Double Integrated Buck Offline Power Supply for LED Lighting Applications

Divya Vincent[1], Kapil Das[2]

[1] *M.Tech Student, Electrical and Electronics, Jyothi Engineering College,Kerala,India*
[2] *Assistant Professor, Electronics and Communication, Jyothi Engineering College,Kerala,India*

---***---

Abstract - ***A Double integrated buck converter is presented in this paper. This converter finds application in fields of solid state lighting. The buck Converter is widely used for step down dc-dc conversion when there is no isolation requirement. The narrow duty cycle of the buck converter limits its application for high step down applications. The double integrated buck converter overcomes its limitaion. This converter also provides high power factor and output current regulation. A Double integrated buck converter uses for the offline power supply for LED lighting based on the integration of a buck power factor corrector (PFC) and the tapped buck dc/dc converter having high step down capability and output current regulation. Due to the high reliability, the simple structure, and the low component count, the proposed topology effectively results to be very suitable for medium-power solid-state lighting applications.The simulation of the circuit with 230V input, 30V/500mA output is done using PSIM. Output levels are obtained as per the design values for converter operations.***

Key Words: *Tapped inductor, AC/DC converters, LED Lamps, lighting power supply*

1. INTRODUCTION

In recent years, high brightness light emitting diodes (HBLEDs) have increasingly attracted in the area of both industrial manufacturers and academic research community. Among these several aspects that make LED technology so attractive, the most appreciated characteristics are related to their high efficiency, small size, long lifetime, easy dimming capability, robustness, very short switch-on/switch-off times and mercury free manufacturing.

Even if all such qualities would seem to give to solid state lighting having a clear advantage over all the other kinds of lighting technologies. there are some issues deriving from the need of LED technology improvement and the development of suitable electronic ballasts to properly drive such solid state light sources, on the other, have so far hindered the expected practical applications.[1]-[3]

In particular, the most important feactures for a LED lamp ballast are: high reliability and efficiency, high power factor, output current regulation, low cost, dimming capability, and volume minimization. The main goal is, therefore, to find out simple switched mode power converter topologies, characterized by reduced component count and low current/voltage stresses, that avoid the use of short lifetime devices like electrolytic capacitors. in order to optimize HBLED operation, also other matters, like the lamp thermal management concern, should be properly addressed in order to minimize the stress suffered by the light emitting diodes and the deterioration of the light quality and of the expected lamp lifetime. However, being this paper focused on the issues related to the research of innovative driving solutions of solid state devices technology.

In [4] Many PFC converters have been presented. They usually can be divided into two categories: the single-stage and two-stage approaches. The two-stage approach actually includes two power-conversion stages. The first stage is a PFC stage like a buck or boost converter, and the second stage is a dc/dc converter or dc/ac converter to regulate the output voltage. This approach has good performance for power factor (PF) and output-voltage regulation. The main disadvantage of this two stage is high cost due to an increase in the device count. This two-stage ac/dc converter usually increases the cost about 15%, compared with that of an ac/dc converter without PFC.

The single stage approach investigated based on the use of a simple structure relying on a single power conversion stage, capable of concurrently ensuring: the standards limiting the input current harmonics and regulation of the load current. In order to reduce the cost, the single-stage approach [5]–[9], which integrates the PFC stage with a dc/dc converter into one stage. These integrated single-stage PFC converters usually use a boost converter to get PFC with discontinuous current mode (DCM) operation and constant on-time control. When using such kind of single stage topology for low power LED driving purposes.

Another approach, that will be considered, is based on the use of integrated topologies [10] in which two power conversion stages are sharing the same power switch and control circuitry. In the resulting converter, power factor correction and LED current regulation are thus performed by two combined semi-stages in which both the input power and the output current have to be managed by the same shared switch. Compared with a conventional two-stages configuration, lower circuit complexity and cost, reduced component count and higher compactness can be achieved through integration, at cost of increased stress levels on the power switch and of losing a degree of freedom in converter design. Galvanic isolation can be provided or not depending on the topologies selected for integration. If non-isolated topologies are considered for both semi-stages, the user safety has to be guaranteed by assuring mechanical isolation throughout the LED lamp case. The issue, deriving from the need of smoothing the pulsating power absorbed from the line while avoiding the use of short lifetime electrolytic capacitors, will be addressed. A set of integrated topologies, used as HBLED lamp power supplies, will be investigated and a generalized analysis will be presented. Their input line voltage ripple attenuation capability will be examined and a general design procedure will be described.[10]
In [11] describes new family of single stage isolated power-factor correctors features fast regulation of the output voltage, one or two power switches operated in unison, a single control loop, and automatic shaping of the line current.
[12]-[13] By using a tapped inductor, low or high voltage transfer ratios can be achieved with relatively high efficiencies and low component cost.[12] present tapped inductor technology based DC-DC converter which is an integration of buck and boost converter via tapped inductor. Coherent working from stepping down to stepping up can be achieved by proper control scheme. This paper presents comparison of conventional converters and tapped inductor technology based converters. Also includes detailed working of tapped inductor technology based buck-boost converter. In [13] deals with a classification scheme is used to categorize tapped-inductor switched-mode power supplies. This new scheme allows the many possible circuit variants to be displayed in a logical manner and analyzed for practicality and performance. The scheme offers a way of ensuring that no tapped inductor converter circuit is neglected when a tapped-inductor circuit is to be chosen for any particular application.
The conventional buck converter for instance, is very efficient when not too large a potential difference separates the output voltage from the input voltage (i.e., when the duty cycle D is high, and typically over 50%). However in industrial applications, it is not unusual that a 48 V input voltage needs stepping down to 3.3V(and even below) for the supply of semiconductors or microprocessors. When such a conversion ratio is required, the duty cycle D must be very low to achieve such a transfer ratio and the efficiency of the conventional buck converter becomes unacceptably low. This leads to poor utilization of passive components and poor current waveform.
The efficiency of the DC-DC converters when a large conversion ratio is required needs therefore to be improved. The conversion ratio can be extended significantly by cascading two DC-DC converters. However, such applications require twice as many components as a basic converter, which is very costly and difficult to manage.
The step-down power conversion technique is widely used in power sources for microprocessors, battery chargers, LED drivers, solar power regulators and so on. These applications require low current ripple, which can be achieved by increasing the switching frequency. However, these may lead to high semiconductor losses. The buck converter is widely used for step-down dc-dc conversion when there is no isolation requirement, but nowadays interleaving [14] of the buck converters have become more common, since the current ripple can be reduced without increasing the switching frequency of the converter. Introducing a transformer helps attaining large step-up or step-down voltage conversion ratio [15.]Transformers' turn ratio should be chosen as to provide the desired voltage gain while keeping the duty cycle within a reasonable range for higher efficiency. The transformer, however, brings in a whole new set of problems associated with the magnetizing and leakage inductances, which cause voltage spikes and ringing, increased core and cooper losses as well as increased volume and cost.

Single-transistor converter topologies, with were proposed in [16] and demonstrated large step-down conversion ratio. This method has successfully achieved wide conversion range in the step done direction. The applications of quadratic converters are only tolerable where conventional, single stage converters are in adequate- in particular for high frequency applications where the specified range of input voltages and the specified range of output voltages call for an extremely large range of conversion ratios. Another drawback is that even though these converters utilize a single transistor switch, the number of components is still higher than basic converters.

A different approach to obtain wide conversion range by using coupled inductors was proposed in [17]. With only minor modification of the tapped-inductor buck, [17]

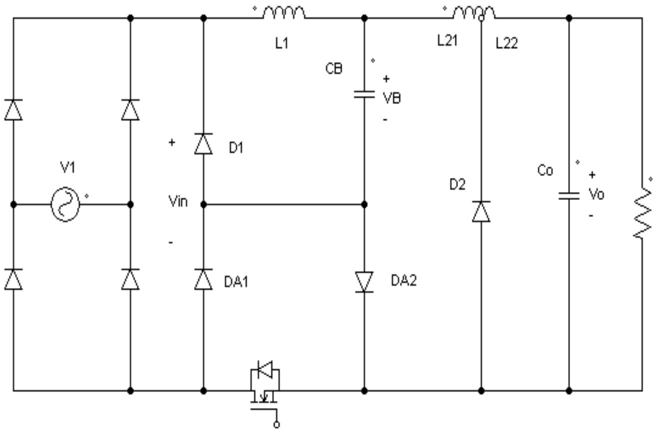


Fig.1. Scheme of the DIB LED Ballast

shows low component count and solves the gate-drive problem by exchanging the position of the second winding and the top switch. The problem of a high turn -OFF voltage spike on the top switch was solved by applying a lossless clamp circuit. Due to the coupled inductor action, the converter demonstrated high step-down dc--dc conversion ratio, whereas the converter's efficiency was improved by the extended duty cycle. A tapped-inductor buck with soft switching was introduced in [18]. Derivations of the tapped inductor buck were also suggested in [19] and [20]. Another modification of the tapped-buck converter was realized in [21] for power factor correction (PFC) application. With the addition of a line-frequency-commutated switch and a diode, both flyback and buck characteristics were achieved and large step-down was demonstrated. In [22] describes about the grafting tec technique. switches of the two original power conversion stages have been replaced with only one shared controlled switch and two auxiliary diodes (DA1 and DA2). In recent years, several novel converter topologies have been proposed in the literature, based on the idea of merging converters by sharing the main switch, such as in [23]–[26].

2. DIB CONVERTER TOPOLOGY

Fig.1 shows the electric diagram of the integrated double buck converter. The purpose is to get a simple, reliable and low cost power supply, characterized by low voltage operating levels, so as to improve robustness avoiding the use of electrolytic capacitors, and capable of power factor correction, to comply with the harmonic injection and energy saving standards. In order to reach this goal, the simplest solution seems to be the use of two buck stages. The first one allows to immediately step-down the input line voltage, reducing voltage stresses and improving functional safety, while the second one provides the proper voltage level to feed the LED lamp placed at load

TABLE-1: CONVERTER DESGIN OUTCOMES

Converter Parameters	Symbol	Value
Switching frequency	F_{SW}	100kHZ
Bus voltage	V_B	160V
PFC Choke	L_1	1mH
Bus Capacitance	C_B	30μH
Converter duty cycle	D	0.42
Tapped inductor magnetizing inductance	L_2	90mH
Tapped inductor ratio	Δ	3.85
Tapped inductor Turns ratio	$\frac{N1}{N2}$	2.85
Ripple transformation factor	v	0.038
Output capacitance	C_O	50 μH

side. The converter behaves as two buck converters in cascade. The input buck converter is made by L_1,C_B,D_1,D_{A1},D_{A2} and S, and the output converter comprises C_0,D_2 and tapped inductor. The integration of two step-down power conversion stages sharing the same controlled switch. The input semi-stage provides PFC, whereas the output semistage guarantees LED current regulation and light dimming.

3. SIMULATION RESULTS

The simulation of the integrated double buck converter with high step down capability, output current regulation and high power factor has been carried out and the simulation model is shown in Fig.2.An input voltage of 230V and switching frequency of 100 kHz is chosen and an output of 30V/500mA is obtained. The duty ratio of the switch equal to 0.42 and the corresponding parameters are listed in Table I.

Fig.3 shows the input voltage and input current waveforms. As it can be observed, converter behavior effectively meets the design specification, being the resulting actual power factor equal to 0.92 and the LED current peak to peak ripple equal to ±10% of the nominal

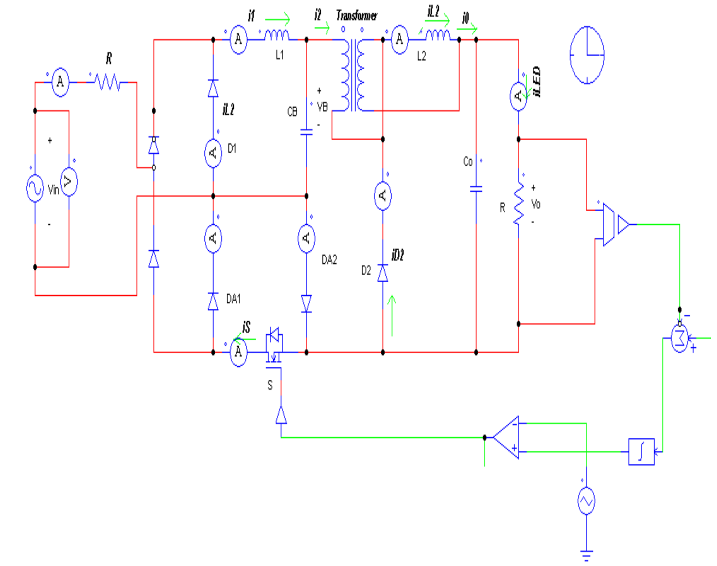


Fig -2 Simulation Model of DIB converter

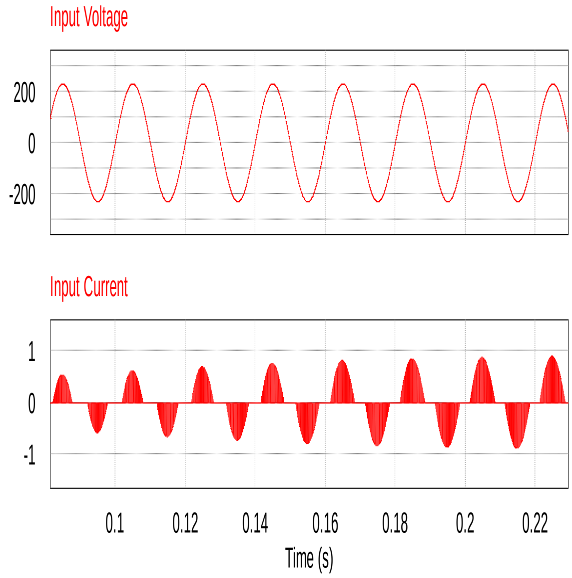


Fig-3 Input voltage and input current waveforms

value, as required. In order to achieve good voltage regulation closed loop control methods are introduced. In pulse width modulation (PWM) control, the duty ratio linearly modulated in a direction that reduces the error. when the input voltage is perturbed, that must be sensed as an output voltage change an error produced in the output voltage is used to change the duty ratio to keep the output voltage to the reference value. In Fig.4 shows the output voltage and output current of the new converter. The converter output voltage is 30V and output current is 0.5A. Bus Voltage waveform shown in Fig 5. Fig.6 shows the waveforms of the current through the first filter inductor,tapped inductor primary winding, secondary winding and magnetizing inductance and also shows the active controlled switch waveform, in correspondence of the line voltage peak.Current through the Freewheeling diodes are shown in Fig.7. Current through auxiliary diodes as shown in Fig.8.

Inductor(i_{L1}) cannot be constantly equal and neither constantly greater than the tapped inductor primary side current (i_{L2}), so that the auxiliary diode D_{A1} will consequently result to be necessary. On the other hand, as concerns the other extra diode, the condition that has to be verified, in order to be allowed to remove DA2,is that iL 1 is constantly lower than i_{L2}. The load regulation can be seen in Fig.9. The line regulation at Vin = 220 V and Vin = 180 V are given in Fig 10(a) and Fig.10(b) respectively.

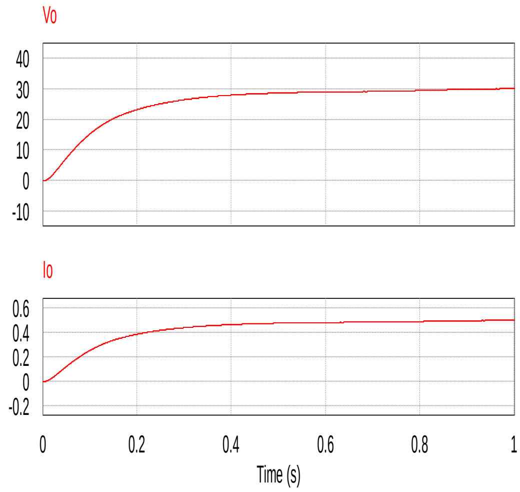


Fig-4 Output voltage and Output current

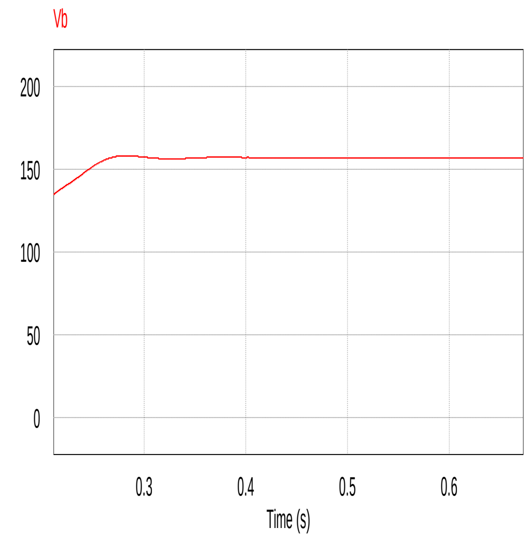


Fig-5. Bus Voltage waveform

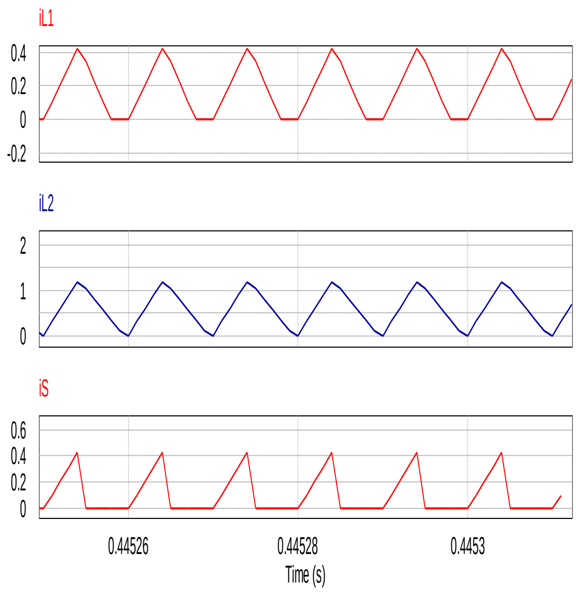


Fig-6 Current through inductors and switch

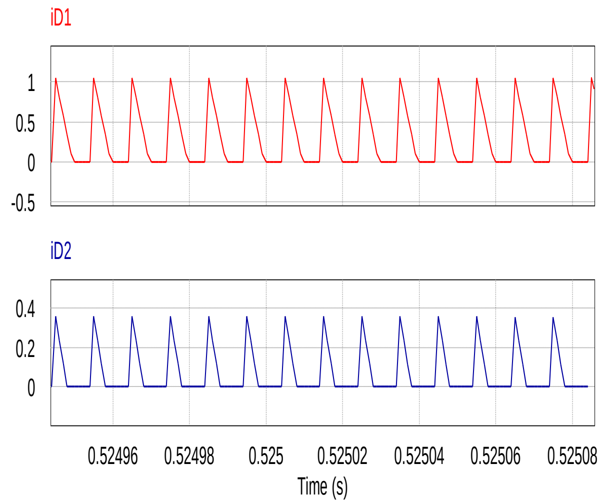


Fig-7 Current through diodes iD1 and iD2

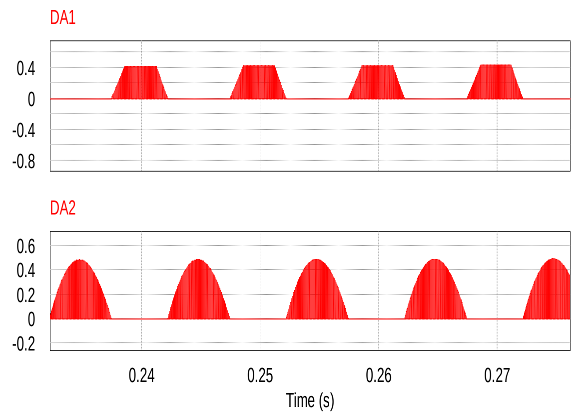


Fig-8 Current through the Auxilary diodes iDA1 and iDA2

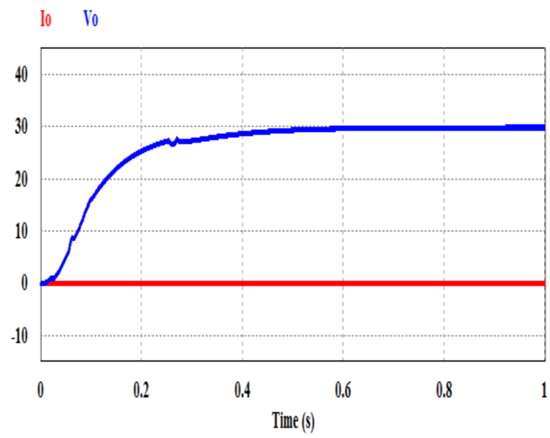
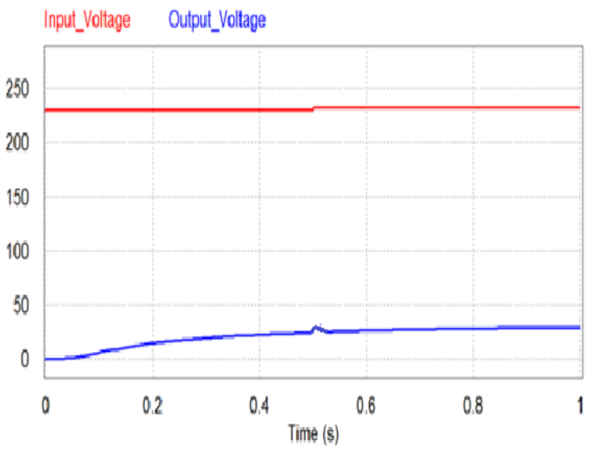
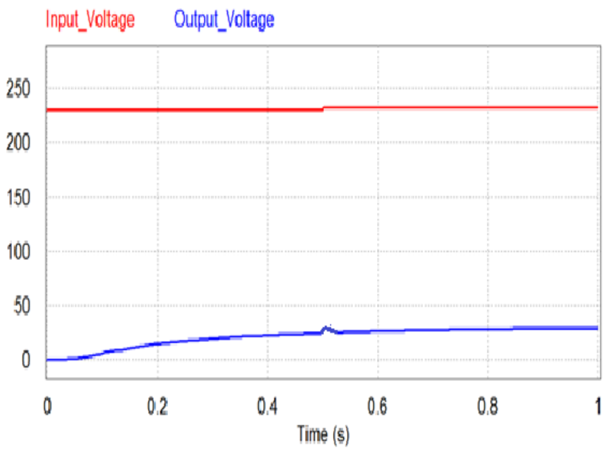


Fig-9.Load regulation of the converter at no load



(a)



(b)

Fig-10. Line regulation of the converter at (a) Vin = 232.3 V (b) Vin = 227.7 V

4. CONCLUSION

Closed loop control of Double integrated buck ac to dc converter for offline power supply for solid state lighting applications has been discussed. The DIB Converter essentially relies on the integration of a buck PFC with a tapped buck dc/dc converter. Compared with other solutions, the two-stage converter with a dedicated PFC input stage, the proposed solution can provide much better control of input PF and low-frequency LED current ripple than the former and much more simplicity and lower cost than the latter. Despite its simplicity, the described solution is capable of guaranteeing both high PFC performance at the line side and an accurate regulation of the current through the LEDs at the load side. Moreover, being characterized by low bus voltage values, this topology also allows improving the ballast functional safety and its overall robustness, avoiding the use of short lifetime electrolytic capacitors. The proposed converter operation principles have been carefully analyzed, as well as the performance of both the input and the output semi-stages.

The simulation of the integrated double buck converter with high step down capability, output current regulation and high power factor has been carried out in PSIM. An input voltage of 230V and switching frequency of 100 kHz is chosen and an output of 30V/500mA is obtained.

5. REFERENCES

[1] D. Camponogara, G. F. Ferreira, A. Campos, M. A. Dalla Costa, and J. Garcia, “Offline LED driver for street lighting with an optimized cascade structure,” *IEEE Trans. Ind. Appl.*, vol. 49, no. 6, pp. 2437–2443, Nov./Dec. 2013.

[2] S. Li, S.-C. Tan, S. Y. R. Hui, and C. K. Tse, “A review and classification of LED ballasts,” in *Proc. IEEE ECCE*, Sep. 15–19, 2013, pp. 3102–3109.

[3] Francesco Sichirollo, J. Marcos Alonsoand Giorgio Spiazzi,” A Novel Double Integrated Buck Offline Power Supply for Solid-State Lighting Applications” IEEE transactions on industry applications, vol.51, no.2, march/april 2015

[4] J. Qian, Q. Zhao, and F. C. Lee, “Single-stage single-switch power-factorcorrection ac/dc converters with dc-bus voltage feedback for universal line applications,” *IEEE Trans. Power Electron.*, vol. 13, no. 6, pp. 1079–1088, Nov. 1998.

[5] J. Qian and F. C. Lee, “A high efficient single-stage single-switch high power factor ac/dc converter with universal input,” in *IEEE Applied.Power Electronics Conf.*, 1997, pp. 281–287.

[6] F. Tsai, P. Markowski, and E. Whitcomb, “Off-line flyback converter with input harmonic correction,” in *IEEE Int. Telecommunications Energy Conf.*, 1996, pp. 120–124.

[7] L. Huber and M. M. Jovanovic, “Single-stage, single switch, isolated power supply technique with input-current shaping and fast outputvoltage regulation for universal input-voltage-range applications,” in *IEEE Applied Power Electronics Conf.*, 1997, pp. 272–280.

[8] J. Qian and F. C. Lee, “A novel single stage high power factor rectifier with a coupling inductor,” in *Virginia Power Electronics Seminar*, 1996, pp. 1–7.

[9] M. J. Willers, M. G. Egan, J. M. D. Murphy, and S. Daly, “A BIFRED converter with a wide load range,” in *IEEE IECON’94*, pp. 226–231.

[10] J. M. Alonso, J. Vina, D. G. Vaquero, G. Martinez, and R. Osorio, “Analysis and design of the integrated double buck–boost converter as a highpower- factor driver for power-LED lamps,” *IEEE Trans. Ind. Electron.*, vol. 59, no. 4, pp. 1689–1697, Apr. 2012.

[11] R. Redl, L. Balogh, and N. O. Sokal, “A new family of single-stage isolated power-factor correctors with fast regulation of the output voltage,” in *IEEE PESC*, 1994, pp. 1137–1144.

[12] V. R. Tintu and M. George, “Tapped inductor technology based dc–dc converter,” in *Proc. ICSCCN*, 2011, pp. 747–753.

[13] D. A. Grant, Y. Darroman, and J. Suter, “Synthesis of tapped-inductor switched-mode converters,” *IEEE Trans. Power Electron.*, vol. 22, no. 5, pp. 1964–1969, Sep. 2007.

[14] M. Esteki, B. Poorali, E. Adib and H. Farzanehfard, “Interleaved buck converter with continuous input current, extremely low output current ripple, low switching losses and improved step-down conversion ratio, ” IEEE Trans. Ind. Electron., vol. 62, no. 8, pp. 4769-4776, Aug 2015.

[15] K. Yao, Y. Ren, J. Wei, M. Xu, and F. Lee, ‘‘A family of buck type dc-dc converters with autotransformers,’’ in Proc. Appl. Power Electron. Conf. Expo. (APEC 2003), pp. 114--120.

[16] D.Maksimovic and S. Cuk, ‘‘Switching converter with wide dc Conversion range,’’ *IEEE Trans. Power Electron.*, vol. 6, no. 1, pp. 151--157, Jan. 1991.

[17] K. Yao,M. Ye, M. Xu, and F. C. Lee, ‘‘Tapped-inductor buck converter for high-step-down dc--dc conversion,’’ IEEE Trans. Power Electron., vol. 20,no. 4, pp. 775--780, Jul. 2005.

[18] M. M. Jovanovic, D. M. Tsang, and F. C. Lee“Reduction of voltage stress in integrated high-quality rectifier-regulators by variable frequency control,” in IEEE Applied Power Electronics Conf., 1994, pp. 569–575.

[19] K. Yao, Y. Ren, J. Wei, M. Xu, and F. Lee, ‘‘A family of buck type dc-dc converters with autotransformers,’’ in Proc. Appl. Power Electron. Conf. Expo. (APEC 2003), pp. 114--120.

[20] F. Tsai, P. Markowski, and E. Whitcomb, “Off-line flyback converter with input harmonic correction,” in IEEE Int. Telecommunications Energy Conf., 1996, pp. 120–124.

[21] L. Huber and M. M. Jovanovic, “Single-stage, single switch, isolated power supply technique with input-current shaping and fast outputvoltage regulation for universal input-voltage-range applications,” in *IEEE Applied Power Electronics Conf.*, 1997, pp. 272–280.

[22] T.-F. Wu, T.-H. Yu, and Y.-H. Chang, “A systematic illustration of the applications of grafted converter trees,” in *Proc. 22nd IEEE IECON*, 1996, vol. 3, pp. 1536–1541.

[23] D. Gacio, J. M. Alonso, A. J. Calleja, J. García, and M. Rico-Secades,“A universal-input single-stage high-power-factor power supply for HB-LEDs based on integrated buck-flyback converter,” *IEEE Trans. Ind. Electron.*, vol. 58, no. 2, pp. 589–599, Feb. 2011.

[24] C.-A. Cheng, H.-L. Cheng, F.-L. Yang, and C.-W. Ku, “Single-stage driver for supplying high-power light-emitting-diodes with universal utility-line input voltages,” *IET Power Electron.*, vol. 5, no. 9, pp. 1614–1623, Nov. 2012.

[25] C.-A. Cheng, F.-L. Yang, C.-W. Ku, and C.-H. Yen, “A novel single-stage high power LEDs driver,” in *Proc. 8th IEEE ICPE ECCE Asia*, 2011, pp. 2733–2740.H]

[26] S. Li, S.-C. Tan, S. Y. R. Hui, and C. K. Tse, “A review and classification of LED ballasts,” in *Proc. IEEE ECCE*, Sep. 15–19, 2013, pp. 3102–3109.