 standards. The results indicate that proposed UPQC control approach provides a reliable and efficient solution for mitigating power quality issues in renewable energy-based AC systems, making it a valuable contribution to the development of more resilient and sustainable power systems.

ABSTRACT

यह थीसिस एक एकीकृत बिजली गुणवत्ता कंडीशनर (UPQC) अक्षय ऊर्जा-आधारित एसी सिस्टम के लिए एक उन्नत नियंत्रण रणनीति प्रस्तुत करता है, जो ग्रिड-कनेक्टेड और स्टैंडअलोन परिचालन मोड दोनों को संबोधित करता है | चूंकि अक्षय ऊर्जा स्रोत (आरईएस) आधुनिक बिजली प्रणालियों में तेजी से एकीकृत हो जाते हैं, बिजली की गुणवत्ता को बनाए रखना उनके रुक -रुक कर मिलने वाली प्रकृति के कारण एक महत्वपूर्ण चुनौती बनी हुई है | नवीकरणीय ऊर्जा स्रोतों, जैसे कि सौर फोटोवोल्टिक (पीवी) सरणी प्रणाली और हाइड्रो बिजली की पीढ़ियों के बढ़ते एकीकरण, विद्युत ग्रिड में बिजली की गुणवत्ता (पीक्यू) से संबंधित महत्वपूर्ण चुनौतियां हैं। यूपीक्यूसी, श्रृंखला और शंट कम्पेस्टर्स का एक संयोजन, वोल्टेज एसएजीएस, हार्मोनिक्स और प्रतिक्रियाशील शक्ति असंतुलन जैसे बिजली की गुणवत्ता के मुद्दों को कम करने के लिए एक प्रभावी समाधान प्रदान करता है। ग्रिड-कनेक्टेड मोड में, UPQC को ग्रिड वोल्टेज की गड़बड़ी की भरपाई करके और RES के सुचारू एकीकरण को सुनिश्चित करके बिजली की गुणवत्ता को बढ़ाने के लिए डिज़ाइन किया गया है। स्टैंडअलोन मोड में, यह चर लोड स्थितियों के तहत भी वोल्टेज और आवृत्ति स्थिरता को बनाए रखने के द्वारा माइक्रोग्रिड की स्थिरता और विश्वसनीयता सुनिश्चित करता है। इस शोध कार्य का उद्देश्य एक अनुकूली नियंत्रण एल्गोरिथ्म के माध्यम से वोल्टेज और वर्तमान गुणों में सुधार की क्षमता को संबोधित करना है, जो गतिशील रूप से UPQC के संचालन को नियंत्रित करता है। नियंत्रण रणनीतियाँ उन्नत तकनीकों जैसे कि एक सौर पीवी प्रणाली के साथ ग्रिड-एकीकृत UPQC के लिए दूसरे क्रम के सामान्यीकृत सामान्यीकृत इंटीग्रेटर (ESOGI) नियंत्रण विधि जैसे उन्नत तकनीकों को एकीकृत करती हैं। यह दृष्टिकोण ग्रिड साइड पर वोल्टेज सेंसर की आवश्यकता को समाप्त करता है, प्रभावी रूप से डीसी ऑफसेट को कम करता है और संदर्भ संकेतों की गणना करने के लिए मौलिक तत्वों का अनुमान लगाता है। एक डबल-स्टेज सोलर पीवी सरणी एकीकृत UPQC को तीन-चरण तीन

तार और चार-तार वितरण नेटवर्क के लिए विकसित किया गया है। सिस्टम प्रभावी रूप से कई पीक्यू मुद्दों को संबोधित करता है, जिसमें एक सामान्य डीसी बस के माध्यम से जुड़े दो चार-पैर वोल्टेज स्रोत इनवर्टर के माध्यम से तटस्थ वर्तमान और हार्मोनिक्स शामिल हैं। प्रदर्शन विश्लेषण विविध परिचालन स्थितियों के तहत उच्च पीक्यू स्तर बनाए रखने के लिए सिस्टम की क्षमता की पुष्टि करता है। थीसिस एक नम अनुपात एडेप्टिव सेकंड ऑर्डर सामान्यीकृत इंटीग्रेटर (DRASOGI) कंट्रोल और मॉडल प्रेडिक्टिव कंट्रोल (MPC) विधि के अनुप्रयोगों की जांच करता है, जो UPQC के प्रदर्शन को बढ़ाने के लिए PICO-Hydro टर्बाइन द्वारा संचालित स्टैंडअलोन सिस्टम में है। प्रस्तावित प्रणाली को व्यापक सिमुलेशन और प्रयोगात्मक अध्ययनों के माध्यम से मान्य किया गया है, जो ग्रिड-कनेक्टेड और स्टैंडअलोन मोड दोनों में बिजली की गुणवत्ता और सिस्टम स्थिरता में सुधार करने में इसकी प्रभावशीलता का प्रदर्शन करता है। हार्डवेयर प्रोटोटाइप के माध्यम से प्रायोगिक सत्यापन आगे IEEE-519, IEEE-1159, IEC 61727 मानकों का पालन करने के लिए सिस्टम की क्षमता की पुष्टि करता है। परिणाम बताते हैं कि प्रस्तावित UPQC नियंत्रण दृष्टिकोण अक्षय ऊर्जा-आधारित एसी सिस्टम में बिजली की गुणवत्ता के मुद्दों को कम करने के लिए एक विश्वसनीय और कुशल समाधान प्रदान करता है, जिससे यह अधिक लचीला और टिकाऊ बिजली प्रणालियों के विकास में एक मूल्यवान योगदान है |

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UPQC FOR SCIG BASED HYDRO ELECTRIC SYSTEM

UPQC FOR PMSG BASED HYDRO GENERATION SYSTEM

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LIST OF ABBREVIATIONS

UPQC	Unified Power Quality Conditioner
PV	Photovoltaic
SPVA	Solar photovoltaic Array
VSC	Voltage Source Converter
VSI	Voltage Source Inverter
PQ	Power Quality
SECS	Solar Energy Conversion System
BESSs	Battery Energy Storage Systems
MPPT	Maximum Power Point Tracking
PID	Proportional Integral Derivative
RES	Renewable Energy Sources
RECS	Renewable Energy Conversion System
P&O	Perturb and Observed
DSP	Digital Signal Processor
DSO	Digital Signal Oscilloscope
DSTATCOM	Distribution Static Compensator
DVR	Dynamic Voltage Regulator
APF	Active Power Filter
SEAPF	Series Active Power Filter
SHAPF	Shunt Active Power Filter
BDC	Bidirectional DC–DC Converter
SCIG	Squirrel Cage Induction Generation
PMSG	Permanent Magnet Synchronous Generator
SyRG	Synchronous Reluctance Generator
THD	Total Harmonics Distortion
SOGI	Second Order Generalized Integrator
C-SOGI	Cascaded Second Order Generalized Integrator
MPC	Model Predictive Controller
DRASOGI	Damped Ratio Adaptive Second Order Generalized Integrator

LIST OF SYMBOLS

V_{DC}	DC bus voltage of voltage source converter
C_{DC}	DC bus capacitance of voltage source converter
a	Over loading factor
P_{pv}	Solar power generation
f_{sw}	Switching frequency
v_{sabc}	Line voltage of the grid
i_{sabc}	Three phase grid currents
i_{Labc}	Three phase line currents
i_{vsc}	Three phase currents of the voltage source converter
D	Duty ratio
I_{loss}	Loss component
I_{pvff}	Solar photovoltaic feed-forward component
I_{load}	Load component
I_{net}	Total amplitude of reference grid currents
$i_{ref\text{-}abc}$	Three phase reference grid currents
L	Interfacing inductor of voltage source converter
$L_{vsc\text{-}n}$	Interfacing inductor of fourth leg of voltage source converter
V_{pv}	Solar PV array voltage
I_{pv}	Solar PV array current
V_t	Terminal voltage of common coupling point
u_{pabc}	In-phase unit templates
u_{qabc}	Quadrature unit templates
v_{pabc}	Positive sequence of phase voltages
P_s	Active power in the grid
Q_s	Reactive power in the grid
P_L	Active power of load
Q_L	Reactive power of load
P_{pv}	Solar MPPT Power
P_{Bat}	Battery charging and discharging power