AN ACTIVE CLAMP BASED TECHNIQUE FOR A HIGH EFFICIENT FLYBACK CONVERTER

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Abstract— **This paper proposes a flyback converter with a new active clamp control method. With the proposed control method, the energy in the leakage inductance can be fully recycled. The soft switching can be achieved for the main switch and the absorbed leakage energy is transferred to the output and input side. Compared to the conventional active clamp technique, the proposed methods can achieve high efficiency both for heavy-load and light-load condition, and the efficiency is almost not affected by the leakage inductance. A Z - source converter network is also included between the converter main circuit and power source to achieve higher efficiency. The detailed operation principle is proposed.**

I. INTRODUCTION

Flyback converters are widely adopted for low-power offline application due to its simplicity and low cost. Usually, an RCD clamp circuit is necessary to dissipate the leakage energy during the switch is OFF. And a well-coupled transformer with minimized leakage inductance is critical to achieve the high efficiency and to minimize the voltage spikes across the switch. How to further improve the efficiency of a flyback converter still challenges the power supply designers.

The first way to improve the efficiency is reducing the leakage inductance energy loss. The conventional RCD clamp circuit absorbed the leakage energy and dissipated it in the snubber resistor. If the leakage inductance is large, the dissipated energy due to part of the magnetizing energy fed to the snubber circuit during the commutation time, which deteriorate the efficiency. The active clamp flyback converter can recycle the energy in the leakage inductor and achieve soft switching for both primary and auxiliary switch. Although it has good performance in efficiency at full-load condition, it is sensitive to parameters variations.

Also, many control schemes are proposed to improve the efficiency of the conventional flyback converter. They mainly focus on how to reduce the switching loss. The efficiency of conventional constant frequency control usually is low due to the high-switching loss caused by high drain to source voltage across the switch. Many variable frequency (VF) control schemes are proposed in the recent years to improve the performance compared to the conventional constant frequency control.This paper presents a flyback converter with a new active clamp control method to achieve soft switching and high efficiency in whole load range, which is quite attractive for low power application with universal ac inputs, such as external adaptors. The power stage is the same as the conventional active-clamp circuit, but the control method and operation principle are different.Flyback derived topologies are attractive because of their relative simplicity when compared with other topologies used in low power applications. Incorporation of active-clamp circuitry into the flyback topology serves to recycle transformer leakage energy while minimizing switch voltage stress. The addition of the active flyback clamp circuit also provides a mechanism for achieving zero-voltage-switching (ZVS) of both the primary and auxiliary switches. ZVS also limits the turn-off di/dtof the output rectifier, reducing rectifier switching losses, and switching noise due to diode reverse recovery.In the proposed control method, the auxiliary switch is turned ON for a short time before the main switch is turned ON. And the recycled leakage energy is used to achieve the soft switching of the main switch, which dramatically reduce the circulating energy compared to the conventional active clamp flyback. Furthermore, the proposed control scheme can be adopted to VF control to reduce the switching loss and improve light-load efficiency.Also, a Z – source converter network, a unique impedance network, is incorporated between the converter main circuit and power source. The Z – source converter is a buck – boost converter that has wide obtainable voltage. Thus, this circuit enables high efficiency at any condition.

In **T. Ninomiya, T. Tanaka, and K. Harada, “Analysis and optimization of a nondissipative LC turn-off snubber”, IEEE Trans. Power Electron,** a nondissipative LC turn- off snubberis proposed to reduce the voltage stress on a switching transistor, which is caused by the energy stored in the transformer

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leakage inductance. The basic characteristics and the turn-off and turn-on transient operations for a buck boost converter with LC snubber was analyzed. It is found that the transformer current increases with the snubber capacitance.

It has the advantage that the power dissipation by snubber resistor is eliminated. But the snubber parameters makes the relative energy relative large during normal operation, which limit the efficiency improvement.

In **R. Watson, F.C. Lee and G. Hua, "Utilization of an active-clamp circuit to achieve soft switching in flyback converters", IEEE Trans. Power Electron,** an active clamp circuitry is incorporated into the flyback topology to recycle transformer leakage energy, while minimizing switch voltage stress. It was found that the addition of a active clamp circuit also provides a mechanism for achieving zero voltage switching of both primary and auxillary switches.

It has the advantage that the turn-off di/dt of the output rectifier is limited, reducing rectifier switching losses, and switching noise due to diode reverse recovery. But it is sensitive to parameters variation and the two switches also increases the cost.

In **Y. K. Lo and J. Y. Lin, " Active-clamping ZVS flyback converter employing two transformers", IEEE Trans. Power Electron,** a two – transformer active clamping ZVS flyback converter which is mainly composed of two active clamping flyback converters is presented. The presented two- transformer active clamping ZVS flyback converter can approximately share the total load current between two secondaries. Therefore, the transformer copper loss and the rectifier diode conduction loss can be decreased.

In **P. Alou, A. Bakkali, I. Barbero, J. A. Cobos, and M. Rascon, "A low power topology derived from flyback with active clamp based on a very simple transformer",** a low power flyback topology with active clamp based on very simple and low cost transformers is presented. The main feature is that the ratio between magnetizing inductance and the series inductance is very low.Here an inductance in series with the transformer is used. The lower the ratio between magnetizing and series inductance, the higher the energy handled by the series inductance. Thus it affects the operation of the flyback with active clamp technology.

In **Y. Panov and M. M. Jovannovic, "Adaptive off-time control for variable frequency, soft switched flyback converter at light loads", IEEE Trans Power Electron,** a control methodology to maintain soft switching at light loads and reduction of switching frequency at light loads is proposed. The soft switching of a flyback converter can be achieved by operating the circuit in the critical conduction mode. But it cannot regulate the output as the load current approaches a zero value.

In **M. T. Zhang, M. M. Jovanovic, and F. C. Lee, "Design considerations and performance evaluations of synchronous rectifications in flyback converters", IEEE Trans. Power Electron,** performance comparisons of various implementations of flyback converter with a synchronous rectifier is presented. Specifically, the merits and limitations of the CF CCM, CF DCM, VF DCM, and zero voltage switched DCM flyback converters with synchronous rectifications were discussed.It is obtained that the variable frequency discontinuous conduction mode flyback converter implementation is most suitable for synchronous rectification. It has the disadvantage of increased conduction loss and circulating energy.

In **D. Fu, Y. Liu, F. C. Lee, and M. Xu, "A novel driving scheme for synchronous rectifiers for LLC resonant converters", IEEE Trans. Power Electron,** a novel synchronous rectifier driving scheme for resonant converters is proposed. In this paper, an LLC resonant converter with the proposed synchronous rectification is analyzed. It is suitable for high frequency, high efficiency and high power density. It is not suitable for wide input range operation. The driving scheme eliminates the reverse recovery problem of synchronous rectifiers.

In **D. Fu, Y. Liu, F. C. Lee, and M. Xu, "An improved novel driving scheme of synchronous rectifier for LLC resonant converters",** an improved novel synchronous rectifier driving scheme for resonant converters is proposed, which is suitable for high frequency, high efficiency and high power density dc-dc resonant converters with synchronous rectifications.With this scheme synchronous rectifier body diode conduction is almost reduced to none. Both the current and voltage stresses are greatly decreased. Also, conduction loss and switching loss of synchronous rectifiers are considerably reduced.

In **C. T. Choi, C. K. Li, and S. K. Kok, "Control of an active clamp discontinuous conduction mode flyback converter", in Proc. IEEE Power Electron,** design of an active clamp discontinuous conduction mode flyback convert er (ADCMFC) is presented with the emphasis on output efficiency. The control of such a converter using PI, PID had been explored.

Although it has good performance in efficiency at full-load condition, it is sensitive to parameters variation. The variation of leakage inductance and snubber capacitor affects the conduction angle of the secondary-side rectifier, which lowers the efficiency.

II. EXISTING METHOD

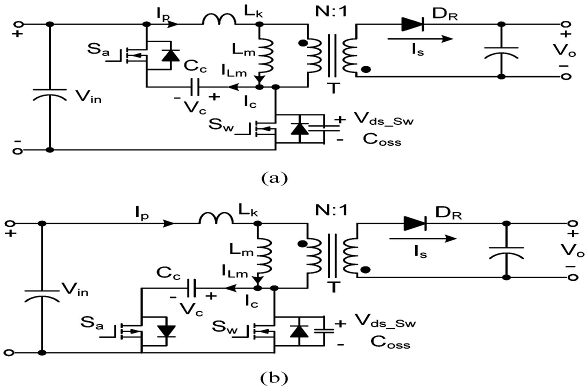


Fig. e Topology of the active clamp flyback converter. (a) N-type clamp circuit. (b) P-type clamp circuit

Fig. shows the circuit configuration of the proposed active clamp flyback converter. L_m is the transformer magnetizing inductance N and L_k is the transformer leakage inductance. S_W is the primary main switch, and D_R is the output rectifier diode. Auxiliary switch S_a can be a NMOS or PMOS, as shown in Fig. 3.2. C_{oss} is the equivalent parasitic capacitance of S_w, S_a, and the parasitic winding capacitance of the transformer. The transformer turns ratio is N. The output voltage is V_o.

To simplify analysis of the steady-state circuit operation, the clamp voltage is assumed to be constant. The theoretical waveforms at discontinuous conduction mode (DCM) and continuous conduction mode (CCM) operation are shown in Fig. 3.2.2. The N-type in DCM operation is used as example, the steady-state waveform and equivalent circuit are shown in Figs. 3.2.2(a) and 3.2(a), respectively. Each operation mode is described next.

MODE 1 [t0–t1]: In this mode, primary-side switch S_w is ON and the auxiliary switch S_a is OFF. The energy is stored to the magnetizing inductor and the primary-side current I_p increases linearly, which is the same as the conventional flyback converter.

MODE 2 [t1–t2]: At t_1, when S_w turns OFF, C_{oss} is charged up by the magnetizing current. Due to relative large magnetizing inductance, the drain–source voltage V_{ds_Sw} of main switch S_w increases linearly. This mode ends when the drain–source voltage V_{ds_Sw} reaches the input voltage V_{in} plus the clamp voltage V_c, i.e., $V_{in} + V_c$. Due to the large clamp capacitor, there is no parasitic ring or voltage spike, which helps to reduce the EMI noise and the voltage rating of S_w. During this mode, the secondary-side rectifier D_R may turn ON, which depends on the clamp voltage V_c and the ratio of the leakage inductance and the magnetizing inductance, i.e., $m = L_k/L_m$. Once the clamp voltage

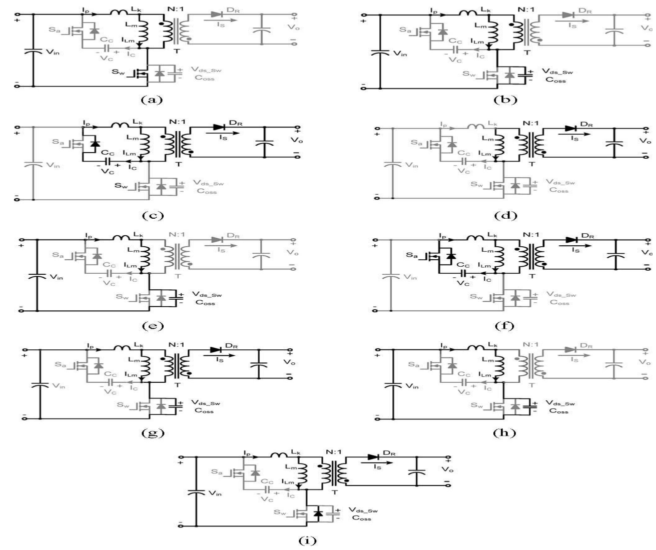


Fig f Equivalent circuits in steady-state operation.

(a) Mode 1 [$t0$ –$t1$](b) Mode 2 [$t1$ –$t2$](c) Mode 3 [$t2$ –$t3$] (d) Mode 4 [$t3$ –$t4$] (e) Mode 5 [$t4$–$t5$] (f) Mode 6 [$t5$ –$t6$] (g) Mode 7 [$t6$ –$t7$] (h) Mode 7B [$t6$ –$t7$] (i) Mode 8 [$t7$ –$t8$].

V_c is larger than $(1 + m)NV_o$, the secondary-side rectifier diode D_R turns ON firstly, and then, the leakage energy keeps to charge up the parasitic capacitor C_{oss}. If the V_c is smaller than $(1 + m)NV_o$, the clamp voltage may charges up, once the Vc reaches $(1 + m) NV_o$, the secondary-side rectifier D_R turns ON.Based on the aforementioned assumption, here we simply assumed that the V_c is almost equals to $(1 + m)NV_o$. Once the V_{ds_Sw} reaches $V_{in} + V_c$, the secondary-side rectifier D_R also turns ON.

MODE 3 [t2–t3]: At t_2, the voltage V_{ds_Sw} reaches $V_{in} + V_c$, the antiparalleled diode of Sa turns ON and the secondary-side rectifier D_R also turns ON. The energy stored in the magnetizing inductor starts to deliver to the output. And the energy in the leakage inductor is absorbed by the clamp capacitor. This mode can be treated as a primary to secondary commutation period. If the clamp capacitor is large enough and the circuit is lossless, the leakage inductor current I_p decreases linearly. Otherwise, the current may decay like a transient in a two-order circuit. During this mode, the difference between the magnetizing current and primary current is delivered to secondary side. As soon as the current in the leakage inductor reaches zero, this mode is finished. And all the magnetizing current is transferred to the secondary side, though part of them is absorbed by the clamp capacitor during this mode.

MODE 4 [t3–t4]: At t_3, the current through leakage inductance is zero and the antiparalleled diode of S_a is OFF. The magnetizing energy is delivered to the load as conventional flyback converter and the magnetizing current decreases linearly.

MODE 5 [t4–t5]: At t_4, magnetizing current decreased to zero, and D_R turns OFF. A parasitic resonance occurs between L_m and C_{oss} as conventional flyback at DCM condition.

MODE 6 [t5–t6]: At t_5, auxiliary switch S_a is turned ON. The voltage across the magnetizing inductance L_m and leakage inductance L_k is clamped to V_c, and secondary winding is forward-biased, so D_R is ON. The current through L_k increases reversely. The magnetizing current I_{Lm} increases reversely too, but the magnitude may be smaller than the leakage current. These negative current is used to achieve ZVS of main switch S_w. The absorbed leakage energy in Mode 3 is transferred to the output side and the leakage inductor again. The auxiliary switch ON time determines the circulating energy and clamp voltage.

MODE 7 [t6–t7]: At t_6, the auxiliary switch S_a turns OFF. The negative current I_p discharges the parasitic capacitor C_{oss}. If the leakage energy is larger than the energy in the parasitic capacitor C_{oss}, the secondary D_R keeps ON, the difference between I_p and I_{Lm} is fed to the secondary side.Once the leakage energy is smaller than the parasitic capacitor, the magnetizing inductor also helps to realize the soft switching. As soon as the leakage inductor current Ip reaches I_{Lm}, the secondary D_R is OFF, and both the magnetizing inductor and the leakage inductor discharge C_{oss}, as shown in Fig. 3.2.1(h) (referred as Mode 7B).

MODE 8 [t7–t8]: At t_7, the output capacitor C_{oss} voltage decreased to zero and the antiparallel diode of main switch S_w turns ON. If the leakage inductor current I_p is still larger than I_{Lm}, the equivalent circuit is shown in Fig. 3.2.1(i). If the leakage inductor current I_p reaches I_{Lm} during Mode 7, the equivalent circuit is same as Fig. 3.2.1(h). The primary-side switch S_w should be turned ON before the primary current I_p changes the polarity.

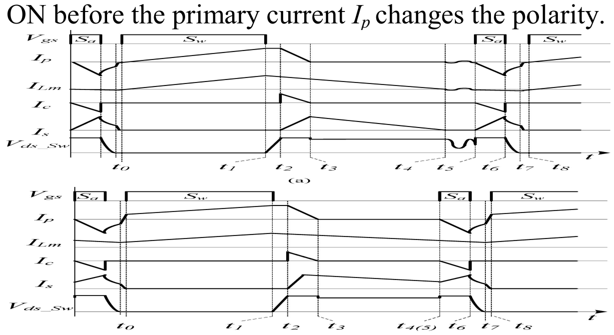


Fig. g Steady-state operation waveforms with proposed control method.

(a) DCM operation. (b) CCM operation.

For CCM condition shown in Fig. 3.2.2(b), Mode 5 does not exist anymore, and other modes are almost the same as those described earlier. Also, due to CCM operation, only the leakage energy can be used to achieve ZVS.

Based on the aforementioned description, the proposed circuit can be applied to any control scheme to recycle the leakage energy, such as CF or VF.

ADVANTAGES

- High efficiency.
- Soft switching.
- Reduced switching stress.

DISADVANTAGES

- the larger dead time will results in low-equivalent switching frequency, which will deteriorate the overall efficiency.
- increasing the auxiliary switch ON time helps to increase the negative magnetizing current to help ZVS operation, and it causes extra conduction loss.

III. PROPOSED METHOD

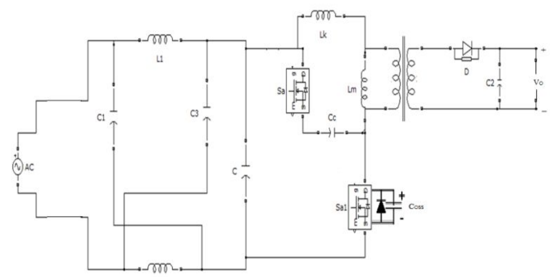
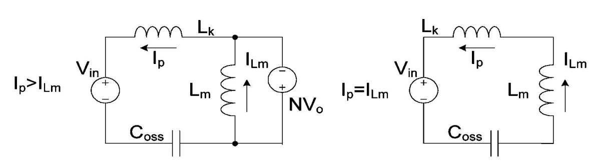


Fig. h. Schematic of a Z-source converter based flyback converter

A Z – source converter based flyback converter will improve the efficiency of a conventional flyback converter. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source (or voltage-fed) and current-source (or current-fed) converters where a capacitor and inductor are used, respectively.

Condition for achieving ZVS operation:

During the switching transient, i.e., Mode 7, a more simple equivalent circuit is shown in fig.



(a)

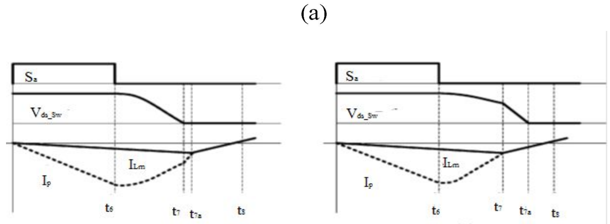


Fig i Switching transient with large and small leakage energy for ZVS.

(a) Simplified equivalent circuit for Mode 7 (b) Large leakage energy (c) Small leakage energy

In this mode, the leakage inductor current *Ip* value decreases. If the leakage energy E_{Lk} is larger than the parasitic capacitor energy E_{Coss}, the ZVS operation of primary switch S_w can be achieved easily:

$$E_{Lk} = \frac{1}{2} L_k \, Ip\_neg^2 \geq E_{Coss} = \frac{1}{2} C_{oss} \, (Vin + NVo)^2$$

where, I_{p_neg} is the peak negative current and the value is related to the load condition.

More detailed transient waveforms is shown in Fig. if $E_{Lk}>E_{Coss}$. Once the drain–source voltage V_{ds_Sw} of main switch reaches zero, the leakage current drops fast due to the voltage applied to L_k becomes $V_{in} + NV_o$. When leakage current I_p reaches the magnetizing current I_{Lm}, both of them increase linearly through the antiparalleled diode of main switch S_w, as shown in Mode 8 of Fig. 3.2.1. Under DCM operation or critical DCM operation (available for almost all VF control schemes), the magnetizing current increases reversely (secondary-side rectifier diode D_R is ON) during Mode 6 and Mode 7.

The ZVS of S_w can be maintained even E_{Lk} is smaller than E_{Coss} due to the magnetizing energy E_{Lm}, which helps to realize ZVS of *Sw*, as shown in Fig. 3.3.1(c).

The expression is shown as follows:

$$\frac{1}{2} L_k \, Ip\_neg^2 + \frac{1}{2} L_m \, Ilm\_neg^2 \geq 1/2 C_{oss} \, (Vin + NVo)^2$$

where, I_{Lm_neg} is negative peak value of magnetizing current, which is proportional to the peak current (load condition) and circulating energy.

- High efficiency at light load and full load condition.
- Low switching stress.
- Soft switching operation.
- Suitable for low – power offline applications.
- Suitable for low ripple current operation.

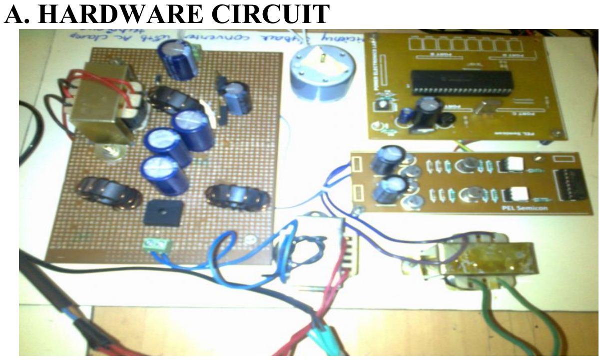
IV. HARDWARE WORKING

230 V AC supply is given as input supply and it is step down to 24V using a step – down transformer. This 24 V is fed to the control circuit. The control circuit consists of a rectifier, filter circuit, IC voltage regulators (LM7805), and PIC Microcontroller (PIC16F877A). The rectifier circuit converts ac voltage to a steady dc voltage, then filtering to a dc level and then regulating to obtain a desired fixed 5V DC. The PIC microcontroller is operating at 5V DC to generate pulses for the switches. The pulses generated from PIC will be given to the two switches as gate pulses. The switches used here are MOSFET (IRF840).

This pulses will be given to the main circuit through a driver circuit. The driver circuit consists of a buffer amplifier (OP-07C/301/T), optocoupler (MCT2E), and a TTL circuit. The pulses from PIC will be divided into two using the buffer amplifier. Then the optocoupler uses a beam of light to these pulses. Optocouplers are used where signals and data need to be transferred from one subsystem to another within an electronics equipment. This is used mainly for isolation purposes, as source and destination are at different voltage levels, like a microprocessor operating from 5V DC used to control a circuit that is switching at 24V AC. So, it is required to protect microprocessor from overvoltage damage. Relays can course provide this kind of isolation, but even small relays tend to be fairly bulky.

A separate 230 / 24V AC is given to the main circuit which consists of inductors, capacitors, MOSFET, and a step- down transformer. The 24V AC will be fed to the switches as drain – source voltage. The two switches used are auxillary switch and main switch. The auxillary switch will be turned ON for a short time before main switch, and the circulating energy is used to achieve soft switching for the main switch. The output voltage from the circuit, ie, 3V DC is used to drive a DC shunt motor of 12V, 1A, and running at 500rpm.

A. HARDWARE CIRCUIT



B . RESULTS

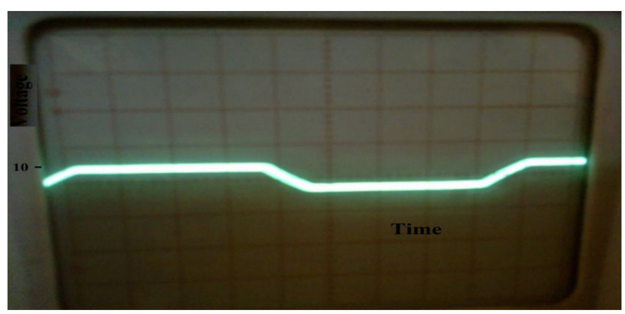


Fig. 4.7.1 Input voltage of active clamp based flyback converter

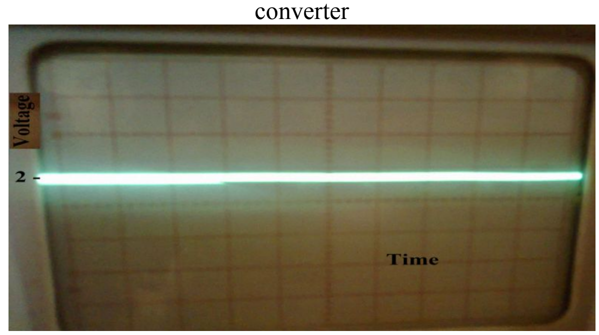


Fig. 4.7.2 Output voltage of active clamp based flyback converter

Sl. No.	Components	Ratings
1	Capacitor	1000µF
2	Inductor	3mH
3	MOSFET	IRF840
4	PIC Microcontroller	PIC16F877A
5	Diode	IN4001
6	Load	12V, 1A, 500rpm DC Shunt Motor

CONCLUSION

This paper proposes a Z - source converter based high efficiency flyback converter with new active clamp control method. The Z-source converter employs a unique impedance network to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source (or voltage-fed) and current-source (or current-fed) converters where a capacitor and inductor are used, respectively. The proposed circuit has very attractive features, such as low device stress, soft switching operation, and high efficiency both for full-load and light-load condition. It can be adopted to various control schemes, such as CF and VF. Also, it is not sensitive to leakage inductance variation. All the advantages make it suitable for low-power offline application with strict efficiency and standby power requirement.

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