

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

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Indian Institute of Technology Delhi
February 2025**

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

by

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Submitted

In fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to the



Indian Institute of Technology Delhi

February 2025

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 supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

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ACKNOWLEDGEMENTS

I wish to express my deepest gratitude and indebtedness to **Prof. Bhim Singh** for his unwavering guidance and supervision throughout my Ph.D. journey. Working under his mentorship has been an enriching experience, providing me with profound insights into the realm of research. Determination, dedication, innovativeness, resourcefulness and discipline of **Prof. Bhim Singh** have served as a constant source of inspiration, propelling me to successfully complete this work. His consistent encouragement, meticulous oversight, and commitment to excellence have continuously motivated me to strive for improvement and harness my full potential. Under his tutelage and blessing, I have not only gained invaluable research experiences but also acquired skills that will benefit me throughout my life.

I extend my heartfelt thanks and deep gratitude to **Prof. Anandarup Das, Prof. Sumit Pramanick, Prof. T. C. Kandpal, Dr. Ramkrishan Maheshwari**, and all SRC members for their invaluable guidance and unwavering support during my research work.

I also express my sincere appreciation to **Prof. Bhim Singh, Prof. B. P. Singh, Prof. M. Veerachary**, and **B. K. Panigrahi** for their invaluable insights during my coursework, laying a strong foundation for my research. I am thankful to the **Indian Institute of Technology Delhi** for providing me with the necessary research facilities.

Special thanks are due to **Prof. Bhim Singh** and **Prof. M. Veerachary**, as Prof. in-charge of PG Machine Lab, generously providing me with facilities to conduct experimental work at the PG Machine Lab.

I extend my gratitude to Sh. Srichand, Sh. Puran Singh, Sh. Jagbir Singh, Sh. Amit Kumar, and Sh. Jitendra of PG Machines Lab, UG Machines Lab and Power Electronics Lab., Indian Institute of Technology Delhi for their assistance and provision of facilities.

I would like to thank all my seniors, Dr. Priyank Mukeshkumar Shah, Dr. VL Srinivas, Dr. Sachin Devassy, Dr. Nishant Kumar, Dr. Vandana Jain, Dr. Aniket Anand, Dr. Shadab Murshid, Dr. Anshul Varshney, Dr. Sreejith R, Dr. Shailendra Kumar Dwivedi, Dr. Piyush Kant, Dr. Seema Kewat, Dr. Subarni Pradhan, Dr. Anjaneer Kumar Mishra, Dr. Deepu Vijay M, Dr. Utkarsh Sharma, Mr. Debasish Mishra, Dr. P. Sambasivaiah, Dr. Pavitra Shukl, Dr. Farheen Chishti, Dr. Rohini Sharma, Dr. Mohd. Kashif, Dr. Hina Parveen, Dr. Aryadip Sen, Dr. Gaurav Modi, Dr. Souvik Das, Dr. Jitendra Gupta, Mr. Utsav Sharma, Dr. Shalvi Tyagi, Mr. Syed Bilal Qaiser Naqvi, Mr. Sudip Bhattacharyya, Mr. Sandeep Kumar Sahoo, Mrs. Yashi Singh, Dr. Vivek Narayanan, Mr. Saran Chaurasiya, Mr. Sayandev Ghosh, Mr. Suri Rama Naga Praneeth, and Mr. Priyvat Vats, who have constantly helped me on all technical and non-

technical issues.

My sincere thanks are due to for cooperation and informal support Dr. Priyank Mukeshkumar Shah, Dr. VL Srinivas, Dr. Sachin Devassy, Dr. Subarni Pradhan, and Dr. Nishant Kumar, in pursuing this research work.

Special thanks to Mr. Deepak Singh, Mr. Rahul Kumar, Mr. Deepak Saw, Mr. Sharankumar Shastri, Mrs. Kousalya V, Mr. Shivam Kumar Yadav, and all other colleague for their valuable aid and cooperation.

Moreover, I would like to thank, Mr. Saurabh Mishra, Mr. Mohammad Junaid, Mr. Muhammad Zarkab Farqooi, Mrs. Kripa Tiwari, Mr. Rohit Kumar, Mr. Vipin Kumar Singh, Mr. Arjun Kumar, Mr. Biswajit Saha, Ms. Farha Siddique, Mr. Sumit Kumar, Mr. Gaurav Kumar, Mr. Himansu Sahoo, Mr. Adnan Farooq Khan, Mr. Chetan Shashank Matwankar, Ms. Smita Mohanty, and all PG Machines lab group for their valuable support.

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), UKICERI (RP03391), Clean Energy (RP03195), UI-ASSIST (RP03443), SERIII, J C Bose Fellowship (RP03128) and SERB NSC Fellowship.

I am deeply indebted to my father **Mr. (L) Sanjenbam Gouramani Singh**, mother **Mrs. Sanjenbam Mema Devi**, for their unwavering support and encouragement. Special thanks to my sisters **Mrs. Sanjenbam Sarojini Devi** and **Ms. Sanjenbam Gyanabati Devi**, brothers **Mr. Sanjenbam Jodhachandra Singh** and **Mr. Krishnamohan Singh**, for their continuous support and belief in my abilities. Moreover, I would like to thank all my family member and **Mr. Deepak Singh** for giving me the inner strength and wholehearted support. Their trust in my capabilities had been a key factor to all my achievements.

Finally, I express my gratitude to the Almighty for blessing me with the strength, wisdom, and determination to reach this academic milestone. I pray for their continued guidance and blessings in all my future endeavors.

Dated: 20/02/2025

Sanjenbam Chandrakala Devi

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।

TABLE OF CONTENTS

	Page No.
Certificate	i
Acknowledgements	ii
Abstract	iv
Table of Contents	v
List of Figures	xiv
List of Tables	xxv
List of Abbreviations	xxvi
List of Symbols	xxvii
CHAPTER – 1 INTRODUCTION	
1.1 General Introduction	1
1.2 State of art	2
1.2.1 Control of UPQC for Grid Tied Renewable Energy Sources System	3
1.2.2 Maximum Power Point Tracking	4
1.2.3 Standalone Renewable Energy Interfaced AC System	4
1.3 Scope of Work	6
1.4 Outlines of Chapters	8
CHAPTER – 2 LITERATURE REVIEW	
2.1 General	14
2.2 Literature Survey	14
2.2.1 Review on UPQC with Solar Power Generation	15
2.2.2 Review of Self-Excited Induction Generator Based Renewable Energy System	19
2.2.3 Review of Permanent Magnet Synchronous Generator Based Renewable Energy System	22
2.2.4 Review of Synchronous Reluctance Generators Based Renewable Energy System	25
2.2.5 Review of Battery Energy Storage System (BESS)	28
2.3 Identification of Research Areas	29
2.4 Conclusions	31
CHAPTER – 3 GENERALIZED INTEGRATOR BASED CONTROL OF UPQC FOR GRID CONNECTED SINGLE STAGE SOLAR PV ARRAY	
3.1 General	33
3.2 System Configurations of Grid Connected Single Stage SPVA – UPQC System	34

3.2.1	Configuration of Three Phase Three Wire Single Stage SPVA-UPQC	34
3.2.2	Configuration of Three Phase Four Wire Single Stage SPVA-UPQC	35
3.3	Design of Single Stage SPVA – UPQC Systems	35
3.3.1	Design of Three Phase Three Wire Single Stage SPVA-UPQC	35
3.3.2	Design of Single Stage Three Phase Four Wire SPVA-UPQC System	41
3.4	Control of Single Stage SPVA – UPQC Systems	42
3.4.1	Control of Three Phase Three Wire Single Stage SPVA-UPQC System	42
3.4.2	Control of Three Phase Four Wire Single Stage SPVA-UPQC System	49
3.4.3	Comparative performance of presented modified SOGI with state-of-art	53
3.5	MATLAB/Simulink Based Modeling of Single Stage SPVA – UPQC System	56
3.5.1	MATLAB/Simulink Based Modeling of Three Phase Three Wire SPVA – UPQC System	57
3.5.2	MATLAB/Simulink Based Modeling of Three Phase Four Wire SPVA – UPQC System	57
3.6	Hardware Implementation of Single Stage SPVA – UPQC	58
3.6.1	Circuit Interface for Hall Effect Voltage Sensors	60
3.6.2	Circuit Interface for Hall Effect Current Sensors	62
3.6.3	Interfacing Circuit for Gate Driver	63
3.7	Results and Discussion	64
3.7.1	Simulation Results for Three Phase Three Wire Grid Connected Single Stage SPVA-UPQC	64
3.7.1.1	System Response During Grid Voltage Harmonics	65
3.7.1.2	Response at Asymmetrical Voltages Sag and Swell	66
3.7.1.3	Response at Imbalanced Load Condition	68
3.7.1.4	Response During Solar Insolation Variation	69
3.7.2	Simulation Results for Three Phase Four Wire Grid Connected Single Stage SPVA-UPQC	69
3.7.2.1	System Response During Load Unbalancing Condition	69
3.7.2.2	Performance during Asymmetrical Voltage Sag	71
3.7.2.3	Performance during Insolation Variation	71
3.7.3	Hardware Results for Three Phase Three Wire Single Stage SPVA-UPQC	74
3.7.3.1	Performance at Steady State Condition Three Phase Three Wire Single Stage SPVA-UPQC	74
3.7.3.2	System Performance During Voltage Sag	76
3.7.3.3	Performance for Load Unbalancing	76
3.7.3.4	System performance with Solar Insolation Variation	77
3.7.3.5	Performance during SPV OFF Mode	78

3.7.4	Hardware Results for Three Phase Four Wire Single Stage SPVA-UPQC	79
3.7.4.1	Performance at Steady State Condition	79
3.7.4.2	Performance at Steady State Condition	81
3.8	Conclusions	81

CHAPTER – 4 GENERALIZED INTEGRATOR BASED CONTROL OF UPQC FOR GRID CONNECTED DOUBLE STAGE SOLAR PV ARRAY SYSTEM

4.1	General	85
4.2	System Configurations of Grid Connected Double Stage SPVA – UPQC System	86
4.2.1	Configuration of Three Phase Three Wire Double Stage SPVA-UPQC	86
4.2.2	Configuration of Three Phase Four Wire Double Stage SPVA-UPQC	87
4.3	Design of Double Stage SPVA – UPQC System	88
4.3.1	Design of Double Stage Three Phase Three Wire SPVA-UPQC System	88
4.3.2	Design of Double Stage Three Phase Four Wire SPVA-UPQC System	94
4.4	Control of Double Stage SPVA – UPQC System	95
4.4.1	Control of Three Phase Three Wire Double Stage SPVA-UPQC System	96
4.4.2	Control of Three Phase Four Wire Double Stage SPVA-UPQC System	100
4.5	MATLAB/Simulink Based Modeling of Double Stage SPVA – UPQC System	101
4.5.1	MATLAB/Simulink Based Modelling of Three Phase Three Wire Double Stage SPVA-UPQC System	101
4.5.2	MATLAB/Simulink Based Modelling of Three Phase Four Wire Double Stage SPVA-UPQC System	102
4.6	Hardware Implementation of Double Stage SPVA – UPQC	103
4.7	Results and Discussion	105
4.7.1	Simulation Results of Three Phase Three Wire Grid Connected Double Stage SPVA-UPQC	105
4.7.2	Simulation Results of Three Phase Four Wire Grid Connected Double Stage SPVA-UPQC	110
4.7.3	Hardware Results of Three Phase Three Wire Grid Connected Double Stage SPVA-UPQC	112
4.7.4	Hardware Results of Three Phase Four Wire Grid Connected Double Stage SPVA-UPQC	118
4.8	Conclusions	122

CHAPTER – 5 DESIGN, CONTROL AND IMPLEMENTATION OF

UPQC FOR SCIG BASED HYDRO ELECTRIC SYSTEM

5.1	General	124
5.2	System Configurations of UPQC for SCIG based Hydro Electric System	125
5.2.1	Configuration of UPQC Integrated SCIG-Battery Hydro System	125
5.2.2	Configuration of UPQC Integrated Hydro Driven SCIG and Bidirectional Converter for Battery	126
5.2.3	Configuration of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Battery	127
5.2.4	Configuration of UPQC Integrated Hydro Driven SCIG, Single Stage SPVA and Bidirectional Converter Battery	128
5.2.5	Configuration of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Bidirectional Converter Battery	130
5.3	Design of UPQC for SCIG based Hydro Electric System	130
5.3.1	Design of UPQC Integrated SCIG-Battery Hydroelectric System	131
5.3.1.1	Design and Selection of Excitation Capacitor	131
5.3.1.2	Design and Selection of DC link Voltage	132
5.3.1.3	Design and Selection of DC link Capacitor	132
5.3.1.4	Design and Selection of Interfacing Inductor	133
5.3.1.5	Design and Selection of Ripple Filter for Shunt VSC	133
5.3.1.6	Selection of Device (IGBT) Ratings of Shunt VSC	134
5.3.1.7	Selection of an Injection Transformer	134
5.3.1.8	Design and Selection of Interfacing Inductors of Series VSC	135
5.3.1.9	Device Rating of Series VSC Selection	135
5.3.1.10	Design and Selection of Battery Rating	136
5.3.2	Design of UPQC Integrated Hydro Driven SCIG and Bidirectional DC-DC Converter for Battery	136
5.3.2.1	Design of Bidirectional DC-DC Converter Parameters	136
5.3.3	Design of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA, and Battery	137
5.3.3.1	Design and Selection of Double Stage SPVA	137
5.3.3.2	Design and Selection of Boost Inductor	138
5.3.4	Design of UPQC Integrated Hydro Driven SCIG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	139
5.3.4.1	Design and Selection of Single Stage SPVA	139
5.3.5	Detailed Design of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	140
5.4	Control of UPQC for SCIG based Hydro Electric System	141

5.4.1	Control of UPQC Integrated SCIG-Battery Hydro	141
5.4.2	Control of UPQC Integrated Hydro Driven SCIG and Bidirectional DC-DC Converter for Battery	147
5.4.2.1	Control of Bidirectional DC-DC Converter for Battery	148
5.4.3	Control of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Battery	149
5.4.3.1	MPP Technique for Double Stage Solar PV Array	149
5.4.4	Control of UPQC Integrated Hydro Driven SCIG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	150
5.4.4.1	MPP Technique for Single Stage Solar PV Array	150
5.4.5	Control of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	151
5.5	MATLAB/Simulink Based Modeling of UPQC for SCIG based Hydro Electric System	151
5.5.1	MATLAB/ Simulink Based Modelling of UPQC Integrated SCIG-Battery Hydroelectric System	151
5.5.2	MATLAB/ Simulink Based Modelling of UPQC Integrated Hydro Driven SCIG and Bidirectional DC-DC Converter for Battery	152
5.5.3	MATLAB/Simulink Based Modelling of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Battery	153
5.5.4	MATLAB/Simulink Based Modelling of UPQC Integrated Hydro Driven SCIG, SPVA and Bidirectional DC-DC Converter for Battery	154
5.5.5	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Bidirectional DC-DC Converter for Battery	155
5.6	Hardware Implementation of UPQC for SCIG based Hydro Electric System	155
5.7	Results and Discussion	157
5.7.1	Performance of UPQC Integrated SCIG-Battery Hydroelectric System	158
5.7.2	Performance of UPQC Integrated Hydro Driven SCIG and Bidirectional DC-DC Converter for Battery	167
5.7.3	Performance of UPQC Integrated Hydro Driven SCIG, Double Stage SPVA and Battery	174
5.7.4	Performance of UPQC Integrated Hydro Driven SCIG, SPVA and Battery with Bidirectional DC-DC Converter Topology	183
5.7.5	Internal Signals of Control Algorithm with Comparative Analysis	196
5.8	Conclusions	199

CHAPTER – 6 DESIGN, CONTROL AND IMPLEMENTATION OF

UPQC FOR PMSG BASED HYDRO GENERATION SYSTEM

6.1	General	201
6.2	System Configurations of UPQC for PMSG based Hydro Generation System	202
6.2.1	Configuration of UPQC Integrated PMSG-Battery Hydro System	202
6.2.2	Configuration of UPQC Integrated Hydro Driven PMSG and Bidirectional Converter for Battery	204
6.2.3	Configuration of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Battery	205
6.2.4	Configuration of UPQC Integrated Hydro Driven PMSG, Single Stage SPVA and Bidirectional Converter Battery	205
6.2.5	Configuration of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Bidirectional Converter Battery	207
6.3	Design of UPQC for PMSG based Hydro Generation System	207
6.3.1	Design of UPQC Integrated PMSG-Battery Hydroelectric System	207
6.3.2	Design of UPQC Integrated Hydro Driven PMSG and Bidirectional DC-DC Converter for Battery	212
6.3.3	Design of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA, and Battery	214
6.3.4	Detailed Design of UPQC Integrated Hydro Driven PMSG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	216
6.3.5	Detailed Design of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	217
6.4	Control of UPQC for PMSG based Hydro Generation System	217
6.4.1	Control of UPQC Integrated PMSG-Battery Hydro System	218
6.4.2	Control of UPQC Integrated Hydro Driven PMSG and Bidirectional DC-DC Converter for Battery	225
6.4.3	Control of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Battery	226
6.4.4	Control of UPQC Integrated Hydro Driven PMSG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	227
6.4.5	Control of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	228
6.5	MATLAB/Simulink Based Modeling of UPQC for PMSG based Hydro Generation System	229
6.5.1	MATLAB/Simulink Based Modeling of UPQC Integrated PMSG – Battery Hydro System	229

6.5.2	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven PMSG and Bidirectional DC-DC Converter for Battery	230
6.5.3	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Battery	231
6.5.4	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven PMSG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	233
6.5.5	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	234
6.6	Hardware Implementation of UPQC for PMSG based Hydro Generation System	235
6.7	Results and Discussion	236
6.7.1	Performance of UPQC Integrated PMSG-Battery Hydro System	236
6.7.2	Performance of UPQC Integrated Hydro Driven PMSG and Bidirectional DC-DC Converter for Battery	249
6.7.3	Performance of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Battery	254
6.7.4	Performance of UPQC Integrated Hydro Driven PMSG, SPVA and Battery with Bidirectional DC-DC Converter Topology	263
6.7.5	Performance of UPQC Integrated Hydro Driven PMSG, Double Stage SPVA and Battery with Bidirectional DC-DC Converter Topology	271
6.7.6	Predicted Signals of MPC	276
6.8	Conclusions	277

CHAPTER – 7 DESIGN, CONTROL AND IMPLEMENTATION OF UPQC FOR SyRG BASED HYDRO GENERATION SYSTEM

7.1	General	279
7.2	System Configurations of UPQC for SyRG based Hydro Generation System	281
7.2.1	Configuration of UPQC Integrated SyRG -Battery Hydro System	281
7.2.2	Configuration of UPQC Integrated Hydro Driven SyRG and Bidirectional Converter for Battery	282
7.2.3	Configuration of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Battery	283
7.2.4	Configuration of UPQC Integrated Hydro Driven SyRG, Single Stage SPVA and Bidirectional Converter Battery	284
7.2.5	Configuration of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Bidirectional Converter Battery	285

7.3	Design of UPQC for PMSG based Hydro Generation System	286
7.3.1	Detailed Design and Selection of UPQC Integrated SyRG-Battery Hydro	286
7.3.2	Detailed Design and Selection of UPQC Integrated Hydro Driven SyRG and Bidirectional DC-DC Converter for Battery	291
7.3.3	Detailed Design and Selection of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Battery	293
7.3.4	Detailed Design of UPQC Integrated Hydro Driven SyRG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	295
7.3.5	Detailed Design of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	296
7.4	Control of UPQC for PMSG based Hydro Generation System	296
7.4.1	Control of UPQC Integrated PMSG-Battery Hydro System	297
7.4.2	Control of UPQC Integrated Hydro Driven SyRG and Bidirectional DC-DC Converter for Battery	302
7.4.3	Control of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Battery	304
7.4.4	Control of UPQC Integrated Hydro Driven SyRG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	305
7.4.5	Control of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	306
7.5	MATLAB/Simulink Based Modeling of UPQC for SyRG based Hydro Generation System	306
7.5.1	MATLAB/Simulink Based Modeling of UPQC Integrated SyRG – Battery Hydro System	307
7.5.2	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven SyRG and Bidirectional DC-DC Converter for Battery	307
7.5.3	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Battery	308
7.5.4	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven SyRG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	310
7.5.5	MATLAB/Simulink Based Modeling of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	310
7.6	Hardware Implementation of UPQC for SyRG based Hydro Generation System	311
7.7	Results and Discussion	313

7.7.1	Performance of UPQC Integrated SyRG-Battery Hydro	313
7.7.2	Performance of UPQC Integrated Hydro Driven SyRG and Bidirectional DC-DC Converter for Battery	323
7.7.3	Performance of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Battery	330
7.7.4	Performance of UPQC Integrated Hydro Driven SyRG, Single Stage SPVA and Bidirectional DC-DC Converter Battery	338
7.7.5	Performance of UPQC Integrated Hydro Driven SyRG, Double Stage SPVA and Bidirectional DC-DC Converter Battery	347
7.8	Conclusions	352
CHAPTER – 8 MAIN CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK		
8.1	General	354
8.2	Main Conclusions	355
8.3	Suggestions for Further Work	358
REFERENCES		359
APPENDIX		370
LIST OF PUBLICATIONS		374
AUTHOR BIO-DATA		377

LIST OF FIGURES

- Fig.3.1 Configuration of three phase wire single stage SPVA-UPQC system
- Fig.3.2 Configuration of three phase four wire single stage SPVA – UPQC system
- Fig.3.3 (a-b) Presented ESOGI-mFLL control scheme for fundamental estimation
- Fig.3.4 Amplitude estimation of sensed line voltages of the load side network
- Fig.3.5 Schematic diagram of pulse generation for series VSC
- Fig.3.6 Schematic diagrams of net active current calculation for control of shunt VSC
- Fig.3.7 Schematic diagrams of pulse generation for shunt VSC
- Fig.3.8 Schematic diagrams of net active current calculation for control of shunt VSC
- Fig.3.9 (a-c) Schematic diagram of fundamental component estimation
- Fig.3.10 (a-b) Comparative response of presented modified SOGI and the conventional control algorithms
- Fig.3.11 (a-b) Comparative response of presented modified SOGI and the conventional control algorithms
- Fig.3.12 MATLAB/Simulink based modelling of three phase three wire single stage SPVAUPQC system.
- Fig.3.13 MATLAB/Simulink based modelling of three phase four wire single stage SPVAUPQC system
- Fig.3.14 Photograph of experimental prototype of single stage SPVA-UPQC system
- Fig.3.15 Schematics diagram of interfacing circuit for voltage sensor based on Hall Effect
- Fig.3.16 Photograph of Hall Effect based voltage sensor coupled printed circuit board
- Fig.3.17 Schematics diagram of interfacing circuit for current sensor based on Hall Effect
- Fig.3.18 Photograph of Hall Effect based current sensor
- Fig.3.19 Schematics of interfacing circuit for optocoupler
- Fig.3.20 Photograph of gate driver and optocoupler
- Fig.3.21 (a-e) Simulated results of SPVA-UPQC system during grid voltage harmonics
- Fig.3.22 (a-b) Simulated results for SPVA-UPQC system during asymmetrical voltage sag and swell

- Fig.3.23 (a-b) Simulated results of UPQC-PV system during: (a) load imbalanced condition, (b) variation of solar irradiation
- Fig.3.24 (a-c) Dynamic performance of four wire UPQC for grid integrated solar PV array based distribution network for load unbalancing condition, with corresponding signals
- Fig.3.25 (a-c) Dynamic performance of four wire UPQC for grid integrated solar PV array based distribution network for unbalanced voltage sag, with corresponding signals
- Fig.3.26 (a-c) Dynamic performance of four wire UPQC for grid integrated solar PV array based distribution network for unbalanced voltage sag, with corresponding signals
- Fig.3.27 Steady-state operation of SPVA-UPQC system for nonlinear load
- Fig.3.28 Performance of system during voltage sag
- Fig.3.29 (a-c) Performance of SPVA-UPQC system during load unbalancing
- Fig.3.30 (a-b) Performance of SPVA-UPQC system for solar insolation variation
- Fig.3.31 (a-b) Performance of SPVA-UPQC system for nonavailability of solar power
- Fig.3.32 (a-i) Steady state performances of four wire UPQC for grid integrated solar PV array-based distribution network with signals
- Fig.3.33 (a-c) Dynamic performances of four wire UPQC for grid integrated solar PV array-based distribution network for transition of UPQC off to on, with signals
- Fig.3.34 (a-c) Dynamic performances of four wire UPQC for grid integrated solar PV array based distribution network for load removal at one of the phases, with signals
- Fig.4.1 Configuration of three phase three wire double stage SPVA – UPQC system
- Fig.4.2 Configuration of three phase four wire double stage SPVA – UPQC system
- Fig.4.3 Control algorithm for series compensator of double stage three phase three wire grid interfaced SPVA-UPQC system
- Fig.4.4 Control algorithm for shunt compensator of double stage three phase three wire grid interfaced SPVA-UPQC system
- Fig.4.5 Control algorithm for shunt compensator of double stage three phase four wire grid interfaced SPVA-UPQC system
- Fig.4.6 MATLAB/Simulink based modelling of three phase three wire double stage SPVAUPQC system
- Fig.4.7 MATLAB/Simulink based modelling of three phase four wire double

- stage SPVAUPQC system
- Fig.4.8 Photograph of experimental prototype of double stage SPVA-UPQC system
- Fig.4.9 Simulated results of double stage SPVA-UPQC system during voltage sag and swell condition
- Fig.4.10 Simulated results of double stage SPVA-UPQC system during load unbalance condition
- Fig.4.11 Simulated results of double stage SPVA-UPQC for SPVA ON to OFF and OFF to ON state
- Fig.4.12 Comparative performance of the presented control algorithm with the ANN, SOGI and FOGI-FLL
- Fig.4.13(a-b) Comparative performance during imbalanced voltage sag-swell
- Fig.4.14 Dynamic performance of four wire UPQC for grid integrated double stage solar PV array based distribution network for load unbalancing condition
- Fig.4.15 Dynamic performance of four wire UPQC for grid integrated double stage solar PV array for assymetrical voltage sag condition
- Fig.4.16 Steady-state performance of double stage SPVA-UPQC system at voltage sag
- Fig.4.17 Steady state performance of double stage SPVA-UPQC system
- Fig.4.18 Dynamic performance of double stage SPVA-UPQC system at load unbalancing
- Fig.4.19 (a-f) Dynamic performance of three phase three wire double stage SPVA-UPQC system
- Fig.4.20 Steady state performance of three phase four wire grid connected double stage solar PV array integrated UPQC system
- Fig.4.21 (a-e) Experimental results of four wire UPQC for grid integrated double stage solar PV array based distribution network for imbalanced grid voltages, with corresponding signals
- Fig.4.22 (a-c) Experimental results of four wire UPQC for grid integrated double stage solar PV array based distribution network for load current imbalanced, with corresponding signals
- Fig.4.23 (a-d) Experimental results of four wire UPQC for grid integrated double stage solar PV array based distribution network for insolation change, with corresponding signals
- Fig.5.1 Configuration of UPQC integrated SCIG-battery hydroelectric system
- Fig.5.2 Configuration of UPQC integrated hydro driven SCIG and bidirectional converter for battery system

- Fig.5.3 Configuration of UPQC integrated hydro driven SCIG, double stage SPVA and battery
- Fig.5.4 Configuration of UPQC integrated hydro driven SCIG, single stage SPVA, and bidirectional converter for battery energy storage
- Fig.5.5 Configuration of UPQC integrated hydro driven SCIG, single stage SPVA and bidirectional converter for battery energy storage
- Fig.5.6 Presented DRASOGI with mFLL control scheme for fundamental estimation
- Fig.5.7 Schematic diagram of pulse generation for series VSC
- Fig.5.8 Schematic diagrams of net active current calculation for control of shunt VSC
- Fig.5.9 Schematic diagrams of control of DC-DC bidirectional converter for battery
- Fig.5.10 MATLAB/Simulink based modelling of UPQC integrated SCIG-battery hydroelectric system
- Fig.5.11 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SCIG and bidirectional DC-DC converter for battery
- Fig.5.12 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SCIG, double stage SPVA and battery
- Fig.5.13 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SCIG, single stage SPVA and bidirectional DC-DC converter for battery
- Fig.5.14 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SCIG, double stage SPVA and bidirectional DC-DC converter for battery
- Fig.5.15 Photograph of experimental prototype of UPQC for SCIG based hydroelectric system
- Fig.5.16 (a-g) Simulated performance of presented DGS for operation in steady state
- Fig.5.17 (a-b) Simulated performance during load unbalancing for UPQC integrated SCIG-battery standalone hydroelectric system
- Fig.5.18 (a-l) Hardware results of UPQC integrated SCIG-battery standalone hydroelectric system for steady – state operation
- Fig.5.19 Steady-state operation UPQC integrated SCIG-battery standalone hydroelectric system for voltage dip
- Fig.5.20 (a-e) Dynamic performance of UPQC integrated SCIG-battery standalone hydroelectric system during UPAF ON condition
- Fig.5.21 (a-e) Dynamic performance of UPQC integrated SCIG-battery standalone

- hydroelectric system during load removal condition
- Fig.5.22 (a-e) Performances of UPQC integrated hydro driven SCIG, and bidirectional DC-DC converter for battery topology for increment in load demand
- Fig.5.23 (a-b) Performances of UPQC integrated hydro driven SCIG, and bidirectional DC-DC converter for battery topology for load unbalancing
- Fig.5.24 (a-h) Steady-state performances of UPQC integrated hydro driven SCIG, and bidirectional DC-DC converter for battery topology
- Fig.5.25 (a-d) Dynamic performances of UPQC integrated hydro driven SCIG, and bidirectional DC-DC converter for battery topology
- Fig.5.26 (a-b) Performances of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for unavailability of solar power generation
- Fig.5.27 (a-d) Performances of UPQC integrated hydro-driven SCIG, double stage SPVA, and battery topology during voltage sag (a-b) UPQC OFF (c-d) UPQC ON
- Fig.5.28 (a-b) Performances UPQC integrated hydro driven SCIG, double stage SPVA and battery topology at unbalancing condition of load
- Fig.5.29 (a-l) Performance of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for steady state operations with increment in load demand
- Fig.5.30 (a-c) Dynamic performances of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for increment in load demand
- Fig.5.31 (a-c) Dynamic performances of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for unbalancing of loading condition
- Fig.5.32 (a-b) System performance during imbalance loading condition of UPQC integrated hydro driven SCIG, SPVA and battery with bidirectional DC-DC converter topology
- Fig.5.33 (a-c) Total harmonics distortion for various signals
- Fig.5.34 (a-b) System performance for unavailability of solar PV insolation
- Fig.5.35 (a-d) Experimental results for presented system at the event of solar PV array transition mode with signals
- Fig.5.36 (a-e) Experimental results for presented system at event of load unbalancing with signals
- Fig.5.37 (a-d) Experimental results for presented system at event of load increment with signals
- Fig.5.38 (a-d) Steady state waveforms and their harmonics profile.
- Fig.5.39 (a-b) Performance of system at load unbalancing
- Fig.5.40 (a-b) Performance at SPV OFF

Fig.5.41 (a-c)	Steady state harmonic analysis for signals
Fig.5.42 (a-e)	Hardware validation of system during load unbalancing condition
Fig.5.43 (a-d)	Hardware validation of system during SPV off
Fig.5.44 (a-b)	Comparative performance of UPQC integrated induction generator with two stage solar PV and battery system with the presence of DC offset in voltage measurements
Fig.5.45 (a-b)	Effectiveness of presented GI control while eliminating noises present in voltage measurement
Fig.6.1	Configuration of UPQC integrated PMSG-battery hydroelectric system
Fig.6.2	Configuration of UPQC integrated hydro driven PMSG and bidirectional converter for battery system
Fig.6.3	Configuration of UPQC integrated hydro driven PMSG, double stage SPVA and battery
Fig.6.4	Configuration of UPQC integrated hydro driven PMSG, single stage SPVA, and bidirectional converter for battery energy storage
Fig.6.5	Configuration of UPQC integrated hydro driven PMSG, single stage SPVA and bidirectional converter for battery energy storage
Fig.6.6	Single phase equivalent diagram of standalone hydroelectric system integrated UPQC
Fig.6.7	Schematic diagram of estimation optimal switching sequence with model predictive control
Fig.6.8 (a-b)	Schematics of estimation of reference signals
Fig.6.9	Schematic diagrams of control of DC-DC bidirectional converter for battery
Fig.6.10	Developed MATLAB/Simulink based model of UPQC integrated PMSG-battery hydroelectric system
Fig.6.11	Developed MATLAB/Simulink based model of UPQC integrated standalone hydro driven PMSG and bidirectional DC-DC converter for battery
Fig.6.12	Developed MATLAB/Simulink based model of UPQC integrated standalone hydro driven PMSG, double stage SPVA and battery
Fig.6.13	Developed MATLAB/Simulink based model of UPQC integrated standalone hydro driven PMSG, single stage SPVA and bidirectional DC-DC converter for battery
Fig.6.14	Developed MATLAB/Simulink based model of UPQC integrated standalone hydro driven PMSG, double stage SPVA and bidirectional DC-DC converter for battery

- Fig.6.15 Photograph of experimental prototype of UPQC for PMSG based hydro generation system
- Fig.6.16 (a-d) Results of presented UPQC based hydro driven PMSG system for linear loads.
- Fig.6.17 (a-b) Results of presented UPQC based hydro driven PMSG system for steady state operation of nonlinear loads
- Fig.6.18 (a-d) Results of presented UPQC based hydro driven PMSG system with and without the UPQC control
- Fig.6.19 (a-b) Dynamic performance during load unbalancing condition
- Fig.6.20 (a-f) Performance of system during steady state operation without UPQC
- Fig.6.21 (a-f) Performance of system at steady state with UPQC switched ON
- Fig.6.22 (a-b) UPQC integrated PMSG-Battery hydroelectric system behavior while eliminating voltage sag.
- Fig.6.23 (a-b) Results of UPQC integrated standalone hydroelectric based PMSG system during unbalance loading
- Fig.6.24 (a-b) Results of UPQC integrated standalone hydroelectric based PMSG system with voltage dip
- Fig.6.25 (a-b) Performances of UPQC integrated hydro driven PMSG, and bidirectional DC-DC converter for battery topology for load unbalancing
- Fig.6.26 (a-e) Performances of UPQC integrated hydro driven PMSG, and bidirectional DC-DC converter for battery topology for increment in load demand
- Fig.6.27 (a-b) Steady-state performances of UPQC integrated hydro driven SCIG, and bidirectional DC-DC converter for battery topology
- Fig.6.28 (a-h) Steady-state performances of UPQC integrated hydro driven PMSG, and bidirectional DC-DC converter for battery topology
- Fig.6.29 (a-d) Performances of UPQC integrated hydro-driven PMSG, double stage SPVA, and battery topology during voltage sag (a-b) UPQC OFF (c-d) UPQC ON
- Fig.6.30 (a-b) Performances of UPQC integrated hydro driven PMSG, double stage SPVA and battery topology for unavailability of solar power generation
- Fig.6.31 (a-b) Performances UPQC integrated hydro driven PMSG, double stage SPVA and battery topology at unbalancing condition of load
- Fig.6.32 (a-l) Performance of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for steady state operations with increment in load demand. (a-f) less load requirement and (g-l) higher load requirement
- Fig.6.33 (a-c) Dynamic performances of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for increment in load demand

- Fig.6.34 (a-e) Dynamic performances of UPQC integrated hydro driven SCIG, double stage SPVA and battery topology for unbalancing of loading condition
- Fig.6.35 (a-b) System performance during imbalance loading condition of UPQC integrated hydro driven PMSG, SPVA and battery with bidirectional DC-DC converter topology
- Fig.6.36 (a-b) System performance for unavailability of solar PV insolation
- Fig.6.37 (a-h) Steady state operation of UPQC integrated hydro driven PMSG, SPVA and battery with bidirectional DC-DC converter.
- Fig.6.38 Steady-state performances of PMSG based standalone hydro generation system incorporated with UPQC while eliminating voltage dip
- Fig.6.39 (a-c) Dynamic performances of UPQC integrated hydro driven PMSG, SPVA and battery with bidirectional DC-DC converter topology for transition of solar PV array is OFF to ON.
- Fig.6.40 (a-d) Dynamic performances of PMSG based standalone hydro generation system incorporated with UPQC for load unbalancing condition
- Fig.6.41 (a-b) Performance at SPV power unavailability of UPQC integrated hydro-driven PMSG, double stage SPVA, and battery with bidirectional DC-DC converter topology
- Fig.6.42 (a-c) Steady state harmonic analysis of UPQC integrated hydro-driven PMSG, double stage SPVA, and battery with bidirectional DC-DC converter topology for signals
- Fig.6.43 (a-b) Performance of system at load unbalancing of UPQC integrated hydro-driven PMSG, double stage SPVA, and battery with bidirectional DC-DC converter topology
- Fig.6.44 (a-c) Hardware validation of system during SPV off
- Fig.6.45 (a-c) Hardware validation of system during load unbalancing condition
- Fig.6.46 (a-b) Tracking performance of the presented MPC method during the dynamic condition of load unbalancing
- Fig.7.1 Configuration of UPQC integrated SyRG-battery hydroelectric system
- Fig.7.2 Configuration of UPQC integrated hydro driven SyRG and bidirectional converter for battery system.
- Fig.7.3 Configuration of UPQC integrated hydro driven SyRG, double stage SPVA and battery
- Fig.7.4 Configuration of UPQC integrated hydro driven SyRG, single stage SPVA, and bidirectional converter for battery energy storage
- Fig.7.5 Configuration of UPQC integrated hydro driven SyRG, single stage SPVA and bidirectional converter for battery energy storage

- Fig.7.6 Control scheme of buck-boost converter for battery bank of SyRG-based standalone hydro generation system
- Fig.7.7 Control scheme of series compensator of UPQC for SyRG-based standalone hydro generation system
- Fig.7.8 Control scheme of parallel compensator of UPQC for SyRG-based standalone hydro generation system
- Fig.7.9 Schematic diagram of control of DC-DC bidirectional converter for battery
- Fig.7.10 MATLAB/Simulink based modelling of UPQC integrated SyRG battery hydro generation system
- Fig.7.11 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SyRG and bidirectional DC-DC converter for battery
- Fig.7.12 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SyRG, double stage SPVA and battery
- Fig.7.13 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SyRG, single stage SPVA and bidirectional DC-DC converter for battery
- Fig.7.14 MATLAB/Simulink based modelling of UPQC integrated standalone hydro driven SyRG, double stage SPVA and bidirectional DC-DC converter for battery
- Fig.7.15 Photograph of experimental prototype of UPQC for SyRG based hydro generation system
- Fig.7.16 (a-b) Results of presented UPQC based hydro driven SyRG system for linear loads
- Fig.7.17 (a-b) Results of presented UPQC based hydro driven SyRG system for steady state operation of nonlinear loads
- Fig.7.18 (a-b) Dynamic performance during load unbalancing condition
- Fig.7.19 (a-f) Performance of system during steady state operation without UPQC
- Fig.7.20 (a-f) Performance of system at steady state with UPQC switched ON
- Fig.7.21 (a-b) UPQC integrated SyRG-Battery hydro generation system behavior while eliminating voltage sag
- Fig.7.22 (a-b) Results of UPQC integrated standalone hydroelectric based SyRG system during unbalance loading
- Fig.7.23 (a-b) Results of UPQC integrated standalone hydroelectric based SyRG system with voltage dip
- Fig.7.24 (a-b) Performance of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology for steady state voltage dip

- Fig.7.25 (a-c) Harmonics profile of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology during steady state operation
- Fig.7.26 (a-b) Performance of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology for load unbalancing
- Fig.7.27 (a-h) Test results of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology during steady state
- Fig.7.28 (a-c) Test results of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology during steady state operation with linear load
- Fig.7.29 (a-c) Test results of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology for steady state operation with nonlinear load
- Fig.7.30 (a-d) Test results of UPQC integrated hydro driven SyRG, and bidirectional DC-DC converter for battery topology during load unbalancing operation for nonlinear load
- Fig.7.31 (a-b) Performances of UPQC integrated hydro driven SyRG, double stage SPVA and battery topology for unavailability of solar power generation
- Fig.7.32 (a-b) Performances UPQC integrated hydro driven SyRG, double stage SPVA and battery topology at unbalancing condition of load
- Fig.7.33 (a-l) Performance of UPQC integrated hydro driven SyRG, double stage SPVA and battery topology for steady state operations with increment in load demand. (a-f) less load requirement and (g-l) higher load requirement
- Fig.7.34 (a-c) Dynamic performances of UPQC integrated hydro driven SyRG, double stage SPVA and battery topology for increment in load demand
- Fig.7.35 (a-e) Dynamic performances of UPQC integrated hydro driven SyRG, double stage SPVA and battery topology for unbalancing of loading condition
- Fig.7.36 (a-b) Results of UPQC integrated hydro driven SyRG, SPVA and battery with bidirectional DC-DC converter topology for SPV OFF
- Fig.7.37 (a-b) Simulated results of UPQC integrated hydro driven SyRG, SPVA and battery with bidirectional DC-DC converter topology during unbalanced loading
- Fig.7.38 (a-c) THDs of UPQC integrated hydro driven SyRG, SPVA and battery with bidirectional DC-DC converter topology, for waveforms
- Fig.7.39 (a-h) Steady state operation of UPQC integrated hydro driven SyRG, SPVA and battery with bidirectional DC-DC converter topology
- Fig.7.40 (a-d) Experimental results of UPQC integrated hydro driven SyRG, SPVA and battery with bidirectional DC-DC converter topology for unavailability of

- solar PV array generation
- Fig.7.41 (a-e) Dynamic performances of UPQC integrated hydro driven SyRG, SPVA and battery with bidirectional DC-DC converter topology for load unbalancing condition
- Fig.7.42 Steady-state performances of UPQC integrated hydro driven SyRG, SPVA and battery's bidirectional DC-DC converter topology for steady state voltage dip
- Fig.7.43 (a-b) Performance at SPV power unavailability of UPQC integrated hydro-driven SyRG, double stage SPVA, and battery with bidirectional DC-DC converter topology
- Fig.7.44 (a-c) Steady state harmonic analysis of UPQC integrated hydro-driven SyRG, double stage SPVA, and battery with bidirectional DC-DC converter topology
- Fig.7.45 (a-b) Performance of system at load unbalancing of UPQC integrated hydro-driven SyRG, double stage SPVA, and battery with bidirectional DC-DC converter topology
- Fig.7.46 (a-c) Hardware validation of system during load unbalancing condition
- Fig.7.47 (a-c) Hardware validation of system during SPV off

LIST OF TABLES

Table 3.1	Harmonics Rejection Capabilities
Table 3.2	Comparative Analysis with Conventional Algorithm
Table 3.3	Cost Comparison of Proposed System
Table 3.4	Experimental Parameters for Single Stage SPVA-UPQC
Table 4.1	Experimental Parameters for Double Stage SPVA-UPQC
Table 5.1	Experimental Parameters of UPQC for SCIG Based Hydroelectric System
Table 5.2	Comparison in Terms of Harmonic Rejection Capabilities
Table 6.1	Switching Vectors Possible
Table 6.2	Experimental Parameters of UPQC for PMSG Based Hydro generation System
Table 7.1	Experimental Parameters of UPQC for SyRG Based Hydro generation System

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
$i_{ref-abc}$	Three phase reference grid currents
L	Interfacing inductor of voltage source converter
L_{vsc-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