DESIGN AND DEVELOPMENT OF IMPROVED POWER QUALITY SWITCHED MODE POWER SUPPLY SYSTEMS

by

Shikha Singh

Thesis Submitted
In fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI

DECEMBER 2013

CERTIFICATE

This is to certify that the thesis entitled, "**Design and Development of Improved Power Quality Switched Mode Power Supply Systems,**" being submitted by **Ms. Shikha Singh** for the award of the degree of **Doctor of Philosophy** is a record of the bonafide research work carried out by her in the Department of Electrical Engineering of Indian Institute of Technology Delhi.

Ms. Shikha Singh has worked under our guidance and supervision and fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The results obtained here, have not been submitted to any other University or Institute for the award of any degree.

Dated:

(Prof. G. Bhuvaneswari)
Professor
Electrical Engineering Department
Indian Institute of Technology Delhi
Hauz Khas, New Delhi-110016, India

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

ACKNOWLEDGEMENTS

I express my deepest gratitude and indebtedness to **Prof. G. Bhuvaneswari** and **Prof. Bhim Singh** for providing me the lifetime opportunity to do the Ph.D. work under their supervision. Working under them has been a wonderful experience, which has provided me with a deep insight into the world of research. Continuous monitoring, useful discussions, valuable guidance and time management by them was an inspiring force for me to complete this work. From time to time, they encouraged me for excelling in my work and it is their quest for excellence that has actuated me to improve my work and constantly introspect myself.

My sincere gratitude is reserved for all the SRC members **Prof. Sukumar Mishra, Prof. T.S. Bhatti, a**nd **Dr. N. Senroy** who have been a part of the evaluating team of experts, providing me their valuable insights, suggestions and encouragement throughout my research work.

I am thankful to IIT Delhi for providing the research facilities. Thanks are due to **Mr. Gurucharan Singh**, **Mr. Negi**, **Mr. Srichand** and **Mr. Puran Singh**, lab staff of Power Electronics and PG Machines labs for their sustained help and co-operation rendered to carry out my dissertation work.

I extend my special thanks to the fellow research scholars **Swati Narula**, **T. Chadrasekhar**, **Anmol Ratan Saxena, B. Amarendra Reddy, Ankit Kumar Singh, E. Vargil Kumar, F. T. Feleke, Kirti Mathuria, Kratika Sharma, Md. Junaid, Sandeep Madishetti**, **Vashist Bist**, **N K Swami Naidu**, **Chinmay Jain**, **Sabharaj Arya, M. Rajesh**, **Arun Verma**, **Ujjawal Kalla**, **Rajasekhar Reddy**, **Priya Nayar, Jincy Philip** and **Neha Adhikari**. My thanks are also due to **Dr. R. Kalpana**, **Dr. Sarsing Gao**, **Dr. V. Rajagopal**,

Dr. Sanjeev Singh Chauhan, Dr. Hemant Ahuja, Dr. S. Jeevanand, **Dr. Rajesh Kumar Ahuja, Dr. Ashish Srivastava, Dr. Vuddanti Sandeep**, **Dr. Shailendra Sharma, Dr. Gaurav Kasal** and **Dr. Madan Mohan** who have given me immense moral support and shown exemplary attitude and dedication for research.

Words cannot express the feelings and gratitude I have for my mother **Mrs. Rajni Singh** for the constant unconditional encouragement, support and personal sacrifices she made to push me forward to allow me to reach new levels of excellence. I thank my sister **Yashi Singh** and brother **Naval Singh** for their love that allowed me to complete my PhD work. Once again, I bow to all those who indirectly or indirectly helped me but whose names are left out. This acknowledgement cannot end without expressing sincere thanks to my respected grandfather **Mr. Pritam Singh** and my aunt **Mrs. Sushila Singh** who have supported me and encouraged me throughout my stay in IIT Delhi.

Last but not the least I thank **Almighty God** for His blessings to help me to raise my academic level to this stage. I pray for His benediction in my future professional career.

(Shikha Singh)

New Delhi 2009EEZ8609

ABSTRACT

Switched Mode Power Supplies (SMPSs) are universally used in various household and industrial applications due to their rugged and efficient nature, low cost, reliability and compactness. The use of various single-phase and three-phase ac mains fed SMPS systems are becoming commonplace in medical and electronic equipments such as laptops, computers, cell-phones and net-books, chargers, small motor drives, utility interface with non-conventional energy sources, welding power supplies, telecommunication tower power supplies, aerospace and military environment and hence their demand is ever growing. As technology advances, highly efficient power supplies are preferred by consumers so that their size and weight are reduced. Most of these power supplies use ac-dc converters at the front-end. Traditionally, ac-dc power conversion has been dominated by diode or phase-controlled rectifiers which depict nonlinear characteristics and draw input currents which are rich in harmonics and have poor power factor (PF), thus creating power quality problems in the power distribution network and also for other electrical systems in the vicinity of these converters. This lowers efficiency, and subjects system components to voltage and current stresses thus lowering their shelf-life.

Increasing awareness about power quality and harmonics pollution has instigated most of the power supply manufacturers to maintain total harmonic distortion (THD) and PF within acceptable levels that are dictated by international standards, such as IEEE-519 and IEC-61000. These standards have also imposed a constraint on the new electronic devices coming up these days in terms of maintaining a reasonable input power quality. In fact, many of the single-phase and three-phase ac mains fed power supplies are to be universally acceptable only if they adhere to these specifications set by the international standards. Emphasis is laid

on the development of simple, economical and energy efficient SMPSs with low input current harmonics and high PF. Of course, cost, size and availability of components are challenging constraints to deal with the goal of high power quality, which should be achieved while also maintaining low cost, compact size and design simplicity. Different methods for improving power quality at the point of common coupling (PCC) for single-phase and three-phase ac mains fed power supplies for personal computers (PCs) at low power rating and for telecommunication towers at medium power rating are investigated in this research work.

The conventional computer SMPS is fed from a single-phase ac supply through a diode bridge rectifier (DBR) followed by a filter capacitor. It draws highly distorted non-sinusoidal current from the single-phase ac mains due to the uncontrolled charging of the capacitor. The challenge is to achieve a sinusoidal input current irrespective of input voltage and load variations with regulated dc output voltages and high PF that meets the international power quality standards. Similarly, telecommunication tower power supplies fed by three-phase ac mains are also expected to draw a sinusoidal unity PF current from the utility maintaining galvanic isolation of the regulated dc output voltage. The challenge in this case is to provide a suitable utility interface with a simple, low cost three-phase power supply system that conforms to the international standard specifications.

This research work aims at mitigating the harmonics in the input ac mains of single-phase and three-phase SMPS systems for PCs and telecommunication towers using various ac-dc front-end converters. Detailed investigations have been carried out to provide suitable utility interface for both low rated and medium rated power supply systems. Various single-stage and two-stage power factor corrected (PFC) isolated and non-isolated converters, and also bridgeless converters have been designed, modeled and developed to improve the power quality indices at single-phase ac mains for the PC power supply. Similarly, in three-phase ac mains fed power supplies, single-stage and two-stage configurations have been investigated for improving the power quality at PCC.

The simplest approach for harmonics current reduction with PFC in computer power supply is by using various ac-dc buck-boost converters at the front-end. At the output of the PFC converter, an isolated converter is used to achieve multiple dc voltages. The component design of all the front-end converters have been carried out in discontinuous conduction mode (DCM) for achieving simple control. This also aids in the reducing of second order harmonics. Pulse width modulation (PWM) control technique is used for switching of the high frequency switches used in the PFC converters.

Various bridgeless converter configurations have been explored to mitigate power quality problems. These have been designed, modeled and simulated to demonstrate their improved performance. These PFC bridgeless converters based SMPS systems have also been realized in hardware and are able to perform well even under light load conditions and during input voltage variations.

Three-phase ac mains fed single-stage and two-stage power supplies for telecommunication systems are also presented in this thesis. The single-stage power supplies are in demand due to the advantages like high efficiency, high power density, smaller size/weight, load sharing capability and power expandability. The aim of the single-stage configurations is to overcome the disadvantages of the three-stages of conversion (initially PFC stage then the ac-to-ac stage and finally ac-to-dc stage in cascade) and to increase the robustness and modularity of the overall power supply systems. The rating of the power supply can be increased by employing multiple numbers of single-phase units. Various isolated dc-dc converter configurations have been designed, modeled and simulated in this work to achieve low input current THD and close to unity PF at the three-phase ac mains.

Different configurations of telecommunication tower power supplies have been studied using various PFC converters at the front-end. The front-end PFC provides regulated dc output voltage to the isolation stage that makes use of a high frequency transformer (HFT) for isolation. A front-end PFC converter with third harmonic current injection has been used in the first configuration of the three-phase ac mains fed SMPS system. Third harmonic is injected with a zig-zag transformer. It also provides a high magnetizing impedance path for the line frequency voltage and low impedance for the zero sequence third harmonic current. The design methodology and design values have been presented and the performance has been evaluated at varying loads on the developed PFC harmonic injected boost converter.

The integrated boost converter configuration is used at the front-end for PFC and the output converter configuration is used for voltage scaling and isolation. The closed loop control of integrated boost converter consists of two loops, one is voltage control loop to regulate the output voltage and another is current control loop to shape the three-phase input ac mains current respectively. At the output stage, control scheme is used to regulate the dc output voltage. The overall configuration ensures that the output voltages have been regulated irrespective of input voltage and load variations with reasonable power quality at the PCC.

The main contributions of this thesis are two-fold: (i) low rated single-phase ac mains fed PC power supplies with improved power quality and stiff output voltage regulation have been designed, modeled, simulated and developed using single-stage, two-stage and bridgeless converter configurations, (ii) medium power rated three-phase ac mains fed telecommunication tower power supplies have been designed, modeled, simulated and developed for single-stage and PFC ac-dc converter based power supplies with improved power quality. In both these cases, significant power quality improvements have been achieved under varying loads and ac mains voltages.

TABLE OF CONTENTS

CHAPTER X MAIN CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK