SINGLE-STAGE LED DRIVERS BASED ON INTEGRATED BCM BOOST AND LLC CONVERTERS FOR STREET LIGHTING

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2017

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by

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Thesis submitted in fulfillment of the requirements

for the degree of

Master of Science

January 2017

ACKNOWLEDGEMENTS

First and above all, I praise God, the almighty for providing me this opportunity and granting me the capability to proceed successfully. This thesis appears in its current form due to the guidance and assistance of several people. I would therefore like to offer my sincere thanks to all of them.

I would first like to express my hearty gratitude to thesis advisor Dr. Shahid Iqbal for the continuous support, motivation, critical comments and immense knowledges. His thoughtful guidance has helped me a lot throughout the process of researching and writing this thesis. This accomplishment would not have been possible without him. Besides, I would like to thank my co-advisor Assoc. Prof. Ir. Dr. Mohamad Kamarol for his encouragement and accepting me as his student.

I would also like to thank the fellow staffs Mr. Mohamad Nazir, Mr. Hairul Nizam, Mr. Ahmad Shaukhi and Mr. Jamaluddin for their technical guidance on handling the instruments during my laboratory work. Many thanks to Mr. Elias and Mr. Mohd Zuber for helping me in the PCB fabrication of my laboratory prototype. My deep gratitude to fellow labmates Nor Azura, Mohamad Faizal, Adrian and Imran Shahzad for helping and supporting me spiritually during the whole period of my MSc study. I must also express my very profound gratitude to dearest parents, brother and sisters for providing me with unfailing support, love and understanding.

Last but not the least, thanks to Universiti Sains Malaysia for providing all necessary facilities and equipment to make this research possible. I also greatly appreciate the financial support by Fundamental Research Grant Scheme (FRGS) 203/PELECT/6071307 from Ministry of Education Malaysia.

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LIST OF SYMBOLS

A	Inductance ratio
C_1, C_2	Voltage divider capacitors
C_{bus}	Bus capacitor
C_{o1} - C_{o5}	Output capacitors
C_r	Resonant capacitor
C_{p1}, C_{p2}	Parasitic capacitors
D	Duty cycle
D_1, D_2	Boost diodes
D_{r1}, D_{r2}, D_{r3}, D_{r4}	Output diodes of full-bridge rectifier
D_{r5}, D_{r6}	Output diodes of voltage doubler rectifier
D_{r7}, D_{r8}, D_{r9}, D_{r10}	Output diodes of dual half-wave rectifier
D_{p1}, D_{p2}	Parasitic diodes
f_m	Magnetizing frequency
f_n	Normalized frequency
f_r	Resonant frequency
f_s	Switching frequency
i_{D1}, i_{D2}	Boost diode currents
i_{Dr1} - i_{Dr10}	Output diode currents
I_{DS1}, I_{DS2}	Drain-source current of switches S_1, S_2
i_{in}	Input current
i_{Lb}	Boost inductor current
i_m	Magnetizing current

I_o	Output current
I_p	Rms current at primary-side transformer
I_{pk}	Boost inductor peak current
i_r	Resonant current
i_s	Current at secondary-side transformer
i_{so}	Secondary-side input current
L_b	Boost inductor
L_m	Magnetizing inductor of transformer
L_r	Leakage inductor of transformer
L_{sr}	Secondary-side leakage inductance
M	Voltage-gain
M_p	Peak voltage-gain
n	Transformer turns ratio
n_p	Number of turns for primary winding
n_s	Number of turns for secondary winding
P_o	Ouput power
Q	Quality factor
R_{led}	Resistance of LED load
R_o	Resistance of output load
S_1, S_2,	Power switches
v_{ab}	Input square-wave voltage
v_{ab}^f	Fundamental components of input square-wave voltage
V_{bus}	Bus voltage
V_{DS1}, V_{DS2}	Drain-source voltage of switches S_1, S_2
V_F	Voltage drop at output diode

V_{GS1}, V_{GS2}	Gate voltage of switches S_1, S_2
v_{in}	Input voltage
V_o	Output voltage
v_{so}	Secondary-side input square-wave voltage
$v_{so}{}^f$	Fundamental component of secondary-side input voltage
β	Phase angle
η	Efficiency
ω_m	Angular magnetizing frequency
ω_r	Angular resonant frequency
ω_s	Angular switching frequency

LIST OF ABBREVIATIONS

AC-DC	Alternating Current to Direct Current
BCM	Boundary conduction mode
BR	Bulged reflector
CCM	Continuous conduction mode
CRM	Critical conduction mode
CST	Current-sharing transformer
DCM	Discontinuous conduction mode
EMI	Electro-magnetic interference
HID	High-intensity discharge
HPFC	High power factor correction
IBFC	Integrated buck-flyback converter
IEC	International electro-technician commission
LED	Light-emitting-diode
MR	Multifaceted reflector
PAR	Parabolic reflector
PCB	Printed circuit boards
PF	Power factor
PFC	Power factor correction
PFM	Pulse frequency modulation
PSR	Primary-side regulation
QR	Quasi-resonant
R	Reflector
RGB	Red green blue

SEPIC	Single-ended primary-inductor converter
THD	Total harmonic distortion
UV	Ultraviolet
VCO	Voltage-controlled oscillator
ZCS	Zero-current-switching
ZVS	Zero-voltage-switching

PEMACU-PEMACU LED SATU-PERINGKAT BERDASARKAN PENUKAR-PENUKAR BOOST BCM DAN LLC BERSEPADU UNTUK PENCAHAYAAN JALAN

ABSTRAK

Pencahayaan elektrik telah menjadi teknologi yang mustahak kepada masyarakat moden. Memandangkan peningkatan kebimbangan mengenai isu-isu alam sekitar dan penjimatan tenaga, diod-pemancar-cahaya (LED) telah menjadi tumpuan penyelidikan kerana ciri-ciri penyingkiran merkuri dan kecekapan tenaga yang tinggi berbanding lampu-lampu konvensional. Aspek prestasi pencahayaan LED adalah berkait dengan pemacu LED, jadi penukar yang sesuai perlu direka untuk memberi kuasa kepada LED dengan faktor kuasa pemasukan yang baik dan kecekapan yang tinggi. Untuk mencapai elemen-elemen ini, penukar arus ulang-alik kepada arus terus (AU-AT) satu-peringkat dengan pembetulan faktor kuasa (PFC) adalah dicadangkan sebagai pemacu LED untuk penggunaan pencahayaan jalan. Dalam topologi ini, sepasang litar boost yang berkongsi induktor tunggal digabungkan sebagai peringkat PFC dan kemudian disepadukan dengan tetimbang separuh LLC penukar salunan. Tiga jenis litar penerus dicadangkan bagi pembetulan pada sisi-menengah; gelombang-penuh tetimbang penerus, gelombang-penuh voltan pendua penerus dan dua gelombang-separuh penerus. Kesemua litar penerus mempunyai kelebihan masing-masing dan menghapuskan keperluan pengubah pusat-tetapan dalam reka bentuk litar. Suis kuasa dipandu oleh voltan-tinggi pengawal salunan IC L6598 dengan hampir 0.5 kitaran tugas dan masa selang yang kecil. Kesemua pemacu-pemacu LED yang dicadangkan telah diuji di dalam makmal untuk membekalkan 12 LED berkuasa

tinggi dari pemasukan ac voltan 240-V. Dari keputusan perbandingan, pemacu LED yang menggunakan gelombang-penuh voltan pendua penerus telah menunjukkan prestasi yang paling baik, diikuti oleh pemacu LED yang menggunakan gelombang-penuh tetimbang penerus dan kemudian pemacu LED yang menggunakan dua gelombang-separuh penerus. Faktor kuasa yang tertinggi diukur adalah hampir kesepaduan pada 0.99, jumlah herotan harmonik (THD) yang terendah ialah 13.8%, kecekapan yang tertinggi ialah 93.39% dan bas voltan yang terendah ialah 330-V. Pembetulan faktor kuasa telah berjaya dicapai dan kecekapan penukaran yang tinggi telah diperolehi kerana ciri-ciri pensuisan lembut oleh pemacu LED. Tekanan voltan pada kapasitor bas telah dikurangkan kepada 1.36 kali daripada puncak-voltan-pemasukan. Keupayaan malapan juga telah dicapai. Akhir sekali, pengurangan muatan kapasitor penyimpanan telah berjaya dengan riak arus keluaran dalam julat yang boleh diterima untuk pencahayaan LED tanpa kerlipan.

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ABSTRACT

Electrical lighting has been an important technology to modern society. Given the increasing concerns about environmental and energy saving issues, light-emitting-diode (LED) has become the research focus due to the features of mercury elimination and high energy efficiency compared to conventional lamps. Performance aspects of LED lighting are related with LED driver, thus an appropriate converter should be designed to power up the LEDs with good input power factor and high efficiency. To achieve these elements, single-stage alternating current to direct current (AC-DC) converter with power factor correction (PFC) is proposed as LED driver for application in street lighting. In this topology, a pair of boost circuits which share a single inductor are combined as a PFC stage and then integrated with half-bridge LLC resonant converter. Three kinds of rectifier circuits are proposed for the secondary-side rectification; full-wave bridge rectifier, full-wave voltage doubler rectifier and dual half-wave rectifiers. All rectifier circuits have their own advantages and remove the requirement of center-tapped transformer in circuit design. The power switches are driven by a high-voltage resonant controller IC L6598 with nearly 0.5 duty cycle and a small dead time. All proposed LED drivers have been tested in the laboratory for supplying 12 high-power LEDs from ac input voltage of 240-V. From the comparison results, LED driver using full-wave voltage doubler rectifier has shown the best performances, followed by LED driver using full-wave bridge rectifier and then LED driver using dual half-wave rectifiers. The highest power factor measured is almost

unity at 0.99, the lowest total harmonic distortion (THD) is 13.8%, the highest efficiency is 93.39% and the lowest bus voltage is 330-V. The power factor correction was successfully achieved and high conversion efficiency was obtained due to soft-switching characteristics of the LED driver. The voltage stress on bus capacitor is considerably reduced to 1.36 times of the input-peak-voltage. The dimming capability was also accomplished. Lastly, the minimization of storage capacitance was successful with an acceptable range of output current ripple for flicker-less LED lighting.