Review of Soft Switched Flyback Converters

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***Abstract*—Fly back converters are widely used in different low power domestic and industrial applications due to its simple structure and low component count. It is desirable that modern power electronic converters must have features like reduced size, high power density, high efficiency etc. By employing soft switching cells to existing converter structure, performance of the converter can be improved significantly. Soft switching enables converters to reduce switching loss and also enables the converter to operate at very high frequency. This facilitates reduction in size and volume of the converter, which improves power density and efficiency of the converter. This paper reviews detailed study of different soft switched fly back converters topologies to improve performance of the converters.**

***Keywords*— Flyback converters , Zero Voltage Switching (ZVS), Zero Current Switching (ZCS), Snubber circuit, Soft switching**

I.INTRODUCTION

DC-DC converters are widely used in numerous applications. Reduction in converter size, weight and increase in efficiency are of main concern. Flyback converters among all DC-DC converters are widely used in low power applications [8-9] due to its simplicity, low component count, less control complexity. Flyback converters mostly suffer from the drawbacks such as low power conversion efficiency, high voltage spike of the main switch during turn off. To overcome these issues generally active clamping [1, 5 ,6] and soft switching [2- 6] methods are employed. Active clamping methods is generally used to reduce voltage spike across the main switch at turn off whereas soft switching methods reduce the switching losses of the converters significantly, which enables the converters to operate at very high frequency. This high frequency operation leads to reduction in converters size, weight and improves power density [2—4]. In many literature different soft switched flyback converters topologies such as ZCS operated flyback converters [4], ZVS operated flyback converter [2], ZVZCS flyback converter [3] have been presented.

This paper presents an overview of different soft switched flyback converter topologies with their detailed operating principles with their merits and demerits.

II. REVIEW OF DIFFERENT SOFT SWITCHED FLYBACK CONVERTERS

A. Transformer Assisted ZVS Scheme for Flyback Converter [1]

There is a trend to operate the power supplies at high switching frequencies because of the high power density required. However, high switching frequency will bring high switching losses and lower the conversion efficiency. Soft switching techniques are normally employed to resolve this problem. The zero voltage switching (ZVS), as a type of soft switching.

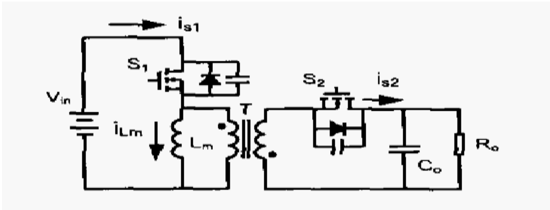

Figure 1 One type of ZVS flyback converter is a secondary side regenerating flyback converter [1]

Magnetizing current of transformer is controlled bi-directional (positive and negative). The magnetizing current of the transformer and the current flowing through S1 and S2 are shown in the waveform below.

OPERATIONAL PRINCIPLE:

T is an auxiliary transformer; The magnetizing inductance of it is far smaller than that of main transformer

Stage 1:

Switch S_1 is on, switch S_2 and diode D is off. The magnetizing inductance L_m, is charged linearly just as normal flyback operation.

Stage 2:

When S_1 is turned off, the diode D is forward biased, and resonance occurs between the magnetizing inductance Lm, and snubber capacitors (C_{r1}, C_{r2},). Hence C_{r1} is charged and C_{r2} is discharged at a time.

Stage 3:

At this time the voltage across C_{r2} becomes zero and the anti-parallel diode of S_2 begins to conduct.

Stage 4:

S_2 is turned on at zero voltage, and it begins to carry current. As the magnetizing inductance L_{mr} is comparatively small, its current decreases much faster than that of L_m. i_{Lmr} reduces to zero, then increases in opposite direction. When i_{Lmr} becomes ($i_{Lm,\ min}$) S_2 is turned off . The i_{min} is set by controller so as to make the energy stored in L_{mr} is

Stage 5:

S_2 is turned off which makes resonance to occur between the magnetizing inductance L_{mr} and snubber capacitors (C_{r1}, C_{r2}). Once again it returns to stage 2 & again Capacitor C_{r1} is discharged while C_{r2} is charged.

Stage 6 :

The voltage across C_{r1} becomes zero and the anti-parallel diode of S_1 begins to conduct.

The current in magnetizing inductance L_{mr}, increases very During fast at this stage.

Stage 7 :

Here S_1 is turned on at zero voltage, and current is being carried by it . In this interval, the current in magnetizing inductance L_{mr} still increases very fast, and finally it will be equal to iLm so that the current i_D becomes zero. & hence diode is off . The magnetizing inductance L_m and L_{mr}, begin to linearly charge again.

Strength:

- Soft switching of switching devices.
- Reduced Voltage spikes.
- High frequency operation which reduces the filter size.
- large ripple in the magnetizing current (also in the current flowing through S1and S2).
- A high ratio of the leakage inductor to magnetizing inductor of transformer.
- A very high loss of leakage inductor is generated which in turn will lower the efficiency.
- It needs large filter parameters.
- Since all output filter capacitors have Equivalent Series Resistor (ESR), large ripple current will be generated hence high loss in the capacitors. Thus for good efficiency the magnetizing current must have low ripples.

Weakness:

Control complexity.

- More magnetic materials are used.
- Use of conventional transformer increases the no load loss hence use of electronic transformer can improve the efficiency and the overall performance for the low power application.

B. Operation principle of the ZVS-PWM flyback dc/dc converter with a simple auxiliary circuit [2]

The power stage diagram of the proposed ZVS-PWM flyback dc/dc converter is shown The circuit can be divided in two sections. The first section is a conventional flyback converter. It is contains switch Sm, diode D_1, an isolated transformer, and output filter capacitor C_o. L_m and L_S are the magnetizing inductor and leakage inductor of the isolated transformer, respectively. This section performs the operation of the conventional flyback dc/dc converter. Another section is a ZVS-PWM commutation cell to provide the zero-voltage-switching on all semiconductors in the circuit of the first section **[1].** It is composed of the auxiliary diodes D_2, D_3, the resonant inductors L_r, the resonant capacitors C_r, and auxiliary switch S_a, which are of small ratings.

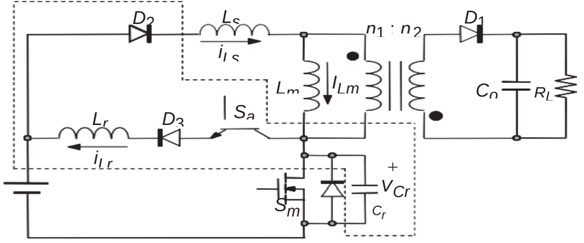

Fig2 ZVS-PWM flyback dc/dc converter with a simple auxiliary circuit [2]

It is considered that ZVS-PWM flyback converter is operating in a steady-state.

Assumptions made in one cycle.

1. Ideal components and device.
2. $L_m >>> L_r$.
3. o/p capacitor is high enough to have ripple free output voltage.
4. Input voltage is const.
5. Initially at t=to resonant voltage $V_{cr(t)} = V_{cro}$

OPERATIONAL PRINCIPLE:

Stage 1:

At t = t_0, the switches S_m and S_a were in turn-off state.

The energy stored in magnetizing inductor L_m is delivered to output filter capacitor C_o and load through ideal transformer and diode D_1.

Sa is turned on with ZCS at t=t_o

L_m and capacitor C_r is started following the path of V_{in}, C_r, S_a, D_3, and L_r. The energy stored in magnetizing inductor L_m is delivered to output. Thus, the resonant current $i_{Lr}(t)$ is increased and the resonant voltage $v_{Cr}(t)$ is decreased and the diode D_2 is turned on and this stage is ended here.

Stage 2:

It is intended that the supply of energy from the magnetizing inductor L_m is delivered continuously to the output terminal in this stage. Hence the voltage across the magnetizing inductor L_m is a constant voltage source nV_o. Diode D_2 is turned on which makes resonant circuit by D_2, L_s, nV, V_{in}, C_r, S_a, D_3, and L_r. The current $i_{Ls(t)}$ on the leakage inductor is increased. When the resonant voltage $v_{Cr(t)}$ is dropped to null, the body diode of the switch S_m is naturally turned on and this stage is finished.

Stage 3:

when the resonant voltage $v_{Cr(t)}$ is dropped to null this stage is started and the body diode of the switch S_m is naturally turned on. the voltage across switch S_m switched to zero by its body diode in this stage, it is the best time to turn on the switch Sm under zero-voltage switching condition.

Hence ZVS switching is achieved

The leakage inductor L_s is linearly charged by voltage source Vin+nVo and the current $i_{Ls(t)}$ is linearly increased.

The resonant inductor L_r is linearly discharged by V_{in} hence resonant current $i_{Lr(t)}$ also decreases and finally. D_3 is turned off and this stage is ended.

Stage 4:

As $i_{Lr(t)}$ is dropped to null, the diode D_3 does not allow resonant inductor to discharge via input voltage source Vin. Therefore, the current through main switch Sm is blocked at zero by the diode D_3 in this stage and hence once again ZCS is achieved & it is the high time to turn off the auxiliary switch Sa under ZCS condition **[4]**

Stage 5:

In this stage, the magnetizing inductor Lm and the leakage inductor Ls are linearly charged Vin. Hence it operates as the conventional PWM flyback dc/dc converter operating at turn-on state.

Stage 6:

In this stage the switch Sm is turned off as the voltage across resonant capacitor cannot be changed instantly, the voltage across the switch Sm equals to zero and the switch Sm turs off and hence ZVS is achieved

In this stage i_{Lm} charges the resonant capacitor Cr and the resonant voltage $v_{Cr(t)}$ is linearly increased and diode D_1 is turned on.

STAGE 7:

As D_1 turns on, the energy stored in magnetizing inductor Lm supplies the output terminal again hence, the voltage across magnetizing inductor Lm is equal to nVo as before. The resonance of the Ls and the C_r is started following the path of Vin, Ls, nVo, and Cr. The resonant voltage $v_{Cr(t)}$ is increased and the current $i_{Ls(t)}$ in the leakage inductor Ls is decreased. When $i_{Ls(t)}$ is dropped to zero, the diode D_2 is turned off.

STAGE 8:

The energy stored in magnetizing inductor L_m continuously supplies the output terminal. This operating behavior is the same as the conventional PWM flyback dc/ dc converter operating at turn-off state. After this stage, the circuit operation is returned to the first stage.

Strength:

- Soft switched operation
- Reduced Voltage spikes
- High frequency operation

Weakness:

- Leakage energy can be recovered
- Reverse recovery loss of diodes

C. Full Soft Switching ZVZCS Flyback Converter Using an Active Auxiliary Cell [3]

A soft switching flyback DC-DC converter is shown. The auxiliary resonant cell added to the conventional flyback converter contains a switch (S_2) a diode (D_3), an inductor (L) and two capacitors (C_1 and C_2)[2]

Assumptions:

The non-ideal transformer having a magnetizing inductance, Lm and an ideal transformer.

The Lm inductance is large.

The output filter capacitor, Co is large

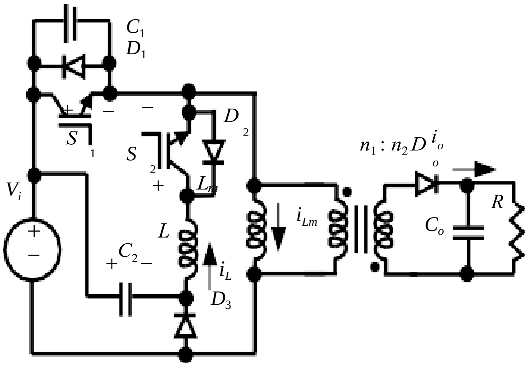

Fig3 proposed soft switching flyback

The features of switches are:

the S_1 switch is operated with a PWM control and S_2 switch is activated only during transition of switch S_1.

OPERATIONAL PRINCIPLE:

Mode 1**:**

The switches of S_1 and S_2 are off, and the energy saved in the magnetizing inductance, L_m is transferred directly to the output through output diode, D_o.

The parameter a is the transformer turns ratio and is determined as n1/n2.

Mode 2:

At the end of the previous stage 1, switch S_2 is on under ZVZCS, since the resonant inductor. In this mode, the L inductor and C_2 capacitor starts resonating

Mode 3:

At the end of mode 2 diode D_3 turns on under ZVZCS. During this mode, the voltage across inductor L achieves a constant value of aVo.

Mode 4:

Do diode turns off under ZCS and L inductor and C_1 capacitor start to resonate. This resonance makes inductor current i_L to increase and V_{c1} decrease.

Mode 5:

the body diode of switch S_1 and D_1, turns on under ZVZCS and the inductor current (i_L) decreases linearly.

Mode 6:

D diode turns off and S1 switch is turned on, both under ZVZCS. The inductor current (i_L) continues to decrease .

Mode 7:

D diode turns off, D_2 diode turns on and S_2 switch is turned off all under ZVZCS.

During this mode, L inductor and C_2 capacitor resonate for half of a resonant period which reverses the polarity of the capacitor voltage (V_{c2}).

Mode 8:

D2 diode turns off under ZCZVS.

Mode 9:

S_2 switch is turned on under ZVZCS. During this mode, L inductor and the C_2 capacitor resonate, makes the inductor current (i_L) and capacitor voltage (V_{c2}) to increase .

Mode 10:

Mode 9 ends when the switch current (i_{S1}) decreases to zero. D_1 turns on under ZVZCS and S_1 switch turns off under ZVZCS.

During this mode, the resonance between L and C_2 makes V_{c2} positive.

Mode 11:

D_1 diode turns off under ZVZCS. During this mode, L inductor resonates with C_1 and C_2 capacitors.

Mode 12:

diode D_3 turns on under ZVZCS. The capacitor voltage (Vc2) is equal to Vi and the inductor current (i_L) decreases and the capacitor voltage (V_{c1}) increases due to the resonance between L and C_1

Mode 13:

D2 diode turns on under ZVZCS, due to the existence of L inductor in the current flow path of this diode, D_3 diode turns off under ZVZCS and switch S_2 can be turned off under ZVZCS.

Mode 14:

D_2 diode turns off under ZVZCS. During this mode, the capacitor voltage (V_{c1})

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is linearly increased by the constant magnetizing inductance current I_{Lm}.

Strength:

- Soft switched operation
- Reduced Voltage spikes
- High efficiency
- High frequency operation ZVZCS switching

Weakness:

- Leakage energy can be recovered
- No consideration of leakage inductance in converter analysis

D. A Novel ZCS-PWM Flyback Converter With a Simple ZCS-PWM Commutation Cell. [4] [7]

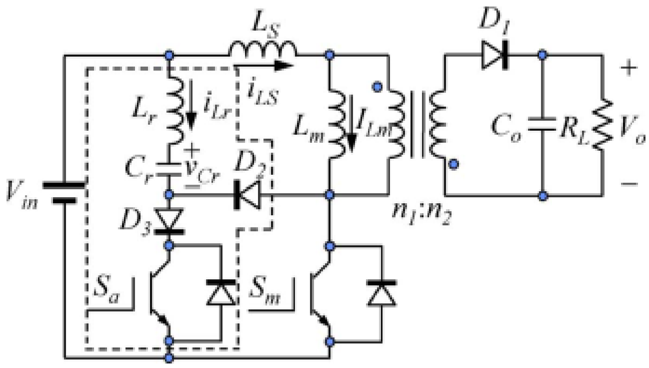

Fig 4 ZCS-PWM Flyback Converter With a Simple ZCS-PWM Commutation Cell [4]

It is composed of an isolated transformer, a switch S_m, a diode D_1, and output filter Co. The second section is a ZCS-PWM commutation cell to provide the ZCS on the switch Sm. It is composed of the auxiliary diodes D_2, D_3, the resonant inductor L_r, the resonant capacitor C_r, and auxiliary switch S_a, which are rated for small power when compared to the output power.

The following assumptions are made during one switching cycle of operation
1) All components and devices are ideal.
2) The magnetizing inductor L_m is large enough to assume that the current I_{Lm} on the inductor L_m is constant [5]
3) The output filter capacitor C_o is large enough so as to assume that the output voltage Vo is constant and ripple-free.
4) Input voltage V_{in} is constant.
Following parameters are defined:
n = n1/ n2
nL = Ls/Lr

Mode 1:
switches S_m and S_a maintain turn-off state. The energy stored in magnetizing inductor L_m is delivered to output filter capacitor C_o and loaded through the ideal transformer anddiodeD1[6].
The stage ends when the current in the leakage inductor L_s reaches I_{Lm} and diode D_1 turns off with ZCS [4]

Mode 2:
$i_{Ls(t)}$ in leakage inductor Ls reaches I_{Lm} and diode D_1 is turned off with ZCS. The magnetizing inductor Lm and the leakage inductor L_s are linearly charged by V_{in}.This achieves a same operating behavior as like a conventional PWM flyback dc/dc converter.
operating at turn-on state.
Mode 3:
Switch S_a is turned on as the initial value of resonant current $i_{Lr(t)}$ is zero, ZCS in auxiliary switch Sa can be achieved. The resonance of resonant inductor Lr and capacitor Cr is started by V_{in}, Lr, Cr, D_3, and Sa.
This state ends when the resonant current $i_{Lr(t)}$ drops to null again.
Mode 4:
In this stage, the resonant behavior in stage 3 is maintained, but the resonant route changes following Vin, Lr, Cr, D_2, and S_m. The resonant voltage $v_{Cr(t)}$ decreases and the resonant current $i_{Lr(t)}$ rises negatively
Mode 5:
As the resonant current $i_{Lr(t)}$) rises to $-I_{Lm}$ and its flow path is changed by Vin, Lr, Cr, D_2, and the antiparallel diode of Sm hence no current flows through the main switch S_m along with the diode D_3 is naturally closed at t = t3 hence no current flows through the auxiliary switch Sa. It is the best time to turn off the switches Sm and Sa under ZCS
Mode 6:
D_1 is turned on with ZCS hence another resonant route is formed via Cr, Lr, Ls, nVo, and D_2. The resonant voltage vCr(t) continuously decreases. The resonant current $i_{Lr(t)}$ rises toward zero the current $i_{Ls(t)}$ in the leakage inductor drops toward zero value. This stage ends when the energies stored in the resonant inductor L_r and the leakage inductor Ls are completely transferred to the resonant capacitor C_r.
Mode 7:
The resonant current $i_{Lr(t)}$ and the current $i_{Ls(t)}$ in leakage inductor Ls equals to zero, and the diodeD_2 is naturally turned off with ZCS. The energy stored in magnetizing inductor L_m is continuously loaded through D_1. This operating behavior is the same as the conventional PWM flyback dc/dc converter operating at turnoff state.
After stage 7, the circuit operation returns to the first stage.

Strength:

- Soft switched operation
- Reduced Voltage spikes
- High efficiency
- High frequency operation ZCS operation of power switches

Weakness:

- Leakage energy can be recovered
- Voltage stress of output diode can be reduced

CONCLUSION:

A detailed study on different soft switched flyback converter topologies have been presented with their merits and demerits. All the topologies were aimed to performed switching transition of the semiconductor switches either in a ZCS or in ZVS condition employing different soft switching cells and active clamping methods .this soft switching cells used auxiliary switch which is also operated under ZCS or ZVS . By doing this converters were operated with very high frequency, which improves converter efficiency, power density and reduces converter size and weight. In addition the leakage energy of flyback transformer was utilized properly or sent to the input side for further improvement of converter efficiency.

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