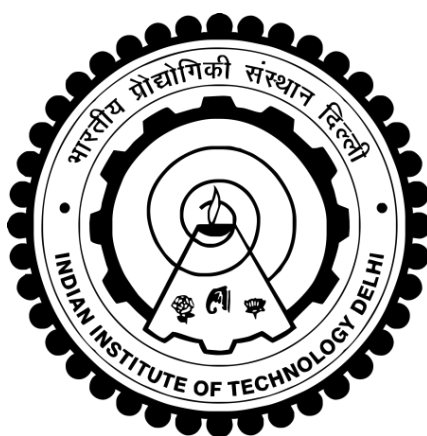


DESIGN AND DEVELOPMENT OF IMPROVED POWER QUALITY CONVERTERS FED LED DRIVER FOR LED LIGHTING

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OCTOBER 2017

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by

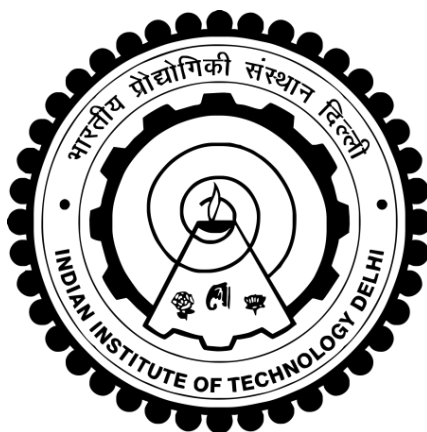
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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCT 2017

CERTIFICATE

It is certified that the thesis entitled “**Design and Développment of Improved Power Quality Converters Fed LED Driver For LED Lighting**,” being submitted by **Mr. Aman Kumar Jha** 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: OCT 10, 2017

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ACKNOWLEDGEMENTS

I wish to express my deepest gratitude and indebtedness to **Prof. Bhim Singh** for providing me an opportunity to carry out the Ph.D. work under his supervision. His keenness and vision have played an important role in guiding me throughout this study. 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.

My sincere thanks and deep gratitude are to **Prof. T.S. Bhatti, Prof. G. Bhuvaneswari, Prof. B. K Panigrahi** and **Prof. Sukumar Mishra**, 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. B. P. Singh, Prof. S. S. Murthy, Prof. M. Hanmandlu, Prof. G. Bhuvaneswari, Prof. Subrat Kar, Dr. Mashuqun Nabi** and **Dr. S. Janardhanan** for their valuable inputs during my course work which helped me to enrich my knowledge. I am grateful to IIT Delhi for providing me the research facilities. I am too grateful to **Prof. G. Bhuvaneswari**, Prof. in-charge, Power Electronics Lab for her whole hearted support in my research work. Thanks are due to Sh. Gurcharan Singh, Sh. Dhan Raj Singh, Sh. Srichand, Sh. Puran Singh, Sh. Jagbir Singh, Sh. Satey Singh Negi 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 offer my sincere thanks to Dr. Vasisht Bist, Dr. Shailendra Sharma and Dr. Ashish Srivastava who have endorsed me during initial start-up of my research work. I too would wish to thank Dr. Sandeep V., Dr. Rajashekhar Reddy, Dr. Sabharaj Arya, Dr. Shikha Singh, Dr. Rajesh Mutharath, Dr. Raj Kumar Garg, Dr. Ram Niwas, Dr. Arun Kumar

Verma, Dr. Swati Narula, Dr. Madishetti Sandeep, Dr. N K Swami Naidu, Dr. Chinmay Jain, Mr. Saurabh Mangalik, Mr. Shailendra Tiwari, Mr. Rahul Pandey, Mr. Rajan Kumar Sonkar, Mr. Ikhtlaq Bohru, Mr. Anshul Varshney, Mr. Utkarsh Sharma for their valuable aid and co-operation. My sincere thanks are due to for co-operation and informal support in pursuing experimental work. How could I forget my office mates from Barco Electronics, Mr. Rajeev Sharma and Mr. Rajeev Lochan Sharma, Mr. Divesh Garg and Mr. Niraj Kumar. ST Microelectronics colleagues, Mr. Akshat Jain, Mr. Jitendra Jain and Dr. Manoj Kumar are thankful for his help in my project. I am likewise thankful to those who suffer directly or indirectly helped me to finish my dissertation study.

Blessings of my father, Mr. Arun Kumar Jha have always strengthened me in my entire life. My richest love, appreciation and indebtedness go to my mother, Mrs. Prema Jha, for her dreams, sacrifices and wholeheartedly endorses. Her trust and trust in my capabilities have always motivated me to reach higher academic degrees. I must appreciate my wife, Mrs. Arti and daughters Miss. Arya and Miss. Ananya for handling family responsibilities in my absence and there kind 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:

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ABSTRACT

Energy efficiency and cost reduction in the development of lighting have gained importance after invention of blue LEDs (Light Emitting Diodes) for their advantageous features over conventional lighting. High efficacy, high power density, compact size, constant current operation, high reliability and long life time of the LED, makes it a suitable choice in many low and medium power applications. Due to these features, LEDs are widely used in household lighting, industrial lighting, display lighting, projection and architecture lighting applications. This research work aims at the development of the power factor correction (PFC) converters for feeding multi-string red-green-blue LED as a cost effective solution for projection as well as LED street lighting application starting from 100W-300W ratings.

The LED requires a constant current driver for achieving a required lumen and color from LED. The multi-string LED is driven by single phase AC supply using an uncontrolled diode bridge rectifier (DBR) and high value of DC bus capacitor. Such combination draws peaky current from the supply system, which is rich in harmonics and has very high total harmonic distortion (THD) of supply current at AC mains. This leads high crest factor (CF) of the supply current and very low power factor (PF) at AC mains. Such power quality indices are not acceptable within the limit of IEC 61000-3-2 class C for lighting. Hence, single phase PFC converters are used to improve the power quality LED driver at AC mains.

The selection of suitable PFC converter for particular application depends upon various aspects such as total number of components, voltage and power rating of LED, requirement of galvanic isolation, cost and efficiency of the overall system. There are many available configurations of the PFC converters, which are classified into different categories of three stages (PFC, DC-DC and LED driver), two stage (PFC, DC-DC and LED driver integrated) and single stage (all three integrated) with non-isolated PFC converters, bridgeless non-

isolated PFC converters, and isolated PFC converters. Among them, the bridgeless configurations are designed for reducing the conduction losses in the front end PFC converter by partial elimination of the diode bridge rectifier. Moreover, the control strategy of the PFC converter also plays a vital role in deciding the performance and cost of the overall system. In this work, PFC converters operating in discontinuous conduction mode (DCM) and critical conduction mode (CRM) are used to control using an approach of voltage follower as well as first resonating drain waveforms.

Analysis, design and control of buck-boost PFC converters for improvements in power quality at AC mains of the LED driver is presented in this work. The other major aspect of the work includes simplicity in control, reducing the number of sensors and cost and increasing the overall efficiency of the system. Many new configurations of single phase PFC converters are presented in this work for feeding the LED driver. Moreover, the lumen is controlled by adjusting the LED current using pulse width modulation (PWM).

The performance of these PFC based LED driver is estimated on the models developed in MATLAB/Simulink environment. Moreover, the performance of selected configurations of PFC converters feeding LED driver is also verified experimentally on a developed hardware prototype. This performance evaluation includes the steady state performances at various LED load and dynamic performance during dimming, loading of LED and supply voltage fluctuations at AC mains.

The steady state performance also includes the voltage and current waveforms of various components (semiconductors, magnetic and capacitive) of PFC converters for selection criteria of these components. An acceptable power quality indices of these PFC converters fed LED driver are also evaluated at AC mains. These power quality indices are found within the acceptable limits of international power quality standard IEC 61000-3-2 Class C for lighting.

सार

प्रकाश के विकास में ऊर्जा दक्षता और लागत में कमी ने परंपरागत प्रकाश व्यवस्था पर अपने लाभप्रद सुविधाओं के लिए नीले एल ई डी (लाइट एमिटिंग डायोड) के आविष्कार के बाद महत्व प्राप्त किया है। उच्च प्रभावकारिता, उच्च शक्ति घनत्व, कॉम्पैक्ट आकार, निरंतर चालू संचालन, उच्च विश्वसनीयता और एलईडी के लंबे जीवन समय, यह कई कम और मध्यम ऊर्जा अनुप्रयोगों में एक उपयुक्त विकल्प है। इन सुविधाओं के कारण, एलईडी व्यापक रूप से घरेलू प्रकाश, औद्योगिक प्रकाश, प्रदर्शन प्रकाश, प्रक्षेपण और वास्तुकला प्रकाश अनुप्रयोगों में उपयोग किया जाता है। इस शोध कार्य का उद्देश्य प्रोजेक्शन के लिए लागत प्रभावी समाधान के साथ-साथ 100W-300W रेटिंग से शुरू होने वाले एलईडी स्ट्रीट लाइटिंग एप्लीकेशन के रूप में बहु-स्ट्रिंग लाल-हरे-नीले एलईडी के लिए शक्ति कारक सुधार (पीएफसी) कन्वर्टर के विकास के लिए करना है।

एलईडी से एक आवश्यक लुमेन और रंग प्राप्त करने के लिए एक ड्राइवर की आवश्यकता होती है। बहु-स्ट्रिंग एलईडी एकल चरण एसी की आपूर्ति से एक अनियंत्रित डायोड सही करनेवाला) डीबीआर (और डीसी बस संधारित्र का उपयोग करके संचालित होता है। इस तरह के संयोजन आपूर्ति प्रणाली से चोटी वाला है, जो हार्मोनिक्स में समृद्ध है और एसी मेन पर आपूर्ति की वर्तमान उच्च हार्मोनिक विरूपण) टीएचडी (है। यह एसी मेन पर आपूर्ति वर्तमान और बहुत कम पावर कारक) पीएफ (की उच्च शिखर कारक) सीएफ (का नेतृत्व करता है। ऐसी विद्युत गुणवत्ता सूचकांक प्रकाश व्यवस्था के लिए IEC61000 -3- 2वर्ग सी की सीमा के भीतर स्वीकार्य नहीं हैं। इसलिए, एकल चरण पीएफसी कन्वर्टर का उपयोग एसी मेन पर बिजली की गुणवत्ता एलईडी ड्राइवर में सुधार के लिए किया जाता है।

विशेष रूप से आवेदन के लिए उपयुक्त पीएफसी कनवर्टर का चयन विभिन्न पहलुओं पर निर्भर करता है जैसे कुल घटकों, वोल्टेज और एलईडी की शक्ति रेटिंग, बिजली की अलगाव की आवश्यकता, समग्र प्रणाली की लागत और दक्षता। पीएफसी कन्वर्टर के कई उपलब्ध कॉन्फिगरेशन हैं, जिन्हें तीन चरणों (पीएफसी, डीसी-डीसी और एलईडी ड्राइवर), दो चरण (पीएफसी, डीसी-डीसी और एलईडी ड्राइवर एकीकृत) और एकल चरण में वर्गीकृत किया गया है (सभी तीन एकीकृत) गैर-पृथक पीएफसी कन्वर्टर, बेतरतीब गैर-पृथक पीएफसी कन्वर्टर और पृथक पीएफसी कन्वर्टर के साथ। उनमें से, बेकार विन्यास डायोड पुल शुद्ध करने वाले के आंशिक उन्मूलन द्वारा सामने वाले पीएफसी कनवर्टर में प्रवाहकीय घाटे को कम करने के लिए तैयार किए गए हैं। इसके अलावा, पीएफसी कनवर्टर की नियंत्रण रणनीति भी समग्र प्रणाली के प्रदर्शन और लागत का निर्णय लेने में महत्वपूर्ण भूमिका निभाती है। इस काम में, असंतत चालन मोड (डीसीएम) और महत्वपूर्ण प्रवाहकत्व मोड (सीआरएम) में कार्य करने वाले पीएफसी कन्वर्टर का इस्तेमाल वोल्ट अनुयायी के साथ-साथ पहले अनुनातन नाली तरंगों के उपयोग के नियंत्रण के लिए किया जाता है।

एलईडी ड्राइवर के एसी मेन पर बिजली की गुणवत्ता में सुधार के लिए पीएफसी कन्वर्टर्स को बढ़ावा देने के विश्लेषण, डिजाइन और नियंत्रण इस कार्य में प्रस्तुत किए गए हैं। काम के दूसरे प्रमुख पहलू में नियंत्रण में सादगी, सेंसर की संख्या को कम करने और सिस्टम की समग्र दक्षता में वृद्धि शामिल है। एकल चरण पीएफसी कन्वर्टर्स के कई नए कॉन्फिगरेशन इस काम में एलईडी ड्राइवर को खिलाने के लिए प्रस्तुत किए गए हैं। इसके अलावा, लुमेन को पल्स चौड़ाई मॉड्यूलन (पीडब्ल्यूएम) का उपयोग करके एलईडी चालू को समायोजित करके नियंत्रित किया जाता है। इन पीएफसी आधारित एलईडी ड्राइवर का प्रदर्शन मैटलब / सिमुलिक विकसित मॉडलों के अनुमान है। इसके अलावा, एलईडी ड्राइवर को पीएफसी कन्वर्टर्स चयनित कॉन्फिगरेशन का प्रदर्शन भी एक विकसित हार्डवेयर प्रोटोटाइप पर प्रयोगात्मक रूप से सत्यापित किया गया है। इस निष्पादन के मूल्यांकन में विभिन्न एलईडी भार और गतिशील प्रदर्शन शामिल हैं, डीएमआई के लोडिंग, एसी मेन पर लोड और लोड वोल्टेज में उतार-चढ़ाव।

स्थिर अवयव के प्रदर्शन में इन घटकों के चयन मानदंड के लिए पीएफसी कन्वर्टर्स के विभिन्न घटकों (अर्धचालक, चुंबकीय और कैपेसिटिव) के वोल्टेज और वर्तमान तरंग शामिल हैं। इन पीएफसी कन्वर्टर्स के एक स्वीकार्य बिजली गुणवत्ता के सूचक को भी एसी मेन पर मूल्यांकन किया गया है। इन पावर क्वालिटी इंडेक्स प्रकाश व्यवस्था के लिए अंतरराष्ट्रीय पावर गुणवत्ता मानक IEC 61000-3-2 कक्षा सी के स्वीकार्य सीमा के भीतर पाए जाते हैं।

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LIST OF ABBREVIATIONS

AC	Alternating Current
BL	BL
BLDC	Brushless DC Motor
CCM	Continuous Conduction Mode
CF	Crest Factor
CFLs	Compact Florescent Lamps
CCM	Continuous Current Mode
CISPR	Committee International Special de Perturbations Radioelectronics
CSC	Canonical Switching Cell
CCT	Correlated Color Temperature
CIE	International Commission on Illumination
CRI	Color Rendering Index
DBR	Diode Bridge Rectifier
DC	Direct Current
DCM	Discontinuous Conduction Mode
DICM	Discontinuous Inductor Conduction Mode
DF	Distortion Factor
DPF	Displacement Power Factor
DSP	Digital Signal Processor / Digital Signal Processing
EMI	Electro Magnetic Interference
GDP	Gross Domestic Product
HB	High Brightness
HFT	High Frequency Transformer
HID	High Intensity Discharge
IEC	International Electrotechnical Commission
LED	Light Emitting Diode
LLC	Inductor–Inductor - Capacitor
Lm	Lumen
PET	Photo-Electro-Thermal
PF	Power Factor
PFC	Power Factor Correction
PMBLDC	Permanent Magnet Brushless DC
PSR	Primary Sensing Regulation
PQ	Power Quality
PWM	PWM Pulse Width Modulation
QR	Quasi Resonant
RGB	Red-Green-Blue
SEPIC	Single Ended Primary Inductance Converter
THD	Total Harmonic Distortion
UL	Underwriters Laboratory (UL)
UV	Ultra-Violet
ZCD	Zero Current Detection
ZVS	Zero Voltage Switching

LIST OF SYMBOLS

C_f	Input Filter Capacitance
C_{f1}, C_{f2}	Isolated Flyback Secondary Capacitor
C_r, C_g, C_b	Synchronous Buck Converter Capacitors
C_d	DC Bus Capacitor
D, D_{f1}, D_{f2}	Diodes
D	Duty Ratio
D_{max}	Maximum Duty Ratio
f_c, f_L, f_{sw}	Filter Cut-off frequency (Hz), Line frequency (Hz), Switching frequency (Hz)
i_s	Input Current
I_r, I_g, I_b	RGB Modules Current
i_{sw}, i_{sw1}, i_{sw2}	PFC converter's Switch Current (A)
I_{dl1}, I_{dl2}	Flyback Primary Current
k_{p2}, k_{i2}	Proportional and Integral Gains of the PI Controller
Q_1, Q_2, Q_3, Q_4	LLC Based Half Bridge Active Switches
S_w	Active PFC Switches
S_{f1}, S_{f2}	Flyback Converter Switches
$S_{r1}, S_{g1}, S_{b1}, S_{r2}, S_{g2}, S_{b2}$	Synchronous Buck Switches
L_i, L_o	Input Inductor
L_r, L_g, L_b	Synchronous Buck Converter Inductor
V_s	Input Voltage
V_{sw}	Voltage Across Switch