UNIVERSITI PUTRA MALAYSIA

DESIGN OF SINGLE SWITCH RECTIFIER FOR ELECTRIC VEHICLE BATTERY CHARGER APPLICATION

I N D R A N I SJA

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By

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Thesis Submitted to the School of Graduate Studies Universiti Putra Malaysia in Fulfillment of the Requirements for the Degree of Master of Science

February 2002

Dedicated to:

My Parents, My Wife Ellyza bt Zainal Arifin, My Daughters Siti Inelza Ramadhani bt Indra and Siti Febryza bt Indra, My Sister and Brothers

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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INDRA NISJA

February 2002

Chairman: Associate Professor Norman Mariun, Ph.D., P. Eng.

Faculty: Engineering

A single switch rectifier was developed in this thesis, which has continuous input and output currents. The design and implementation of a single switch three-phase multi resonant rectifier delivering 147 V_{dc} at 2.2 kW output has been carried out. By the use of a multi resonant scheme, the IGBT operates with zero current switching and the diode operates with zero voltage switching.

This multi-resonant rectifier with a single transistor is capable of drawing a higher quality input current waveform, good power factor and low stresses on the semiconductor devices. Buck type converter was used for the power stage, and hence the output voltage is lower than the input voltage. Moreover, these rectifiers have a wide load range with low stress on semiconductor devices. Simulation and experimental results are presented. The total harmonic distortion (THD) of the

line current is less than 5% and the system efficiency is about 90% at 25% of maximum load.

The single switch rectifier using multi resonant zero current switching has been simulated using OrCad release 9.1 software for 25% of maximum load. A good agreement between simulation and experimental results has been achieved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK PENERUS SUIS TUNGGAL UNTUK APLIKASI PENGECAS BATERI KERETA ELEKRIK

Oleh

I N D R A N I S J A

Februari 2002

Pengerusi: Profesor Madya Norman Mariun, Ph.D., P. Eng.

Fakulti: Kejuruteraan

Sebuah penerus suis tunggal telah dibangunkan dalam tesis ini, yang mempunyai arus masukan dan arus keluaran yang terus menerus. Rekabentuk dan pembuatan sebuah penerus suis tunggal menghantarkan voltan keluaran 147 V_{dc} dan kuasa keluaran 2.2 kW telahpun dilaksanakan. Dengan menggunakan sebuah skim berbilang salunan, IGBT beroperasi pada pensuisan arus sifar dan diod beroperasi pada pensuisan voltan sifar.

Penerus berbilang salunan dengan transistor tunggal ini mempunyai kemampuan untuk menghasilkan bentuk gelombang arus yang berkualiti tinggi pada faktor kuasa yang baik dan tekanan yang rendah pada peranti semikonduktor. Penerus jenis lekuk ini digunakan untuk tingkatan tenaga, dan sebab itu voltan keluaran

lebih rendah daripada voltan masukan. Lebih dari itu, penerus ini mempunyai kadar beban yang luas dan tekanan yang rendah pada peranti semikonduktor. Hasil simulasi dan ujikaji dibentangkan pada tesis ini. Herotan harmonik menyeluruh (THD) pada arus fasa ialah kurang daripada 5 peratus dan kecekapan sistem lebih kurang 90 peratus untuk 25 peratus beban maksimum.

Penerus suis tunggal menggunakan berbilang salunan pensuisan arus sifar telah disimulasikan dengan menggunakan perisian OrCad release 9.1 untuk 25 peratus daripada beban maksimum. Perbandingan diantara hasil simulasi dengan hasil ujikaji yang diperolehi menunjukkan persamaan yang hampir diantara satu sama lain.

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ABBREVIATIONS

Symbols

A	Ampere/Gain of Voltage Sense Amplifier
AC	Alternating Current (A)
A_e	Area of Center Pole (m^2)
AH	Ampere Hour
A_x	Wire Cross Sectional Area (m^2)
A_w	Total Winding Window Area (m^2)
B_{max}	Maximum Flux Density (Tesla)
BJT	Bipolar Junction Transistor
C	Capacitor (Farad)
C_b	Bypass Capacitor(Farad)
C_{bs}	Bootstrap Capacitor(Farad)
CCM	Continuous Conduction Mode
C_d	Output Side Resonant Tank Capacitor(Farad)
C_f	Capacitor Filter (Farad)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
C_r	Input Side Resonant Tank Capacitor (Farad)
CSI	Current Source Inverter
D	Diode
D_b	Freewheeling Diode
D_{bs}	Bootstrap Diode

DC	Direct Current
DCM	Discontinuous Conduction Mode
D_d	Output Diode Resonant Component
D_p	Output Protection Diode
EMI	Electro Magnetic Interference
F	Normalized Switching Frequency(Hz)
f	Frequency (Hz)
FB	Full Bridge
Fe_2O_3	Iron Oxide
FEC	Future Electric Concept Vehicle
FET	Field Effect Transistor
f_o	Operating frequency (Hz)
HP	Horse Power
IC	Integrated Circuit
I_c	Collector Current (A)
IEC	International Electrotechnical Commision
ICE	Internal Combustion Engine
$I_{cbs(leak)}$	Bootstrap capacitor leakage current (A)
I_E	Emitter Current (A)
I_f	Fundamental Current (A)
I_g	Peak Input Current (A)
I_{lson}/I_{lsoff}	level shift currents required to switch output on/off (A)
IGBT	Insulated Gate Bipolar Transistor
i_L	Line Current (A)

I_n	n Level of Harmonic Current
I_{out}	Output Current (A)
i_S	IGBT Switch Current (A)
IR	International Rectifier
I_{qbs}	Quiescent VBS Supply Current (A)
J	Junction, or energy density (Joule)
J_g	Normalized peak Input Current
kg	Kilo Gram
kHz	Kilo Herzt
KM	Kilo Meter
kVA	Kilo Volt Ampere
K_u	Winding Packing Factor
L	Inductor (H)
LC	Inductor Capacitor Filter
L_f	Filter Inductor (H)
LISN	Line Impedance Stabilization Network
L_o	Output Inductor (H)
L_r	Resonant Inductor (H)
M	Modulation Index
M_g	Normalized peak Input Voltage
MOSFET	Metal Oxide Silicon Field Effect Transistor
N	Number of Turns
NC	Number of Cells
N_{min}	minimum turns

NiMH	Ovonic-Nickel Metal Hybride
NiCd	Nickel Cadmium
NO	Nitrogen Oxide
p	Number of Pulse
P	Active Power
PCB	Printed Circuit Board
p.f	Power Factor
PFC	Power Factor Correction
Pin	Input Power (W)
PRC	Parallel Resonant Converter
PWM	Pulse Width Modulation
Q	The charge (Coulomb), or IGBT symbol
Q_g	Gate charge of high side FET
R	Resistor (Ohm)
R_{CS}	Current sense resistor (Ohm)
R_{CS}	Thermal Resistance from Junction to Case (^{O}C/W)
R_G	Gate Resistor (Ohm)
RMS	Root Mean Square
RP_1	Thermistor Emulation Potentiometer
RTF	Rotating Field Transformer
SO_2	Sulfur Dioxide
T	Tesla
t	Time (Second)

T_A	Ambient Temperature (^OC)
THD	Total Harmonic Distortion (%)
T_J	Junction Temperature (^OC)
t_w	pulse width of level shift currents
U_2	Lead Acid Battery Charger Controller IC
UPS	Uninterruptible Power Supply
V	Voltage
V_b	Base Voltage (V)
V_{Cr}	Resonant Capacitor Voltage (V)
V_{CE}	Collector to Emiter Voltage (V)
V_f	Forward voltage drop across the bootstrap diode (V)
V_{GE}	Gate to Emitter Voltage (V)
V_g	Peak Phase Voltage (V)
V_G	Gate Voltage (V)
V_{in}	Input Volatge (V)
V_L	Line Voltage (V)
V_{LS}	Voltage drop across the low side FET or load(V)
V_{MAX}	Maximum Voltage (V)
V_o	Output Voltage (V)
VSI	Voltage Source Inverter
V_Q	IGBT Voltage (V)
VRLA	Valve Regulated Lead Acid Battery
V_{cra}	Resonant Capacitor Voltage on Phase A
V_{th}	Threshold Voltage(Volt)