International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 09, September-2015

# Power Factor Corrected Single Stage AC-DC Full Bridge Resonant Converter

Gokul P H
Mar Baselios College of Engineering
Mar Ivanios Vidya Nagar,
Nalanchira

C Sojy Rajan
Assisstant Professor
Mar Baselios College of Engineering
Mar Ivanios Vidya Nagar, Nalanchira

***Abstract*— A resonant high power factor corrected AC to DC converter with symmetrical topology is compared with traditional full bridge series parallel converter. Conventional AC to DC converter consists of diode full bridge rectifier followed by a bulky DC link capacitor and a high frequency DC to DC converter. This type of converters introduces high distorted input current, resulting high harmonics and low power factor. Proposed converter adopts full bridge series resonant converter and two level buck boost PFC converter circuits. Switch utilization factor is drastically improved by reducing the number switches used in different stages. High power factor can be achieved by operating converter with DCM. Output voltage is regulated by adjusting the switch frequency. Zero voltage switching is achieved by series resonant tank which consists of resonant capacitor and a resonant inductor. A closed loop is introduced by PI controller. A proto type of 200W DC output was built and tested to verify the analytical predictions.**

## I. INTRODUCTION

AC to DC converters are widely used in many offline power supplies like SMPS. We should develop more efficient, smaller size and cheep ac to dc converters. Multi stage converters introduce a highly distorted input current, resulting in a large amount of odd harmonics and a low power factor. In order to reduce input current distortions and to improve the power factor need an additional ac to dc conversion stage of power factor correction (PFC) is should be clubbed in front of the dc to dc converter. It leads to provide a two-stage approach that includes a PFC stage to rebuild the input current into a sinusoidal shape and a dc to dc conversion stage for the regulation of output voltage. Two stage converters have better performance than other multi stage converters but it requires more circuit components and two power-conversions [4], resulting in higher component cost and lower efficiency.

To overcome the drawbacks of the two-stage approach, single-stage ac/dc converters have been developed by single stage PFC circuit with dc/dc converter. By sharing one or more active switches and the control the overall circuit thereby reduced size. In spite of these good qualities this converters leads to hard-switching operation which results in low circuit efficiency and limits the output power rating. Application of higher switching frequency to realize smaller magnetic components and capacitors gives better performance. In order to reduce switching losses, various auxiliary circuits and wide ranges of snubbers are required. It will add the circuit complexity and overall component cost. So we require soft-switching characteristics by using resonant topologies. We need to include resonant tanks in the converters to create oscillatory voltage or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. The resonant transition converters are more efficient family of soft switching topologies. They include the low switching loss characteristics of the resonant converters and the constant frequency and low conduction loss characteristics of the PWM converters under discontinuous mode. These are typically square wave converters during their mode of operations, except during the resonant transitions.

## II. CONVENTIONAL FULL BRIDGE CONVERTER

Conventional off-line power supplies usually include the full-bridge rectifier and large input filter capacitor at their input stages .They inevitably generate highly distorted input current waveforms with a large amount of harmonics. Therefore, we need ac–dc converter is the one that draws a pure sinusoidal current at unity power factor from the mains. The operation for switching mode power supplies (SMPS) is to use two separate converter stages, first one having ac–dc conversion stage and another isolated dc–dc conversion stage, [5]to convert the input ac mains voltage into an isolated and regulated dc voltage as shown below in Fig.1 . A boost converter is typically used as the ac–dc conversion stage because it can perform power factor correction (PFC) by shaping the input current so that it is sinusoidal and in phase with the input voltage. In order to reduce the cost and complexity associated with operating two separate converter stages, converters that integrate the functions of PFC and isolated dc–dc conversion in a single stage PFC converter are preferable. Most conventional power factor correcting systems introduced so far employ pulse width modulation (PWM) techniques [6] to achieve the features of the PFC converter mentioned above.

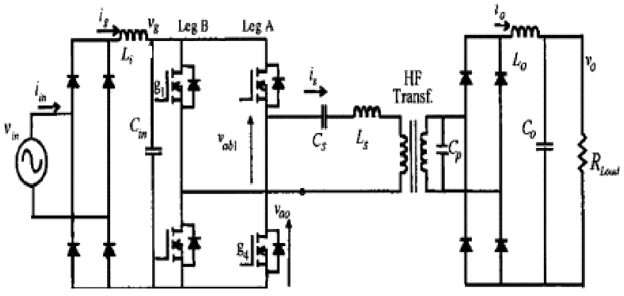


Fig.1 Series parallel full bridge resonant converter

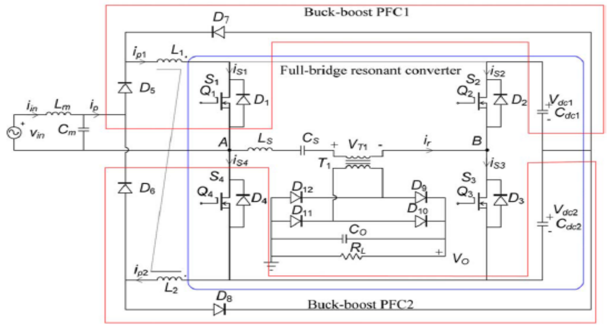


Fig.2 Resonant single stage PFC AC to DC converter voltage

## III RESONANT SINGLE STAGE PFC CONVERTER

Here we have resonant single stage PFC converter which can be used for all SMPS applications. In order to raise the power capability low switching loss, two buck–boost-type PFC circuits integrated with resonant converter. Actually switches are shared by both these converter topologies clubbed to a single PFC AC to DC converter. In order to fulfil high power factor discontinuous mode of operation is implemented. All the active switches can be operated at ZVS to effectively reduce the switching losses and the circuit has the advantages of less component compared to conventional one explained above. There by we can achieve low cost and high conversion efficiency. Circuit consists of a half bridge diode rectifier (D5 and D6), two buck–boost-type PFCs, and a full-bridge series resonant dc/dc converter as shown below in Fig.2 . DC output from buck boost PFC's is supplied to resonant converter having four active switches. The buck–boost converters serve as the PFC circuits (PFC1 and PFC2) by wave shaping the input current to be sinusoidal and in phase with the input line voltage.

The diodes (D1, D2, D3, and D4) represent the intrinsic body diodes of the MOSFETs and these provides important role in mechanism of zero voltage switching. [3] Series resonant energy tank (LS, CS), and a transformer T1 form the load resonant circuit with high loaded factor. Four active switches, namely, $S_1$, $S_2$, $S_3$, and $S_4$ are controlled by four gated signals, namely, $v_{gs1}$, $v_{gs2}$, $v_{gs3}$, and $v_{gs4}$, respectively. Gated signals vgs1 and vgs3 and gated signals vgs2 and vgs4 form two pairs which is complimentary to each other with a short dead time. Each gated signal has a duty ratio of 0.5. Due to symmetrical operation modes for the negative half cycle of the line voltage are similar to those of the positive half cycle, except that the reactive components and the power switches of $PFC_1$ are replaced by that of $PFC_2$. Designed parameters are shown below in the Table.1.

| PARAMETERS | DESIGN VALUES |
|---|---|
| Lm | 5mH |
| Cm | 41.6μF |
| Lp | 0.17mH |
| Fs | 40kHz |
| Cdc | 1000μF |
| Ls | 2.81mH |
| Cs | 9.6nF |
| Vin | 110V,50Hz |

Table.1 Design parameters

## IV SIMULATION RESULTS

MATLAB simulation model of open loop configuration is shown below in Fig.3, which consists of input LC filter two buck boost PFC's and a resonant converter. Passive harmonic filters work on the principle of electrical resonance in tuned circuits which is useful in mitigating harmonic orders corresponding to a particular frequency. The concept is that at resonant frequency the tuned RLC circuit considered to be the passive filter provides a least resistance path for the harmonic current to flow out of the system that feeds the loads. Thus it reduces harmonics in the system. The impedance offered by the filters is minimum and purely influenced only by the resistive nature of the circuit at resonance conditions. Thus maximum current corresponding to the harmonic order is filtered out from the path that feeds the loads.

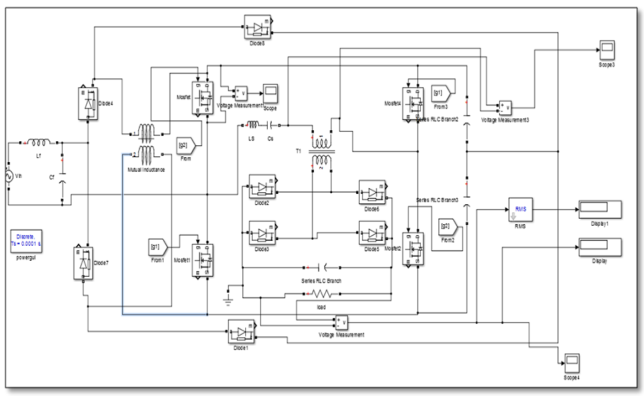

Fig.3 Open loop simulink model of resonant single stage converter

Coupled inductor shared by two buck boost PFC converters which have single core an two identical windings. Coupled inductor was designed with coefficient of coupling and self inductance and coefficient of coupling is taken as 0.9.Four switches were used for both Buck boost and series resonant converter. Output loaded quality factor of resonant converter is taken as very high value.

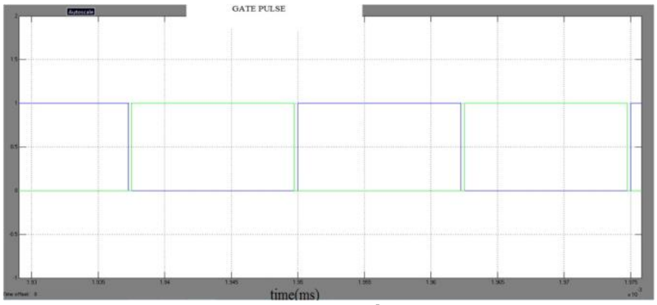


Fig.4 Gate pulse

Switching frequency used here is 40 kHz and having 50% duty cycle. A short dead time is provided in between two complimentary pulses. [4]Open loop pulses were generated by pulse generator block from MATLAB as shown above in Fig 4. Simulation work is done through discrete level because operation of converter is under discontinuous mode of operation.

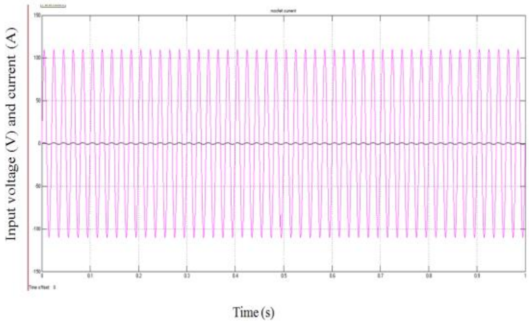


Fig.5 Input voltage and current

Voltage should be phase with current as shown in the Fig.5.Output voltage measured by voltmeter is shown below in Fig.6.Output voltage measured is around 155Vwith respect to 200ohm resistor load. Output voltage was drastically varied with respect to output capacitance. The value of output capacitance is limited to 6600 µF. Single stage converter with R and R-L load was analyzed and the results obtained for R-L load was similar to R load.

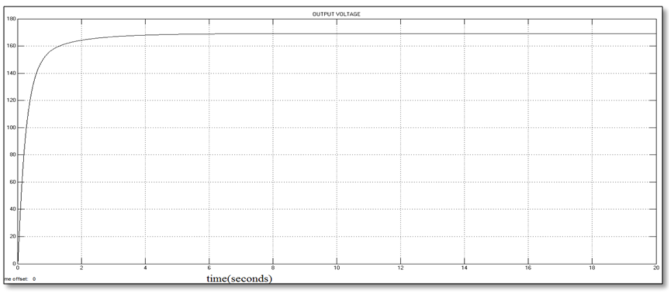


Fig.6 Output Voltage waveform of Open loop operation

Zero voltage switching of MOSFETS are shown below, switching happens on both positive half cycle as well as in negative half cycle is shown below in Fig.7 and Fig.8.

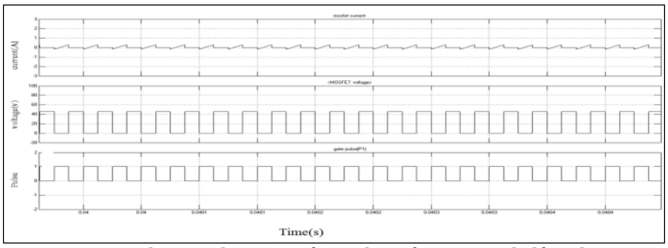


Fig.7 Voltage and current of switch S1 for positive half cycle

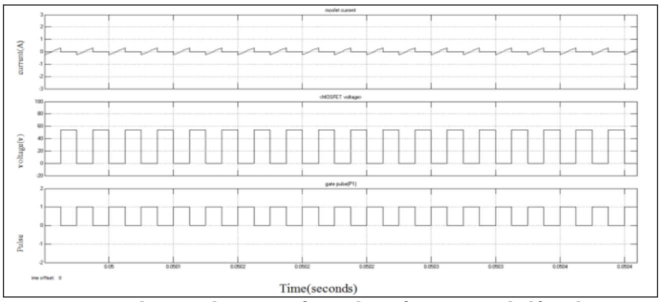


Fig.8 voltage and current of switch S1 for negative half cycle

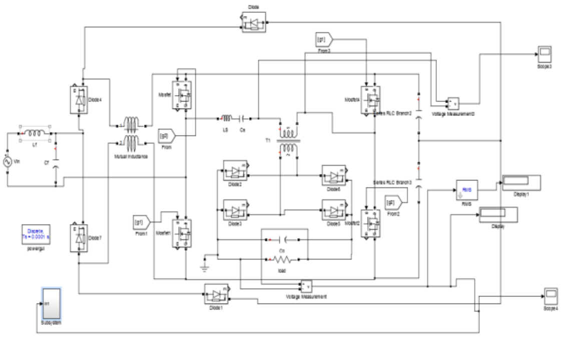

Fig.9 Simulink model for Closed loop operation

The closed-loop circuit model of the LC Series-parallel Resonant full-Bridge DC-DC Converter is shown in Fig.9 The closed loop system consists of comparator and PID controller. The output voltage is sensed and it is compared with the reference voltage. The error signal is sent to the PID controller [9]. The output of the PID controller is given to the MOSFET. The output of the PID controller controls the dependent source. The steady state error signal is reduced by properly turning the PI controller. Scopes and displays are connected to measure the input voltage, output voltage. Closed loop pulse generating simulation model is shown in Fig.10.

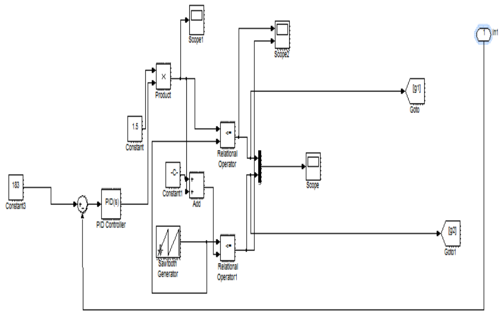

Fig 10 Simulink model Closed loop PWM control

THD analysis of both resonant single stage pfc converter and conventional full bridge series parallel converter is compared. From harmonic analysis proposed converter have better power factor than conventional resonant converter. [8] THD obtained in resonant single stage PFC converter lies below the value 8.

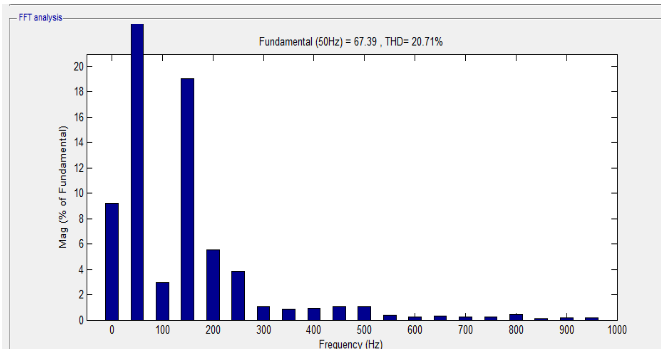


Fig.11 THD of line current in series parallel full bridge resonant converter

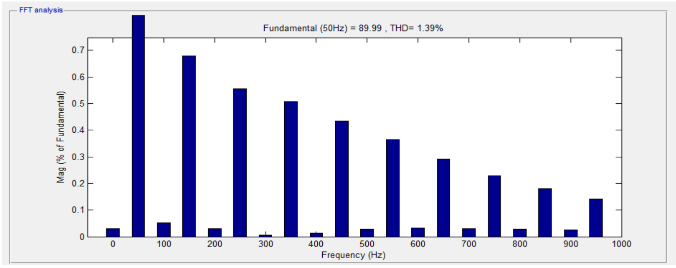


Fig.12 THD of line current in single stage PFC converter

## 10.6 HARDWARE RESULTS

A low voltage proto type were developed which consists of DSPIC micro controlled two pairs of complimentary pulses which is shown in the Fig.13.1below.actually pulses have 5V amplitude and 50% duty cycle and 40KHz frequency.

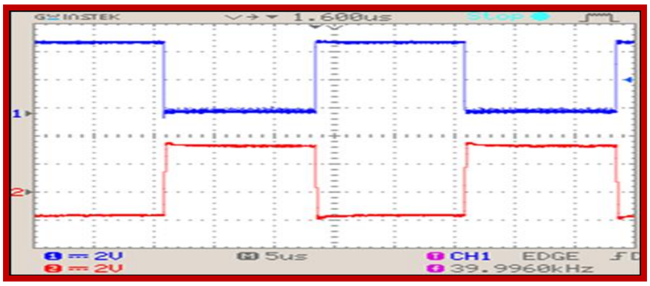

Fig.13 DSPIC output pulses

Driver output have isolated level amplified output with TLP250 supply amplitude as shown in the Fig.14. Peak initial voltage of driver output is avoided by snubber capacitor having 630V voltage capacity. Actually peak to peak voltage developed in the driver output was provided by TLP250 power supply(12V). Due to some loading effect voltage decremented across driver output. Pulse generation is done with some dead time (2 micro second). Due to short dead time there is no chance for short circuit along one leg of full bridge resonant converter.

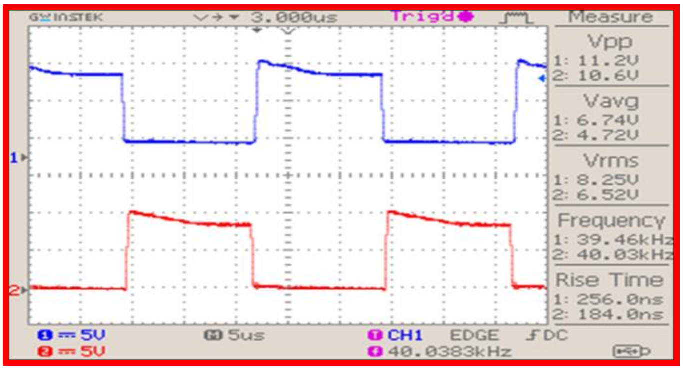


Fig.14 Driver output

Zero voltage switching of switches were shown below having resonating output is shown below having 40KHz frequency. Peak initial voltage drop is avoided by snubber capacitor having 630V voltage capacity. During hardware implementation I got oscillated output wave forms across the device and the output. These oscillations mainly due to inductive effect formed across the device. Large amount of these peak oscillations can be avoided by adding high value DC link capacitors. Actually in the Fig.15 device voltage is provide with respect to gate pulse of $S_1$. Soft switching is mostly analyzed by wave forms related to device current and voltage. Zero current is force fully done at on state and zero voltage is done at switch off state. Here we got zero voltage at both switch off and on stages.During switch off condition current is resonated and voltage is made to zero by resonating circuit shown in Fig.16.

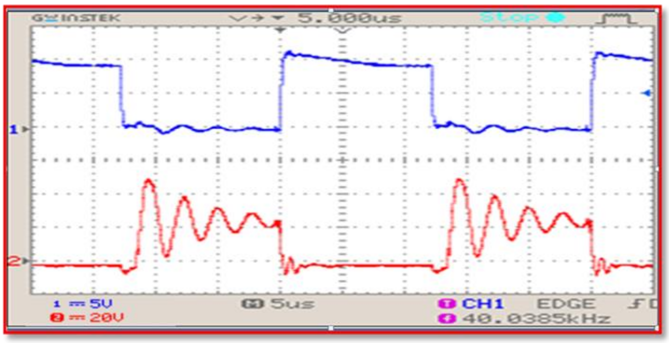


Fig.15 Zero voltage switching waveform with respect to gate pulse

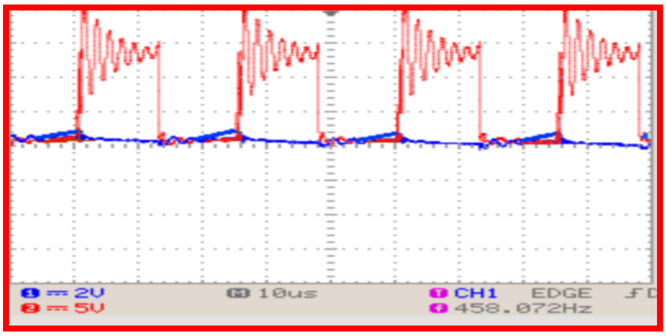


Fig.16 Zero voltage switching with respect to device current

Power factor correction circuits are analyzed by input current and voltage wave forms. Power factor improved circuit shows in phase input voltage and current wave forms. Fig.17. Slight phase difference was obtained from the hard ware results because of some constructional limitation of coupled inductor used in the power circuit. Actually Power factor improvement is always done by PFC circuits connected in the power circuit.Buck boost PFC circuit having discontinuous mode operation will improve power factor. Input voltage is plotted under low voltage conditions. Input current is measured using hall effect sensor. Input current is scaled with respect to series resistance connected to the hall effect sensor.

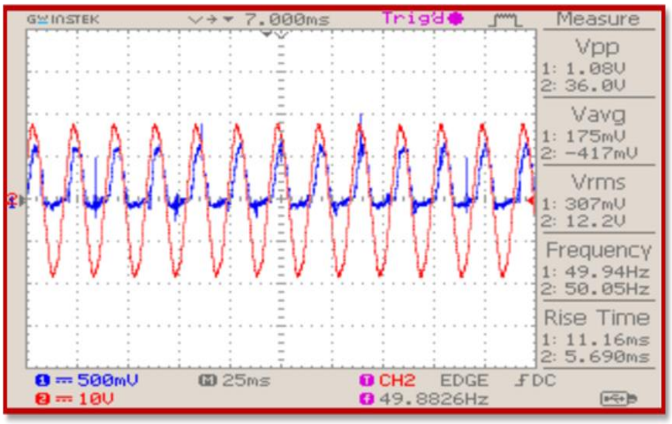


Fig.17 Input voltage and current

## V CONCLUSION

A high power factor single-stage ac/dc resonant resonant converter with symmetrical topology has been implemented and compared with conventional full bridge series parallel resonant converter. From the simulation results proposed converter have better power factor and efficiency from the conventional topologies. The proposed converter circuit was obtained by combining two buck–boost PFCs and a full-bridge series resonant converter. The circuit operation was described and the design equations were derived and closed loop operation is implemented by PI controller. The switch-utilization factor and the power-handling compatibility were improved by adopting two active power switches to serve in the PFC circuits. A 200W prototype of high power factor ac to dc resonant converter was designed and the output waveforms obtained were verified.

## REFERNCES

[1] F. S. Kang, S. J. Park, and C. U. Kim, "ZVZCS single-stage PFC AC-to-DC half-bridge converter," *IEEE Trans. Ind. Electron.*, vol. 49, pp. 206–216, Feb. 2002

[2] E. H. Kim and B. H. Kwon, "Zero-voltage- and zero-current-switching full-bridge converter with secondary resonance," *IEEE Trans. Ind.Electronics.*, vol. 57, no. 3, pp. 1017–1025, Mar. 2010.

[3] Hung-Liang Cheng, Yao-Ching Hsieh, and Chi-Sean Lin, "Novel Single-stage HPF AC/DC Converter Featuring High Circuit Efficiency*", IEEE transactions on industrial electronics*, vol. 58, no.2, august 2012.

[4] Y. C. Chuang and Y. L. Ke, "A novel high-efficiency battery charger with a buck zero-voltage-switching resonant converter," *IEEE Trans. Energy Conversion* vol. 22, no. 4, pp. 848–854, Dec. 2007

[5] Mohamed Z. Youssef, "A novel single stage ac–dc self-oscillating series-parallel resonant converter" *IEEE Transactions on Power Electronics*, vol. 21, no. 6, november 2006

[6] G. Moschopoulos and P. K. Jain, "Single-phase single-stage power-factor corrected converter topologies," *IEEE Trans. Ind. Electron.*, vol. 52, no. 1, pp. 23–35, Feb. 2005

[7] F. T. Wakabayashi, M. J. Bonato, and C. A. Canesin, "Novel high power factor ZCS-PWM preregulators," *IEEE Trans. Ind. Electron.*, vol. 48, no. 2, pp. 322–333, Apr. 2001

[8] M. K. Kazimierczuk and D. Czarkowski, *Resonant Power Converters*. New York: Wiley, 1995.

[9] T. S. Mundra and A. Kumar, "An innovative battery charger for safe charging of NiMH/NiCd batteries," *IEEE Trans. Consum. Electro*n. vol. 53, no. 3, pp. 1044–1052, Aug. 2007.

[10] F. Boico, B. Lehman, and K. Shujaee, "Solar battery chargers for NiMH batteries," *IEEE Trans. Power Electron*., vol. 22, no. 5, pp. 1600–1609, Sep. 2009

[11] D. L. O'Sullivan, M. G. Egan, and M. J.Willers, "A Family Of Single-stage Resonant AC/DC Converters With PFC" *IEEE Trans. Power Electronics.*, vol. 24, no. 2, pp. 398–408, Feb. 2009

[12] C. K. Tse,M. H. L. Chow, andM. K. H. Cheung, "A family of PFC voltage regulator configurations with reduced redundant power processing," *IEEE Trans. Power Electron.*, vol. 16, no. 6, pp. 794–802, Nov. 2001.

[13]K. W. Seok and B. H. Kwon, "A novel single-stage half-bridge AC–DC converter with high power factor," *IEEE Trans. Ind. Electron.*, vol. 48, no. 6, pp. 1219–1225, Dec. 2001

[14]M. Daniele, P. K. Jain, and G. Joós, "A single-stage power-factor corrected AC/DC converter," *IEEE Trans. Power Electron.*, vol. 14, no. 6, pp. 1046–1055, Nov. 1999.