High Power Factor & Efficient Single-Stage Modified Flyback Converter for LED Drive Circuits

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***Abstract*—This paper presents a dynamic model for single stage forward-flyback switching DC-DC converters. The proposed model significant advantages are the single power switch, single-input inductor, purely capacitive output filter, isolation, low current ripple through the output capacitor, and operation at constant frequency in a conventional pulse-width-modulation scheme. The proposed new converter operates over a wide input-voltage range and can be employed in power factor correction and multiple-output power supplies. The conventional AC/DC flyback converter can achieve a good power factor but it has a high offset current through the transformer magnetizing inductor, which results in a large core loss and low power conversion efficiency. And, the conventional forward converter can achieve the good power conversion efficiency with the aid of the low core loss but the input current dead zone near zero cross AC input voltage deteriorates the power factor. On the other hand, since the proposed converter can operate as the forward and flyback converters during switch on and off periods, respectively, it cannot only perform the power transfer during an entire switching period but also achieve the high power factor due to the flyback operation. Moreover, since the current balanced capacitor can minimize the offset current through the transformer magnetizing inductor regardless of the AC input voltage, the core loss and volume of the transformer can be minimized. Therefore, the proposed converter features a high efficiency and high power factor. A simulation model in MATLAB/Simulink is built & the developed model is validated by executing the model on a simulation platform where several performances are obtained.**

Keywords—Forward-Flyback converters; DC-DC converters; Single Switch design;

I. INTRODUCTION

Recently, light-emitting diodes (LEDs) have become one of the most promising candidates for displays and lighting applications, because LEDs have several favorable advantages such as a high efficiency, long life time and echo-friendliness. Traditional lighting devices such as a light bulb and fluorescent lamp are being replaced by LEDs. Hence these switch-mode drivers are widely used in LED applications due to its high efficiency and high power density. Since drivers for LED lightings have two power conversion stages (ie. a power factor corrector and isolated DC/DC converter) the two-stage configuration can provide the high power factor, good output regulation and excellent ripple voltage, it has several significant disadvantages such as a large system size, high cost of production and low energy conversion efficiency. Therefore, it is common that the two-stage driver is mainly used for high power applications and single-stage driver is adopted as a low power LED driver.

Due to continuous improvement of high-brightness LED lamps, an increasing number of LEDs serve as the replacement for incandescent/fluorescent light. LED drivers are needed to provide highly precise output current regulation because LED brightness and color is dependent on LED current level. At the same time, high Power Factor (PF) and low Voltage stresses have become key design requirements for LED driver designs. In applications where precise output current regulation is required, the conventional control method uses current sensing in the secondary side, which results in additional sensing(transformer) loss.

Modern electronic systems require high quality, small, light weight, reliable and efficient power supplies. Linear regulators can provide a very high quality output voltage. Their main area of applications is at low power levels as low drop-out voltage regulators. Electronic devices in linear regulators operate in their active (linear) mode. At higher power levels switching regulators are used. Switching regulators use power electronic semiconductor switches in on and off states. Since there is a small power loss in those states, switching regulators can achieve high energy conversion efficiencies. Modern power electronic switches can operate at high frequencies. The higher the operating frequencies, the smaller and lighter the transformers, filter inductors and capacitors. In addition, the dynamic characteristics of the converters improve with increasing operating frequencies.

The dc-dc converters can be divided into two main types: hard switching pulse width modulated (PWM) converters and resonant and soft switching converters. Although the linear driver features a simple circuit configuration for LED drives, a fast transient response and an accurate current regulation, it has fatal drawbacks such as a Low efficiency and Serious heat generation. Therefore, the switch-mode driver is widely used in LED applications due to its high efficiency and high power density. To combine high efficiency and high power factor different converter topologies merging the foward and flyback converter is proposed.

II. LITERATURE SURVEY

In order to get a firm grip over the technology and developments in the field of LED drive technology & DC-DC converters, a handful of recent literatures were reviewed.

In [1], addresses a novel approach for designing and modeling of the isolated flyback converter. Modeling is done without parasitic as well as with parasitic components. A detailed analysis, simulation and different control strategy are conferred for flyback converter in continuous conduction mode (CCM). This work highlights the modeling of the transformer and facilitates designers to go for it when they need one or more than one output for a given application.

In [2], Ting Qian and Brad Lehman, propose an integrated magnetic dc–dc converter suitable for high input voltage application. The converter is based on a coupled input-series and output-parallel dual interleaved Flyback converter concept. All the center and outer legs are gapped, and the transformers are integrated into one magnetic core with not so tight coupling. The gap is beneficial for suppressing current spike caused by the voltage mismatch between the windings. The two transformers are inversely coupled, and current ripple reduction can be achieved with suitable coupling design.

In [3], a novel ZVZCS active clamped dual switch flyback converter was proposed, whose main switches and auxiliary switch all realize zero-voltage turning-on, and the rectifier diode on the secondary side also achieves ZCS. It overcomes the demerit of high voltage stress on the main switch in conventional flyback converter; meanwhile the duty cycle can extend to more than 50% by slope compensation. Thus it is favorable for high efficiency, wide input range capacity and suited for the high input voltage occasions. In addition, the converter makes full use of leakage inductor energy, no extra snubber is needed.

In [4], M. Milanovi, et. al, talk about the transformer leakage inductance the converter suffers from the voltage spikes, which can be controlled by the dissipative RCD or non-dissipative LCD clamp circuits. Both of the clamp circuits consist of the diode. The diode reverse recovery charge causes the oscillation, which results in additional dissipation of the clamp circuitry. It also describes this ringing phenomenon and the use of an RC-RCD clamp circuit for damping the clamp-diode's oscillation. This clamp circuit is capable for improving a flyback converter's power ratio.

In [5], Frank Chen,et. al present a zero-voltage switching (ZVS) forward-flyback DC-DC converter, which is able to process and deliver power efficiently over a wide input voltage variation. The converter operates at boundary mode between current continuous and discontinuous mode to achieve ZVS. Variable frequency with fixed off time is used for reducing core losses of the transformer, achieving high efficiency. Meanwhile, power distribution between forward and flyback is analyzed as well that validates the feasibility and good performance of the proposed converter.

III. SINGLE-STAGE BALANCED FORWARD-FLYBACK CONVERTER

In this section, a high efficiency and high power factor single-stage balanced forward-flyback converter merging a conventional forward and flyback converter topologies is proposed. The flyback converter can achieve a good power factor but it has a high offset current through the transformer magnetizing inductor, which results in a large core loss and low power conversion efficiency. And, the conventional forward converter can achieve the good power conversion efficiency with the aid of the low core loss but the input current dead zone near zero cross AC input voltage deteriorates the power factor. On the other hand, since the proposed converter can operate as the forward and flyback converters during switch on and off periods respectively, it cannot only perform the power transfer during an entire switching period but also achieve the high power factor due to the flyback operation. Moreover, since the current balanced capacitor can minimize the offset current through the transformer magnetizing inductor regardless of the AC input voltage, the core loss and volume of the transformer can be minimized. Therefore, the proposed converter features a high efficiency and high power factor. The block diagram of the proposed forward-flyback converter is as shown below in fig 1.

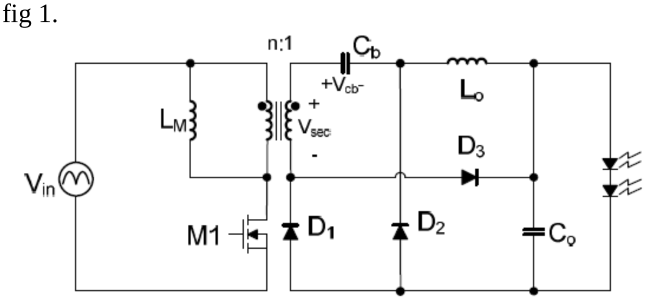

Figure 1: Block diagram of forward-flyback converter

IV. OPERATION PRINICIPLE

The operation of the proposed forward-flyback converter is divided into two modes according to the conduction state of each switch and its key waveforms are shown in Fig.2

For the convenience of the mode analysis in steady state, several assumptions are made as follows:

a. The switch M1 is ideal except for its internal diode.

b. The transformer is ideal except for its magnetizing inductance L_M.

c. The output capacitor Co and DC blocking capacitor C_b are large enough to be considered as constant DC voltage sources V_o and V_{cb}, respectively.

d. The proposed circuit is operated in boundary conduction mode (BCM).

Before t_0, it is assumed that M1 is blocked and the energy stored in L_M is being transferred to the load side through D3 and D1. At this moment, C_b is charged by I_{LM} and I_{Lo} is freewheeling through D2.

Mode 1[t0~t1]: When iLM reaches zero, mode 1 begins at t0. Since M1 is turned on, Vin is applied to LM and ILM is linearly increased with the slope of Vin/LM. At this moment, although Vsec= Vin/n across the transformer secondary side may be lower than Vo, the sum of Vsec= Vin/n and Vcb applied to the input side of output LC filter is higher than the output voltage Vo. Therefore, D1 is conducting and the input energy is transferred to the load side through forward operation. And, the voltage across D2 is Vin/n+Vcb and that across D3 can be clamped on Vo by D1.

Mode 2[t1~t2]: When M1 is turned off at t1, mode 2 begins. While the energy stored in LM is released to the load side through D2 and D3, the transformer secondary current also charges the balancing capacitor Cb as much as discharged quantity in Mode 1. At the same time, the current though Lo freewheels via D2. Since n(Vo+Vcb) is applied to LM, ILM is linearly decreased with the slope of n(Vo+Vcb)/LM. Subsequently, when ILM reaches zero, M1 is turned on and the operation from Mode 1 to Mode 2 is repeated.

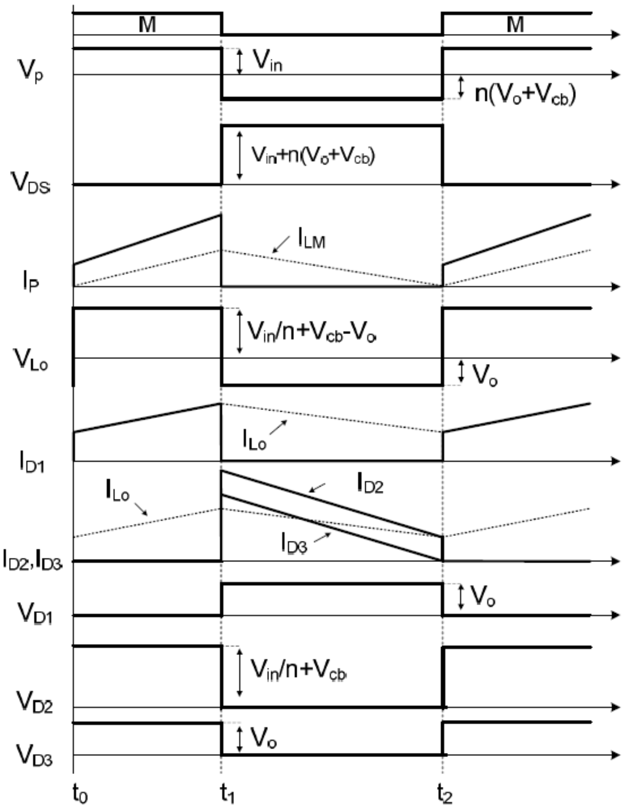

Figure 2: Waveform of forward-flyback converter

V. COMPLETE SIMULATION MODEL OF FORWARD-FLYBACK CONVERTER

As mentioned earlier, the proposed converter with Cb can operate as both forward and flyback converters over an entire range of input voltage with the aid of Vcb. On the other hand, while the proposed converter without Cb can transfer the input energy to the output side at Vin/n>Vo, it cannot at Vin/n<Vo. As a result, the proposed converter with balancing capacitor Cb features a smaller magnetizing offset current, resultant smaller core loss and more reduced transformer volume.

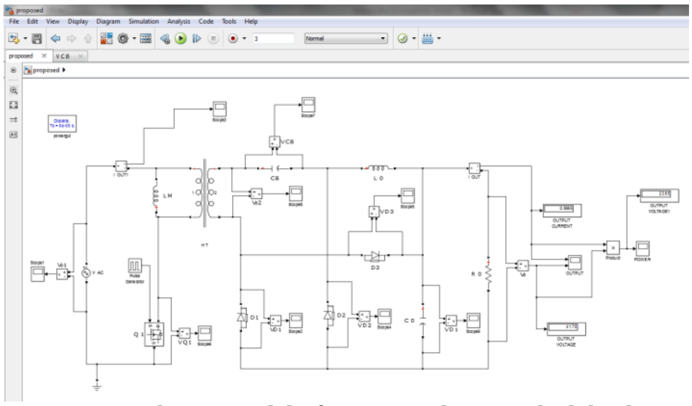

Fig 3: Simulation Model of a Proposed Forward-Flyback Converter

The electrical design parameters are

Table 1: Design Parameters of Forward Flyback Converter

Parameters	Value
Input Voltage [Vin]	90V
Magnetizing Inductance [Lm]	1.8mH
Frequency	100KHz
Primary Voltage [V1]	100V
Secondary Voltage [V2]	180V
Balancing Capacitance [Cb]	100 µF
Output Capacitance [Co]	10mF
Output Resistance [Ro]	73.68Ω
Output Current [Io]	0.56A
Output Voltage [Vo]	42V
Output Power [Po]	24W

As shown in figure – the waveforms are as below:

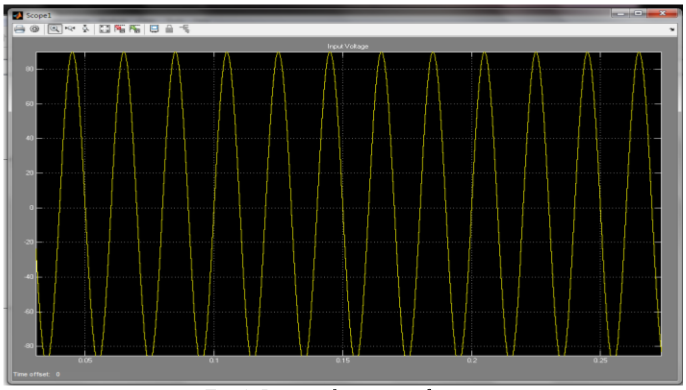

Fig 4: Input voltage waveform

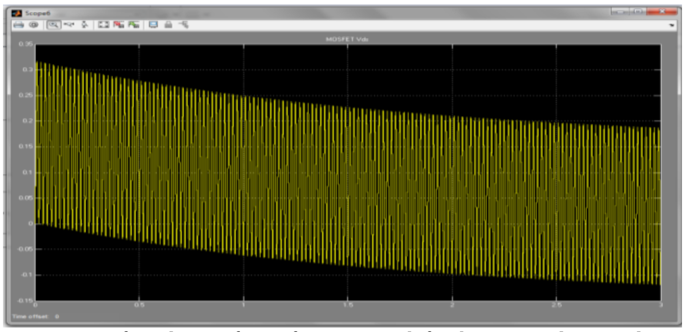

Fig 5: Mosfet Vds waveform of PWM Switch for the Proposed Forward Flyback Converter

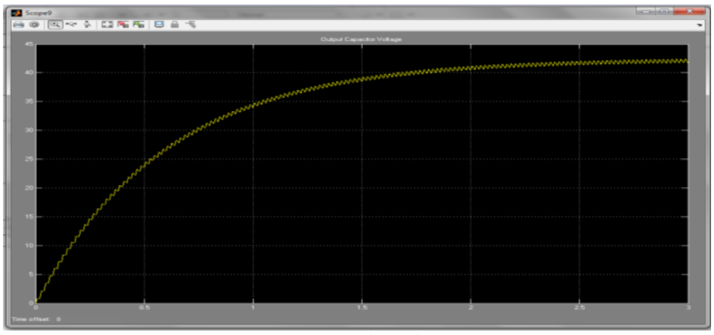

Fig 6: Output Capacitor Voltage waveform for the Proposed Forward Flyback Converter

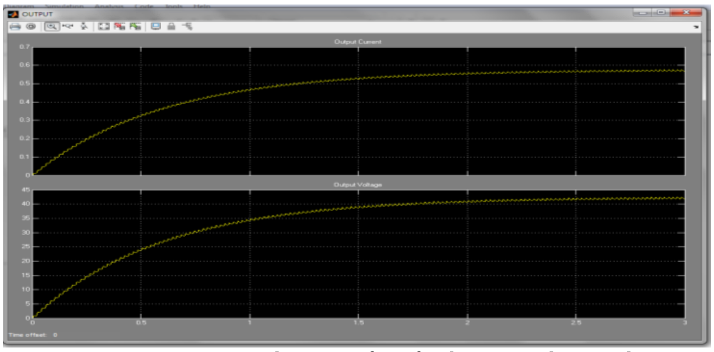

Fig 7: Output Current & Voltage waveform for the Proposed Forward Flyback Converter

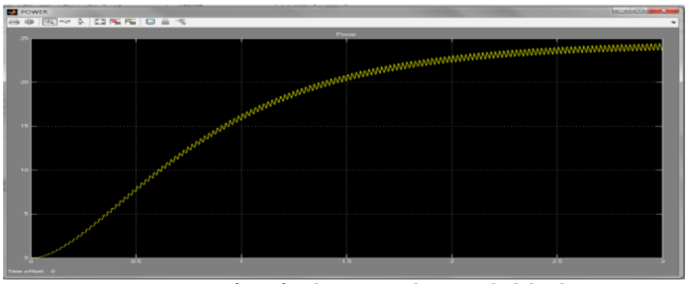

Fig 8: Output Power waveform for the Proposed Forward Flyback Converter

CONCLUSION

A single stage power-factor-correction balanced forward-flyback converter for LED application is presented, and its operation principle analyzed. The proposed forward-flyback converter with the balancing capacitor can always operate as both forward and flyback converters regardless of the input voltage. Therefore, it has a smaller magnetizing offset current, resultant smaller core loss and more reduced transformer core volume. For this reason, the proposed converter can be obtained high efficiency and high power factor. In contrast with the flyback converter, where there are two distinct phases for energy storage and delivery to the output, the forward converter uses the transformer in a more traditional manner, to transfer the energy directly between input and output in the one step. Derived from the simple buck converter, the forward converter delivers energy from the input source to the output filter inductor during the on time of the main switch. In contrast, the flyback converter delivers energy to the output filter capacitor only during the off-time of the main power switch. The forward converter, when compared with the fly-back circuit, is generally more energy efficient and is used for applications requiring little higher power output (in the range of 100 watts to 200 watts). To verify the validity of proposed circuits,simulation circuits for LED application are implemented, which shows that the measured maximum power factor and efficiency. Moreover, the proposed circuit can be perform the power transfer during an entire switching period. Therefore, the proposed circuit having these favorable advantages is expected to be well suited to various LED driver applications.

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