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LED Driver for Home

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Abstract: ***Among the most recent technologies in lighting devices and lamps, LEDs have an increasing number of application niches. Every day, they are becoming more popular and more accessible to the general public. LEDs are unable to regulate their own current, being essentially constant-voltage loads. Since LED light output is directly dependent on forward current, this means that LEDs require a current regulating driving circuit, which performs a function similar to that of a ballast for discharge lamps. Here an LED driver for home application is presented. This converter can be derived by integrating the totem-pole bridgeless boost power factor correction (PFC) circuit and half-bridge LLC resonant converter. Therefore, the number of semiconductors in the line-current path can be significantly minimized, and the power losses in the secondary rectifier diodes and the primary switches can be dramatically reduced. This circuit allows removing the bulky electrolytic capacitors with short lifetime by increasing the bus voltage ripple, and thus, the long lifetime is another advantage of this LED driver.***

Keywords: Power factor correction, LLC resonant converter

1. Introduction

Among the most recent technologies in lighting devices and lamps, LEDs have an increasing number of application niches. Every day, they are becoming more popular and more accessible to the general public. Compared to the conventional fluorescent lamp, high brightness light-emitting diodes (HB-LEDs) have many excellent characteristics, including high efficiency, long lifetime, compact size, high brightness, rich color, and very low maintenance cost [2].At present, HB-LEDs have been widely used in general-purpose lighting, backlighting of LCD panel, streetlight, healthcare, and transportation [3].

LEDs can be classified into two main groups: 1) inorganic LEDs, which are those fabricated from inorganic semiconductors, such as indium-gallium nitride (InGaN) and aluminum-gallium arsenide (AlGa), among others, and 2) organic LEDs (OLEDs), which are fabricated from carbon-based semiconductors and polymers. Both types have seen huge improvements in their light output in recent years. However, while inorganic white-phosphor-based LEDs are now commonly yielding more than 100 lm/W, OLEDs for general lighting applications can onlybe found with ratings of 50 lm/W.

Fortunately, the increase in luminous efficacy has been accompanied by a steady decrease in LED cost. This fact has contributed to the popularization of the technology, making these devices applicable to many types of lighting equipment. Inorganic LEDs are employed in compact and replacement lamps, indoor and street-lighting luminaires, desk lamps, vehicle headlights, liquid crystal display (LCD) backlighting, etc. OLEDs are currently found in many high-resolution slim backlight-less displays for cell phones and tablet computers, showing far superior performance than LCD and plasma.

LEDs also stand out for their exceptional long life span. Some works [5]point out that inorganic LEDs can endure 50,000 h with their light output within 70% of the initial emission. This means more than five years of close-to-nominal luminous output under continuous operation of the LEDs, in the worst case scenario (50,000 h). Naturally, this is only possible provided that adequate thermal management of the devices is done to keep them within the manufacturer recommended safe operating area for junction temperature and driving current. However, LEDs are unable to regulate their own current, being essentially constant-voltage loads. Since LED light output is directly dependent on forward current this means that LEDs require a current regulating driving circuit, which performs a function similar to that of a ballast for discharge lamps. However, as opposed to discharge lamps, LEDs do not require an ignition circuitor present negative incremental resistance. LEDs are also dc loads, which means that they require rectification when operating from mains voltage, such as in indoor offline lighting fixtures and street-lighting luminaires. These characteristics lead to the conclusion that power LEDs for lighting applications will require an electronic driver operating as a constant current source, which can be of passive, active, linear or nonlinear, e.g., a switched-mode power supply (SMPS), which is the most common active nonlinear current regulator.

The connection of the driver to the line voltage imposes further complexities: rectification and power-factor correction (PFC), when required by standards such as IEC 61000-3-2. [The IEC 61000-3-2 standard requires that lighting equipment complying with it should have a limited (maximum) amount of harmonic content in the input current, up to an order of 40 harmonics, thus allows a maximum distortion for input current.] Because the LED is a dc load that is being fed from an ac source, there is a power imbalance between input and output. The single-phase input power pulsates at twice the line frequency, whereas the output power is almost constant. The power imbalance must be handled by a storage element, such as a large inductor or a bulk capacitor, the latter being the most common approach used: a dc bus capacitor filtering out the voltage ripple and sized according to the line frequency and load being fed. Because the frequency of interest in the sizing of the capacitor is low (twice the line frequency),the capacitance required for such filter is usually large. Electrolytic capacitors are used for this. But the life span of electrolytic capacitor is too short. It is mostly because the liquid electrolyte is lost over time due to evaporation or leakage. Moreover, electrolytic capacitors have unsafe catastrophic failure modes, usually resulting in short circuit and hydrogen buildup, eventually leading to an explosion of the casing and/or venting of the electrolyte, which also affects the surrounding power circuitry. Aging also increases the capacitor equivalent series resistance (ESR), which induces self-heating of the capacitor core, thus further reducing lifetime in a thermal runaway behavior.

However, LEDs are unable to regulate their own current, being essentially constant-voltage loads. Since LED light output is directly dependent on forward current, this means that LEDs require a current regulating driving circuit, which performs a function similar to that of a ballast for discharge lamps. LEDs are also dc loads, which means that they require rectification when operating from mains voltage, such as in indoor offline lighting fixtures and street-lighting luminaires. These characteristics lead to the conclusion that power LEDs for lighting applications will require an electronic driver operating as a constant current source, which can be of passive, active, linear or nonlinear, e.g., a switched-mode power supply (SMPS), which is the most common active nonlinear current regulator. And also in order to ensure power decoupling between ac input power and the constant dc input power storage capacitors are necessary. But the life span of electrolytic capacitor is too short compared with LED. Thus studies are going on to eliminate electrolytic capacitor. These all factors are considered while designing an LED driver. In order to find the better efficiency and cost-effective topology while eliminating the electrolytic capacitor, a bridgeless electrolytic capacitor-free LED driver is proposed in this paper. It is derived by sharing switches between the front-end bridgeless boost-type PFC circuit and back-endhalf-bridge LLC resonant converter. Meanwhile, the proposed topology allows eliminating electrolytic capacitors in typical design.

2. Led Driver for Home

Figure 1 shows the quasi-single-stage high-power LED driver. As shown, the HB-LED driver consists of a front-end single-stage bridgeless soft-switched AC-DC converter with twin-bus outputs and multiple twin-bus buck current regulators to balance and control the current of each HB-LED string. The front-end AC-DC converter is derived by integrating the front-end bridgeless boost-type PFC circuit and back-end half-bridge LLC resonant converter. From Figure 1, it is not difficult to know that most of total power is directly derived to LED load. Thus, the back-end twin-bus type current regulators handle very small power, for example, only 15% rated power. This specific percentage depends on the arrangement of LED string forward voltage and twin-bus voltage. Therefore, the proposed LED driver can be considered as the quasi-single-stage solution, which reduces greatly the power conversion stage number.

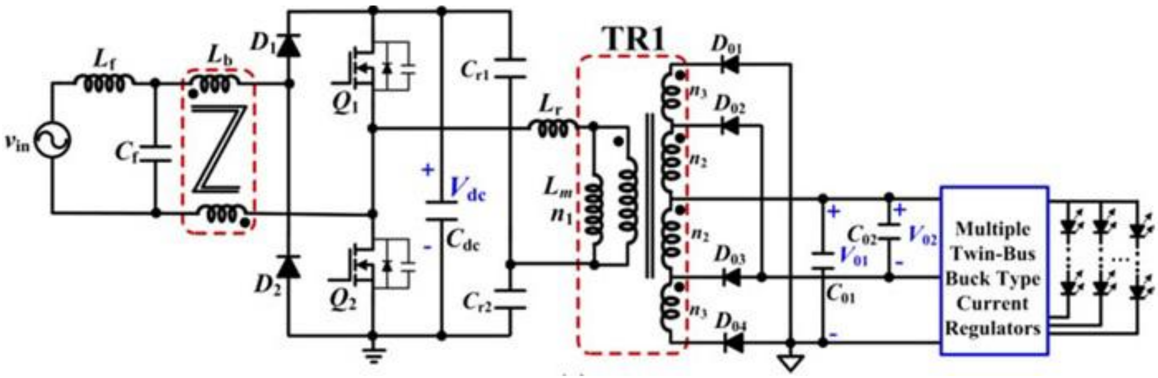

Figure 1: LED driver circuit

As shown in Figure 3.1, the coupled inductor concept and twin-bus outputs are employed to reduce the size and increase the efficiency, respectively. In order to introduce clearly the operation principle of the proposed circuit, the simplified version is depicted in Figure 2.

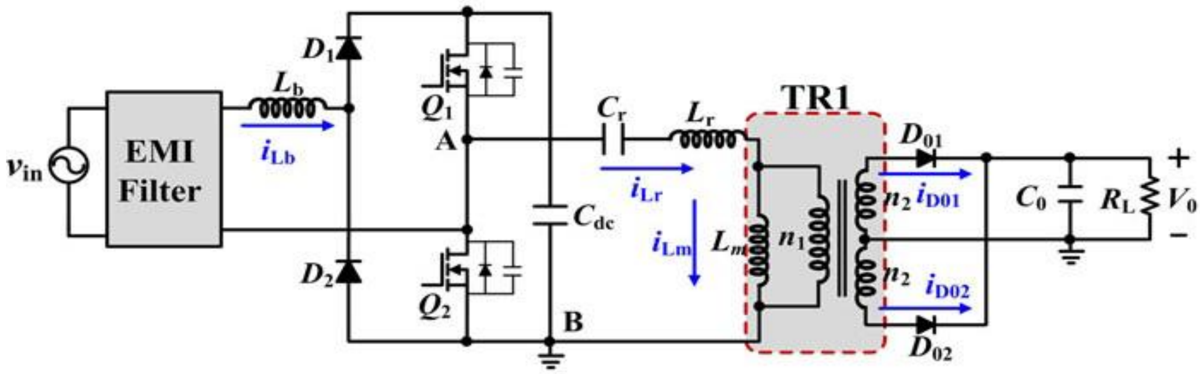

Figure 2: Simplified version

The simplified circuit consists of an EMI filter, a PFC inductanceL_b , two MOSFETs $Q_1$and Q_2 , a dc-bus capacitor C_{DC}, a resonant capacitor C_r, a resonant inductance L_r,a transformer T_1 with center-tap configuration, output rectifier diodes $D_{01}$and D_{02}, and an output capacitor C_0. The primary MOSFET Q_1 and $Q_2$are controlled by two complementary gating signals (V_{gs1}, V_{gs2}) with a well-defined dead time. A well-regulated output voltage can be achieved by pulse frequency modulation (PFM). Meanwhile, the inductor L_b is designed to operate at DCM with naturally the PFC function. The LLC resonant network is designed to be inductive to make the primary MOSFETs operate at ZVS. Hence, the switching losses can be reduced.Q_1andD_1 serve as the power semiconductors of the boost PFC during the positive half-cycle of the input line voltage, while Q_2 and D_2 do during the negative half-cycle.

3. Operating Principle

The steady-state operation can be explained by six modes within one high-frequency cycle. Figure 3 illustrates the theoretical waveforms for each mode.

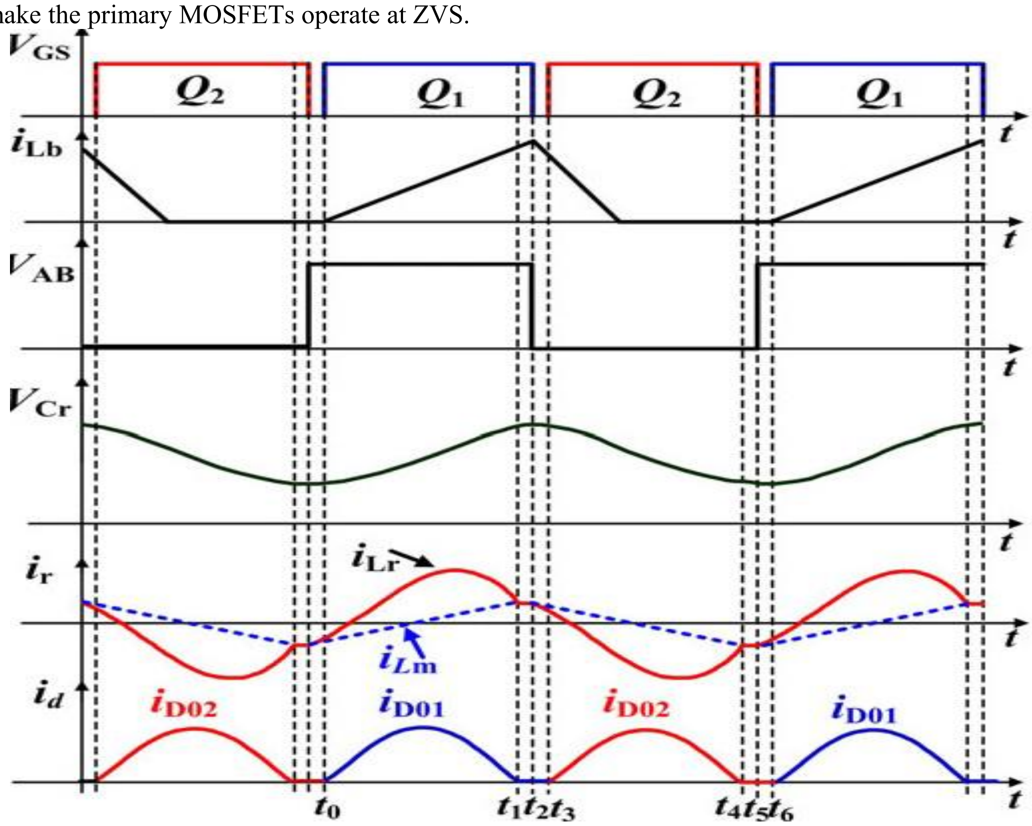

Figure 3: Theoretical waveforms

1) Mode 1 t0 < t < t1

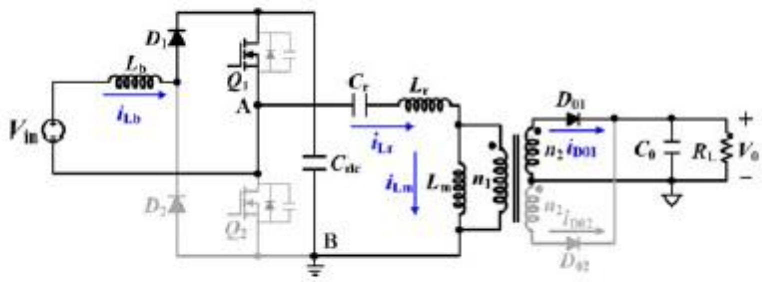

Figure 4: Equivalent Circuit for mode 1

Before t = t_0, the current$i_{Lb}$are at zero level. At the time instantt_0, MOSFETQ_1 is turned on with the zero-voltage switching (ZVS) feature. The line voltageV_{in} is added in the inductorL_b .Meanwhile, the bus voltage is connected to the resonant tank consisting of a capacitorC_r, a resonant inductor L_r, and a magnetic inductance L_m from transformer T_{R1}, The resonant tank current is larger than the magnetizing inductor current, and the difference between the resonant tank current and the magnetizing inductor current is transferred to the load. Thus, the secondary diode D_{01} is conducting. The primary winding voltage of transformer T_{R1} is clamped to nV_0 , the magnetic inductor current iL_m increases linearly. This mode ends at time t_1 when the resonant current iL_r is equal to the magnetic currentiL_m .

2) Mode 2 t1 < t < t2

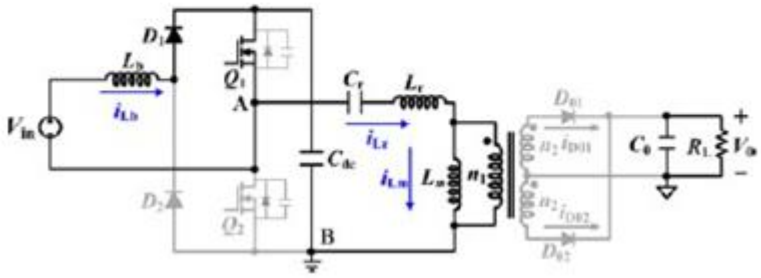

Figure 5: Equivalent Circuit for mode 2

At t_1 , the MOSFET Q_1 continues to turn on, and the inductor currentiL_bcontinues to linearly increase, which reaches the maximum value iL_{bpk} at t =t_2. .The output diode $D_{01}$is turned off with ZCS since the resonant current iL_r is equal to the magnetic current iL_mat time t_1. In this interval, theresonant tank is composed of the capacitorC_r, L_r, and a magnetic inductance L_m.This mode ends at time $t_2$when MOSFET Q_1 is turned off.

3) Mode 3 t2 < t < t3

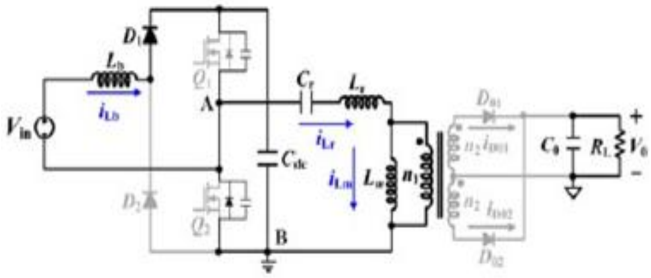

Figure 6: Equivalent Circuit for mode 3

Both Q_1 and $Q_2$are off in this interval, and it is the well-known dead-time period. At t_2 , MOSFET $Q_1$is turned off; thus, the voltage of the inductor L_b will change to $V_{in} - V_{DC}$. Similar to Mode 2, the capacitor C_r , the resonant inductor L_r, and the magnetic inductor $L_m$are resonating. At this interval, all the secondary diodes are off , because the resonant tank current is the same as the magnetizing current and there is no current transferred to load. Due to the junction capacitors of $Q_1$and Q_2 , magnetizing current discharges the capacitors and help achieve ZVS turn on of Q_2 . This mode ends at time t_3 when MOSFET Q_2 is turned on.

4) Mode 4 t3 < t < t4

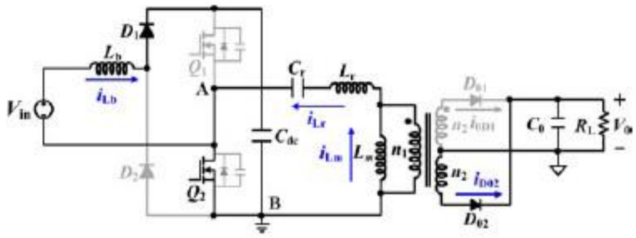

Figure 7: Equivalent Circuit for mode 4

At time t_3 , the drain-to-source voltage v_{dsQ2} is decreasing to zero, and thus,Q_2 can be turned on at ZVS. In this mode, the current iL_b continues to linearly decrease until its value is zero. Because MOSFET $Q_2$is on, the input voltage of the resonant tank is zero. According to the polarity of transformer, the secondary diode D_{02} is conducting. This mode ends at time t_4 when the resonant currentiL_r is equal to the magnetic current iL_m .

5) Mode 5 t4 < t < t5

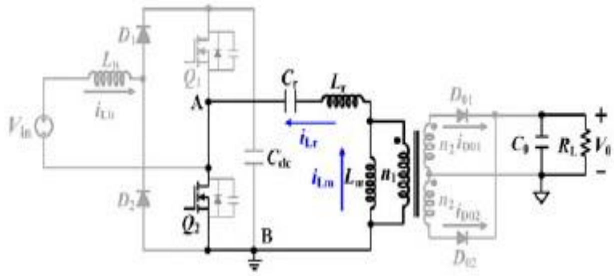

Figure 8: Equivalent Circuit for mode 5

At t_4 , the MOSFET Q_2 still keeps on. The inductor currentiL_b still is zero since the diode is reverse biased. The output diode $D_{02}$is turned off with ZCS since the resonant current iL_r is equal to the magnetic current iL_m at time t_4. This interval is similar to Mode 2. This mode ends at time t_5 when MOSFET Q_2 is turned off.

6) Mode 6 t5 < t < t6

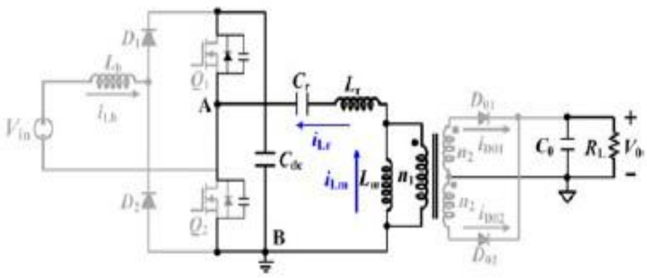

Figure 9: Equivalent Circuit for mode 6

At this interval, all the primary switches and secondary diodes are off, which is used to allow enough time to achieve ZVS, as well as prevent shoot through of two switches. This interval is the same as Mode 3. The magnetizing current charges and discharges the junction capacitors and helps achieve ZVS turn on ofQ_1 .

4. Simulation Results

Simulation results are given to verify the correctness of the analysis. The simulation parameters are: input voltage V_{in} = 100V; Filter Inductor L_f= 390µH; Filter Capacitor C_f = 0.1µF; Coupled Inductor L_b= 270µH; DC link capacitor C_{DC}= 22µF; Resonant Inductor L_r=135µH; Resonant Capacitor C_{r1} &C_{r2} =8.2nF; Output Capacitor C_{o1}&C_{o2}=40µF; Mutual Inductance of transformer =580µ

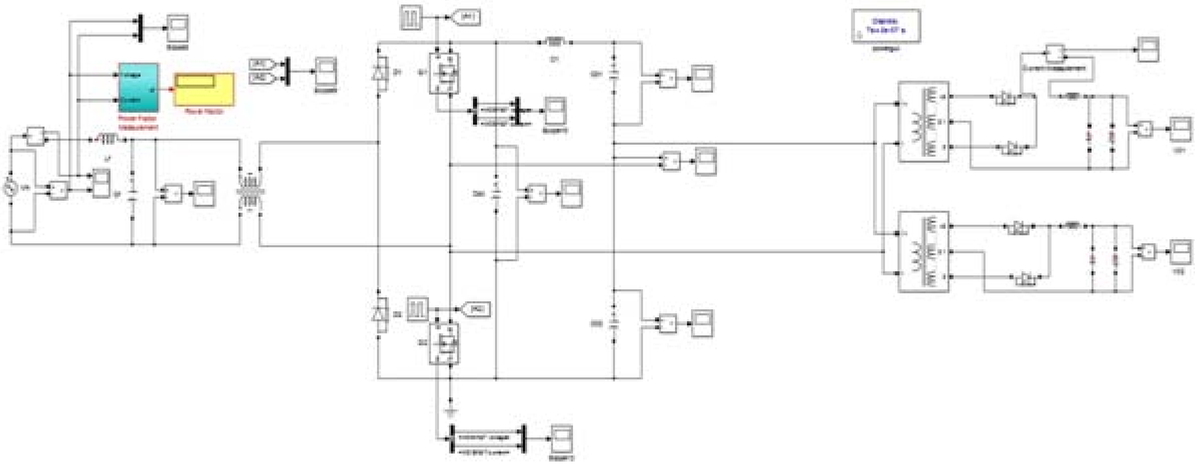

Figure 10: simulation model of the LED driver

The proposed LED driver is simulated for input voltage 100Vrms. The simulation results are shown below.

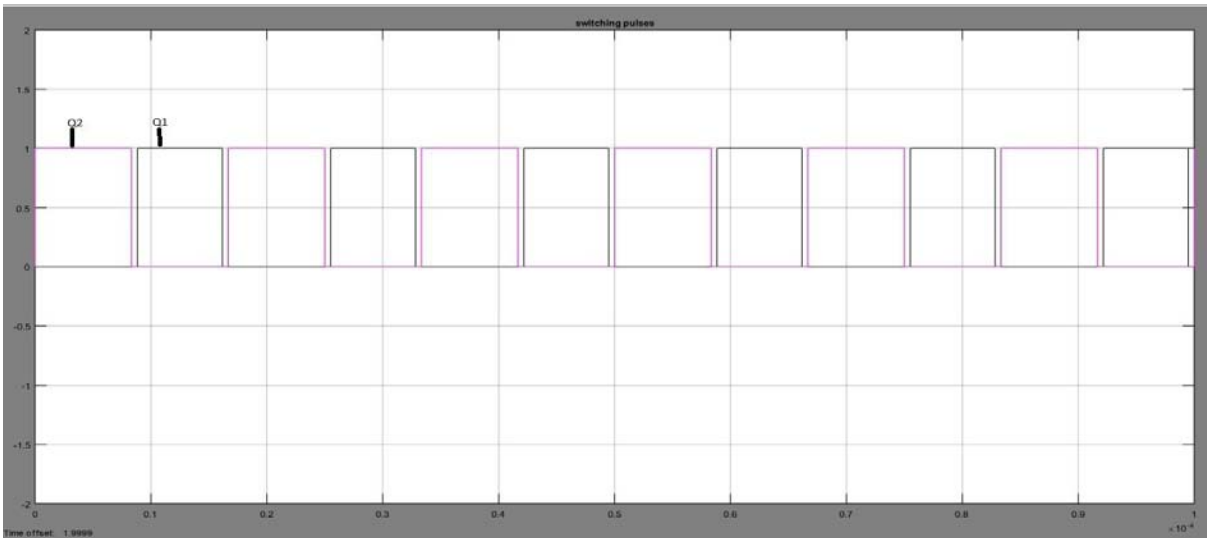

Figure 11: Switching pulses

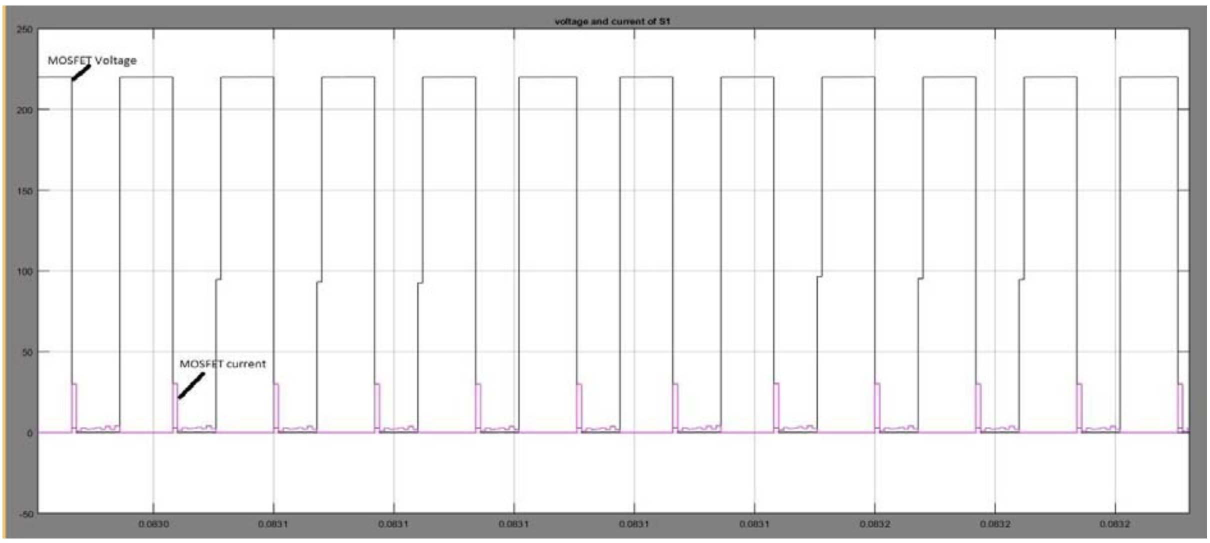

Figure 12: voltage and current of switch Q_1

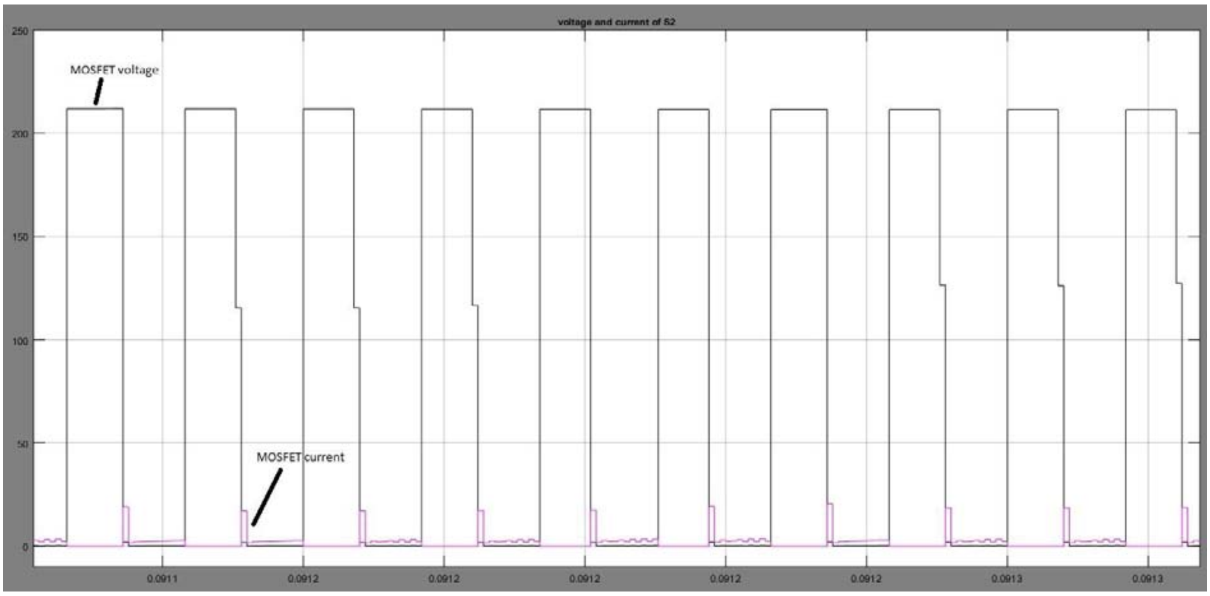

Figure 13: voltage and current of switch Q_2

It is clear from the simulation results that ZVS and ZCS features are achieved.

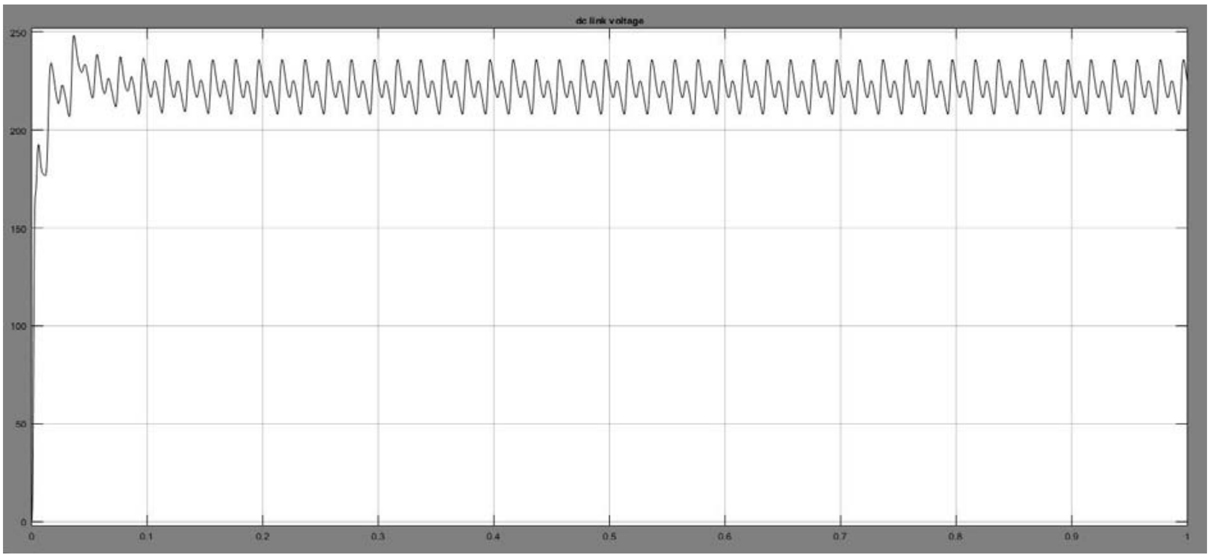

Figure 14: DC link voltage

Figure shows the voltage across DC link capacitor C_{DC}. Two outputs are taken V_{o1} and V_{o2}. Simulation results for output voltages are as shown below.

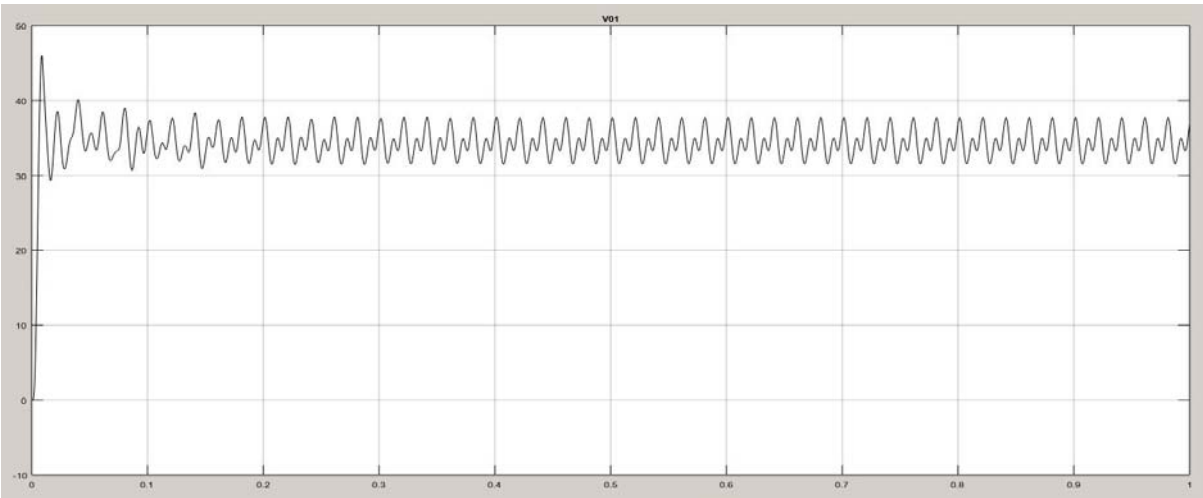

Figure 15: Output voltage V_{o1}

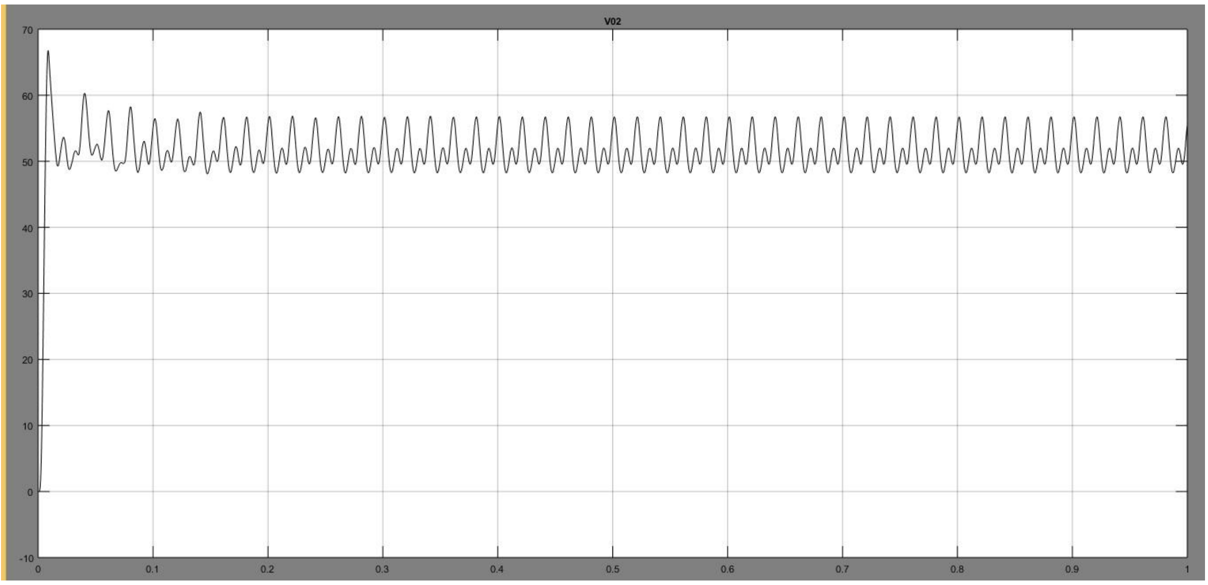

Figure 16: Output voltage V_{o2}

5. Circuit Modification

The input voltage for LED bulb is 12 V dc. Thus the circuit is modified to regulate the output voltage as 12 V. The block diagram for modified circuit is shown below

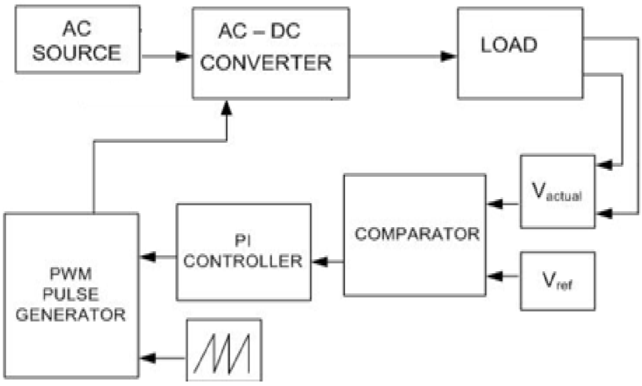

Figure 17: Modified circuit

1) Simulation results for modified circuit

Figure shows the simulation diagram for modified circuit.

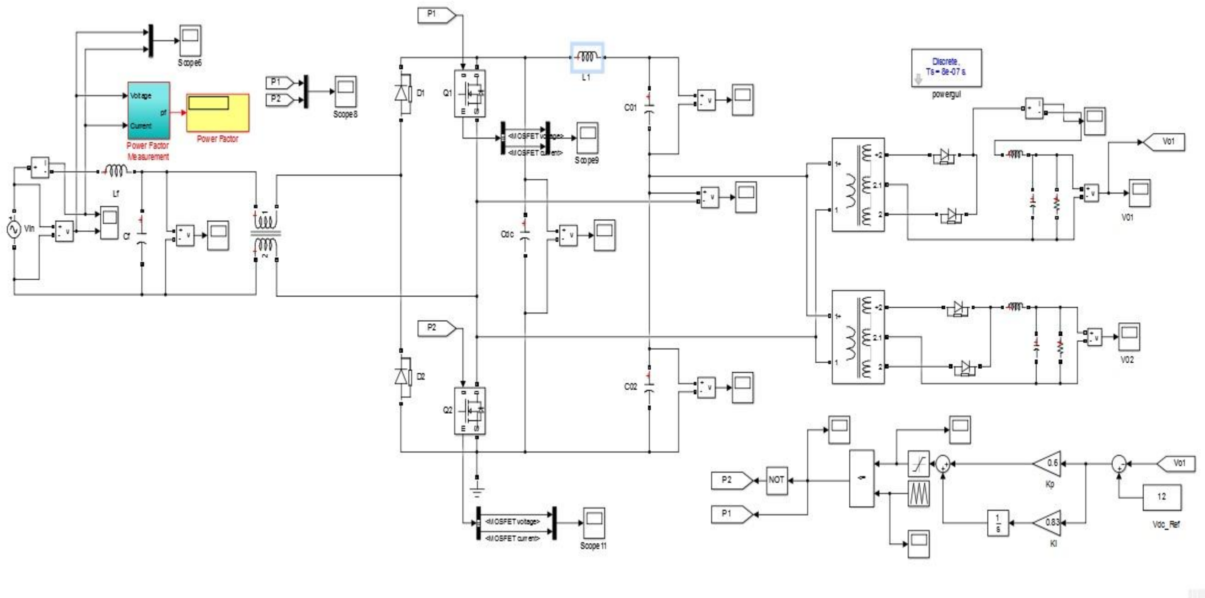

Figure 18: Simulation diagram for Modified circuit

Thus the output voltage is regulated to 12 V. Result is as shown.

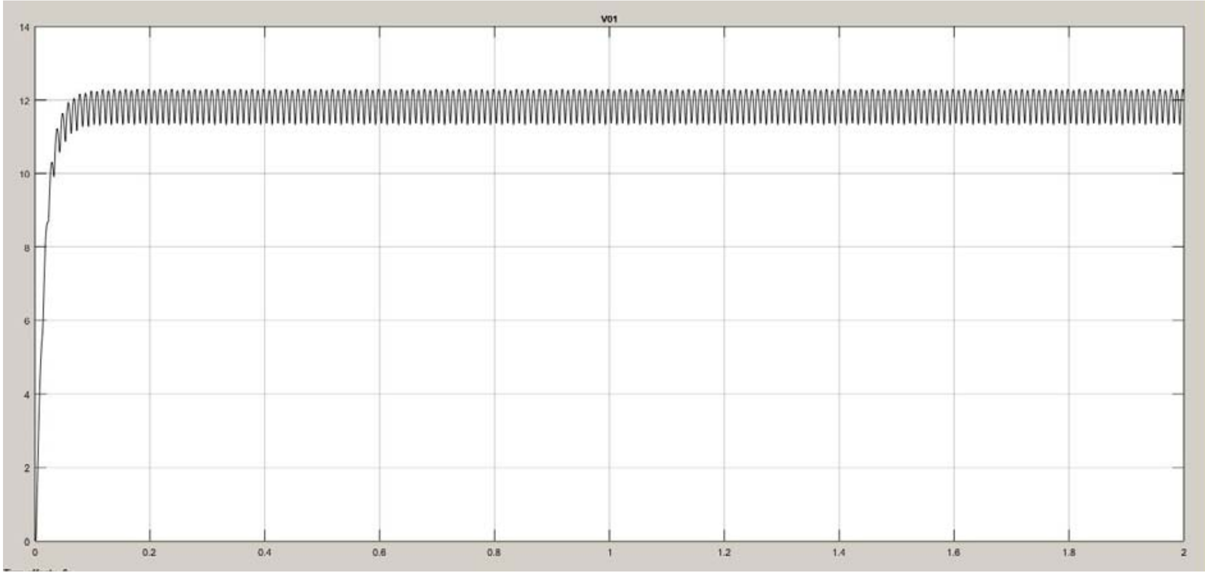

Figure 19: Output voltage

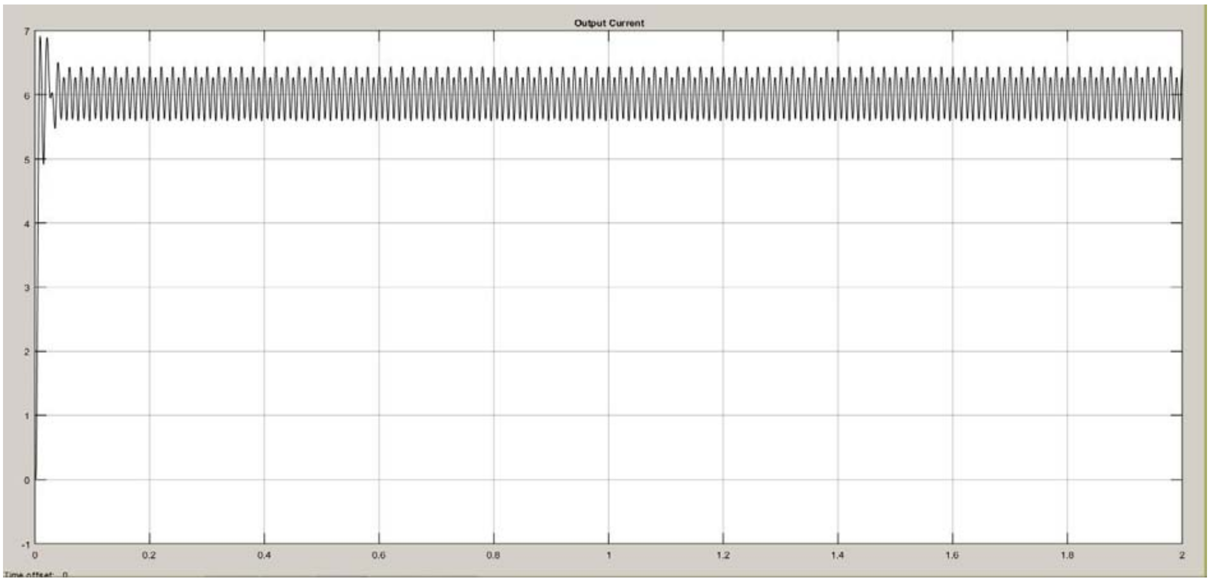

Figure 20: Output current

6. Conclusion

A novel single-stage bridgeless soft-switched AC–DC topology is proposed by integrating totem-pole bridgeless boost PFC and half-bridge *LLC* resonant converter into a single stage. Furthermore, a quasi-single-stage electrolytic capacitor-free LED driver for supplying multiple LED strings is developed based on the proposed AC–DC topology.

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