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Overview of Passive Light Emitting Diode Driver Circuits for Street Lighting

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Abstract

This paper describes the overview and comparison of various passive Light Emitting Diode (LED) driver circuits employed for street lighting applications. Passive LED driver circuits are constructed with diodes and capacitors without using any power electronic semiconductor switches which in turn eliminates the secondary supply unit for control circuits and controllers. Passive LED driver circuits are simple in construction, low cost, less maintenance and control free. 50 W LED driver circuit is identified for performance comparison and simulations are performed in matlab- simulink to get an overview of different passive LED driver circuits. The most predominant parameters such as efficiency and total harmonic distortion are compared to identify the suitiblity of the driver circuits for various applications.

Keywords*: Passive LED driver, valley circuit, voltage doubler*

1. Introduction

A light emitting diode (LED) is a two terminal PN junction semiconductor device that emits visible light when an electric current passes through it. The light is not bright, but in most LEDs it is monochromatic, occurring at a single wavelength. The output from an LED can range from red (at a wavelength of 700 nm) to blue-violet (about 400 nm). LEDs are used in remote control, opto-couplers, car lighting and LCD panel backlighting. The benefits of LEDs are: Low power requirement, High efficiency and long life.

Existing street lighting system uses sodium and fluorescent lamps. LED lighting has technologically advanced as a favourable environment friendly lighting technology to exchange the present energy inefficient incandescent and fluorescent lamps. It also replaces the sodium vapour lamp used in street lighting system. The LED devices have relatively longer life time of typically 80,000 hrs [1] but the life time of LED driver is very short. Because the life time of electrolytic capacitors is very less compared with other components. Initially Passive LED driver with valley-fill circuit using diodes and electrolytic capacitors were used [2] without power electronic switches. The life time of electrolytic capacitor is very less. Later, the polypropylene capacitors were used [3] in order to increase the system life time. The salient features of this driver circuit are simplicity, reliability and long product life time.

A modified valley fill circuit with current source resonant inverter was proposed to improve the power factor and total harmonic distortion [4] of an electronic ballest. The modified valley-fill circuit consists of three diodes with single capacitor during charging action. Three valley-fill circuit and valley fill circuit with current ripple cancellation circuit was used for LED driver applications [5]. Coupled inductor was used in the current ripple cancellation circuit which increases the size of the driver circuit. Sepic converter based valley-fill circuit was used with MOSFET switch with power factor correction circuit [6] and simulation results were provided.

Synchronously rectified fly back converter with front end power factor improvement converter was employed to drive LED strings [7]. A two stage power factor correction converter, linking the fly back converter with the boost converter was utilized. The efficiency of the circuit was 92.3% and total harmonics distortion (THD) was below 9.2 %. The power factor of the circuit was below 0.9.

A combined dual buck-boost converter was implemented as a power factor improvement circuit for offline LED street lighting [8]. The power factor was closer to unity (>96%) and the efficiency of the entire circuit was 84 to 85% which is less than the converter used in [5]. The THD level in the input current was greater than 28% which is less than IEC

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61000-3-2 class C standard limits. Film capacitor was used instead of electrolytic capacitor to increase the driver circuit life time.

A two stage LED driver circuit based on asymmetrical half bridge converter was used to improve the performance of LED driver circuit for street light applications [9]. A PFC boost converter and an asymmetrical half bridge converter were combined. The efficiency is as high as 94.5% for the asymmetrical half bridge converter and the overall efficiency of the circuit is 91.5%. The mean value of the magnetizing current was minimized by the asymmetrical design of the transformer and conduction losses were reduced. A three stage solution was provided by the same authors without electrolytic capacitor [10]. They achieved an overall efficiency of 93%. The multi stage topologies have the problems of high cost, poor efficiency, complex control circuits and high stress components requirement.

A single-stage LED driver with half-bridge-type LLC resonant converter and interleaving power-factor-correction feature was discussed for street-lighting applications [11]. Interleaving topology was employed in the AC-DC resonant converter to attain input-current shaping and to reduce the switching losses and improve the efficiency; soft-switching technique was preferred. The proposed LED driver features reduced number of components, minimized input-current ripple, low switching losses, high power factor and the THD of input current. A modified bridge-less PFC ac-dc converter with a half-bridge-type LLC resonant converter was discussed [12] for further improvement of the driver circuit.

Single inductor shared by two boost converters with half-bridge LLC resonant converter was proposed by Wang et al [13]. The boost circuits were functioned in the boundary conduction mode to achieve high power factor and work under high input voltage conditions. A 100 W prototype model was developed and tested with an efficiency of 91.1% for full load with 220 V ac input. The efficiency of the circuit was less compared with the circuit proposed in [12] – [13]. In the above literatures, the power factor was improved consistently with good efficiency but input current total harmonic distortion ((THD) was not improved much. The cost of the driver circuit is also high because of control circuits. Passive LED driver circuits are still preferred in fluorescent and LED lighting because of the absence of switching and control circuits. Valley-fill circuits are employed without power electronics switches in passive LED drivers. The main objective of this research work is to reduce the THD of the input current waveform without sacrificing the efficiency to compare the performance of passive LED drivers and.

2. Passive LED Driver Circuits

The driver circuit consists of inductors, capacitors and diodes without using any power electronic semiconductor switches. The absence of power electronic switches makes the circuit simple and reliability. Valley fill circuit and doubler circuits are added to improve the performance of passive LED driver circuits. The valley fill circuit comprises of diodes and capacitors. The input current ripple in valley fill circuit is generally very high and is not satisfactory. Input current waveform shape is improved by adding inductor and capacitor filter in the input side. Passive LED driver circuits were combined with either valley-fill circuit or voltage doubler or both. The types of passive LED driver circuits used in this paper are:

a. Passive LED driver with valley fill circuit
b. Passive LED driver with voltage double and valley fill circuit
c. Passive LED driver with single capacitor valley fill circuit
d. Passive LED driver with valley fill circuit and resistor R

2.1. Passive LED Driver with Valley Fill Circuit

The passive LED driver for offline applications was presented in [3] where twelve passive components were used. The circuit was simple, reliable and gives long product life time. The driver was designed for a 50 W LED street light system. Figure 1 depicts the circuit diagram of a passive LED driver with valley fill circuit. The output voltage ripple is reduced by using valley fill circuit. The design details and the necessary of all the passive components and diodes were explained in detail in literature [3]. To increase the life time of the driver circuit, the electrolytic capacitors were replaced by polypropylene capacitors. To improve the input current shape and to reduce the total harmonic distortion, LC filter was added in ac input line.

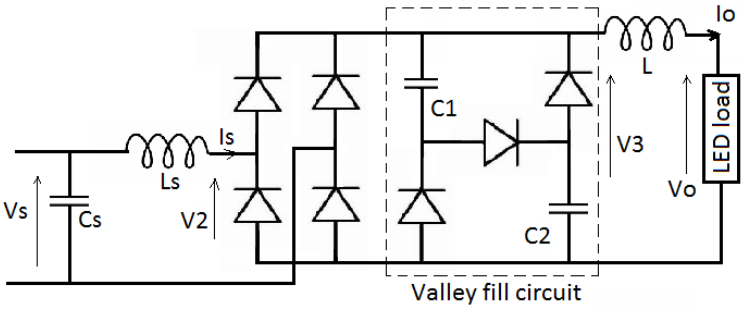


Figure 1. Passive LED driver with valley fill circuit

2.2. Passive LED Driver with Valley Fill Circuit and Resistor R_1

The peak charging current is high in the valley fill circuit and it adds input current harmonics. The peak current is reduced by adding a low value of resistor in series with the capacitor C_1 or C_2 or both.The modified circuit diagram is shown in Figure 2.

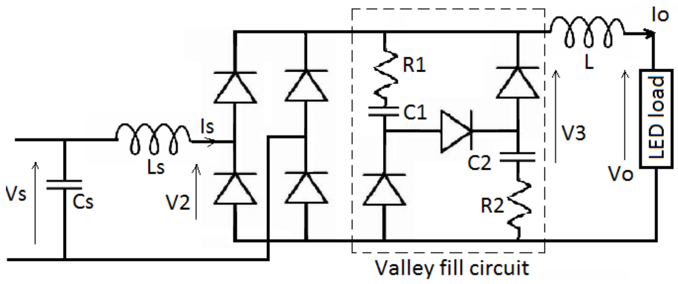


Figure 2. Passive LED driver with valley fill circuit and resistor R_1

2.3. Passive LED Driver with Single Capacitor Valley Fill Circuit

To reduce the size and cost of the capacitors, C_1 is replaced by a resistor in the basic valley fill circuit. It is named as a single capacitor valley fill circuit and is illustrated in Figure 3. Similarly, capacitor C_2 can be replaced by a resistor keeping C_1 in the circuit.

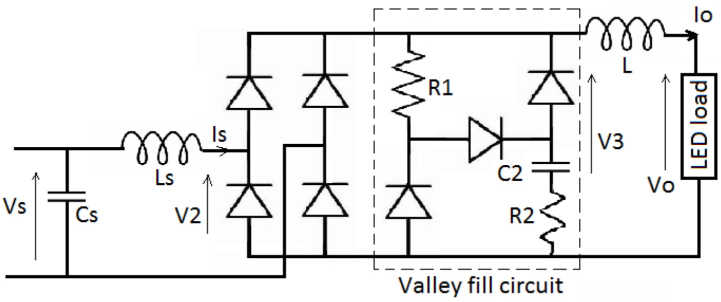


Figure 3. Passive LED driver with single capacitor valley fill circuit

2.4. Passive LED Driver with Voltage Doubler and Valley Fill Circuit

To increase the power factor and to improve the shape of the input current, a voltage doubler circuit is interleaved between the diode rectifier and the valley fill circuit. The modified LED driver with voltage doubler and valley fill circuit is illustrated in Figure 4. The capacitors and resistors of voltage doubler circuit are smaller in size than the valley fill circuit. It contributes a small amount of power to the LED lighting. The resistor R_3 in the doubler circuit removes the current spikes at the cross over points and progresses the feature of the input supply current.

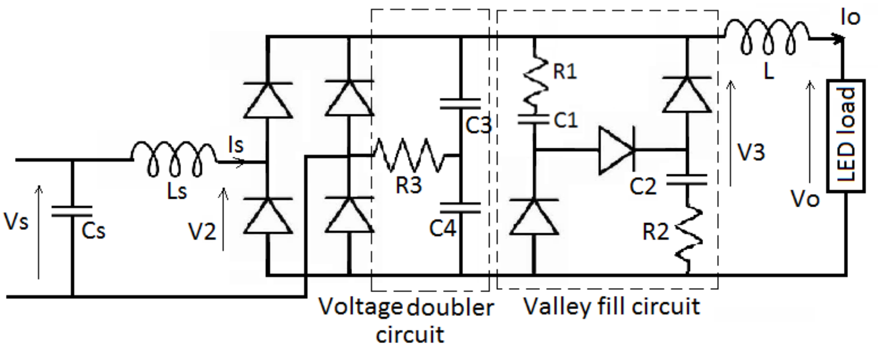


Figure 4. Passive LED driver with voltage doubler and valley fill circuit

3. Results and Discussions

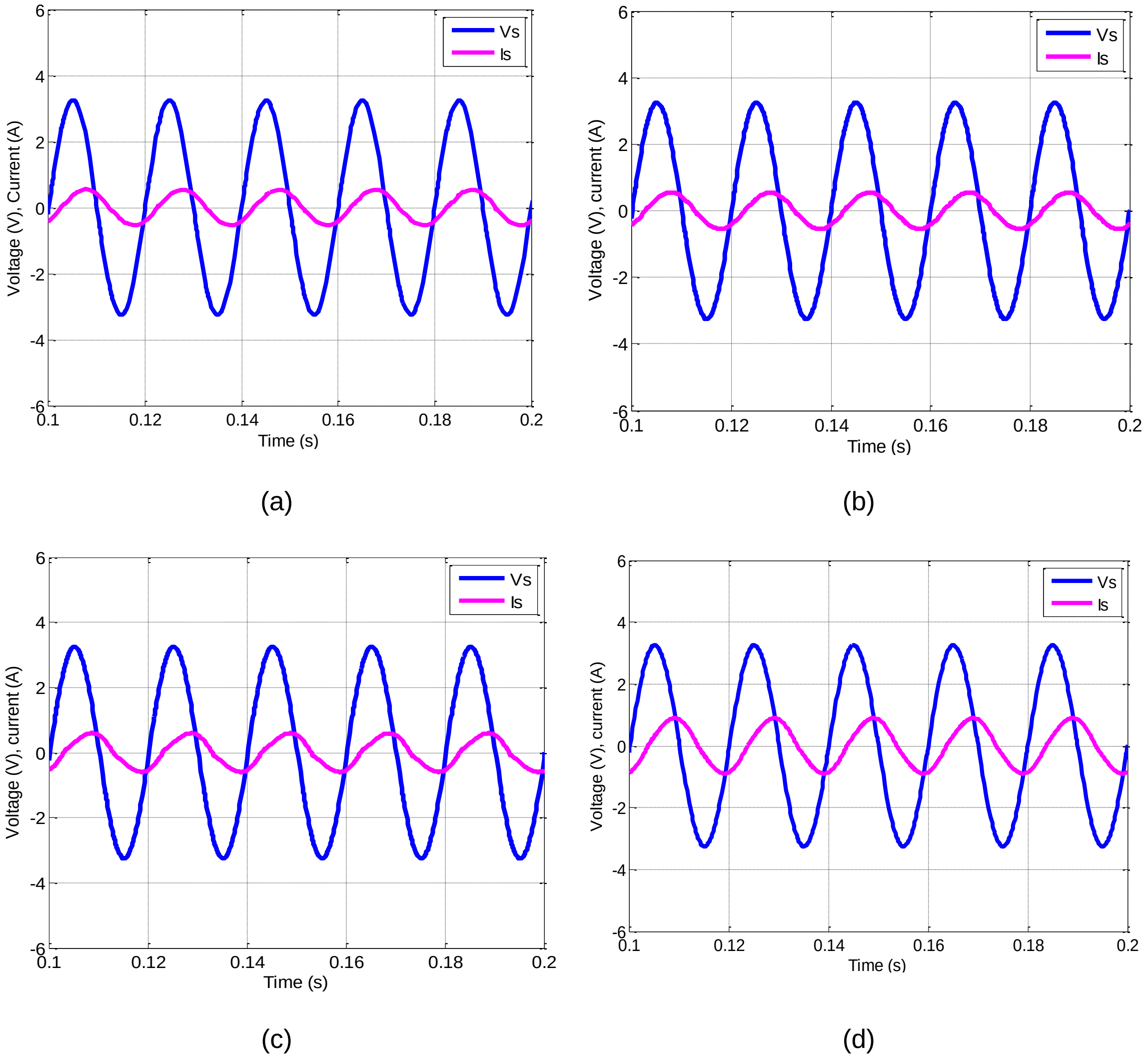
The different passive LED driver topologies discussed in section 2 are constructed in matlab-simulink and simulations are performed to identify the suitability of the driver circuits for street lighting and automotive lighting applications. The performance parameters such as shape of input current, THD, input power factor and efficiency of different topologies are compared and tabulated. Table I shows that the performance of different passive LED driver circuits.

Table I. Performance comparison of passive LED drive circuits

Classification	Circuit Type	Is (A)	I_l (A)	Input current THD (%)	PF	%η
a	2 capacitors valley fill circuit	0.3964	0.3737	2.9	0.67	94.51
b	Valley fill circuit with resistor in series with the capacitor	0.3925	0.387	2.2	0.66	94.15
c	C_1 is removed and replaced by a resistor	0.4152	0.3713	7.5	0.644	92
d	Valley fill circuit with doubler	0.4272	0.3686	3.2	0.707	95

The input current and voltage waveforms of 2 capacitors valley fill circuit, valley fill circuit with resistor in series with the capacitor, C_1 is removed and replaced by a resistor, valley fill circuit with doubler driver circuits and 3 capacitors valley fill circuit are shown in Figure 5 (a) - 5(d) respectively. The input voltage is scale down by a factor of 100 in the simulation waveform to match the voltage and current waveform and aslo to determine the harmonics and input power factor angle easily. The input current is a sinusoidal and it is lagging the supply voltage. The power factor is 0.64 in the circuit in which capacitor is replaced by a resistor and the THD is 7.5%. It is illustrated in Figure 5 (c). The efficiency of this circuit is comparatively less than other passive circuits presented. The distortion in the line current is less and the power factor is better except the circuit in which capacitor is replaced by a resistor. The THD is considerabily less in all the passive LED driver circuits because of LC input filter and is very much below the IEC 61000-3-2 class C standard limits.

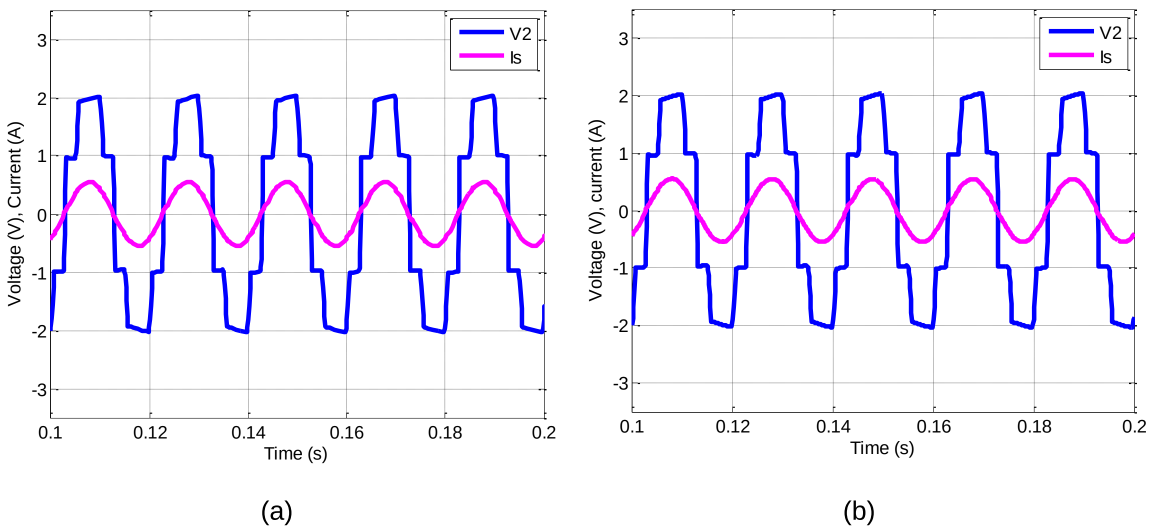
Input voltage V_2 marked in all the passive driver circuits and input current waveforms are given in the order given in table I in Figure 6. The voltage spike is high in Figure 6 (a) compared with other driver circuits. The input current is in phase with voltage V_2 in all passive LED driver circuits.



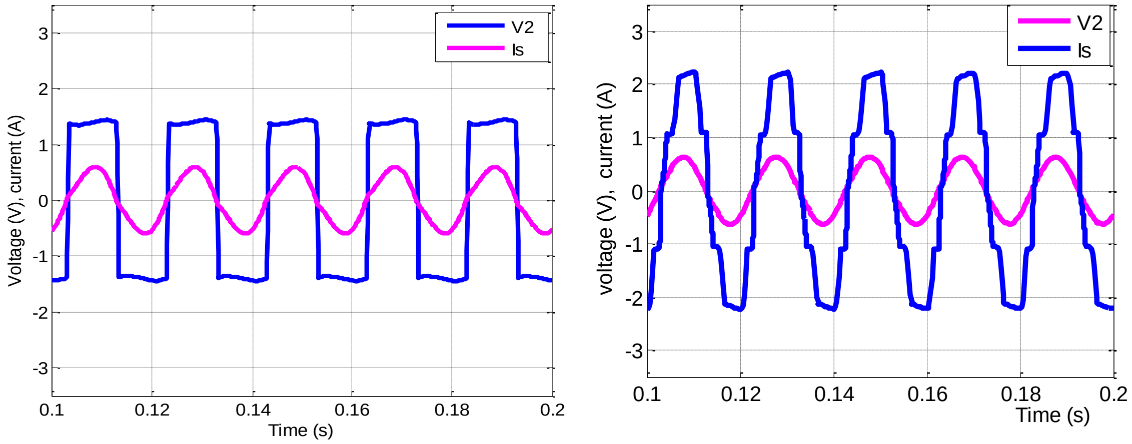
(a) (b)

(c) (d)

Figure 5. Input voltage and input current waveforms

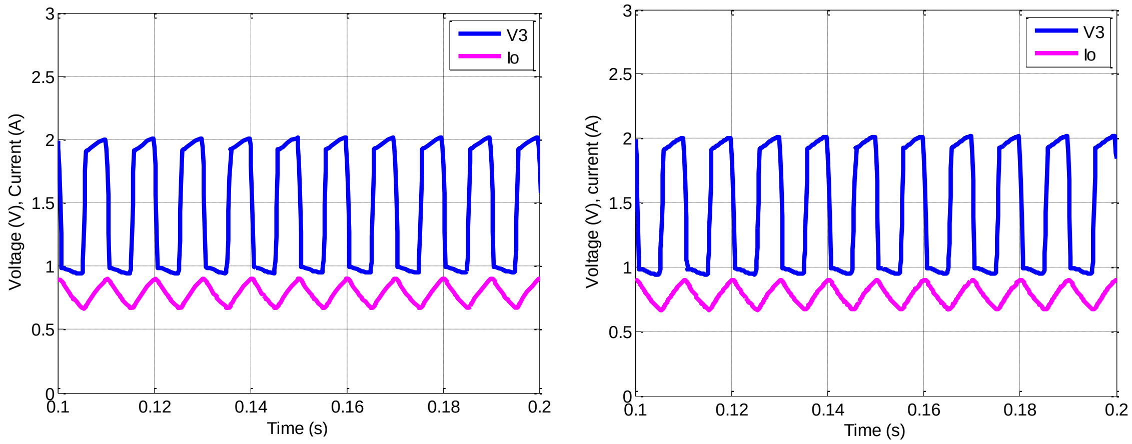


(a) (b)

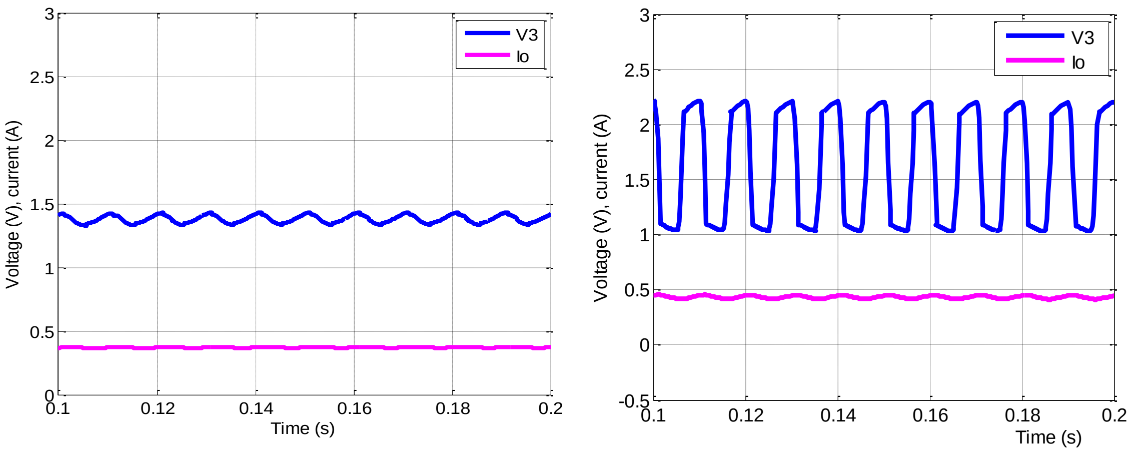


(c) (d)

Figure 6. Input voltage V_2 and input current waveforms



(a) (b)



(c) (d)

Figure 7. Output voltage V_3 and output current waveforms

Output voltage V_3 and output current are illustrated in Figure 7. The load current is dc and the ripple in the voltage V_3 is less in the driver circuit in which the capacitor is replaced by a resistor. The voltage spike is high in Figure 7 (a) and 7 (b). The output power waveforms along with load current and load voltage are presented in Figure 8. Output power and load voltage are scale down by a factor of 100 to find the volage and current ripple and also the power factor angle. Generally, small variation in the output load current will not give obvious luminous difference to human eyes. It is evident that the performance of voltage doubler with valley fill circuit is better than other driver circuits considered for comparison. It is concluded that the performance of voltage double with valley fill circuit and the single capacitor with valley fill circuit are better than the remaining circuits in all aspects.

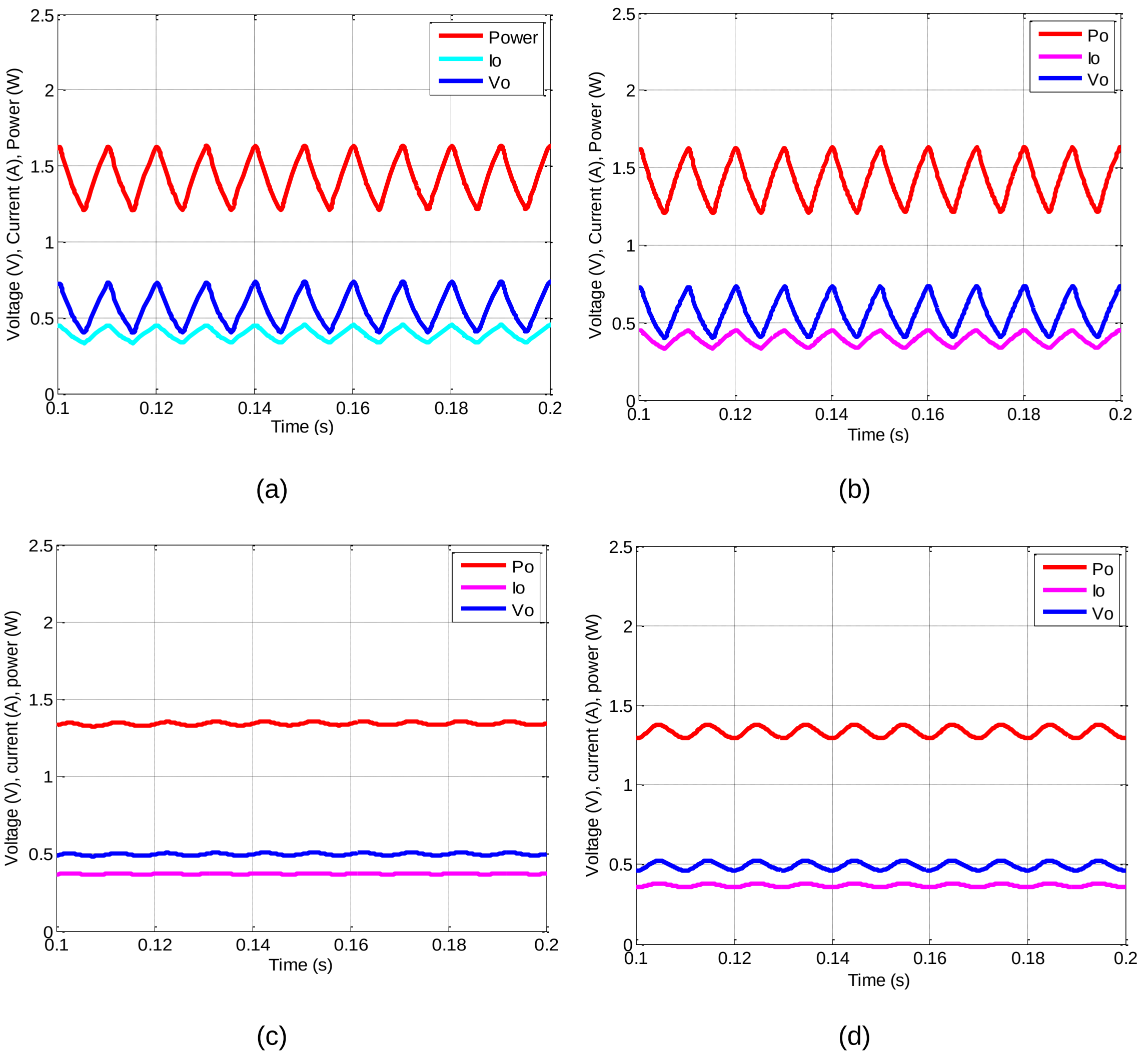


Figure 8. Output voltage, current and power waveforms

4. Conclusion

Different passive LED driver circuits employed for street lighting applications are taken for performance comparison. The desired parameters such as input power factor, THD and efficiency are compared. The input power factor is less in all the circuits because of passive components and the input LC filter. The input current THD is below 8% in all the passive LED driver circuits. The cost of the circuits is less as there are no power electronics switches and associated control schemes. The efficiency of the circuits is better as there are no switching losses. Among the driver circuits, doubler with valley fill circuit and single capacitor valley fill circuit performance are good. A passive driver circuits with suitable modification is still used as a driver circuit for fluorescent and LED street lighting because of its salient features.

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