International Journal For Technological Research In Engineering
Volume 3, Issue 12, August-2016 *ISSN (Online): 2347 - 4718*

A NOVEL BASED CONTINOUS CURRENT MODE OR DISCONTINOUS CURRENT MODE OBSERVER FOR BOOST PFC OF UNIVERSAL CONVERTER

Kishore M P[1], Prakash R[2], Raveendra R[3], Anguraja R[4]
Department of Electrical and Electronics, Don Bosco Institute of Technology, Bangalore, India

Abstract: Power factor correction (PFC) is an essential part of ac/dc converters in order to improve the quality of the current drawn from the utility grid. The PFC closed-loop control system requires a precise measurement of the boost inductor current in order to tightly shape the input current. Current sensors are widely used in the PFC closed-loop control system to measure the boost inductor current. Current sensors introduce delay and noise to the control circuitry. Also, they significantly contribute to the overall cost of the converter. Therefore, they make the implementation of the PFC converter complicated and costly. Current sensor less control techniques can offer a cost-effective solution for various applications. The unique structure of the boost PFC converter makes it challenging to robustly estimate the inductor current due to the nonlinear structure of the converter. Also, it is shown in this paper that the system loses observability at some singular operating points, which makes the observer design more challenging. In addition, the load value is unknown in most applications. Thus, the observer should be able to estimate the inductor current in the presence of uncertainties in the load and other parameters. This paper presents an adaptive nonlinear observer for the boost PFC, which is able to accurately estimate the inductor current. The adaptive structure of the converter allows the robust and reliable performance of the observer in the presence of parameter uncertainties, particularly load variations. Also, an auxiliary compensation is integrated into the observer to circumvent the singular operating points and provide a precise estimation for the entire range of operation. Experimental results are presented to verify the feasibility of the proposed sensor less control approach.

Keywords: AC/DC Converters, Continuous Current Mode (CCM), Discontinuous Current Mode (DCM), Power Factor Correction (PFC), Non Linear System, Observability, Current Sensor, Sensorless, Pulse Width Modulation (PWM), Current Transformer(CT)

I. INTRODUCTION

The AC/DC single-phase power conversion systems are widely used in industry to convert available electrical energy from the utility mains to a dc output voltage. In various industrial applications such as telecom, network server power supplies, plug-in and hybrid electric vehicles, etc., ac/dc converters are extensively employed to provide a dc voltage [1] – [13]. AC/DC power conversion systems generally consist of a single-phase front-end power factor correction (PFC) converter followed by an isolated full-bridge pulse width modulation (PWM) converter [14]. The front-end converter must comply with the stringent regulatory standards on the input current harmonics imposed by different agencies [15], [16]. In order to effectively minimize the high frequency ripple of the converter input current and output capacitor, multiple boost converters are typically interleaved, particularly for higher power applications [17]. In the conventional control system, there is an external voltage loop to regulate the dc-bus voltage and an internal current loop to shape the input current of the converter. In order to implement the internal current loop, precise information of the boost inductor current is required. Since the inductor current is low frequency, a Hall-effect sensor can be used to measure the inductor current [18]–[20]. However, Hall-effect sensors suffer from several practical difficulties. Due to the remnant flux, they introduce a time-varying dc bias into the control system. Therefore, a correction algorithm has to be added to compensate for the time-varying dc bias. This algorithm increases the complexity of the control system in terms of implementation. Also, the bandwidths of the Hall-effect sensors are limited, and they introduce delay into the closed-loop control system, which may jeopardize the stability of the control system. Last but definitely not least, they are very costly and significantly contribute to the overall cost of the converter. The second technique to measure the inductor current is through resistive current sensors. Resistive current sensors require a very precise and noise-free differential amplifier. Also, they increase the power losses of the converter, which is not preferable, particularly in higher power applications. They are also very costly in applications where a very precise current value is required. The most common method, which is widely used in industry, is using a current transformer (CT) to sense the inductor current [21], [22]. Since the inductor current is low frequency, the CT is usually placed in series with the boost MOSFET in order to sample the inductor current when the switch is ON [23]. This sensing technique is an affordable solution, which is widely used in industrial products. However, the current measurement with CT creates some major difficulties for the converter. Placing a CT in series with the boost MOSFET increases the inductive path and causes high voltage spikes across the power semiconductors during the switching transitions. Also, CTs restrict the maximum duty cycle of the converter. This is due to the fact that the magnetizing inductance of CTs needs to be reset in each switching cycle. Therefore, a suitable amount of time is required to guarantee the reliable performance of CTs. This issue is very pronounced at the zero crossings of the input voltage where the converter should operate with very high duty ratio. The other issue related to the application of CT for sensing current occurs when multiple boost converters are interleaved to share the current, and effectively reduce the input current ripple in higher power applications. Due to the phase shift between the boost phases, the switching noise of one phase may affect the sampling of the other phase. This highly degrades the reliability of the control system. Therefore, in practical circuits, a low-pass filter is often used to attenuate the switching noise. Nevertheless, the low-pass filter introduces delay to the control loop and deteriorates the stability margins. Considering all the fundamental issues regarding the current sensors in the boost PFC converter, current sensorless techniques are very advantageous in this particular application. This approach not only can provide a clean and noise-free estimation of the inductor current but also can provide a very cost-effective solution for this application. A single-loop current sensor less control approach is proposed for a boost PFC converter. In the proposed approach a single voltage loop is used to control the converter. In this paper, it is shown that a sinusoidal current can be achieved by nominal duty ratio pattern, which is calculated in open loop and the voltage loop controls the controllable phase of the duty ratio pattern to regulate the output voltage. Although, the proposed method seems to provide a very simple solution for boost PFC converter, it is very sensitive to the converter parameters. In particular, at light loads the performance of the converter significantly degrades especially close to the current zero crossings. A modified version of the single-loop current sensorless control technique has been proposed in which is able to offer better performance in terms of total harmonic distortion (THD) and zero crossing distortion. A sensorless technique is proposed in which is able to determine the duty ratio of the boost PFC converter based on the input ac voltage. The idea is to calculate the output voltage using the input voltage from a voltage sensor and the voltage drop across the inductor derived based on the converter circuit. Then, the duty ratio is determined using the input and output voltage. The proposed control technique can provide a practical and cost-effective solution for some applications where the load variations are very limited and a high quality input current is not required. In another current sensor less technique is proposed for the boost PFC converter, which is able to compensate for the error caused by parasitic components. Although this method demonstrates high quality input current for heavy loads, the current quality deteriorates at light loads. The particular topology of the boost PFC converter makes the design of the observer very challenging. The topology of the boost converter results in a nonlinear mathematical model for the converter. Therefore, a nonlinear observer is required to estimate the inductor current. Also, in many applications, the load information is not available for the observer to be used in the observer structure. Thus, the load value is an unknown parameter for the observer. The other difficulty related to this particular topology is that the converter loses its observability at certain operating conditions. Therefore, the observer cannot provide proper information for those points. In this paper, an adaptive nonlinear observer is proposed to estimate the boost inductor current. The proposed observer adaptively estimates the load value; hence, it does not require the information of the load. Also, an algorithm is embedded into the observer to take care of the non observable operating points. The proposed observer offers a very reliable and cost-effective solution for various applications such as telecommunications, plug-in electric vehicle, aerospace, etc.

II. CONVERTER CLASSIFICATION

The power electronic objective circuit’s objective is to match the voltage and current which is used to load the source requirement. It converts one type of a voltage or current to the other type of waveforms, so it is called converters. Converters acts as an interface between the source and the load as shown in Fig.1.

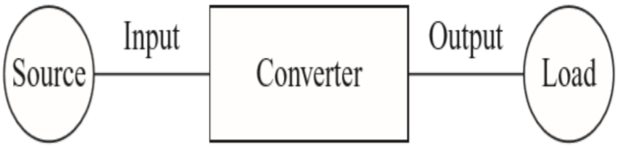

Fig.1. Source and load by converter

A. Converters are classified by the relationship between input and output

- AC/DC converter**:** The AC/DC it produces DC output from the AC input in which the AC source to a DC load average power is transferred. The AC-DC converter classified specially as rectifier. For example, an AC/DC enables integrated circuit as the converting the appropriate AC signal to the DC signal to the appropriate signal.
- DC/AC converter**:** The DC/AC converts DC input to the AC output which is classified in the type of the inverter. From the DC-AC side the average current flows. Examples from the inverter applicator to the solar cell which is the array of the solar cell.
- DC/DC converter**:** The DC/DC converter which takes DC input and produces DC output which is very useful for the load required to generate the unregulated DC value. For example, 5V obtained from the 12V generated by the DC/DC converter.
- AC/AC converter**:** The AC/AC converter converts the AC input to the AC output it is used to change the level of the output which is very useful load required from the frequency of the AC. Example, common light dimmer and the speed control of an inductor.

The supremacy adaptation in the AC-DC-AC involve the one type of the converter, in which AC source can transform the first convert conversion to the direct current and then it converts DC signal to the AC signal amplitude and frequency from the original AC source

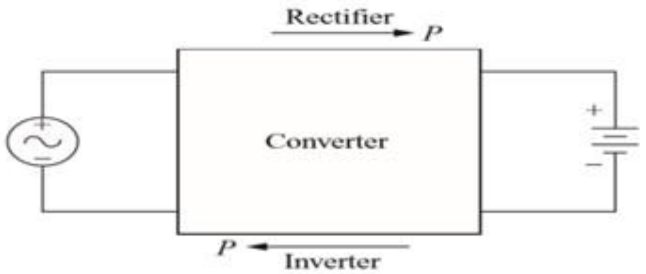

Fig.2. Basic circuit of inverter and rectifier

Fig.2 shows the block diagram of the implemented converter. Field Programmable Gate Array (FPGA) is used to implement the control system. FGPA provides very fast and reliable solution to the sensor less control system which is implemented digitally. Very fast and cost-effective technique for the control of power converts can be obtained with the help of FGPA.

B. AC/DC Converter

Single phase Converter

- Half Wave controlled and uncontrolled
- Full Wave controlled and uncontrolled

Three phase Converter

- Half Wave controlled and uncontrolled
- Full Wave controlled and uncontrolled

C. DC/DC Converter

1. Buck Converter (Step down DC-DC converter).
2. Boost Converter (Step up DC-DC converter).
3. Buck-Boost converter (Step up-down, DC-DC converter).
4. Cuk Converter (Step up-down DC-DC converter).

III. METHODOLOGY

A. Converter

A two-phase interleaved boost converter is used to implement the PFC. It should be noted that, for such high-power applications, a dual-channel boost converter is necessary to reduce the high frequency ripple of the input ac current

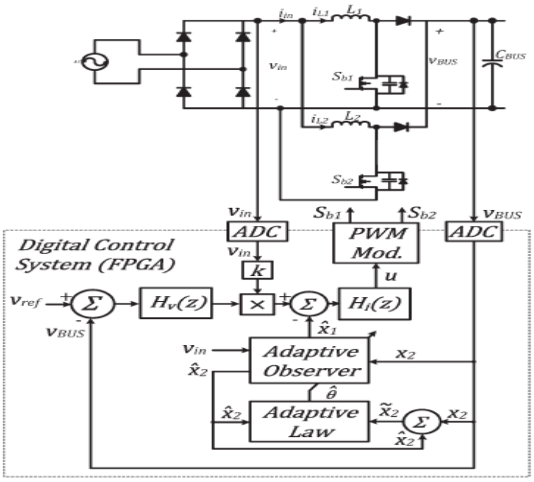

Fig.3. Block diagram of implemented converter

Current sensor is implemented by placing CT's in series with MOSFET this gives an added advantage of the proposed current observer for the boost pfc ac/dc converter. Fig.4 shows the waveform of two current sensors. This figure demonstrates a very noisy current signal is used in the current feedback control loop. Fig.4 also shows that the switching noise from one phase may largely affect the current signal of other phase in random intervals.

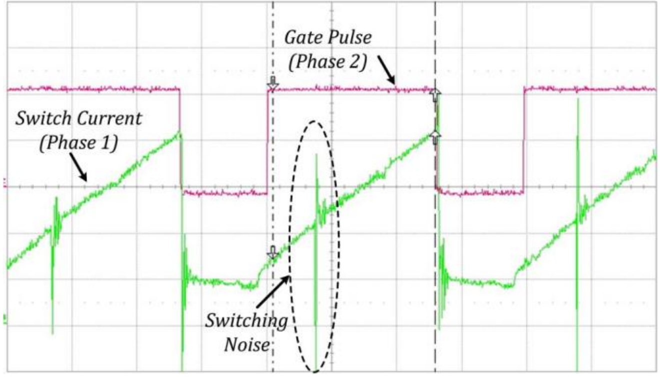

Fig.4. Output waveform of two current sensors

Therefore, if the start of conversion for an analog to digital converter (ADC) coincides with switching noise, the control loop cannot maintain its stability. It's a very serious issue with practical circuits. This noise can be suppressed by using capacitive filters. But the filters introduce delay which affects the stability and reliability of the system. The design of an observer for this system is very difficult and challenging due to the nonlinear character of the system. The operating conditions can vary in wide range because of the variation of input voltage and input current. Thus, linearizing the model is not able to provide a very precise approach. The time varying of the DC bias of the control system is to build up with the system also it is used to the system with lot of the correction algorithm to be added at the time varying of the compensator of the system. The resistive current sensor is used for the induction of the current and also for the noise free differential amplifier in the system. It is used for the power loss converter which not highly preferable for the higher power applications. Placing CT in series with boost MOSFET increases inductance and cause over voltage spikes across the power semiconductor during switching functions. The other problems related to CT for sensing current occurs when multiple boost converters are interleaved to share current, and reduces the input current ripple in high power applications.

B. Adaptive Observer

The block diagram of the proposed adaptive nonlinear observer is shown in Fig.5. The auxiliary compensation block is added to reset the integrator of the inductor current estimation when the output capacitor voltage is equal to its dc value or, equivalently, when the low frequency ac component of the output voltage passes through zero with a negative slope (this points correspond to the operating conditions where the observability is lost). The auxiliary compensation uses the output capacitor information to estimate the inductor currents at those points. This also shows the implementation of auxiliary compensation block. In this diagram, a discrete differentiator is used to extract the low frequency ripple of the output voltage. The produced signal is used to create the reset signal for the inductor current estimation integrator. It is worthwhile to note that a discrete differentiator is used in this block diagram in order to avoid any switching noise amplification.

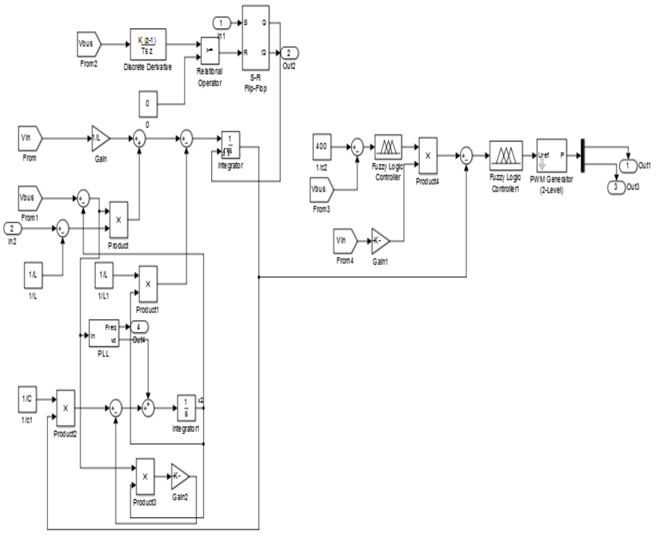

Fig.5. Block diagram of proposed adaptive nonlinear observer

The sample and hold (S/H) in the discrete differentiator, Dz, is able to effectively filter out the switching noise, resulting in a clean signal for the comparator (the sampling is synchronized with the switching frequency). Also, since the switching frequency is much faster than the system's dynamics, the S/H delay has a negligible impact on the performance of the observer.

IV. EXPERIMENTAL RESULTS

However, for higher power applications, the switching noise can be very high, and so will be the filtering requirement for the proper noise removal. Fig.6 shows a situation where the closed-loop control system loses stability due to a very noisy current feedback.

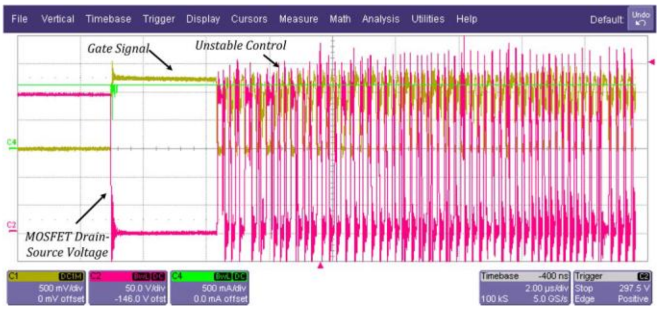

Fig.6. Unstable operation of system due to noisy current feedback

This figure shows that the system reliability can significantly be jeopardized by the current sensor. It is worthwhile to mention that the bandwidth of the observer should be designed much faster that the bandwidth of the controller in order to achieve a reliable and stable operation. Fig.7 shows the performance of the closed-loop control system with the proposed adaptive current observer. This figure demonstrates a very accurate estimation of the observer. Also, the resetting of the current observer during the zero crossings of the input ac voltage helps the observer ride through these singular operating points where the boost PFC converter loses the observability of the inductor current.

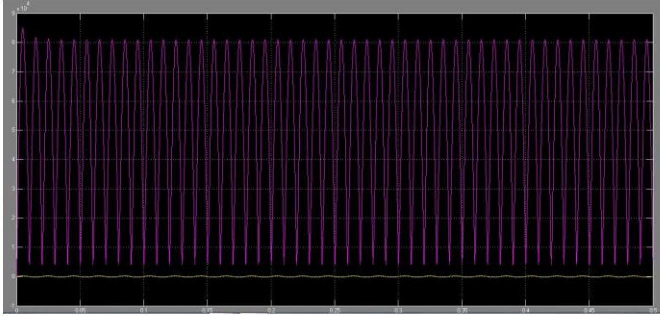

Fig.7. Performance of the system with adaptive current observer

Fig.8 shows the experimental waveforms of the PFC at full load. According to this figure, the converter drains a high quality current from the utility grid, with a very stable performance. Also, the input current and input ac voltage are in phase, thus maintaining near unity power factor (0.997).

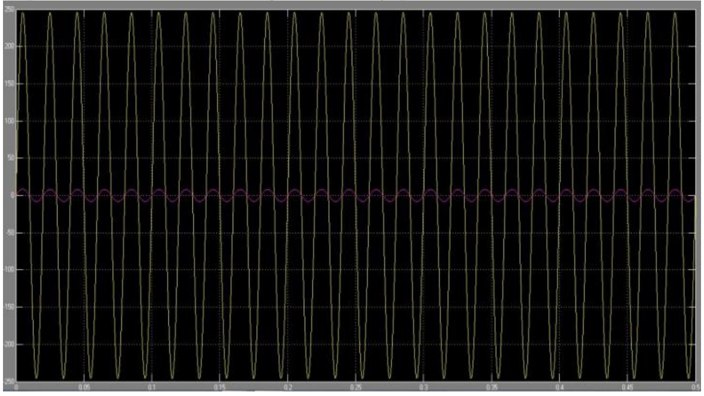

Fig.8. Operation of steady state converter at full load

Fig.9 shows the transient response of the closed-loop control system when a 50% step load change is applied to the converter. This figure shows that the observer is able to accurately estimate the inductor current and maintain the stability of the closed-loop system.

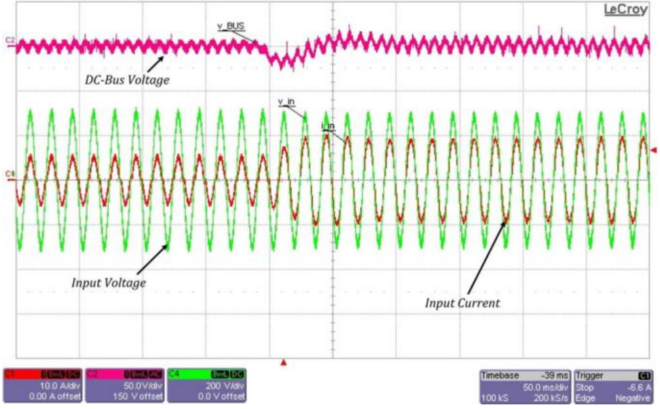

Fig.9. Transient response of the system for50% positive load change

Fig.10 shows the transient response of the converter when a step change is applied to the input voltage. According to this figure, the transient response for the line voltage is very fast and stable. This is due to the fact that the observer immediately takes the instantaneous value of the input voltage and estimates the inductor current accordingly.

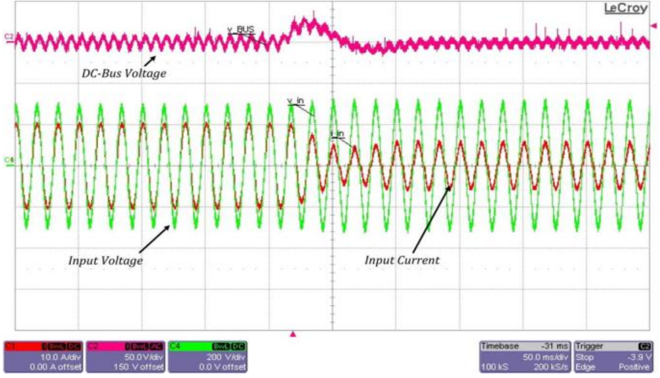

Fig.10. Transient response of the system for50% negative load change

Fig.11 illustrates the impact of the auxiliary compensation. The auxiliary compensation resets the estimated current when the system loses its observability in order to avoid estimation errors. According to Fig.11, the estimated current is reset to zero at the zero crossings of the input voltage where the system loses its observability.

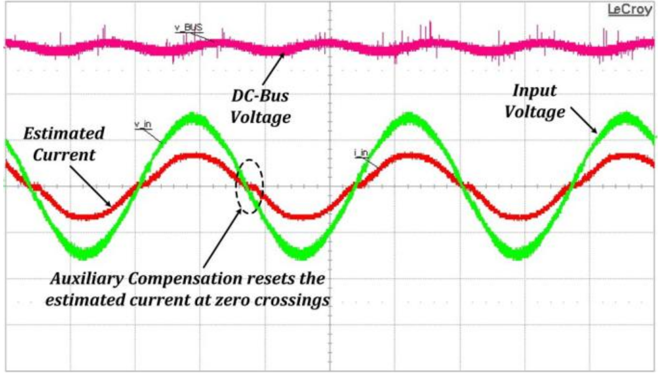

Fig.11. Auxiliary compensation rests the estimated current when system loses its observability

V. CONCLUSION

This paper has presented a novel observer for a boost PFC converter. This paper uses an adaptive nonlinear observer to accurately estimate the inductor current. In addition, an auxiliary compensation is proposed to circumvent the singular points of the system where the observability matrix is not full rank. The proposed adaptive observer is able to precisely estimate the load value due to the persistency of excitation provided by the inherent low frequency ripple present at the output voltage. The performance of the proposed observer has been analyzed from the geometric point of view. The geometric analysis offers an intuitive insight in terms of closed loop control performance. Also, comprehensive experimental results confirm the feasibility of the proposed sensorless control system and demonstrate the superior performance compared to the conventional control system. This paper can provide a general procedure for the design and implementation of the observer for other PFC topologies. After giving controls to the observer for compensating the problems, the THD values has been reduced from 223.29 to 217.96 i.e. up to 5.33% by the system. By looking at the THD values we can conclude that, the proposed work is efficient than the existing work. Also, combining the PFC controller with the proposed observer and implementing it on an application-specific integrated circuit lie in the future scope of this work.

REFERENCES

[1] Design Guidelines for Interleaved Single-Phase Boost PFC Circuits, By Thomas Nussbaumer, Klaus Raggl, and Johann W. Kolar.

[2] Simulation of a ZVS Interleaved Boost DC-DC Converter by using Photovoltaic System By PREM KUMAR1, DR. V.BALA KRISHNA REDDY

[3] Modeling and Small-Signal Analysis of a Switch-Mode Rectifier With Single-Loop Current Sensor lessControl, By Hung-Chi Chen, Zen-How Wu, and Jhen-Yu Liao

[4] Power factor correction by using ac/dc converter with quasi-active scheme, By A.Thejasre, A.Hemasekhar

[5] COMPARISON OF 3-PHASE WIDE OUTPUT VOLTAGE RANGE PWM RECTIFIERS, ByThomas Nussbaumer and Johann W. Kolar

[6] H. Kosai et al., “Coupled inductor characterization for a high performance interleaved boost converter,” IEEE Trans. Magn., vol. 45, no. 10, pp. 4812–4815, Oct. 2009.

[7] C. A. Gallo, F. L. Tofoli, and J. A. C. Pinto, “A passive lossless snubber applied to the ac-dc interleaved boost converter,” IEEE Trans. Power Electron., vol. 25, no. 3, pp. 775–785, Mar. 2010.

[8] J. P. R. Balestero, F. L. Tofoli, R. C. Fernandes, G. V. Torrico-Bascope, and F. J. M. De Seixas, “Power factor correction boost converter based on the three-state switching cell,” IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1565–1577, Mar. 2012.

[9] P. Das, M. Pahlevaninezhad, and G. Moschopoulos, “Analysis and design of a new ACDC single-stage full-bridge PWM converter with two controllers,” IEEE Trans. Ind. Electron., vol. 60, no. 11, pp. 4930–4946,Nov. 2013.

[10] J. Y. Lee and H. J. Chae, “6.6 kW on-board charger design using DCM PFC converter with harmonic modulation technique and two-stage dc/dc converter,” IEEE Trans. Ind. Electron., vol. 61, no. 3, pp. 1243–1252, Mar. 2012.

[11] H. S. Kim et al., “On/off control of boost PFC converters to improve light load efficiency in paralleled power supply units for servers,” IEEE Trans. Ind. Electron., vol. 61, no. 3, pp. 1235–1242, Mar. 2013.

[12] H. S. Athab, D. Lu, A. Yazdani, and B. Wu, “An efficient single-switch quasi-active PFC converter with continuous input current and low dc-bus

voltage stress," IEEE Trans. Ind. Electron., vol. 61, no. 4, pp. 1735–1749, Apr. 2014.

[13] A. Karaarslan, "The implementation of bee colony optimization algorithm to Sheppard Taylor PFC converter," IEEE Trans. Ind. Electron., vol. 60, no. 9, pp. 3711–3719, Sep. 2013.

[14] M. Pahlevaninezhad, P. Das, J. Drobnik, P. K. Jain, and A. Bakhshai, "A novel ZVZCS full-bridge dc/dc converter used for electric vehicles," IEEE Trans. Power Electron., vol. 27, no. 6, pp. 2752–2769, Jun. 2012.

[15] Kovacevic, T. Friedli, A. Muesing, and J. Kolar, "3D electromagnetic modeling of EMI input filters," IEEE Trans. Ind. Electron., vol. 61, no. 1, pp. 231–242, Jan. 2014.

[16] A. Prudenzi, U. Grasselli, and R. Lamedica, "IEC Std. 61000-3-2 harmonic current emission limits in practical systems: Need of considering loading level and attenuation effects," in Proc. Power Eng. Soc. Summer Meet., 2001, vol. 1, pp. 277–282.

[17] Unitrode Application Note SLUA-479B M. O. Laughlin, UCC28070300-W Interleaved PFC Pre-Regulator Design Review, Unitrode Application Note SLUA-479B.

[18] A. Makki, S. Bose, T. Giuliante, and J. Walsh, "Using Hall-effect sensors to add digital recording capability to electromechanical relays," in Proc. 63rd Annu. Conf. Protective Relay Eng., Apr. 2010, pp. 1–12.

[19] J. Pankau, D. Leggate, D. Schlegel, R. Kerkman, and G. Skibiniski, "High frequency modeling of current sensors," in Proc. 14th Annu. APEC Expo., Mar. 14–18, 1999, vol. 2, pp. 788–794.

[20] Honeywell, Application Note, 005715-2-EN IL50 GLO 1198 Hall Effect Sensing and Application, Morristown, NJ, USA, Application Note, 005715-2-EN IL50 GLO 1198.

[21] Unitrode Application Note DN-41 P. C. Todd, Extend Current Transformer Range, Unitrode Application Note DN-41.

[22] D. Y. Qiu, S. C. Yip, H. S.-H. Chung, and S. Y. R. Hui, "On the use of current sensors for the control of power converters," IEEE Trans. Power Electron., vol. 18, no. 4, pp. 1047–1055, Jul. 2003.

[23] TI Application Report SLUA369B M. O. Laughlin, 350-W, Two-Phase Interleaved PFC Pre-Regulator Design Review, Feb. 2005 TI Application Report SLUA369B.