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Speed Control Of Separately Excited Dc Motor Using A High Efficiency Flyback Converter With New Active Clamp Technique

M.Subramanyam*, K.Eswaramma**
*(Assistant Professor, Department of EEE, S.V.C.E.T, Chittoor, Andhra Pradesh, India)
** (Professor, Department of EEE, S.V.C.E.T, Chittoor, Andhra Pradesh, India)

ABSTRACT
This paper deals with Speed control of separately excited DC motor using flyback converter with a new non complementary active clamp control method to achieve soft switching and high efficiency for heavy motor load and light load conditions. This is quite attractive for low power application with universal ac inputs, such as external adaptors. With the proposed control technique, 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. In the Proposed model the resistive and DC motor is connected to flyback converter and it is simulated with different nominal voltages and rated speed is controlled at different levels for the N-type active clamp flyback converter and P-type active clamp flyback converter respectively. N-type active clamp flyback converter is suitable for high speed variation applications and P-type active clamp flyback converter is suitable for low speed variation applications.

Key Words- Active clamp, flyback, high efficiency, noncomplementary control, Speed control, separately excited D.C Motor.

I. INTRODUCTION

(a) Active clamp flyback Converter

Fly-back converter is the most commonly used SMPS circuit for low output power applications where the output voltage needs to be isolated from the input main supply. The output power of fly-back type SMPS Circuits may vary from few watts to less than 100 watts. The overall circuit topology of this converter is considerably simpler than other SMPS circuits. Input to the circuit is generally unregulated dc voltage obtained by rectifying the utility ac voltage followed by a simple capacitor filter. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variation. In respect of energy-efficiency, fly-back power supplies are inferior to many other SMPS circuits but its simple topology and low cost makes it popular in low output power range.

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. However, a labour-intensive manufacturing process is required to produce these well-coupled transformers as well as passing the safety regulation. 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 is much larger than the energy stored in the leakage inductance due to part of the magnetizing energy fed to the snubber circuit during the commutation time, which deteriorate the efficiency. The lossless snubber for single-end converter was proposed to recycle the leakage energy, but the snubber parameters makes the circulating energy relative large during normal operation, which limited the efficiency improvement. 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. The variation of leakage inductance and snubber capacitor affects the conduction angle of the secondary-side rectifier, which lowers the efficiency. And the two active switches also increase the cost.

Furthermore, the conventional complementary gate signal and constant frequency (CF) control method result in poor efficiency at light-load condition, which also leads to lower average efficiency. Other topologies with two active switches in half-bridge structure can absorb the leakage energy with pulse width modulation control or resonant control, such as asymmetrical half-bridge (AHB), asymmetrical flyback, or LLC converter, they can achieve soft switching for main switches and high efficiency, but most of them are not suitable for wide input range application as usually required for universal input condition without front-end power factor corrected (PFC) converter. 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.

II. PRINCIPLE OF OPERATION

Fig.1 shows the circuit configuration of the proposed active clamp flyback converter, which is identical for the conventional active clamp flyback. *Lm* is the transformer magnetizing inductance and *Lk* is the transformer leakage inductance. *SW* is the primary main switch and *DR* is the output rectifier diode. Auxiliary switch *Sa* can be a NMOS or PMOS, as shown in Fig. 1. *C*oss is the equivalent parasitic capacitance of *Sw*, Sa and the parasitic winding capacitance of the transformer. The transformer turns ratio is *N*. The output voltage is *Vo*. To simplify analysis of the steady-state circuit operation, the clamp voltage is assumed to be constant.

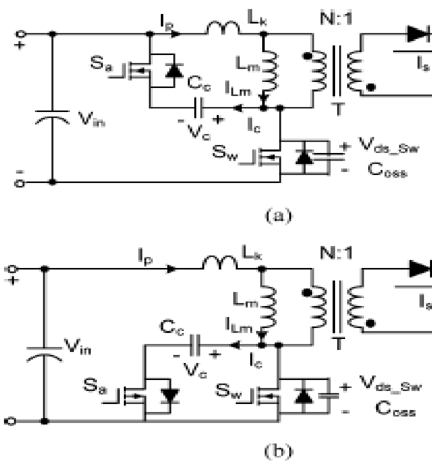

Fig* 1.*Topology of the active clamp flyback converter (a) N-type clamp circuit (b) P-type clamp circuit

Fig. 1 shows the circuit configuration of the proposed active clamp flyback converter, which is identical for the conventional active clamp flyback. *Lm* is the transformer magnetizing inductance and *Lk* is the transformer leakage inductance. *SW* is the primary main switch, and *DR* is the output rectifier diode. Auxiliary switch *Sa* can be a NMOS or PMOS, as shown in Fig. 1. *C*oss is the equivalent parasitic capacitance of *Sw*, *Sa* and the parasitic winding capacitance of the transformer. The transformer turns ratio is *N*. The output voltage is *Vo*. To simplify analysis of the steady-state circuit operation, the clamp voltage is assumed to be constant.

Each operation mode is described next. *Mode 1 [t*0*–t*1*]:* In this mode, primary-side switch *Sw* is ON and the auxiliary switch *Sa* is OFF. The energy is stored to the magnetizing inductor and the primary-side current *Ip* increases linearly, which is the same as the conventional flyback converter. *Mode 2 [t*1*–t*2*]:* At *t*1, when *Sw* 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 *Sw* increases linearly. This mode ends when the drain–source voltage *V*ds *Sw* reaches the input voltage *V*in plus the clamp voltage *Vc* , i.e., *V*in + *Vc* . 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 *Sw* . During this mode, the secondary-side rectifier *DR* may turn ON, which depends on the clamp voltage *Vc* and the ratio of the leakage inductance and the magnetizing inductance, i.e., *m* = *Lk/Lm*. Once the clamp voltage *Vc* is larger than (1 + *m*)*NVo* , the secondary-side rectifier diode *DR* turns ON firstly, and then, the leakage energy keeps to charge up the parasitic capacitor *C*oss. If the *Vc* is smaller than (1 + *m*)*NVo* , the clamp voltage may charges up, once the *Vc* reaches(1+*m*)*NVo*, the secondary-side rectifier *DR* turns ON. Based on the aforementioned assumption, here we simply assumed that the *Vc* is almost equals to (1 + *m*) *NVo,* detailed discussion of clamp voltage *Vc* will be presented in the next section. Once the *V*ds *Sw* reaches *V*in + *Vc*, the secondary-side rectifier *DR* also turns ON. *Mode3 [t*2*–t*3 *]:* At *t*2 , the voltage *V*ds *Sw* reaches *V*in + *Vc* , the antiparallel diode of *Sa* turns ON and the secondary-side rectifier *DR* 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 *Ip* decreases linearly. Otherwise, the current may decay like a transient in a two-order circuit. The detailed expressions will be presented in the next section. 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 [t*3*–t*4*]:* At *t*3, the current through leakage inductance is zero and the antiparalleled diode of *Sa* is OFF. The magnetizing energy is delivered to the load as conventional flyback converter and the magnetizing current decreases linearly.

*Mode 5 [t*4*–t*5*]:* At *t*4, magnetizing current decreased to zero, and *DR* turns OFF. A parasitic resonance occurs between *Lm* and *C*oss as conventional flyback at DCM condition.

*Mode 6 [t*5*–t*6*]:* At *t*5, auxiliary switch *Sa* is turned ON. The voltage across the magnetizing inductance

Lm and leakage inductance *Lk* is clamped to *Vc* , and secondary winding is
Forward-biased, so *DR* is ON. The current through *Lk* increases reversely. The magnetizing current *ILm* increases reversely too, but the magnitude may be smaller than the leakage current. These negative current is used to achieve ZVS of main switch *Sw*. 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. Detailed design consideration will be discussed in the next section.

*Mode 7 [t*6*–t*7 *]:* At *t*6 , the auxiliary switch *Sa* turns OFF. The negative current *Ip* discharges the parasitic capacitor *C*oss. If the leakage energy is larger than the energy in the parasitic capacitor *C*oss , the secondary *DR* keeps ON, the difference between *Ip* and *ILm* 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 *ILm*, the secondary *DR* is OFF, and both the magnetizing inductor and the leakage inductor discharge *C*oss, as shown in

Fig. 2(h) (referred as Mode 7B).

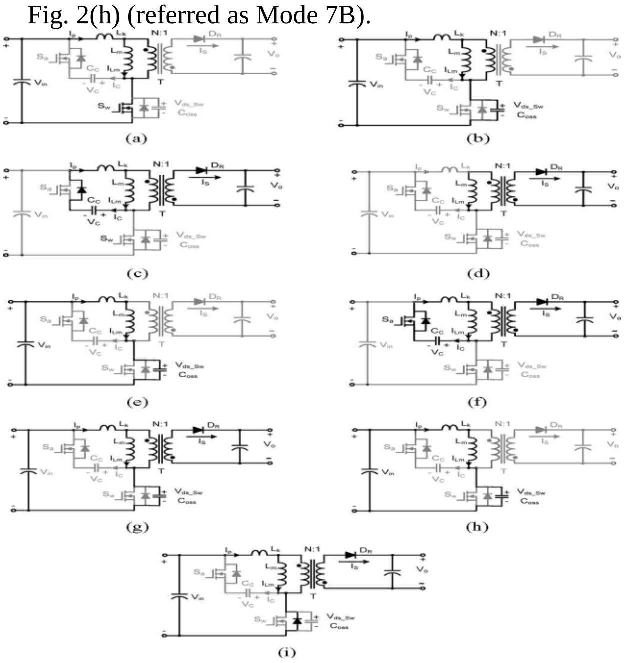

Fig. 2. Equivalent circuits in steady-state operation. (a) Mode 1 [t0 –t1]. (b) Mode 2 [t1 –t2]. (c) Mode 3 [t2 –t3]. (d) Mode 4 [t3 –t4]. (e) Mode 5[t4 –t5]. (f) Mode 6 [t5 –t6]. (g) Mode 7 [t6 –t7]. (h) Mode 7B [t6 –t7].(i) Mode 8 [t7 –t8].

*Mode 8 [t*7*–t*8 *]:* At *t*7 , the output capacitor *C*oss voltage decreased to zero and the antiparallel diode of main switch *Sw* turns ON. If the leakage inductor current *Ip* is still larger than *ILm* , the equivalent circuit is shown in Fig. 3(i). If the leakage inductor current *Ip* reaches *ILm* during Mode 7, the equivalent circuit is same as Fig. 2(h). The primary-side switch *Sw* should be turned ON before the primary current *Ip* changes the polarity.

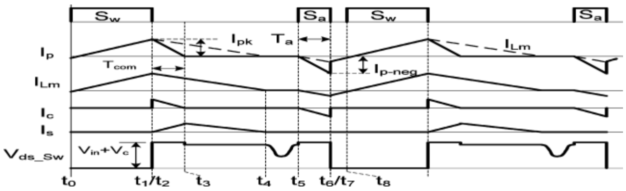

***Fig. 3. Simplified steady-state operation waveforms under DCM*.**

For CCM condition shown in Fig. 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.

IV. EXPERIMENTAL RESULTS

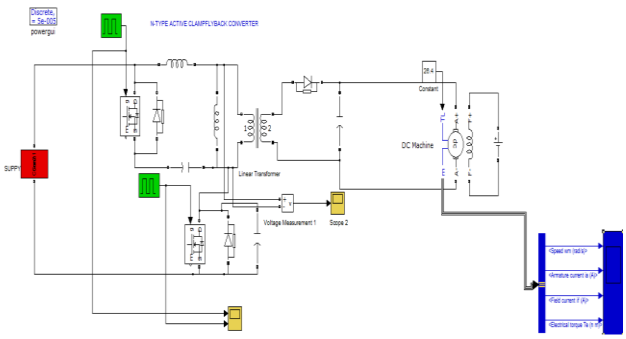

Fig. 4: Simulink circuit for the speed control of separately excited dc motor using N-type active clamp flyback converter

SIMULATION RESULTS FOR SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR USING N-TYPE ACTIVE CLAMP FLYBACK CONVERTER:

The simulation results for speed control of separately excited dc motor using N-type active clamp flyback converter are shown below.

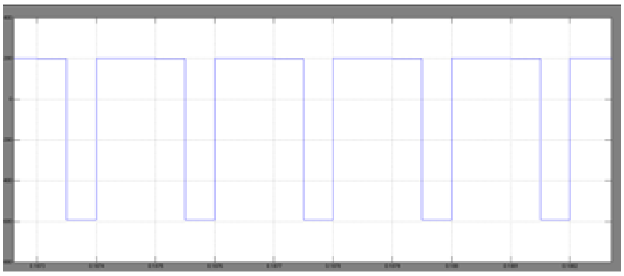

Fig 4.1 represents the results of transformer input voltage for speed control of separately excited dc motor using N-type active clamp flyback converter.

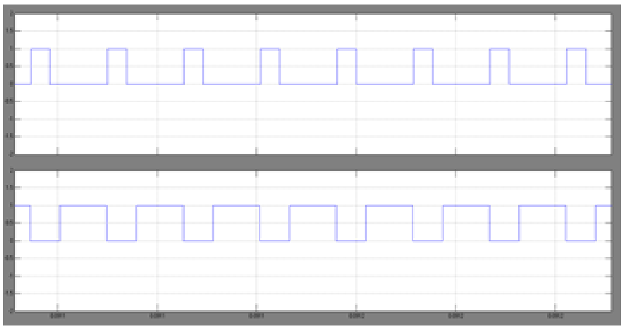

Fig 4.2 represents the results of generation of gate pulses for speed control of separately excited dc motor using N-type active clamp flyback converter.

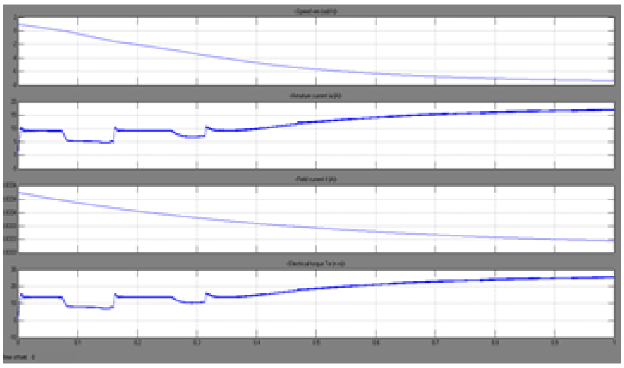

Fig 4.3 represents the results of output for speed control of separately excited dc motor using N-type active clamp flyback converter.

Table No.1

COMPARISON TABLE FOR N-TYPE ACTIVE CLAMP FLYBACK CONVERTER:

S.NO	**INPUT VOLTAGE(V)**	**SPEED N (R.P.M)**	**ARMATURE CURRENT I_a (A)**	**FIELD CURRENT I_f (A)**	**ELECTRICAL TORQUE T_e(N-m)**
1	100	60	5	0.4167	15
2	200	67	10	0.83	25
3	300	87	15	1.2501	35
4	400	1203	21	1.6667	62
5	500	1470	25	2.0834	100
6	600	1537	31	2.50015	149
7	700	1570	35	2.9168	200
8	800	1584	41	3.3335	250
9	900	1604	48	3.7502	310
10	1000	1611	50	4.1669	400

SIMULINK CIRCUIT FOR SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR USING P-TYPE ACTIVE CLAMP FLYBACK CONVERTER:

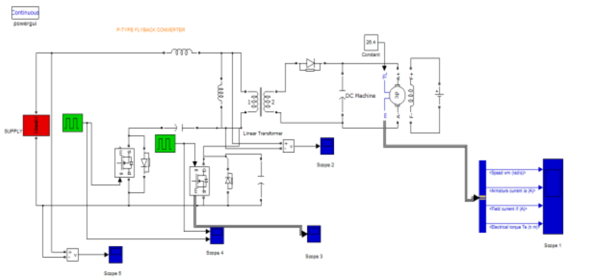

Fig. 5: Simulink circuit for the speed control of separately excited dc motor using P-type active clamp flyback converter

The simulation results for speed control of separately excited dc motor using P-type active clamp flyback converter are shown below:

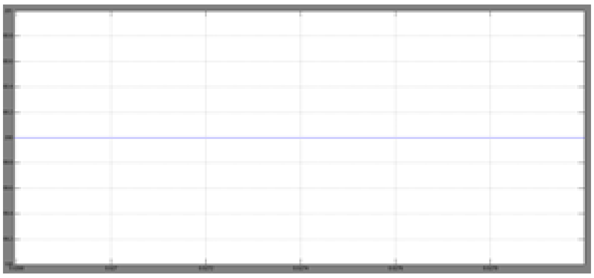

Fig 5.1 Represents The Results Of Input Voltage For Speed Control Of Separately Excited Dc Motor Using P-Type Active Clamp Flyback Converter.

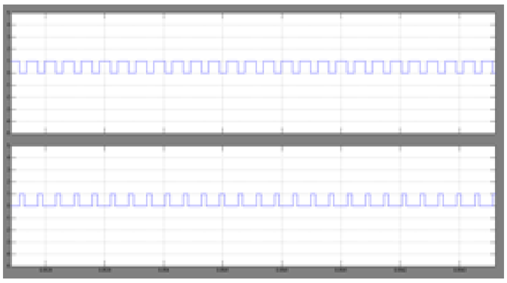

Fig 5.2 Represents The Results Of Generation Of Gate Pulses For Speed Control Of Separately Excited Dc Motor Using P-Type Active Clamp Flyback Converter.

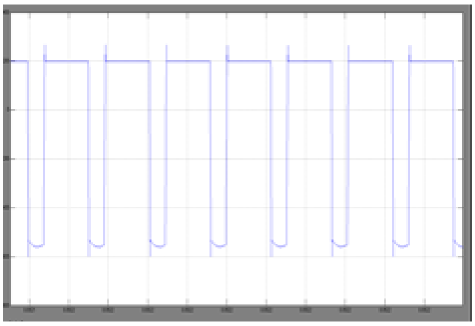

Fig 5.3 Represents The Results Of Transformer Input Voltage For Speed Control Of Separately Excited Dc Motor Using P-Type Active Clamp Flyback Converter.

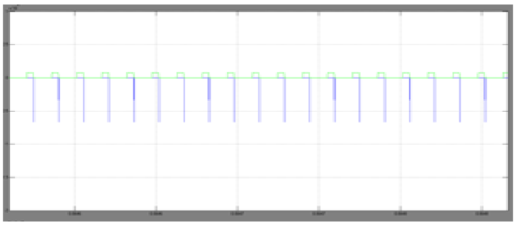

Fig 5.4 represents the results of drain-source voltage of primary main switch for speed control of separately excited dc motor using P-type active clamp flyback converter

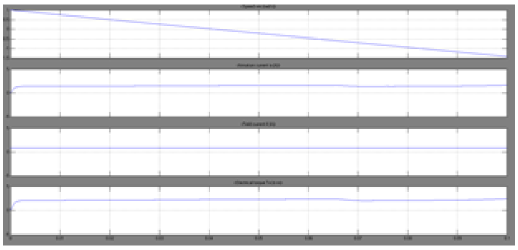

Fig 5.5 represents the results of output for speed control of separately excited dc motor using P-type active clamp flyback converter

Table No.2

COMPARISON TABLE FOR P-TYPE ACTIVE CLAMP FLYBACK CONVERTER

S.NO	INPUT VOLTAGE E(V)	SPEED N (R.P.M)	ARMATURE CURRENT I_a (A)	FIELD CURRENT I_f (A)	ELECTRICAL TORQUE T_e(N-m)
1	100	60	0.8	0.4	0.6
2	200	61	1.6	0.9	2.4
3	300	62	2.1	1.3	5
4	400	64	3.1	1.6	9
5	500	65	4.0	2.1	15
6	600	66	4.5	2.5	20
7	700	67	4.7	2.9	25
8	800	87	5.9	3.3	35
9	900	140	6.2	3.7	44
10	1000	221	7.0	4.1	55

CONCLUSION

This Paper concentrates on Speed control of separately excited DC motor connected to high efficiency flyback converter with new active clamp control method. 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. 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. In the Proposed model the resistive and DC motor is connected to flyback converter and it is simulated with different nominal voltages and rated speed is controlled at different levels for the N-type active clamp flyback converter and P-type active clamp flyback converter respectively. By using N-type active clamp flyback converter the speed of separately excited DC Motor can be controlled. When a DC voltage is applied as an input to the N-type active clamp flyback converter then the same voltage is applied to the Primary of the transformer.

The simulated outputs are obtained for motor load and speed measurements are tabulated as shown in Table No.1. By using P-type active clamp flyback converter the speed of separately excited DC Motor can be controlled. When a DC voltage is applied as an input to the P-type active clamp flyback converter then the same voltage is applied to the Primary of the transformer. The simulated outputs are obtained for motor load and speed measurements are tabulated as shown in Table No.2.In the case of N-type active clamp flyback converter the speed is varied from 60 R.P.M to 1611 R.P.M for the input voltage variation from 100V to 1000V. In the case of P-type active clamp flyback converter the speed is varied from 60 R.P.M to 221 R.P.M for the input voltage variation from 100V to 1000V. N-type active clamp flyback converter is suitable for high speed variation applications and P-type active clamp flyback converter is suitable for low speed variation applications.

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