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A Level Shifted Resonant LED Driver Configuration with Independent Control

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Abstract*:* In this research paper, a level shifted two output resonant LED driver using half-bridge configuration with independent control is proposed. Light emitting diode (LED) systems do not operate below their cut-in voltage. In this proposed configuration, two voltage sources which are connected in series via half-bridge series resonant converter are used to power LED lamp. The voltage difference between operating voltage and cut-in voltage of lamp is produced using half-bridge series converter. LC resonant circuit in each half-bridge helps to zero voltage switching. Thus, power dissipation in switching devices is reduced and energy conversion efficiency can be improved. Since, LEDs are current controlled devices, LED lamp has an inductor in series to reduce ripple current. Thus, this configuration does not require electrolytic capacitor, consequently lifespan of proposed converter for LED application increases. Dimming Operation and regulation of current through the lamp operation are provided using Asymmetrical Duty Cycle (ADC) regulation. Mathematical calculations are performed to validate the proposed two output resonant LED driver.

Keywords: *Light emitting diodes, Resonant dc-dc converters, Zero Voltage Switching and Dimming Control.*

1. Introduction

Light emitting diode (LED) stands out as a highly energy-efficient lighting sourceand has drawn significant attention across the world [1].LEDs possess numerous advantageous characteristics, including high efficiency, reduced energy consumption, diminished greenhouse gas emissions, and environmental friendliness. Consequently, the utilization of LEDs in lighting applications has experienced a significant rise [2-4].The driver circuits, also known as constant DC current controllers, are essential for maintaining a steady flow of electrical current in the LED lighting system. They can be powered from both switch mode power supplies and linear regulator[5]. However, SMP(switch mode power) regulators are preferred and recommended because of their values of efficiency which is high[6].

Various researchers have suggested various driver circuit designs for LED lighting applications, considering the accessibility of power sources, such as LED drivers powered by AC [7-11], and those powered by DC [12-18] etc.While the specifications for LED drivers reliant on AC and DC sources may vary, the LED driver circuit must meet fundamental criteria such as regulation of LED load current, dimming control, high reliability, compact size, and high efficiency, irrespective of the driving source. In recent times, a rising inclination toward the adoption converters with soft-switching in LED lighting systems has emerged, propelled by their increased efficiency, compact dimensions, and reduced levels of electromagnetic interference (EMI). A LC series resonance full bridge input-controlled LED driver for powering various LED loads is presented[19]. However, it faces challenges in terms of independent control and dimming operations. In response to the challenge of independent dimming and regulation, a resonant driver circuit is introduced for the simultaneous operation of two distinct LED lamps.[20]. An implemented LED driver employs a variable inductor in a multi-output half-bridge soft-switched configuration[21]. Dimming control and regulation of the lamp current are achieved through the utilization of a variable inductor. A dual-output LED driver is presented, featuring a series resonant half-bridge converter[22]. The challenges concerning independent dimming and current control have been addressed, although implementing the control circuit for these remains a complex task. A proposed solution involves a series-loaded resonant half-bridge (HB) converter with integrated buck-boost functionality designed for driving multiple LED lighting loads[23]. A high step-down buck converter with dual outputs, utilizing a coupled inductor (CI) and incorporating Zero Voltage Switching is proposed [24]. Class-E resonant converter with modification is used as current regulator for LED lamp in [25]. A converter using LCL-T resonant circuit has been introduced for automotive lighting applications [26]. This driver circuit

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features high efficiency for wide range of input with independent output current.

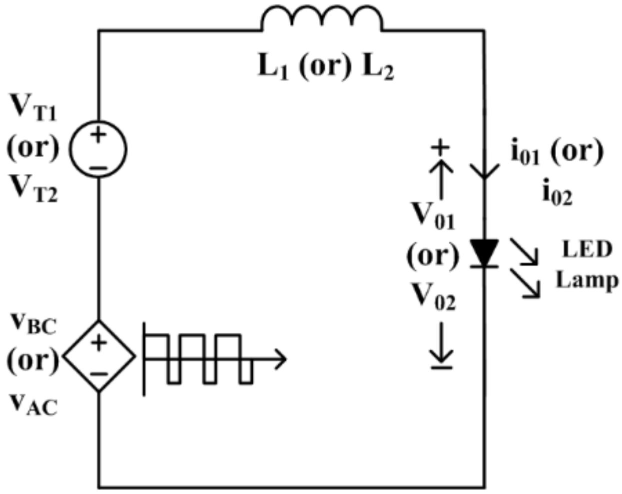


Figure 1. Main concept of proposed resonant LED driver.

This research introduces a driver circuit for a series resonant half-bridge converter designed to power two LED lamps. The fundamental idea behind this suggested converter configuration is depicted in Figure 1. LED *v-i* characteristics are similar to normal p-n junction diode and its current rises exponentially only after threshold voltage. Thus, in this configuration, LED lamp is powered by two voltage sources V_{T1} or V_{T2} and v_{BC} or v_{AC}. V_{T1} or V_{T2} is a constant dc source which is providing the majority of power to the lampand v_{BC} or v_{AC} function as a regulated dc source which processes lesser amount of power to LED lamp. v_{BC} or v_{AC} is produced using dc-dc half bridge resonant converter. The control of LED lamp current control is achieved by regulating the values of v_{BC} or v_{AC} through asymmetric duty cycle control. In addition to that, it also provides the benefits like (a) High efficiency, (b)ZVS operation, (c) dimming control, etc.The application of the configured driver circuit can be broadened to supply and operate several LED lamps. The structure of this study unfolds as follows: Section 2 outlines the design of the presented half-bridge resonant driver and its operating modes. In section-3, The analysis of the LED driver is presented. Section-4, presents the design procedure. Section-5 explains the regulation and dimming capabilities of LED current, while simulation results and the conclusion are detailed in Sections 6 and 7, respectively.

2. Proposed Resonant LED Driver

2.1. Description

The illustrated configuration in Figure 2 depicts the proposed resonant LED driver with two outputs, employing two half-bridge inverters (HBIs). Leg-1 forms one HBI with two power MOSFETs (S_1&S_2). Leg-2 forms another HBI with two power MOSFETs (S_3&S_4). Every MOSFET switch is depicted with an inherent body diode and output capacitance. The series connection of L_{r1} and C_{r1} links terminals B and C. v_{BC} is output voltage of HBI-1. Similarly, the series connection of Lr2 and Cr2 links terminal A and C. v_{AC} is output voltage of HBI-2. This driver circuit supplies two LED lamps. A dc voltage is connected in series with each LED lamp. The introduction of filter inductors L_1 and L_2effectively diminishes the ripple in both LED lamps, respectively. V_{01}&i_{01} are the output voltage &current obtained across the LED lamp-1. Similarly, V_{02}&i_{02} are the output voltage & current across the LED lamp-2.

Figure 3 illustrates the gate voltages for switching devices in HBI-1 and HBI-2, along with the operating waveforms of the proposed resonant converter. Switching devices S1 and S2 operate in complementary fashion with unequal pulse widths, and similarly, switching devices S3 and S4 also operate complementarily with unequal pulse widths. This section provides an explanation of the operating modes of the proposed resonant LED driver.

2.2. Operating Modes

2.2.1 Mode I

At initial time t=t_0, gate voltages are administered to switches S1 and S3, commencing conduction with zero voltage. Figure 4(a) illustrates the equivalent circuit with current direction corresponding to this mode. During the interval from $t_0 – t_1$, switches S_1&S_3 are conducting. The value of output voltage (v_{BC}) across HBI-1 is obtained as $+V_{DC}$. Consequently, the voltage across L_1 is positive, leading to a linear increase in iL1 through S_1. Concurrently, S_1 also carries the resonant current i_{r1}. Likewise, the output voltage (v_{AC}) across HBI-2 obtain as $+V_{DC}$, resulting in a linear increase in i_{L2}. Switch S_3conduct the summation of resonant current i_{r2} and i_{L2}. The duration of this mode is (t_0 - t_1).

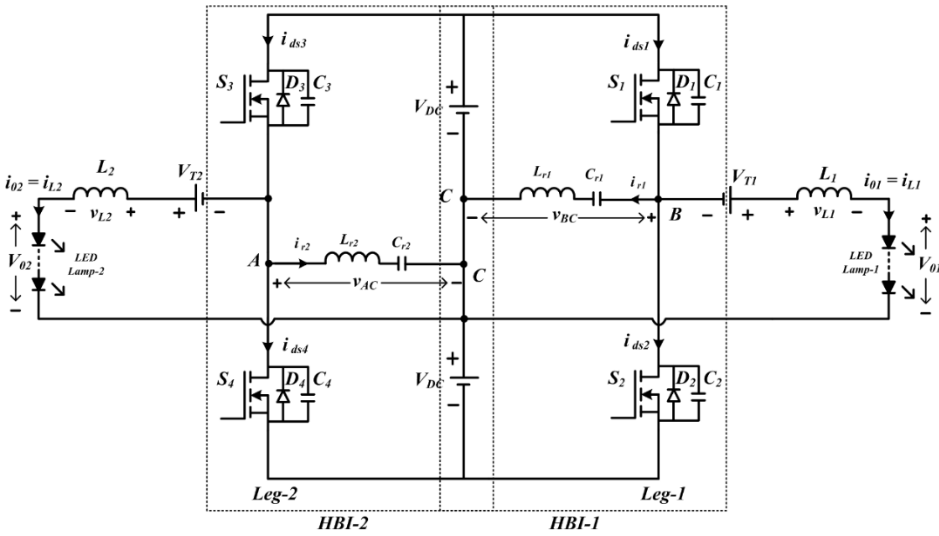


Fig 2. Circuit diagram of proposed resonant LED driver

2.2.2 Mode II

At $t = t_1$, the gate voltages are withdrawn for switches S_1 and S_3. Consequently, they switched off with zero voltage. The gate voltages for switches S_2 and S_4 have not been applied yet. Figure 4(b) displays the corresponding circuit with direction of current during this mode. During this interval $t_1 – t_2$, switch capacitance of S_1 and $S_3$are charged by currents $(i_{r1}+i_{L1})/2$ and $(i_{r2}+i_{L2})/2$from zero to $2V_{DC}$. During same interval, switch capacitance ofS_2 and S_4discharged by$(i_{r1}+i_{L1})/2$ and $(i_{r2}+i_{L2})/2$from $2V_{DC}$ to zero. As C_2 and C_4 discharge to -0.7 V, the body diodes of S_2 and S_4 begin to conduct. This allows switches S_2 and S_4 to be switched on for ZVS. This mode concludes at time instant t = t_2.

2.2.3 Mode III

At $t = t_2$, devices S_2&S_4 are activated by v_{g2}&v_{g4}at zero voltage, Figure 5(a) illustrate the current direction with equivalent circuit. The output voltage (v_{BC}) of HBI-1 is -V_{DC}. The current (i_{L1}) decreases linearly through switch S_2. Thus, S_2 conducts the difference of i_{r1} and i_{L1}.Likewise, the output voltage (v_{AC}) of HBI-2 is -V_{DC}. The current i_{L2} decreases linearly through switch S_4. Now current i_{r2}- i_{L2} flowing through the switch S_4. This mode concludes at time instant $t = t_3$.

2.2.4 Mode IV

At t = t_3, gate voltages are withdrawn for S_2 and S_4at zero voltage. The gate voltages across switchesS_1 and S_3 have not been applied yet. Figure 5(b) illustrates the equivalent circuit with the corresponding current direction. During $t_3 – t_4$, current $(i_{r1}$- $i_{L1})/2$ and $(i_{r2}$- $i_{L2})/2$charge capacitor C_2 and C_4 from zero to$2V_{DC}$respectively. Likewise, current $(i_{r1}$ - $i_{L1})/2$ and $(i_{r2}$ - $i_{L2})/2$ discharge C_1 and C_3 from $2V_{DC}$ to zero respectively. As C_1 and C_3discharge to -0.7 V, the body diodes of S_1 and S_3initiate conduction. As a result, it is possible to turn on devices S_1 and S_3 with ZVS and mode concludes at time t = t_4.

3. Steady State Analysis of Proposed Resonant LED Driver

The study relies on the subsequent set of assumptions

(i) The proposed resonant LED driver is in a steady state.

(ii) Lamp voltages V_{01} and V_{02}remain constant.

(iii) Ideal characteristics are attributed to components of the converter.

The analysis is specifically presented for LED lamp-1, and the same analytical approach can be extended to LED lamp-2. The voltage V_{T1}, which is less than threshold voltage of LED lamp-1 supplies majority of lamp power. The remaining power is supplied through HBI. An asymmetrical voltage v_{BC} is generated by using switches S_1 and S_2. When the switch $S_1$is ON and S_2 is OFF, as depicted in the corresponding circuit in Figure 3 (a),

The voltage drop across inductor L_1 is given by

$$v_{L1} = V_{DC} + V_{T1} - V_{01} = L_1 \frac{di_{L1}}{dt} \quad t_0 \le t < t_1 \qquad (1)$$

The expression for the electric current passing through inductor L_1 is

$$i_{L1}(t) = i_{L1}(t_0) + \frac{1}{L_1}\int_{t_0}^{t} v_{L1}(t)dt = i_{L1}(t_0) + \frac{V_{DC} + V_{T1} - V_{01}}{L_1} \quad t_0 \le t < t_1 \qquad (2)$$

Here, i_{L1} (t_0) represents the initial current value in inductor L_1 at $t = t_0$. At time $t = t_1$, the current i_{L1} (t) attains its peak value, which is expressed as follows:

$$i_{L1}(t_1) = i_{L1}(t_0) + \frac{V_{DC} + V_{T1} - V_{01}}{L_1}(t_1 - t_0) \quad (3)$$

Where the period $(t_1 - t_0)$ is the ON duration of switching device S_1. It is given as,

$$i_{L1}(t_1) = i_{L1}(t_0) + \frac{V_{DC} + V_{T1} - V_{01}}{L_1} D_1 T \quad (4)$$

Where D_1 is duty ratio of switching device S_1 and time period is denoted by T,

By rearrangement of (4), the ripple current across the inductor coil L_1 is specified by

$$\Delta i_{L1} = i_{L1}(t_1) - i_{L1}(t_0) = \frac{V_{DC} + V_{T1} - V_{01}}{L_1} D_1 T \quad (5)$$

During $t_1 - t_0$, (v_{BC}) resonant circuit component (L_{r1} and C_{r1}) voltage *is* V_{DC} and the current across it is expressed as,

$$i_{r1}(t) = \frac{V_{BC}}{Z_0} \sin \omega_0 (t - t_0) + i_{r1}(t_0)$$
$$= V_{DC}\sqrt{\frac{C_{r1}}{L_{r1}}} \sin \omega_0 (t - t_0) + i_{r1}(t_0)$$
$$t_0 \le t < t_1 \quad (6)$$

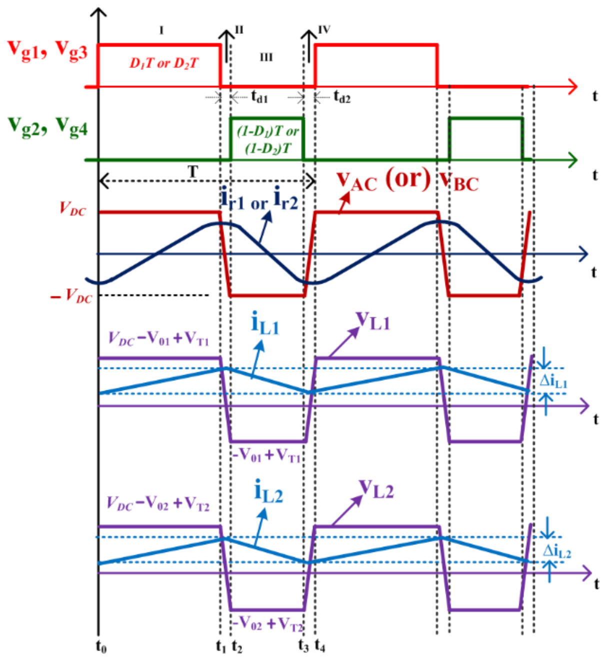
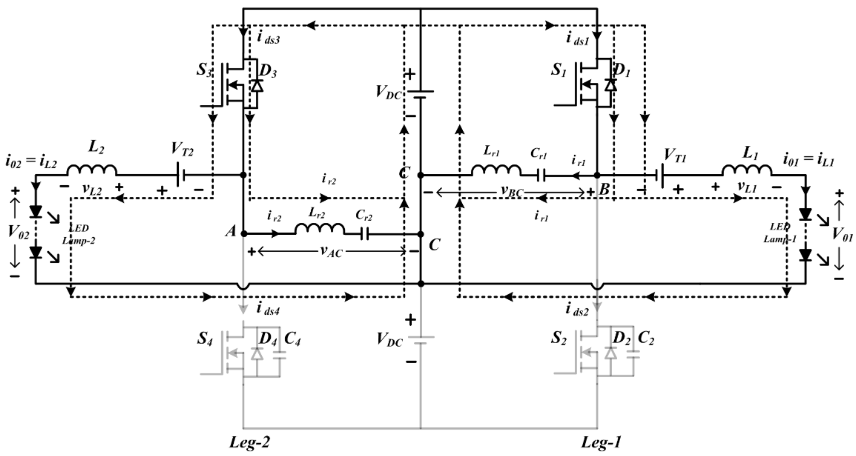
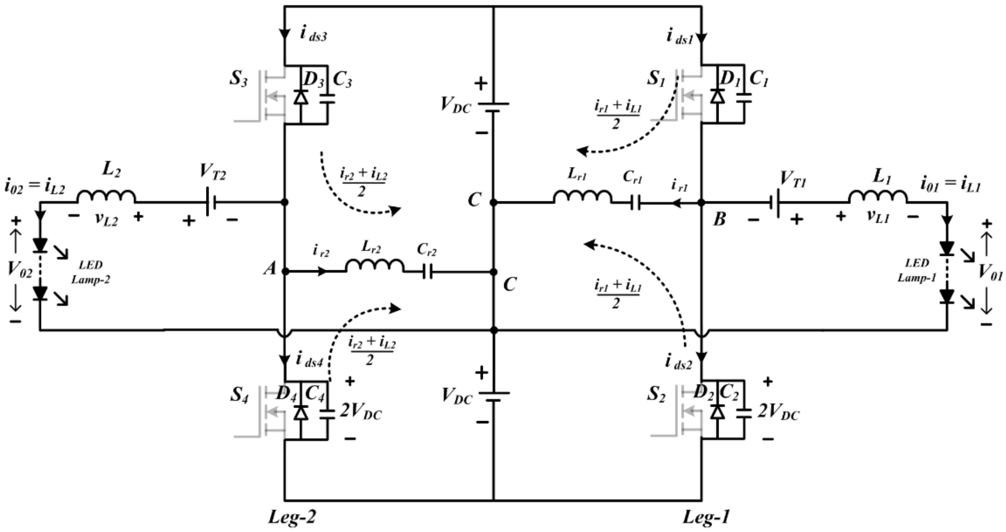


Fig 3. Operating waveforms of the proposed resonant LED driver



(a)



(b)

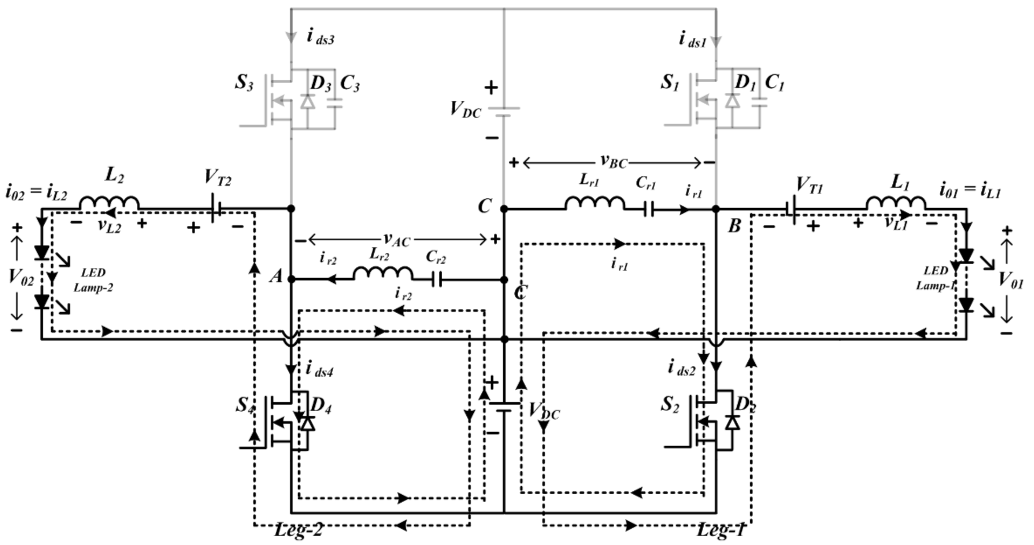
Figure 4 Equivalents circuits during (a) Mode I, (b) Mode II

Where Z_0 = Characteristic Impedance = $\sqrt{\dfrac{L_{r1}}{C_{r1}}}$;

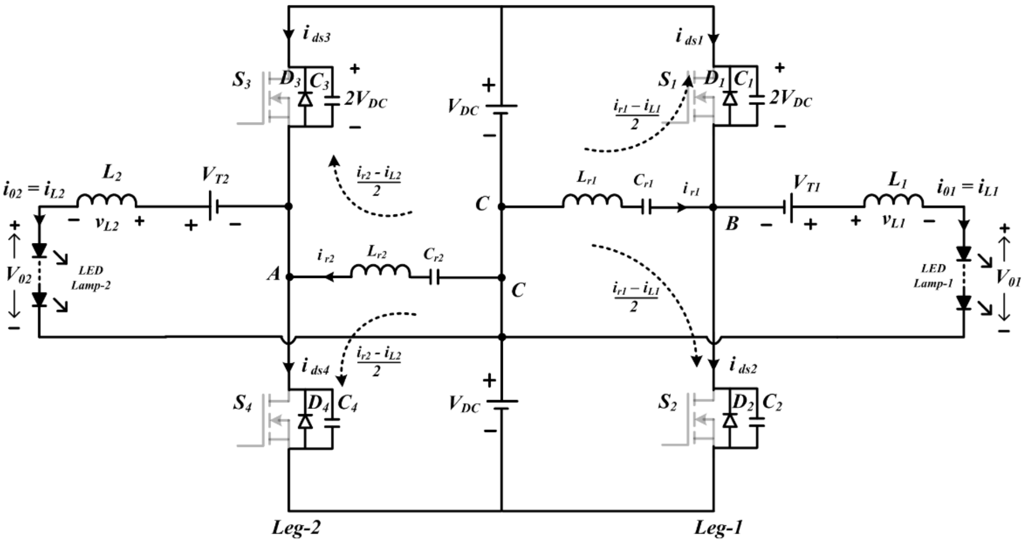
$$\omega_0 = \frac{1}{\sqrt{L_{r1}C_{r1}}}$$ = Resonant Frequency

When S_1 is turned off and S_2 is on, lamp-1 LEDs is powered with the energy stored in inductor L_1. Figure 5(a) illustrates the corresponding the equivalent circuit and equation of the voltage of inductor L_1 is

$$v_{L1} = V_{T1} - V_{DC} - V_{01} = L_1 \frac{di_{L1}}{dt} \qquad t_2 \le t < t_3 \qquad (7)$$



(a)



(b)

Fig 5 Equivalents circuits during (a) Mode III, (b) Mode IV

The equation of the value of current flowing in inductor coil L1 is expressed by

$$i_{L1}(t) = \frac{1}{L_1}\int_{t_2}^{t} v_{L1}(t)dt + i_{L1}(t_2) = \frac{V_{T1} - V_{DC} - V_{01}}{L_1}(t - t_2) + i_{L1}(t_2)$$

$$t_2 \le t < t_3 \qquad (8)$$

Here i_{L1} (t_2) denotes the initial current of the coil L_1at duration $t=t_2$. At time duration $t=t_3$, i_{L1} (t) attains the peak value and it is expressed as

$$i_{L1}(t_3) = \frac{V_{T1} - V_{DC} - V_{01}}{L_1}(t_3 - t_2) + i_{L1}(t_2) \qquad (9)$$

Taking into consideration the values of dead time (t_{d1}, t_{d2}) to be negligible. Therefore, the time period $(t_3 - t_2)$ becomes the off duration of switching deviceS_1, equation (9) is expressed as

$$i_{L1}(t_3) = \frac{V_{T1} - V_{DC} - V_{01}}{L_1}(1 - D_1)T + i_{L1}(t_2) \qquad (10)$$

From equation (10), the ripple current of inductor coil $L_1$is written as

$$\Delta i_{L1} = i_{L1}(t_3) - i_{L1}(t_2) = \frac{V_{T1} - V_{DC} - V_{01}}{L_1}(1 - D_1)T \qquad (11)$$

Similarly, during t_3 $-t_2$, the voltage across the components of the resonant circuitL_{r1} and C_{r1} (v_{BC}) is -VDC. The corresponding current flowing through the resonant circuit can be expressed as

$$i_{r1}(t) = \frac{V_{BC}}{Z_0}\sin\omega_0(t - t_2) + i_{r1}(t_2)$$

$$= -V_{DC}\sqrt{\frac{C_{r1}}{L_{r1}}}\sin\omega_0(t - t_2) + i_{r1}(t_2)$$

$$t_2 \le t < t_3 \qquad (12)$$

In a steady state operating condition, the total variation in current flowing in the inductor coil L_1equals zero over the time period T. Hence, deducing from equations (5) and (11),

$$[i_{L1}(t_1) - i_{L1}(t_0)] + [i_{L1}(t_3) - i_{L1}(t_2)] = 0$$

$$\frac{V_{DC} + V_{T1} - V_{01}}{L_1}D_1T - \frac{V_{T1} - V_{DC} - V_{01}}{L_1}(1 - D_1)T = 0$$

$$V_{01} = V_{T1} + V_{DC}(2D_1 - 1) \qquad (13)$$

The same analysis can be applied seamlessly to lamp-2, thereby rendering equations (5), (11), and (13) relevant to LED lamp-2 as well. As a result, the fluctuating current and voltage across lamp-2 can be formulated as follows,

$$\Delta i_{L2} = \frac{V_{DC} + V_{T2} - V_{02}}{L_2}D_2T = \frac{V_{T2} - V_{DC} - V_{02}}{L_2}(1 - D_2)T \qquad (14)$$

$$V_{02} = V_{T2} + V_{DC}(2D_2 - 1) \qquad (15)$$

Where D_2 is duty ratio of switch S_3

To ascertain the inductor value for a specified current ripple under continuous current flow, one can employ Equation (5), (11), or (14)

4. Design considerations

The process of designs begins with establishing the equivalent circuit parameters [20] for the LED lamp. These parameters are essential for computing the component values needed for the presented resonant LED driver. This driver employs TMX HP3W LEDs, and their voltage-current (v-i) characteristics during operation are illustrated in Figure 6(a).

Each LED consumes 2.017W with 3.42V and draws 590mA current with cut in voltage of 2.4V. The LED lamps consist of 2-strings of 10 LEDs in series, arranged in parallel. Consequently, the forward voltage of each LED lamp totals 34.2 V. Hence, each lamp operates at 34.2 V, 1.18 A, and 40 W, with a cut-in voltage of 24 V for single lamp.

Referring equation (13) and (15), duty ratio of switch S_1 or $S_3$is given by

$$D_1 = \frac{1}{2}\left[\frac{V_{01}-V_{T1}}{V_{DC}}+1\right] (or) \; D_2 = \frac{1}{2}\left[\frac{V_{02}-V_{T2}}{V_{DC}}+1\right] \quad (16)$$

As the cut-in voltage is not reached, each lamp does not conduct, V_{T1} or V_{T2} is chosen as 24 V. With V_{DC} of 24 V, duty ratio (D_1 or D_2) is calculated by

$$D_1 = \frac{1}{2}\left[\frac{34.2-24}{24}+1\right] = 0.712 \, (or) \; D_2 = \frac{1}{2}\left[\frac{34.2-24}{24}+1\right] = 0.712$$

By rearranging equations (5) and (14), the equations for value of$L_1$and L_2(inductors)can be expressed as follows,

$$L_1 = \frac{V_{DC}+V_{T1}-V_{01}}{\Delta i_{L1}} D_1 T \quad (17)$$

$$L_2 = \frac{V_{DC}+V_{T2}-V_{02}}{\Delta i_{L2}} D_2 T \quad (18)$$

With a V_{DC} of 24 V, a V_{T1} of 24 V, a V_{01} of 34.2 V, a D_1 of 0.712, a switching period T of 8, and considering the allowable peak-to-peak LED current ripple to be less than 10% of the operating current (thus taken as 8.3%), the inductor L_1 is determined by

$$L_1 = \frac{(24+24-34.2)}{(0.083)\cdot(1.18)}\cdot(0.712)\cdot 8\cdot 10^{-6} \cong 800\mu\text{H}$$

Likewise, based on equation (18), the inductor L_2 can be expressed as

$$L_2 = \frac{(24+24-34.2)}{(0.083)\cdot(1.18)}\cdot(0.712)\cdot 8\cdot 10^{-6} \cong 800\mu\text{H}$$

To achieve zero-voltage switching throughout the dead time, it is essential for the output capacitors of the all switches in both HBIs to be linked to constant current source for the purpose of charging and discharging. To accomplish this, a resonant LC circuit is utilized. Furthermore, the magnitude of current during the inactive period in HBI needs to surpass the operational current flowing through each lamp. This condition can be realized by ensuring that the resonant frequency of the series resonant circuit is lower than the switching frequency of the devices within each HBI. As a result, a resonant frequency of 105.96 kHz has been chosen. The mathematical representation for HBI-1 resonant frequency is

$$f_{r1} = \frac{1}{2\pi\sqrt{L_{r1}C_{r1}}} \quad (19)$$

The capacitance value (C_{r1}) is chosen to be 47 nF. From equation (19), L_{r1} is calculated as 48 uH.

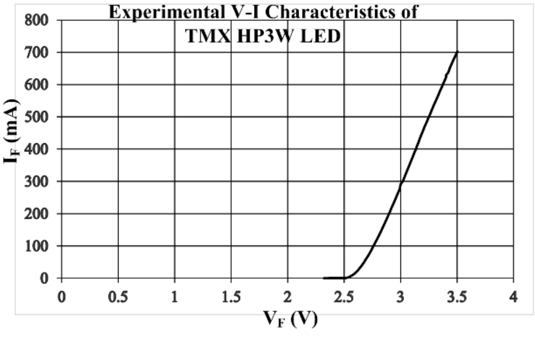


Fig 6(a) Experimental I-V ch/s of TMX HP-3W LED.

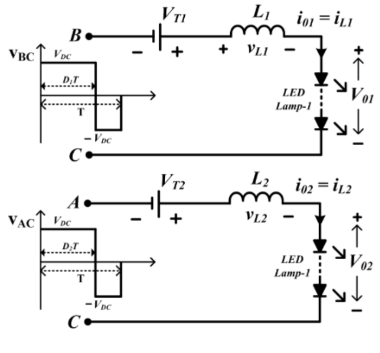


Fig 6(b) Fundamental diagrams of LED lamp-1 and lamp-2.

5. Dimming Operation in Proposed Resonant LED Driver

Dimming of LED lamps is one of the demanding applications in LED lighting system. Controlling the illumination of LED lamp improves the performance of driver circuit. The intensity or brightness of an LED can be accurately regulated through the utilization of pulse width modulation (PWM) or amplitude modulation (AM) techniques. These two approaches are frequently employed in practical applications. In the Amplitude Modulation method, the LED lamp operating current is adjusted, while in the Pulse Width Modulation method, it remains constant, but the average current is regulated. This research work utilizes the Amplitude Modulation type of dimming control. The simplified illustrations of LED lamps (1 & 2) are presented in Figure 6(b). Switching devices in HBI-1 generate v_{BC}, an asymmetrical square wave voltage of ± V_{DC}, which is then supplied to LED lamp-1. The period during which positive v_{BC} is present equals the turn-on time (D_1T) of S_1 in HBI-1. To regulate the brightness of lamp-1, the duty ratio (D_1) of S_1 can be diminished from its basic value. Likewise, the brightness of lamp-2 is regulated by decreasing the duty ratio (D_2) of S_3 in HBI-2.

Table 1 LED driver circuit Specification (Proposed)

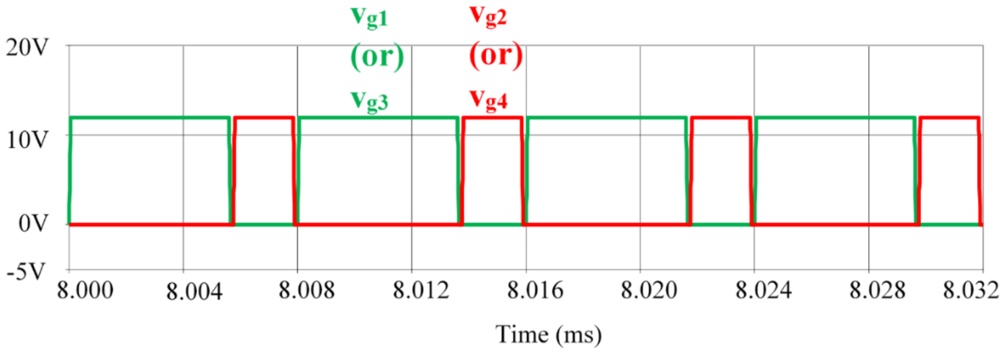
V_{dc} (DC input voltage)	24 V
$V_{T1,T2}$ DC voltage source	24 V
f_s , Switching frequency	125 kHz
$f_{0,}$ Resonant frequency	106 kHz
L_r (Resonant inductor)	48 µH
C_r (Resonant capacitor)	47 nF
Filter inductor $L_{1,2}$	800 µH
V_{01} (or) V_{02}	34.2 V
i_{01} (or) i_{02}	1.18 A
P_{01} (or) P_{02}	40 W
Switching devices used	IRF 640N

6. Simulation Study Discussion

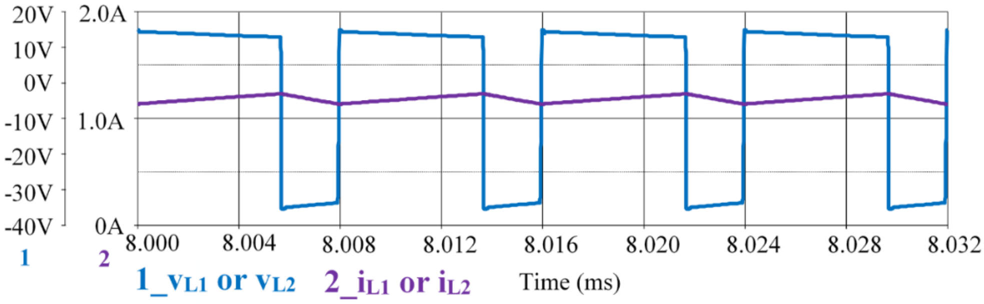
The proposed two output level shifted resonant LED driver is simulated in OrCAD PSpiceenvironment. Table. I shows component values used in simulation. The input voltage to both HBI's (V_{DC}) is deemed to be persistent at 24 V. The design of both LED lamps is tailored for operation at 40W. At full illumination of both lamps, gate voltages of switches in both HBIs, voltage across inductors (v_{L1}& v_{L2}), and current through both lamps (i_{01}& i_{02}) and voltage across both the lamps (V_{01}& V_{02}) are shown in Figure 7. It should be highlighted that both lamps are supplied by an asymmetrical square voltage i.e., D_1 = 0.712 and D_2 = 0.712. It is noted that the voltages of each lamp V_{01} and V_{02} are at 34.23 V with V_{DC} = 24 V, V_{T1}= 24 V and V_{T2} = 24 V, and lamp currents i_{01} and i_{02} are at 1.16 A respectively. It is because of MOSFET(IRF640) used has small values of dead time in both HBI switches for simulation. Therefore, the power dissipated in individual lamp is 39.7Watts which is lesser than the designed value. At this condition, Figure 8 shows output voltages (v_{BC}& v_{AC}), resonant currents (i_{r1}& i_{r2}) and the switching waveforms of both HBIs switches. It is evidently noted that turning ON & OFF of all the devices are done at zero voltage. For this power level, resonant LED driver efficiency is measured as 95.56%.

To demonstrate the independent dimming capability, lamp-1 is supplied with full illumination, while lamp-2 operates at 21W. Figure 9 illustrates the corresponding gate voltages (v_{g1} – v_{g4}), voltage and current in L_1&L_2 and waveforms for the voltage values across lamp-1 and lamp-2. Observing that lamp-1 functions at 34.23 V, 1.16 A, and 39.7 W, whilelamp-2 works at 29.89 V, 0.705 A, and 21 W. At this particular level of power, the resonant LED driver efficiency is measured at 94.12%. Under these operating conditions, Figure 10 shows the output voltage and currents in both HBIs, as well as the switching waveforms of a switch in each leg of HBI. Significantly, it is noted that the switches in both HBIs undergo switching with zero voltage.

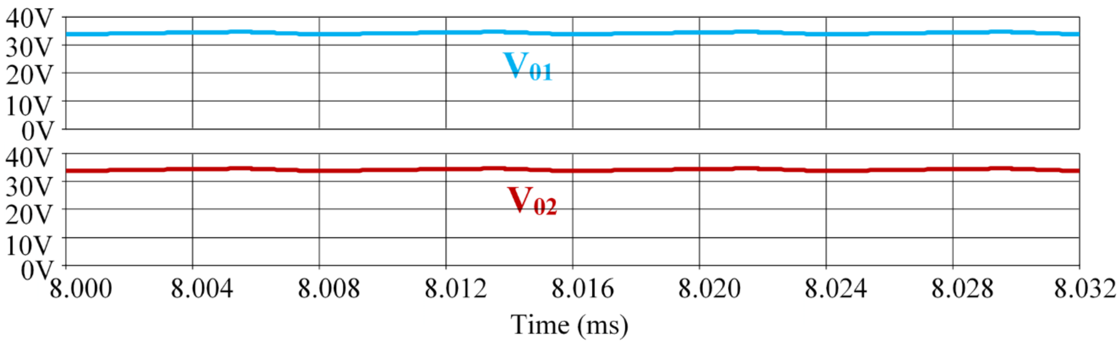
Likewise, lamp-1 receives power with a duty cycle of D1 = 0.65, while lamp-2 operates with a duty cycle of D2 = 0.712. Figure 11 illustrates the gate voltages (v_{g1} – v_{g4}), as well as the voltage and current in L_1&L_2, and voltage waveform across both the lamps (1&2). It is noted that lamp-1 operates at 32.24 V, 0.964 A, and 31 W, while lamp-2 runs at 34.23 V, 1.16 A, and 39.7W. At this juncture, the proposed resonant LED driver efficiency is measured as 94.43%. At this operating conditions, Figure 12 displays the output-voltage and currents in two HBIs, along with the operating waveforms of a switch in each leg of HBI. Similarly, it is obvious that the switches in two HBIs are triggered with zero voltage. The proposed LED resonant driver gives high efficiency at full illumination of both lamps and reduced power levels of both lamps.



(a)

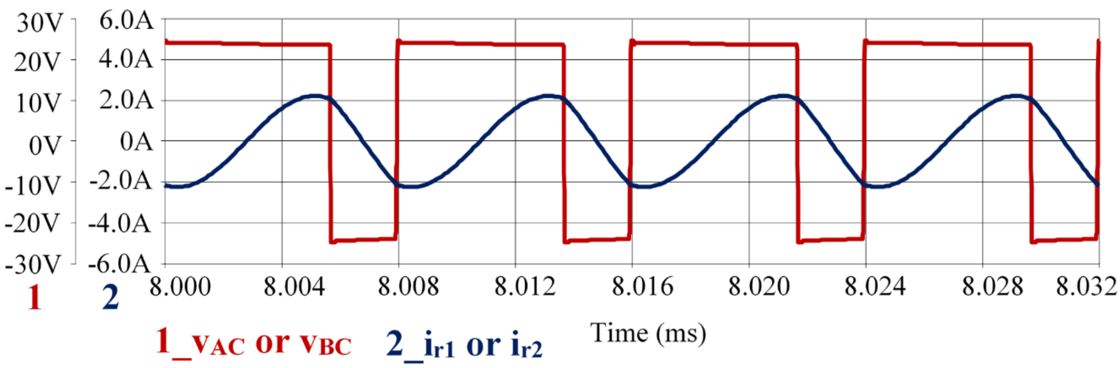


(b)

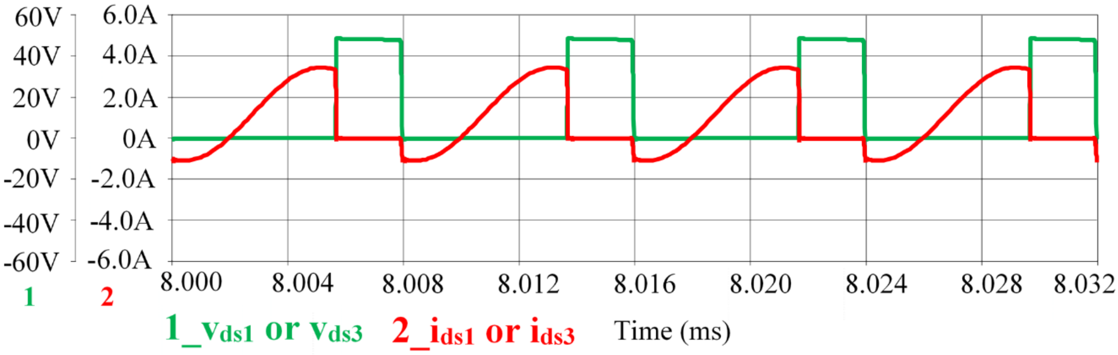


(c)

Fig 7. Simulation waveforms. (a) $v_{g1} – v_{g4}$. (b) v_{L1} or v_{L2} and i_{L1}or i_{L2}(c) V_{01} or V_{02}.



(a)



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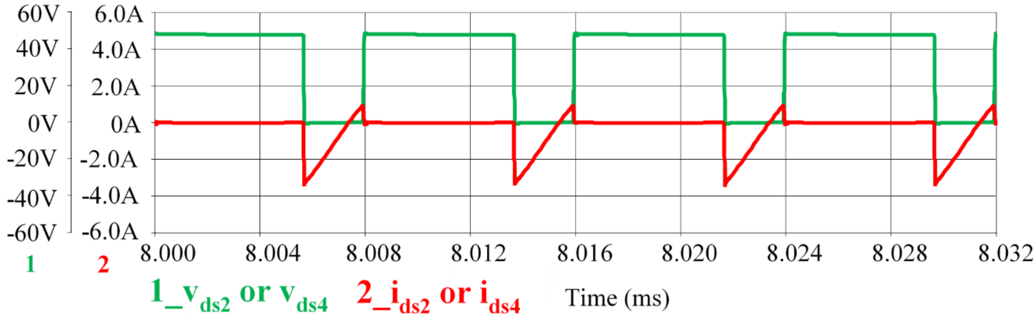
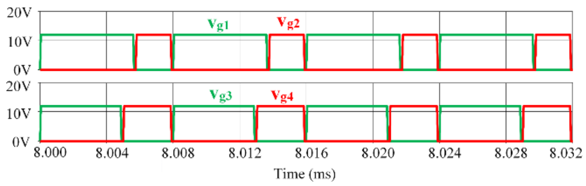
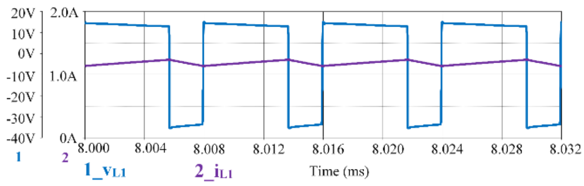


(c)

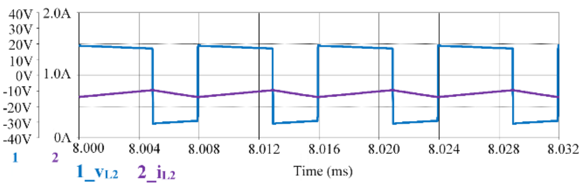
Fig 8. Half bridge inverter voltage and current, switching voltage and current waveforms. (a) v_{BC} or v_{AC} and i_{r1}or i_{r3}. (b) v_{ds1} or v_{ds3} and i_{ds1}or i_{ds3}(c) v_{ds2} or v_{ds4} and i_{ds2}or i_{ds4}.



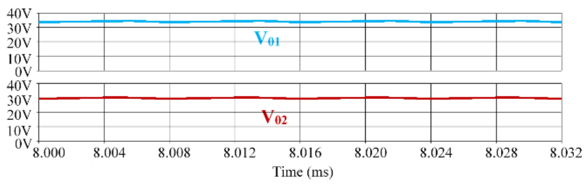
(a) Gate voltages ($v_{g1} – v_{g4}$)



(b) Voltage and current in L_1

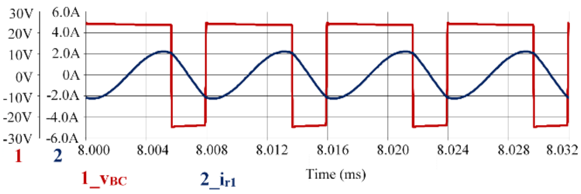


(c) Voltage and current in L_2

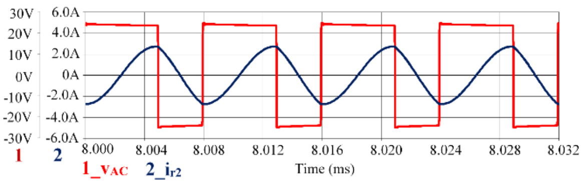


(d) Voltage across lamp-1 and lamp-2

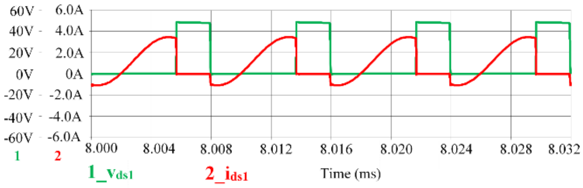
Fig 9. Dimming waveforms with lamp-1 at full illumination and lamp-2 at 21W



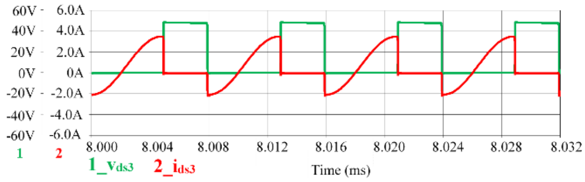
(a) v_{BC} and i_{r1}



(b) v_{AC} and i_{r2}

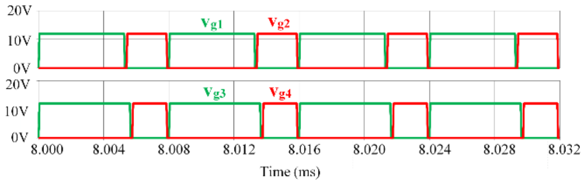


(c) v_{ds1} and i_{ds1}

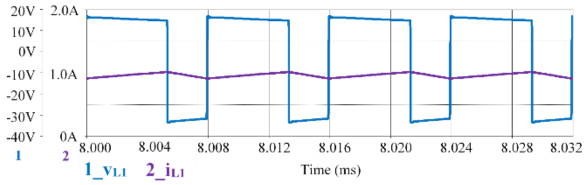


(d) v_{ds3} and i_{ds3}

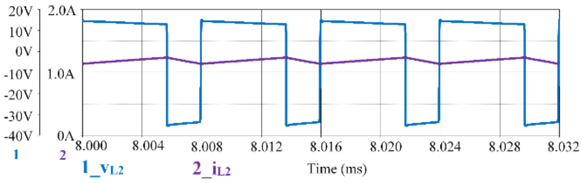
Fig 10. Half bridge voltage, current and switching waveforms under dimming operation



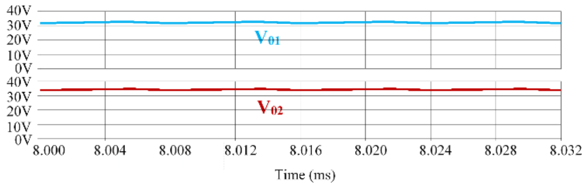
(a) Gate voltages ($v_{g1} – v_{g4}$)



(b) Voltage and current in L_1

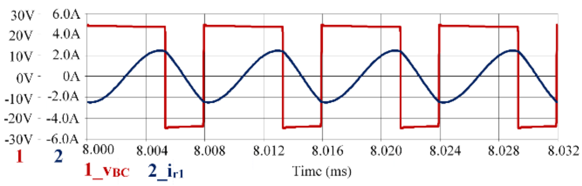


(c) Voltage and current in L_2

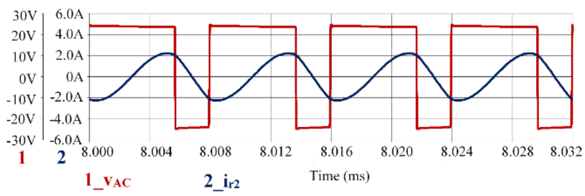


(d) Voltage across lamp-1 and lamp-2

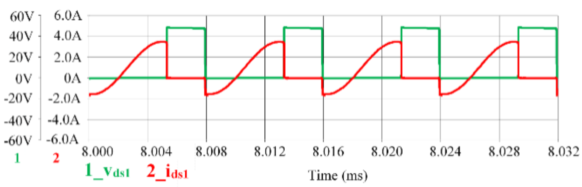
Fig 11. Dimming waveforms with lamp-1 at 31W and lamp-2 at full illumination



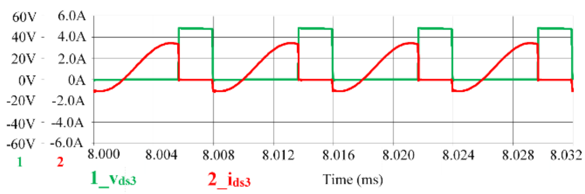
(a) v_{BC} and i_{r1}



(b) v_{AC} and i_{r2}



(c) v_{ds1} and i_{ds1}



(d) v_{ds3} and i_{ds3}

Fig 12. Half bridge voltage, current and switching waveforms under dimming operation

7. Conclusion

This paper introduces a proposal for a resonant half-bridge LED driver designed for several LED lamps, incorporating Asymmetrical Duty Cycle (ADC) control. In this configuration, LED lamp receives power from dual voltage sources. A series resonant LC circuit is used in each half-bridge inverter which helps to obtain zero voltage switching. Thus, power dissipation due to switching operation is reduced and it improves energy conversion efficiency. Dimming operation using amplitude modulation (AM) technique for two LED lamps is achieved independently. At different illumination levels, high energy efficiency is achieved. Variation in input dc side are compensated using ADC. Thus, LED lamp currents are maintained constant. This configuration can be operated from batteries or solar PV systems.

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