ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization
Vol. 4, Special Issue 1, March 2015

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE 2015)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India
On 26th & 27th March 2015

Current mode Control of Improved Bridgeless Flyback Rectifier with Bidirectional Switch for Adapter Applications

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ABSTRACT: Current mode control of flyback rectifier with bidirectional switch is proposed in this paper. Current mode control usually implemented in switching power supplies actually senses and controls peak inductor current. But this leads to many problems such as need for slope compensation, poor noise immunity and peak to average current error. Thus the implementation of average current mode control eliminates these problems and may be used effectively to control currents other than inductor current, allowing a much broader range of topological application. The proposed control scheme employs an outer voltage feedback loop, which maintains the output voltage as constant and an inner loop, which sense the input current. Average current mode control of flyback rectifier is suitable for obtaining a regulated output voltage with a varying input. Voltage equivalent of input current is averaged by using high gain current error amplifier, which again compared with the reference voltage. Reference voltage is produced by multiplying the rectified input voltage with the error output voltage. Gating pulse is generated by using this signal. This control method obtain better line and load regulation with the addition of inner current loop compared with voltage mode control. Also the rectified input voltage feedback achieves better input power factor. Conventional flyback rectifier is the inter connection of a diode bridge rectifier in the input side and a flyback converter. In order to obtain a highly efficient flyback rectifier with fewer losses an improved flyback rectifier is introduced. Here, two switches are connected in back to back to establish the bidirectional switch element, which will conduct both in the positive and negative half cycle of the ac input voltage. The transformer with dual output windings with a diode in each winding reduces the current stress across each diode. New topology adds an extra switch in the primary side and a diode in the secondary side. Improved bridgeless flyback rectifier only introduces a switch with common gate drive, a diode and an additional winding in the secondary side. Thus the weight of the converter is not affected with these additional components. Proposed average current mode control can be used as an adapter. Design and simulated waveforms are added in this paper for an output rating of 20V/1.5A.

KEYWORDS: Bridgeless topologies, current mode control, Average current mode control, Flyback rectifier, power factor correction.

I.INTRODUCTION

Isolated switching power converters have been of great importance in power electronics because of its simple circuits and efficient control schemes. Using this, output voltage can be varied steplesssly by controlling duty ratios of the semiconductor device used in chopper. These converters find its application in SMPC, battery driven vehicles, electric traction, dc drives etc. DC-DC converters, also called as choppers are generally used for stepping up or stepping down the DC supply. Among the various types of conventional DC-DC converters, flyback converter has the added advantages such as simple structure with fewer components, isolation between input and output parts and is economic. Flyback converter is the most commonly used SMPS circuit which has the applications in low output power needs. In respect of energy conversion efficiency flyback converter is inferior to many other SMPS circuits but it’s simple topology and low cost makes it popular in low output power range. Converter can also operate over wide range of input voltage variation with single or multiple output windings. The primary and secondary windings of the flyback transformer do not carry current simultaneously and in this sense flyback transformer works differently from a normal transformer.

Applications of AC-DC converters in industrial and commercial fields are also very wide. Diode bridge circuits will perform the rectification process conventionally. Bridge flyback rectifier is the interconnection of diode bridge and conventional flyback converter. This bridged topology posses less efficiency due to the increased conduction losses of four bridge diodes also with the transformer. Conduction losses can be reduced by eliminating these diodes from the conduction path of the rectifier [2]-[4]. These diodes are present in the primary side of the converter and various bridgeless topologies were introduced by eliminating the front end diodes. First bridgeless boost converter was proposed in 1983 by Mitchell [6], where the objective was to improve the power factor by eliminating the distortions in zero crossing region of ac input voltage. Again different versions of bridgeless boost rectifiers were introduced in order to enhance system performance.

Control scheme adopted in this paper is the average current mode control [7], because of its advantages compared with the voltage mode control. To regulate the output voltage, Pulse-Width Modulation (PWM) is necessary, which adjust duty Cycle to obtain the desired voltage output. There are two control methods for flyback converter: Voltage Mode Control (VMC) and Current Mode Control (CMC). Voltage mode control has simple structure by introducing a single voltage loop. But this control has poor line and load regulation. Another disadvantage is that, there will be a flux imbalance problem in circuit having more than one switch. Due to these above mentioned problems current mode control is introduced. Again, among the various types of current mode control techniques, i.e., peak current mode control, hysteresis current mode control and average current mode control, average current mode control is selected for the efficient operation. Peak current control mode usually senses the output current and is suitable for the control of buck converter where the inductor is in the output. But for boost and flyback topologies the inductor is in the input, the wrong current is sensed and controlled. In flyback converter there is no inductor in the power circuit. Therefore the inner current loop sense the input current. A scaled output voltage is sensed through a resistive divider. [8]. After going through the compensation impedance, the error current was converter to control voltage and was connected to the Pulse Width Modulator (PWM) that drives the MOSFET. In voltage–mode control, this control voltage is compared with a sawtooth ramp. When the converter output voltage changes, the control voltage also changes and thus causes the duty cycle of the power switch to change. The higher the error voltage, the control voltage also changes and thus causes the duty cycle of the power switch to change. The higher the error voltage, the longer is the duty cycle. This change of duty cycle adjusts the output voltage to reduce to error signal to zero. In this paper, it is going to discuss about an improved bridgeless flyback rectifier with voltage mode control. Section II describes about the circuit configuration and modes of operation. Section III describes about the design. Section V deals with the simulation results and section VI concludes the paper.

II. IMPROVED BRIDGELESS FLYBACK RECTIFIER WITH BIDIRECTIONAL SWITCH

A. Circuit configuration and Operation

Fig.1 shows the circuit configuration of improved bridgeless flyback rectifier with bidirectional switch. Rectifier completely eliminates the full diode bridge circuit from the input side. Rectification process is done by the bidirectional switch cell. Bidirectional switch cell is formed by the back to back connection of two MOSFET switches. A few more circuit components are added to the conventional flyback rectifier circuit in order to compensate the elimination of four bridge diodes. Mainly three modifications are done in the circuit. 1. Bidirectional switch cell: It is added to the primary side of the transformer. Two MOSFETs are connected in back to back, thus during positive half cycle of input, current flows in positive direction and in the negative half cycle current flow reverses. Switches S1 and S2 are triggered by common gate signal i.e., both the switches will turn on and off at the same instant. 2. Dual transformer output windings: Transformer of the conventional flyback rectifier and improved bridgeless flyback rectifier are different. In improved bridgeless flyback rectifier, transformer has an extra winding in the secondary side. This addition of extra winding will not affect the size and weight of the circuit. Tertiary winding is added in to the existing core of the transformer, thus the size and weight of proposed bridgeless flyback rectifier is not increased compared to the conventional flyback rectifier. 3. Addition of one more diode: Adding D2 to the secondary side reduces the average

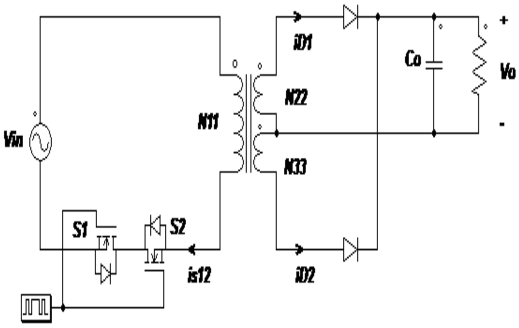
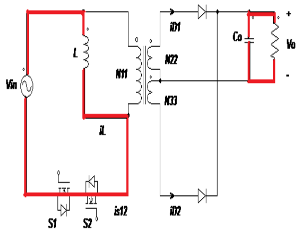
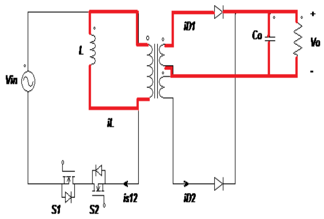


Fig. 1 Circuit configuration of improved bridgeless flyback rectifier

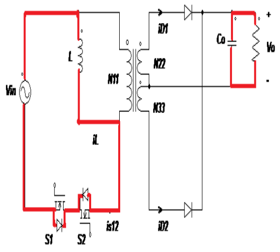
current stress of both the secondary diodes. In conventional flyback rectifier, there was only one diode in the secondary side. Thus the current stress in that diode is greater than the improved bridgeless flyback rectifier.



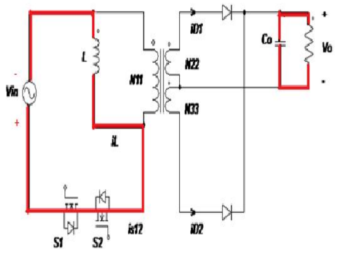
Mode (1)



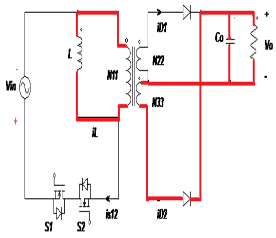
Mode (2)



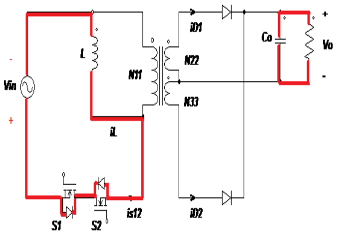
Mode (3)



Mode (4)



Mode (5)



Mode (6)

Fig. 2. Six modes of operations of improved bridgeless flyback rectifier with bidirectional switch.

B. *Modes of Operations*

Before going to the working of improved bridgeless flyback rectifier, there are certain assumptions. Firstly, the transformer leakage inductance is assumed to be zero. Secondly, the circuit is treated as lossless. Based on these assumptions, there are six modes of operations. New bridgeless flyback rectifier operates in constant duty fixed frequency DCM, controlled by voltage mode control. All the six modes are identical to that of conventional flyback converter, except the current flow reverses during the negative half of the input voltage. Fig. 2 shows the equivalent circuit diagram and current flowing path of improved bridgeless flyback rectifier. Mode (1) to Mode (3) occurs when the line voltage Vin is positive. Mode 1 starts when the switches S1 and S2 are turned ON. At this mode, magnetizing inductance L of the transformer stores energy from a non- zero value and the switch current also increases linearly. At the same instant output capacitor Co supply power to the load. Mode 2 starts at the instant when switches S1 and S2 are turn OFF and the inductor will discharges energy from its maximum value. Upper secondary winding (N22) of the transformer carries current through diode D1, Capacitor Co also charges energy at this mode. Mode 3 starts when inductor current reaches the zero value. Current flows through the body diodes and parasitic capacitance of switches and hence energy again builds in the magnetizing inductance. Output capacitor releases its energy to the load at this mode. Mode 4 starts at the start of negative half of supply voltage. From Mode 1 to Mode 3, lower half of the transformer will not carry any current. Modes 4 - Mode 5 are identical to that of Mode 1- Mode 3, except the direction of current flow reverses. Lower windings of the transformer secondary will carry currents in these last three modes. Bridgeless flyback rectifier operates in continuous conduction mode if Mode 3 and Mode 6 are absent.

III. DESIGN AND CONDUCTION LOSS ANALYSIS OF IMPROVED BRIDGELESS FLYBACK RECTIFIER

A. *Design Analysis*

In this proposed bridgeless flyback rectifier, three main design analysis are considered. 1. Transformer turns ratio, 2.Magnetizing inductance of flyback transformer, 3.Output capacitance.

1. *Transformer turns ratio*

Three windings of the transformer are denoted as, N11, N22 and N33. N11 denotes the primary winding of the transformer. N22 and N33 are the upper and lower windings of transformer secondary respectively. These secondary side windings has equal number of turns in order to make the voltage gain and frequency response as same for any input line voltage. Transformer turns ratio denoted as n, has the lowest limit as shown by the equation,

$$n \geq \frac{V_{in\max}}{V_o} \text{.............(1)}$$

Where n is defined as n:1:1 = N11 : N22 : N33. Vin,max denotes the maximum instantaneous input voltage and Vo denotes the specified output voltage.

2. *Magnetizing inductance*

Important design criteria for selecting the magnetizing inductance of transformer is that, it should be smaller than a specified value in order to avoid unexpected operation of rectifier during continuous conduction mode. Magnetizing inductance of the transformer can be calculated based on the following equation,

$$L_M = \frac{(V_{in}-1)V_{in}.T^{2}{}_{D\max}}{2.5P_O.T_s} \text{..............(2)}$$

3. *Output capacitance*

The peculiarity of flyback rectifier is the absence of inductor in the circuit. Thus the design of flyback rectifier will be bit easier than other converter design. Because of the absence of the inductor in the output side, filtering action in flyback topology is done only by the output capacitor and the load resistor. One of the main drawbacks of flyback rectifier is that, the size of the capacitor will be larger in order to carry the full load current. In other converters, output current will share by the inductor and capacitor. Output capacitance can be calculated as

$$C_O = \frac{D_{\max} P_o}{f.V_O.\Delta V_O} \text{............(3)}$$

Primary side conduction loss can be expressed as,

Ploss = 2Psw…………..… (4)

Where Psw denotes the conduction loss across the switch.

IV. AVERAGE CURRENT MODE CONTROL

Current mode control is a two loop system and the inductor is hidden in the current control loop. Thus it reduces the complexity of design and gives better dynamic response. Current mode control as usually implemented in switching power supplies actually senses and controls peak inductor current. This will leads to many problems such as poor noise immunity, need of slope compensation and peak to average current error [17]. Peak current mode control is suitable for duty ratio less than 0.5 and is unstable at duty ratio exceeding 0.5. An additional compensating ramp with slope equal to the inductor current downslope is usually applied to overcome this instability. In the case of a buck regulator, the inductor current down slope equals to Vo/L. As the output voltage always constant, compensating ramp is fixed and also it does complicate the design. In the case of a boost regulator inductor current down slope is equal to (Vin-Vo)/L. Here the slope of the compensating ramp will vary with the input voltage. Thus a fixed ramp will provide adequate compensation also over compensate at some times. In average current mode control there is no need for this slope compensation, but there is a limit to loop gain at the switching frequency in order to achieve stability. Peak to average current error is inherent in peak current mode control and is not a serious issue in lower power buck converter. This is because inductor ripple current is much smaller than the average full load inductor current and the outer loop soon eliminates this difference. In high power buck regulator peak to average current error is more serious as it causes distortions in the input current. Large size inductor is usually needed to decrease the input distortion which again decreases the noise immunity. In conventional peak current mode control, it senses the output inductor current and is suitable for buck converter where the inductor is in the output side. In the case of boost and flyback converter inductor is not in the output side and the wrong current is controlled. In boost topology with its inductor in the input side is suited with input current control but it is not suited for buck and flyback topology. Disadvantages of peak current mode control can be eliminated by average current mode control. It employs a high gain current error amplifier in to the current loop. Average current mode control can sense current in any circuit branch. Converter topology here adopted is the flyback. Hence we can sense input current as well as the output current. Control circuit will be very complex in output current sensing. This requires sensing of diode1 as well as diode2 current. Input current of flyback rectifier is sensed and is compared with the reference current. Current reference is obtained by multiplying the output error voltage and a scaled rectified input voltage. Conceptual circuit diagram of the flyback rectifier with average current mode control is shown in figure.3. Switching pulse is generated by comparing the averaged input current with fixed ramp waveform. High gain current error amplifier will average the input current. This control scheme provides better regulation as well as the input voltage follows the input current leads to obtaining better input power factor. Hence this circuit model is used as power factor correction method. Input and output voltages are denoted as Vg and V0 respectively. Then the reference current Iref can be expressed as

$$I_{ref} = \frac{v_m \sin\omega t}{k} * V_e \text{..................(5)}$$

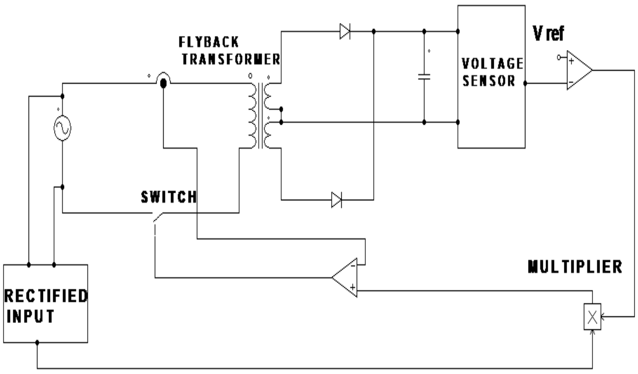


Fig. 3. Schematic diagram of average current mode method for improved bridgeless flyback rectifier with bidirectional switch.

Where Vm is the peak value of input voltage, Ve is the output error voltage and k is the scaling factor. Instantaneous peak switch current ip (t) can be expressed as

$$i_p(t) = I_{ref} - S_e * t_{on} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where Se is the slope of the external ramp and ton is the on- time switches. Integrating operational amplifier configuration will average the input current signal.

V. SIMULATION RESULTS

PSIM simulation program was used to find the performance of voltage mode control of improved bridgeless flyback rectifier with bidirectional switch. The rectifier's performance is analyzed over the line voltage 90- 140 Vrms and the switching frequency is maintained as 40 KHz. The output voltage and maximum output power is specified as Vo=20V and Po,max= 30W. Thus, the turns ratio of the transformer is taken as, n=4.12 in order to attain proper conduction of diodes D1 and D2. The major components and parameters of the converter were presented in Table I. Simulations were done to model a rectifier for using as an adapter with the output ratings as 20V/1.5A. Fig8 and Fig9 shows the line and load regulations of improved bridgeless flyback rectifier. Fig10 shows the input power factor correction.

Table I Specifications of simulation parameters

PARAMETER	SYMBOL	VALUE
Input voltage	Vin	90- 140 Vrms
Output voltage	Vo	20 V
Switching frequency	Fs	40 KHz
Magnetizing inductance	Lm	1.27mH
Capacitance	Co	1.87mf
Turns ratio	N	4.127

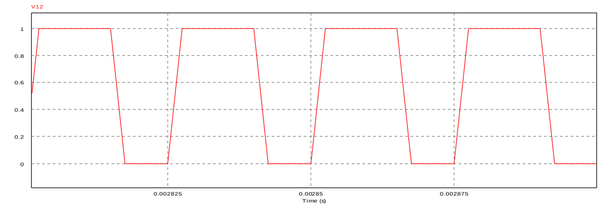


Fig. 4. Switching pulse pattern to switches S1 and S2

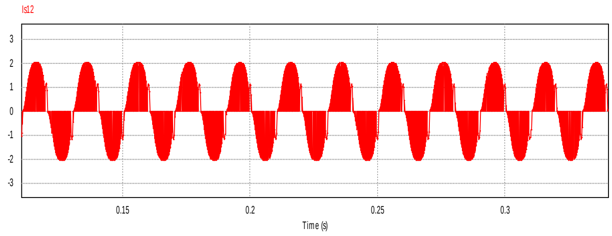


Fig. 5. Simulated waveform of switch current, is12.

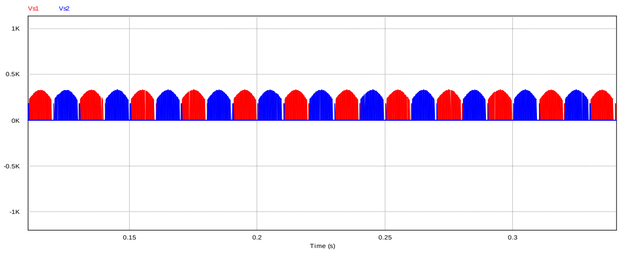


Fig. 6. Simulated waveform of voltage across switches S1 and S2

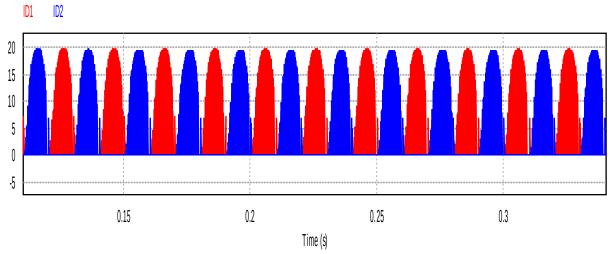
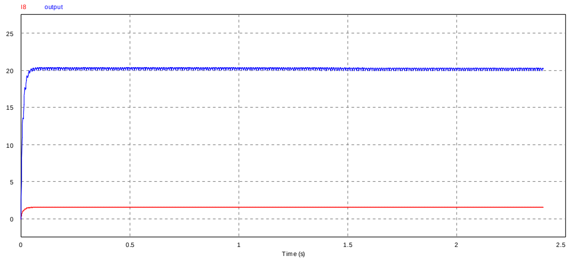
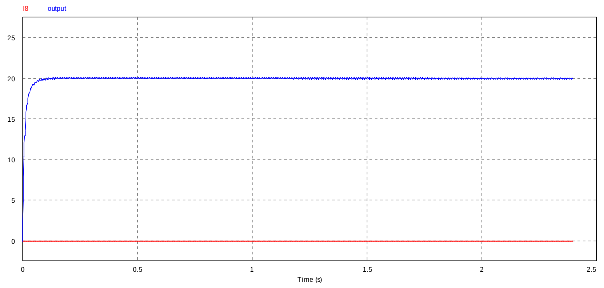


Fig. 7.Simulated waveform of current through diodes D1 and D2.



(a)



(b)

Fig. 8. Load regulation for rated input voltage as 110Vrms (a) for rated load (b) for no load condition.

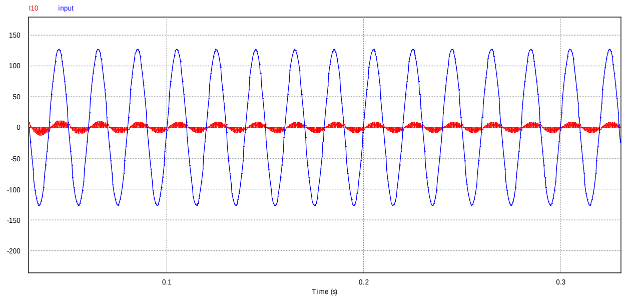


Fig.9.Input voltage and input current (scale factor 4) waveforms showing power factor correction

VI.CONCLUSION

Average current mode control of improved bridgeless flyback rectifier with bidirectional switch is introduced in this paper. Improved bridgeless flyback rectifier completely eliminates the fours bridge diodes from the input side and a bidirectional switch cell is added to primary side. Elimination of four diodes decreases the conduction loss, thus improves efficiency of the converter. Transformer secondary is a dual output winding type and hence decreases the average current stress in the output diodes. This bridgeless flyback rectifier topology is designed to works as an adapter with output ratings as 20V/1.5A. Among various types of current mode control, average current mode control is most suitable control method for flyback topology, which senses the input current and regulate output voltage without slope compensation. Average current mode control gives better noise immunity and eliminates the problem of peak to average current error. Current mode control of improved bridgeless flyback rectifier attains input power factor correction by following the input voltage with respect to input current. MOSFET bidirectional switch can be replaced with an IGBT switch for high power applications.

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