Source Current Ripple Reduction with Input Voltage Controlled LED Driver

Swati Devabhaktuni
Department of Electrical Engineering
National Institute of Technology
Warangal , India
swatikjm@nitw.ac.in

Neti Vishwanathan
Department of Electrical Engineering
National Institute of Technology
Warangal , India

Shunmugam Porpandiselvi
Department of Electrical Engineering
National Institute of Technology
Warangal , India

***Abstract* –With the increase in the power demand for lighting applications, efficiency concerns and developments in LED lighting, majority of lighting applications are becoming LED based. Photo-voltaic (PV) source based industrial or commercial lighting has considerable importance. PV based systems give better performance if the current drawn from it has reduced ripple current. This paper presents an LED driver configuration for PV based systems such that source current ripple can be reduced. A three-phase series resonant converter is used for obtaining the DC output voltage for LED load. The load voltage is regulated by controlling the input voltage of the inverter. A controlled voltage is derived and added to the PV source for regulating the total input to the converter system. The input to the inverter configuration is always maintained to be constant irrespective of increase or decrease in the PV source. A buck-boost converter is used on the source side for deriving controlled voltage for regulation of input voltage to the three-phase series resonant converter feeding the LED load. For dimming the illumination, low frequency PWM technique is used. The proposed converter is studied using MATLAB simulation for 100.3W of output power. The converter is expected to give high efficiency and can handle large lighting loads with reduced ripple in the source current.**

Key Words: 3-phase Full-Bridge inverter, buck-boost converter, source current, LED

I. INTRODUCTION

Considerable energy consumption particularly with lighting loadhas become the global challenge. LEDs are providing the best solution towards this need as they are having the advantages such as high efficiency, long life span, speed of response, right color index and less energy consumption.

With the advancements in the DC-DC converter the Light emitting diode (LEDs) are replacing the fluorescent lamps. Based on the particular application, the LEDs are connected in strings, which are combination of series, parallel or series-parallel LEDs. The maximum number of LEDs connected in series is in between 1 to 15. With these combinations, consequently, the output voltage can be maintained between 2V to 60V[1].

In general, the efficiency of the total system is increased by using the appropriate driver circuit for LED applications. DuringDC/DC conversion, a current loop is always incorporated so that a constant current is obtained, which is always required for a LED to operate[2].

LED is a fixed DC and constant current device. It is always required to see that they are feeding from the high efficient devices[3]. So for driving LEDs a constant power circuit is always required. Earlier, in this regard there are various topologies that were proposed. In comparison with the other topologies, buck-boost converter topology has proved to be the best in many applications especiallyin the application where constant power is required [4].

The LED driver may have the disadvantage of more ripple in the source current. Incorporating a 3-phase full-bridge inverter along with the center tapped transformer is used as a driver circuit for the LED applications to lower the current ripples in the source [5]. Furthermore, a bridgeless buck-boost converter is used as LED driver to reduce the low current ripples. With this converter, not only the cost is reduced but THD in source current is also improved [6]. Apart from using the battery as the source, PV panels may be used as the input [7] for the LED applications. With the PV panels,it is desirable to have low source current ripples. In such kind of applications to reduce these ripples a resonant converter circuit is along with an improvement in the efficiency. In some applications, high voltage gain with controllable current is required. This may be achieved by using buck-boost converter topology[8], where the input voltage is doubled by using switched inductor and switched capacitor.

In this paper, a three-phase resonant converter is proposed with input voltage control for regulation of current in the LED load. Fig.1. shows the typical arrangement of the proposed configuration.

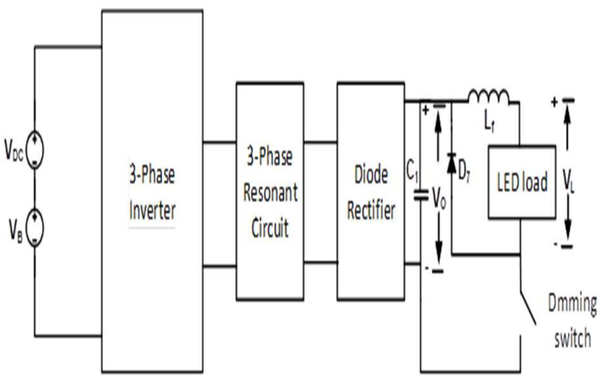

Fig.1. Block diagram representation of the Proposed configuration

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A buck-boost converter fed 3-phase full-bridge inverter driving the LED is studied with the MATLAB simulation. The proposed driver is advantageous from the aspect of ripple reduction in the source current. The buck-boost converter is connected with the source V_{DC} in such a way that the total voltage across this combination becomes as PV voltage and output voltage of buck-boost converter.A dimming switch is placed in series with LED works on the PWM technique for control of illumination level. Section-II gives the detailed description of the proposed model along with its circuit diagram and the design considerations.

II. PROPOSED CONFIGURATION

The proposed configuration feeding LED load is shown inFig.2.

In the circuit, a DC supply V_{DC} is provided by the PV source. This DC source is also used as input to the buck-boost converter so that additional DC voltage, V_B is derived. Utilizing the nature of the buck-boost converter i.e. polarity reversal, the DC voltage V_B (Output of the converter) is added to the source voltage V_{DC}(PV input) and hence a total voltage input to the inverter is PV source and the buck-boost converteroutput i.e.,(V_B+ V_{DC}). The pulse signals for the buck-boost converter are supplied in such a way that the total voltagei.e(V_B+ V_{DC}) is maintained as constant. A feedback circuit is used to generate the pulses to the buck-boost configuration.

As the input PV source is varying w.r.t time,the duty cycle of the buck-boost converter is adjusted such that the total input voltage to the inverter will remain constant. This implies that even there is any fluctuations in the PV source voltage the inputvoltage to the inverter is maintained as constant which ensures the smooth performance of the LED driver. The voltage across the capacitor is V_0 and is compared with reference voltage. The error signal is processed with PI controller and it generates gate pulses to the switching devices of the buck-boost converter i.e., S_1 and S_2.The gate pulses for S_1 and S_2complementary with each other.Henceforth regulating the input voltage of inverter.

A 3-phase full-bridge inverter with constant frequency is used in this configuration and is operated at 180^0 conduction mode. The inverter is operated at the switching frequency of 100kHz.Line voltage is V_{AB} is supplied to the series branch of resonant elements with line current $i_{r,}$being sinusoidal in nature, is flowing through it. Between the gate pulses of any leg of the inverter a dead d time is provided to prevent short circuit of the supply.

The resonant inverter consists of series resonant elements and is operated at switching frequency more than the resonant frequency. In this paper the resonant frequency is 90kHz. The inverter is switched at 100 kHz. This helps in achieving soft switching of the switching components inverter. Output of the resonant inverter is given to the uncontrolled diode rectifier. The rectified DC voltage V_0 appears across the capacitor C_1.

DC voltage, V_0 is fed to the LED load through an inductive filter L_f.A series switch (S_9) is used for dimming purpose. Diode D_7 acts as a freewheeling diode. The variation in the illumination is observed by controlling the duty cycle of the series switch S_9, which is connectedwith the LED load and is operated at 200Hz frequency.

For doing the design of the proposed network there are certain assumptions made, which are as follows:

i) An LED equivalent model is assumed to be a resistance in series with the constant voltage. Hence the voltage across the LED is always constant for a given load current.

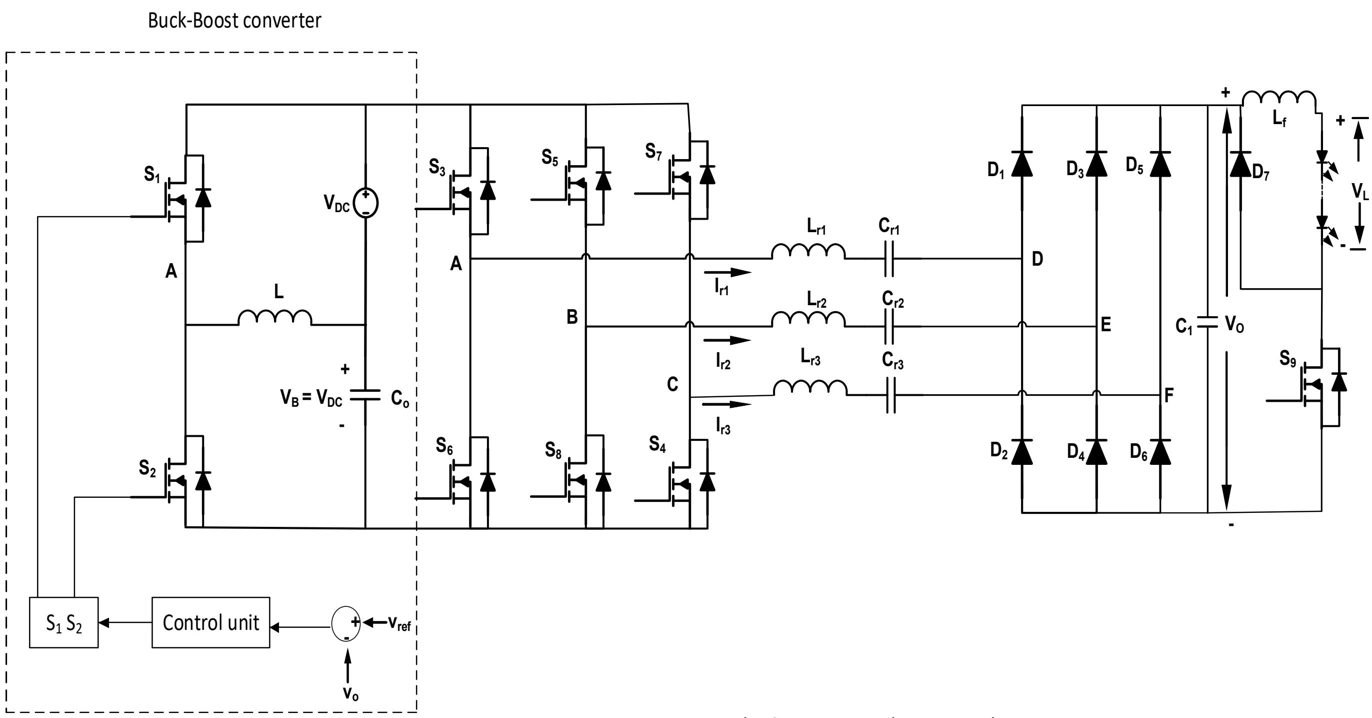


Fig.2: Proposed LED Driver

ii) Converter is assumed to be operating in steady-state.
iii) All Power electronic devices are ideal

Consider the per phase equivalent circuit as shown in Fig.3.

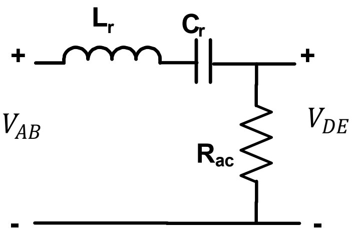


Fig.3. Per Phase equivalent circuit

The following equations were obtained for the equivalent circuit shown in Fig.3.

$$\frac{V_{AB}}{V_{DE}} = \frac{R_{ac}}{R_{ac}+j(X_{Lr}-X_{Cr})} \quad (1)$$

$$R_{ac} = \frac{8R_{LED}}{\pi^2} \quad (2)$$

$$Q = \frac{\omega_o L_r}{R_{LED}} = \frac{1}{\omega_o C_r R_{LED}} \quad (3)$$

$$\omega_o = 2\pi f_o = \frac{1}{\sqrt{L_r C_r}} \quad (4)$$

$$X_{Lr} = 2\pi f L_r \quad (5)$$

$$X_{Cr} = \frac{1}{2\pi f C_r} \quad (6)$$

By substituting equations (2),(3),(5) and (6) in (1) we get

$$\frac{V_{DE}}{V_{AB}} = \frac{1}{[1+j\frac{\pi^2}{8}Q\left(\frac{f_s}{f_o}-\frac{f_o}{f_s}\right)]} \quad (7)$$

The electrical parameters considered for this model are as shown in Table.1.

Parameter	Value
DC Input voltage	48±5% V
Inverter Input voltage	55V
Inverter Switching frequency	100kHz
Resonant frequency	90kHZ
Resonant inductor L_r	70.55 µH
Resonant capacitor C_r	44.32 nF
Capacitor C_1	20µF
Inductor L_f	1 mH
Output voltage V_O	43.8V
Output current I_O	2.29A
Output power P_O	100.3W
LED ratings	Forward Resistance=1.76Ω DC voltage=2.32V
No. of LEDs per string	14 LED in series
No.of strings	5 strings in parallel
Current/string	0.4A
Forward voltage of one string	35V
PWM dimming frequency	200Hz

Table.1. Parameters

III. RESULTS AND DISCUSSIONS

MATLAB is used as the simulation tool to study and analyze the results of the proposed model.

PV source output voltage is shown in Fig.4.The magnitude of the source voltage is taken as 48±5% V

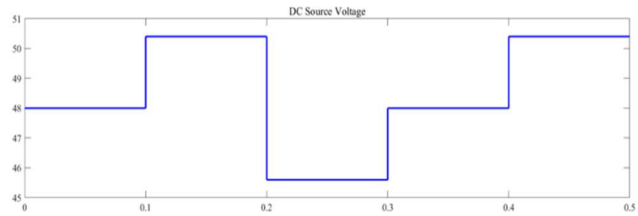


Fig.4. D.C source voltage

Based on variation of the D.C source voltage the buck-boost converter voltage is regulated so that the a constant total voltage is maintained at the inverter input. Buck-boost converter output voltage is shown in Fig.5.

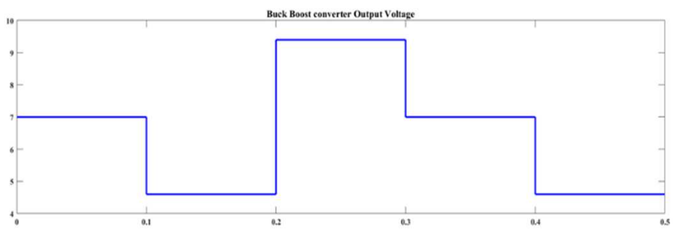


Fig.5. Output voltage of the Buck-Boost converter

Fig.5 shows that variation in the buck-boost converter output voltage is w.r.t PV source. When the D.C voltage is at 48V the buck-boost convertervoltageis

7V.Thereforetotal voltage will be 48+7=55V. When the D.C voltage is increased to 50.4V the buck-boost convertervoltageis 4.8V. And hence the total voltage is equal to 55V.Similarly, when there is decrease in the D.C voltage the buck-boost converter voltage is increased.
The input voltage to the inverter is maintained constant at 55V and is as in Fig.6.

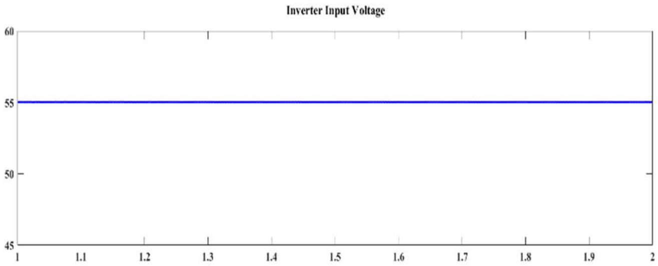


Fig.6. Inverter Input voltage

Output voltage and current through 3-phase inverter are as exhibited in Fig.7. with the input voltage as 55V.

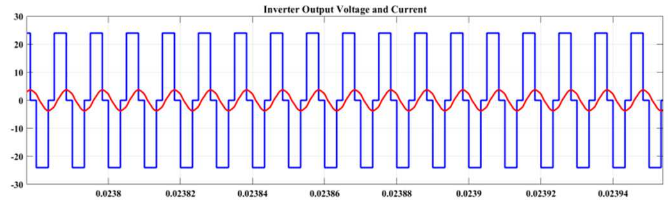
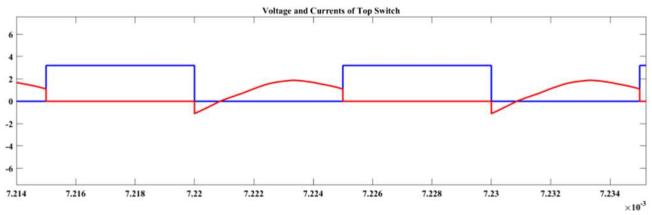
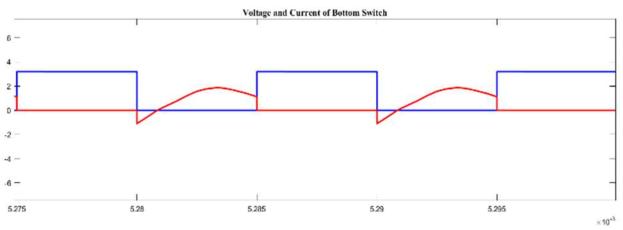


Fig.7. Inverter output voltage and output current

The first leg of the inverter top and bottom switch voltage and current waveforms are observed individually to see the ZVS aspect of the switching devices and thereby ensuring the smooth switching operation of the driver. Current and Voltage waveforms are as shown in Fig.8(a) and 8(b) for top and bottom switches respectively.



(a)



(b)

Fig.8. Voltage and current of
(a) Top Switch (b) bottom switch

From fig.8, ZVS is achieved and henceforth the switching losses are reduced in the driver circuit thereby increasing the efficiency of proposed system.

Fig.9. shows the voltage across the capacitor, C_1.

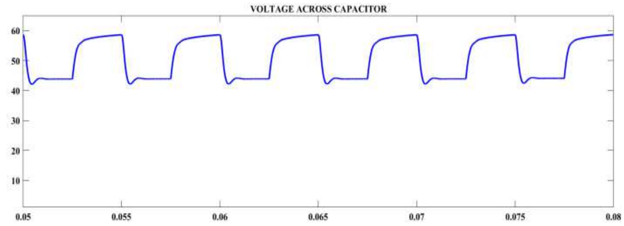


Fig.9. Voltage across the capacitor C_1

Voltage across the capacitor is 44V and 54.8V during the switch S9 ON and OFF conditions respectively. Correspondingly, the voltage across LED varies as 43.8V and 35V respectively. Thevoltage across and current through the LED are presented in Fig.10.

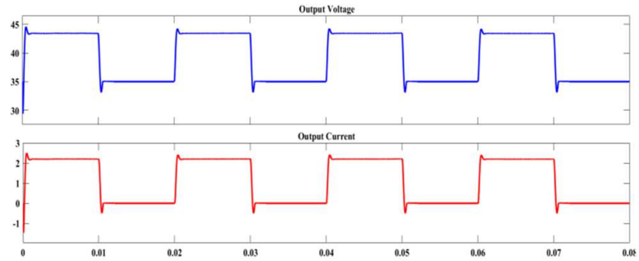


Fig.10. Output voltage and current waveforms

From Fig.10., it is noted that there is a wide variation in the output voltage.
Alternative method is suggested, in this paper, to reduce the fluctuations in output voltage. In this method dimming switch,$S_9$is removed. In order to achieve this, gate pulses of the inverter switches are ANDed with the dimming gate pulse. For dimming purpose, when dimming pulse becomes zero all either all the top switches or all bottom switches are turned ON together. It makes input voltage to the resonant circuit to zero.

After employing this method, Fig.11, shows the voltage across the capacitor.

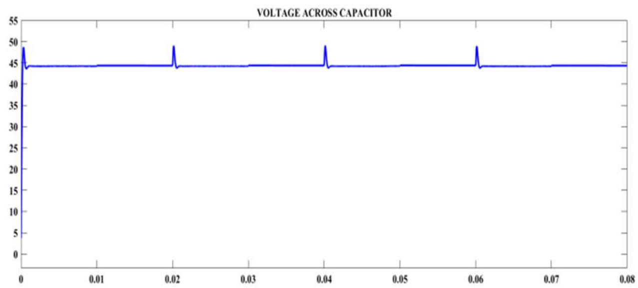


Fig.11. Capacitor voltage

Comparing the waveform in Fig.9 with the Fig.11.,it is observed that voltage fluctuations across $C_1$are reduced.Using the same technique, LEDloadvoltage and load current are seen as in Fig.12.

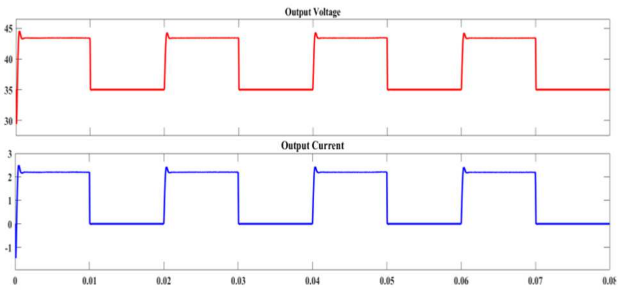


Fig.12. Output Voltage

Here also the transients are reduced in the comparatively with the previous technique.

The source current is as shown in Fig.13.

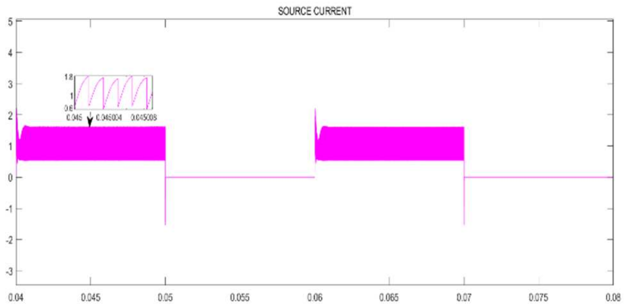


Fig.13.Source current

The variation of the efficiency w.r.t the duty cycle of the dimming switch,S_9 is as shown in Fig.14.

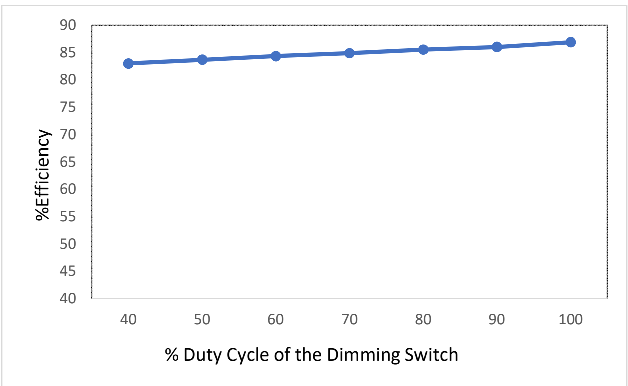


Fig.14.Efficiency vs Duty cycle

At 50% of illumination the efficiency is 83.71% and at full illumination the efficiency is 86.89%

By using the Buck-boost converter when the input of the inverter is maintained as constant, the circuit is offering a good efficiency. With this method the efficiency is increased and the source current ripples are decreased. This configuration can be used for the solar power based applications.

IV. CONCLUSIONS

The proposed configuration is an LED driver with an objective to handle relatively large power and also with reduced source current ripple. This type of configuration is helpful when powered from PV panels and also for industrial or commercial lighting applications.The designed LED driver is meant for an output power of 100.3 W. The three phase inverter handle entire power. The buck-boost converter on the source side handles small amount of power. Hence overall efficiency is high and doesn't reduce much due to the presence of buck-boost converter. The soft switching operation of inverter ensures decrease in the switching losses and thus increases the efficiency. The source ripple current with proposed configuration is 1.2A. The proposed configuration has the advantage of handling large lighting load with good control of illumination and even under considerable variation in the source voltage.

V. REFERENCES

[1] S. Mukherjee, A. Sepahvand, V. Yousefzadeh, M. Doshi and D. Maksimović, "Automotive LED Driver based on Resonant DC-DC Converter with Wide Input and Output Voltage Ranges," 2019 20th Workshop on Control and Modeling for Power Electronics (COMPEL), 2019, pp. 1-6, doi: 10.1109/COMPEL.2019.8769716.

[2] Y. Wang, J. M. Alonso and X. Ruan, "A Review of LED Drivers and Related Technologies," in IEEE Transactions on Industrial Electronics, vol. 64, no. 7, pp. 5754-5765, July 2017, doi: 10.1109/TIE.2017.2677335.

[3] Li, S., Tan, S.C., Lee, C.K., *et al.*: 'A survey, classification, and criticalreview of light-emitting diode drivers', *IEEE Trans. Power Electron.*, 016,**31**, (2), pp. 1503–1516

[4] K. Eguchi, A. Shibata, F. Asadi, T. Ishibashi, Y. Harada and I. Oota, "Design of an LED Sink Driver Using a Switched-Inductor and Switched-Capacitor Buck-Boost Converter with High Voltage Gains," 2020 2nd International Conference on Smart Power & Internet Energy Systems (SPIES), 2020, pp. 33-38, doi: 10.1109/SPIES48661.2020.9243052.

[5] S. Devabhaktuni, N. Vishwanathan and S. Porpandiselvi, "LED Driver with Three-Phase Series Resonant Converter with Reduced Source Ripple Current," 2020 21st National Power Systems Conference (NPSC), 2020, pp. 1-5, doi: 10.1109/NPSC49263.2020.9331864.

[6] A. Jha and B. Singh, "Bridgeless buck-boost PFC converter for multistring LED driver," 2017 IEEE Industry Applications Society Annual Meeting, 2017, pp. 1-8, doi: 10.1109/IAS.2017.8101800.

[7] S.Devabhaktuni, N. Viswanathan and S. Porpandiselvi, "Source Current Ripple Reduction For Multiple Load Induction Cooking Applications," 2019 National Power Electronics Conference (NPEC), 2019, pp. 1-4, doi: 10.1109/NPEC47332.2019.9034887.

[8] K. Eguchi, A. Shibata, F. Asadi, T. Ishibashi, Y. Harada and I. Oota, "Design of an LED Sink Driver Using a Switched-Inductor and Switched-Capacitor Buck-Boost Converter with High Voltage Gains," 2020 2nd International Conference on Smart Power & Internet Energy Systems (SPIES), 2020, pp. 33-38, doi: 10.1109/SPIES48661.2020.9243052.