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Efficacious Single-Stage Modified Flyback Converter with a High Power Factor for LED Drive Applications

***Dr. Kedar Khedkar*[1], *Smita Bhaskar*[2]**
Professor[1], *Student*[2] *Department of*
Electrical Engineering
PRPCEM, Amravati
Corresponding Author's Email: - *smitabhaskar66@gmail.com*[2]

Abstract

Within the scope of this article, a dynamic model for single-stage forward-flyback switching DC-DC converters is presented. A single power switch, a single input inductor, an entirely capacitive output filter, isolation, low current ripple through the output capacitor, and operation at a constant frequency in a conventional pulse-width-modulation scheme are some of the significant advantages that the proposed model offers. The power factor correction and multiple-output power supply applications are two potential uses for the innovative new converter that has been presented. It is capable of operating across a broad variety of input voltages. The typical AC/DC flyback converter is capable of achieving a decent power factor, but it has a high offset current through the transformer magnetising inductor. This high offset current results in a huge core loss and low power conversion efficiency. In addition, the traditional forward converter is capable of achieving strong power conversion efficiency with the assistance of a low core loss; nevertheless, the input current dead zone at the zero cross AC input voltage causes a reduction in the power factor. On the other hand, because the proposed converter is able to operate both as forward and flyback converters during the switch on and switch off periods, respectively, it is not only able to perform power transfer during the entirety of the switching period, but it is also able to achieve a high power factor as a result of the flyback operation. In addition, the core loss and volume of the transformer may be reduced thanks to the current balanced capacitor's capability of reducing the amount *of offset current that flows through the transformer's magnetising inductor. This reduction is possible independent of the AC input voltage. As a result, the converter that has been presented has a high efficiency as well as a high power factor. It begins with the construction of a simulation model in MATLAB/Simulink, which is followed by the validation of the produced model by the execution of the model on a simulation platform, from which multiple performances are acquired.*

Keywords: *Single Switch design, LED Drive Circuits, Flyback Converter, DC-DC Converters*

INTRODUCTION

Recently, light-emitting diodes, also known as LEDs, have emerged as one of the most promising candidates for use in displays and lighting applications. This is due to the fact that LEDs possess a number of advantageous advantages, including a high efficiency, a long life time, and echo-friendliness. LEDs are quickly becoming the standard lighting technology, displacing older options such as light bulbs and fluorescent lamps.

As a result, these switch-mode drivers are utilised extensively in LED applications as a result of their high levels of efficiency as well as their high power densities. The drivers for LED lightings have two power conversion stages, which include a power factor corrector and an isolated DC/DC converter. Although the two-stage configuration can provide a high power factor, good output regulation, and excellent ripple voltage, it does have a number of significant drawbacks, including a large system size, a high cost of production, and low energy conversion efficiency. As a result, it is standard practise for a two-stage driver to be used primarily for high power applications, whilst a single-stage driver is often utilised for usage as an LED driver for low power. Because of the ongoing development of higher-brightness LED lights, an increasing number of incandescent and fluorescent light sources are being supplanted by LEDs.

Because the amount of current that an LED is drawing determines both its brightness and its colour, it is necessary to have LED drivers that can offer very accurate output current control. At the same time, high Power Factor (PF) and low Voltage stresses have emerged as essential requirements for the design of LED driver circuits. The typical technique of control involves current sensing in the secondary side, which results in extra sensing (transformer) loss. This approach is used in situations where accurate output current regulation is required.

Power supply for modern electronic systems need to be of a high quality, while also being compact, lightweight, dependable, and efficient. Linear regulators are capable of producing an output voltage of extremely high quality. Their primary use is in low-power applications as low-dropout voltage regulators, which is also their primary field of application. Electronic components used in linear regulators function in the active (linear) phase of their operation. Switching regulators are utilised when working with greater power levels.

Switching regulators make use of power electronic semiconductor switches that can be in either the on or off state. Switching regulators are able to achieve high energy conversion efficiencies due to the fact that there is only a little loss of power in such states. Switches for modern power electronics are capable of operating at high frequencies. When operating frequencies are increased, transformers, filter inductors, and capacitors tend to decrease in size and increase in weight. In addition, elevating the operating frequencies of the converters results in an improvement in the devices' dynamic properties.

The dc-dc converters may be broken down into two primary categories: hard switching pulse width modulated (PWM) converters and resonant and soft switching converters. Both of these categories have their advantages and disadvantages. Even though the linear driver has a simple circuit architecture for LED drives, a rapid transient response, and accurate current regulation, it suffers from fatal shortcomings such as low efficiency and serious heat production. These limitations prevent the linear driver from being a viable option.

As a result of the switch-mode driver's great efficiency as well as its high power density, it has found widespread use in applications using LEDs. It has been proposed to merge the forward and flyback converters in order to achieve a combination of high efficiency and high power factor in the various converter topologies.

LITERATURE SURVEY

In order to gain a solid grasp on the technology and advances in the field of LED drive technology and DC-DC converters, a few current literatures were looked at. This was done in order to get a better understanding of the technology.

[1] Discusses an innovative methodology for constructing and modelling the isolated flyback converter. The modelling process can be carried out either without or with the use of parasitic components. For a flyback converter operating in continuous conduction mode, a comprehensive analysis and simulation as well as many alternative control strategies are presented (CCM). This work draws attention to the modelling of the transformer and makes it easier for designers to make use of it when they require one or more than one output for a particular application.

Ting Qian and Brad Lehman present their idea for an integrated magnetic dc–dc converter that is appropriate for high input voltage applications in their paper [2]. The notion of a connected input-series and output-parallel dual interleaved Flyback converter serves as the foundation for this particular converter.

All of the centre and outside legs have gaps in them, and the transformers have been combined into a single magnetic core while maintaining a loosely coupled structure. It is useful to have the gap because it helps decrease the current spike that is created by the voltage mismatch between the windings. Inverse coupling exists between the two transformers, and there is potential for current ripple reduction with the use of appropriate coupling design.

A unique ZVZCS active clamped dual switch flyback converter was presented in [3]. This converter's main switches and auxiliary switch all realise zero-voltage turning-on, and the rectifier diode on the secondary side also achieves ZCS. The converter was designed to be active. It eliminates the problem that traditional flyback converters have with high voltage stress on the primary switch, and at the same time, it allows the duty cycle to be increased to more than 50 percent using slope compensation.

As a result, it is advantageous for high efficiency, has the capacity for a wide input range, and is suitable for situations involving high input voltage. In addition, the converter makes complete use of the energy provided by the leaking inductor, therefore an additional snubber is not required.

M. Milanovi et al. discuss the transformer leakage inductance that the converter experiences as a result of the voltage spikes in [4]. These voltage spikes can be managed by the non-dissipative LCD clamp circuits or the dissipative RCD clamp circuits, respectively. The diode is the only component in both of the clamp circuits. Oscillation is caused by the diode's reverse recovery charge, which in turn leads to increased dissipation of the clamp circuitry. In addition to this, it discusses the ringing phenomena as well as the utilisation of an RC-RCD clamp circuit in order to dampen the oscillation of the clamp-diode. Increasing the power ratio of a flyback converter is within the capabilities of this clamp circuit.

In the paper referred to as [5], Frank Chen and his colleagues offer a zero-voltage switching (ZVS) forward-flyback DC-DC converter. This converter is able to efficiently process and supply power over a broad range of input voltage variations. In order to accomplish ZVS, the converter must function in a mode that is a border between the present continuous mode and the discontinuous mode. The core losses of the transformer may be reduced by using variable frequency in conjunction with a predetermined off time, which allows for the achievement of high efficiency. While this is going on, the power distribution between forward and flyback is being studied, which supports the practicability of the suggested converter as well as its high level of performance.

SINGLE-STAGE BALANCED FORWARD-FLYBACK CONVERTER

A single-stage balanced forward-flyback converter with high efficiency and high power factor is suggested in this section. This converter merges the topologies of traditional forward converters and flyback converters to create the balanced forward-flyback converter.

The flyback converter is capable of achieving a decent power factor; nevertheless, it has a high offset current that flows through the transformer magnetising inductor. This high offset current causes the flyback converter to have a substantial core loss and a low power conversion efficiency. In addition, the traditional forward converter is capable of achieving a strong power conversion efficiency with the assistance of a low core loss; nevertheless, the input current dead zone at the zero cross AC input voltage causes a reduction in the power factor.

On the other hand, because the proposed converter is able to operate both as forward and flyback converters during the switch on and switch off periods, it is not only able to perform power transfer during the entirety of the switching period, but it is also able to achieve a high power factor as a result of the flyback operation. In addition, the core loss and volume of the transformer may be reduced thanks to the current balanced capacitor's capability of reducing the amount of offset current that flows through the transformer's magnetising inductor. This reduction is possible independent of the AC input voltage. As a result, the converter that has been presented has a high efficiency as well as a high power factor.

The suggested forward-flyback converter has the block diagram illustrated below in figure 1, which may be found below.

OPERATION PRINICIPLE

The functioning of the proposed forward-flyback converter may be broken down into two distinct modes, each of which is determined by the conduction state of the respective switch, and Fig. 2 presents the important waveforms for each mode.

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 LM.

c. The output capacitor Co and DC blocking capacitor Cb are large enough to be considered as constant DC voltage sources Vo and Vcb, respectively.

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

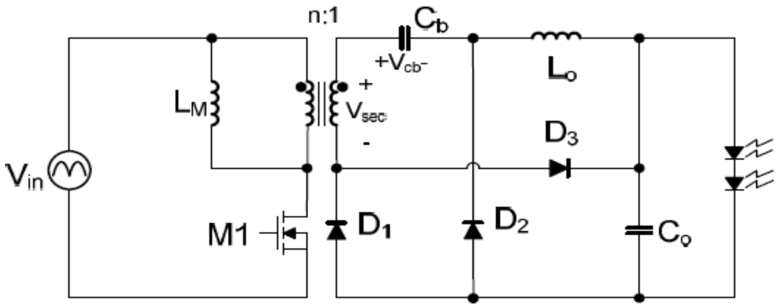


Figure 1: Block diagram of forward-flyback converter

Before t0, it is assumed that M1 is blocked and the energy stored in LM is being transferred to the load side through D3 and D1. At this moment, Cb is charged by ILM and ILo 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.

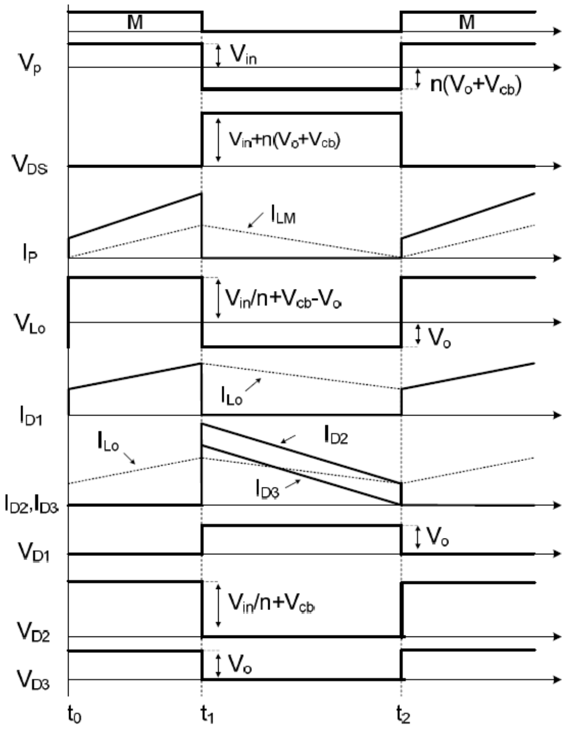
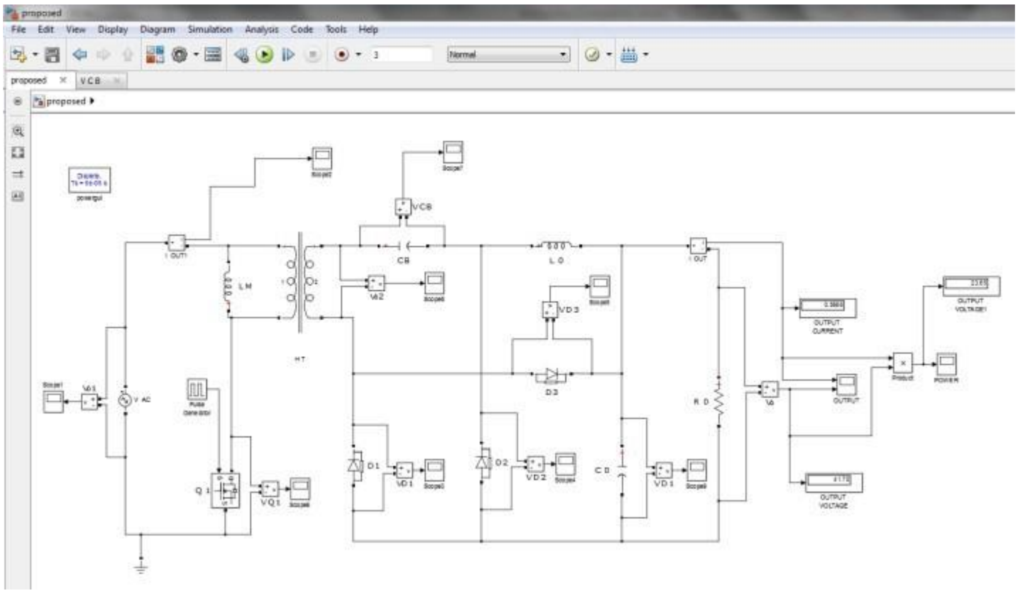


Figure 2: Waveform of forward-flyback converter

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.



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:

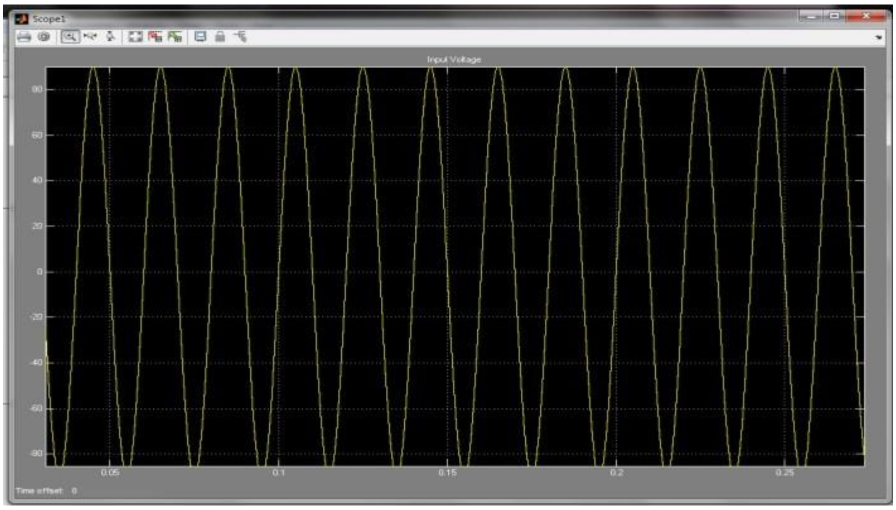


Fig 4: Input voltage wavefor

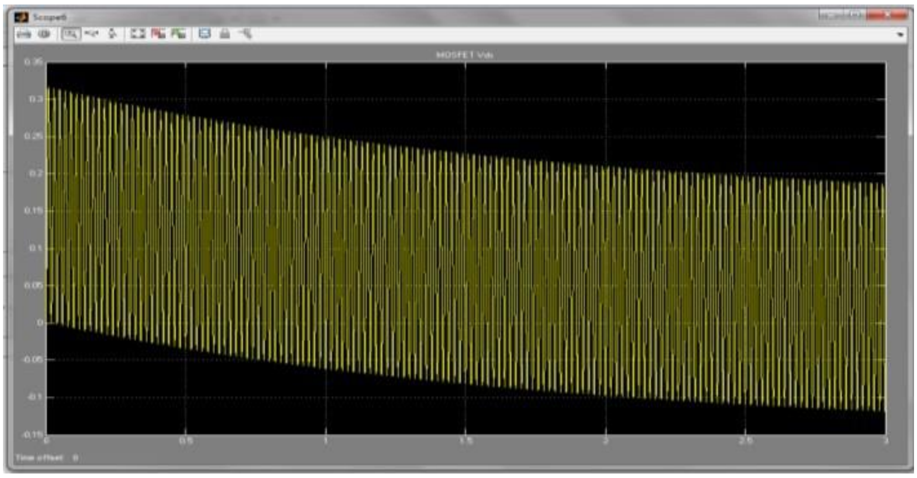


Fig 5: Mosfet Vds waveform of PWM Switch for the Proposed Forward Flyback Converter

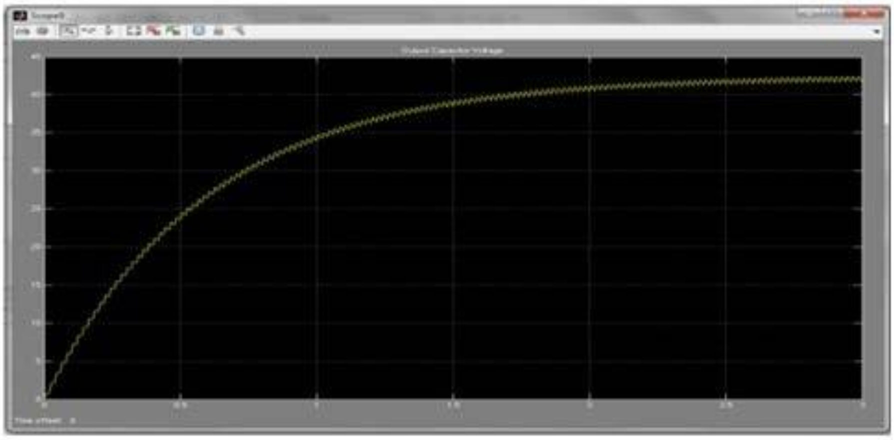


Fig 6: Output Capacitor Voltage waveform for the Proposed Forward Flyback Converter

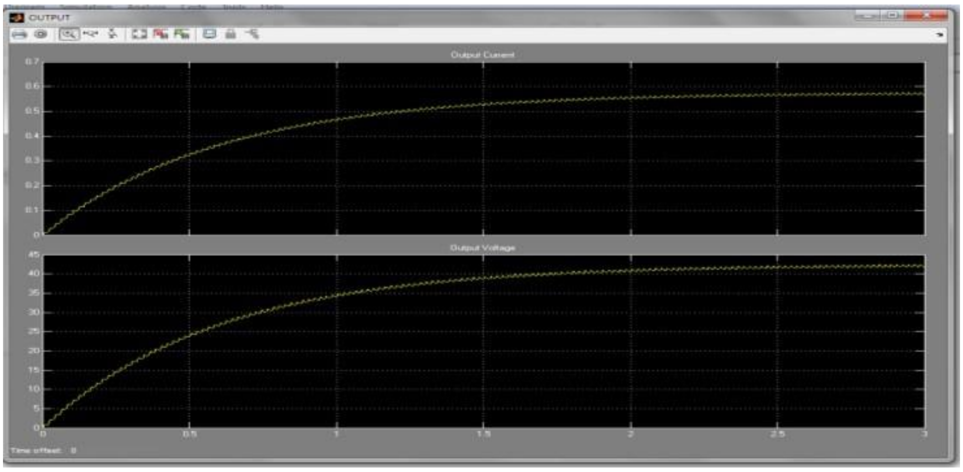


Fig 7: Output Current & Voltage waveform for the Proposed Forward Flyback Converter

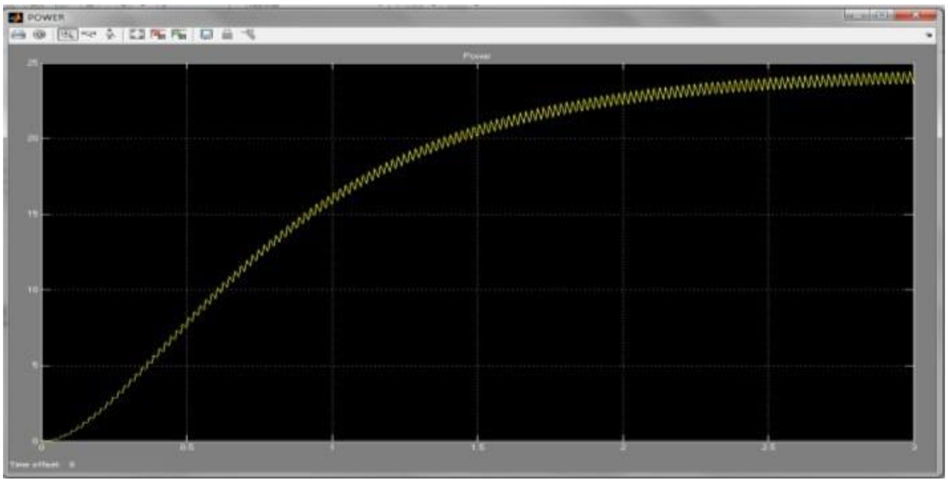


Fig 8: Output Power waveform for the Proposed Forward Flyback Converter

CONCLUSION

In this paper, a single-stage power-factor-correction balanced forward-flyback converter designed specifically for LED applications is given, and the working concept of the converter is investigated. No matter what the input voltage is, the proposed forward-flyback converter with the balancing capacitor will always be able to function as both a forward converter and a flyback converter. As a consequence, it has a lower magnetising offset current, which has led to a lower core loss and a further reduction in the core volume of the transformer. Because of this, the suggested converter has the potential to achieve high levels of efficiency as well as power factor. In contrast to the flyback converter, which consists of two distinct phases for the storage and delivery of energy to the output, the forward converter makes use of the transformer in a manner that is more conventional. This allows the energy to be transferred directly between the input and the output in a single step. The forward converter is derived from the simple buck converter. During the period that the main switch is "on," energy is transferred from the input source to the output filter inductor. On the other hand, the flyback converter is the only one to supply power to the output filter capacitor when the main power switch is turned off. When compared to the fly-back circuit, the forward converter is typically more energy efficient and is utilised for situations that require somewhat higher power output (in the range of 100 watts to 200 watts).

The simulated circuits for the LED application are constructed, which indicates that the measured maximum power factor and efficiency of the suggested circuits. This helps to check the correctness of the proposed circuits. In addition, the suggested circuit has the capability of performing power transfer for the entirety of the switching time. As a result of the numerous benefits that the suggested circuit possesses, it is anticipated that it will be an excellent choice for a variety of LED driver applications.

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