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Design and Development of Single Input Multi Output Flyback Converter Using Digital Controller

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ABSTRACT : A more efficient method of providing electrical isolation between input and output of a dc-dc converter is to use a transformer in the switching scheme. Flyback converter is one of the popular isolated DC-DC converter topology used to obtain regulated output voltage in low power application. The proposed project is aimed at the design and implementation of a high frequency, multiple outputs in a discontinuous mode with resonant switching for industrial applications.

The converter is operated at a switching frequency of 132 kHz using Digital Controller called Link switch which is a combination of MOSFET and PWM controller. The converter is validated with an experimental setup which delivers three outputs with desired efficiency of 80%. This proposed project is a implementation of single input and multiple output Flyback converter with MOSFET as switching device. Simulation is carried out with input of 120V DC and multiple output of one number of 18V, two number of 7V. The power rating is 30W. The prototype of the proposed converter is built. Prototype was conducted for 120V_{DC}-400V_{DC} input.

KEYWORDS : Flyback, DC-DC converter, Link-switch, Discontinuous mode, Resonant Switching.

I. INTRODUCTION

DC-DC converters are mainly used to provide required output voltage by suitably controlling the pulse width modulated (PWM) signal given to the gate of the acting power electronics switches. The main disadvantage of the basic DC-DC converters (Buck, Boost, Buck-Boost, Spic, Cuk) is electrical connection between the input and output. If the input supply is grounded, that same ground will be present on the output. This is overcome by isolating the output from the input electrically with a transformer. The isolated DC-DC converters are namely: Flyback Converter, Forward Converter, Half Bridge and Full Bridge Converters and Push-Pull Converter.

In case of flyback converter topology, converter stores the energy when the switch is on and delivers energy to the load when the switch is off. This eliminates the need of the additional Inductor for storage of energy unlike in the case of forward, half bridge and full bridge topology. Thus it makes the topology simpler and economical. Flyback is most widely used SMPS topology for low power application from 100W down to under 1W, whenever the output needs to be isolated from the input. Its best features are low system cost, simplicity and relative ease of implementation. For low current output and power levels below 50W, DCM flyback is the usually the preferred operating mode, due to its simpler control loop implementation and lower turn on loss. The flyback converter is a buck-boost with inductor split to form a transformer, so that the voltage ratios are multiplied with additional advantage of isolation. The equivalent circuit of flyback converter is shown in Figure 1.

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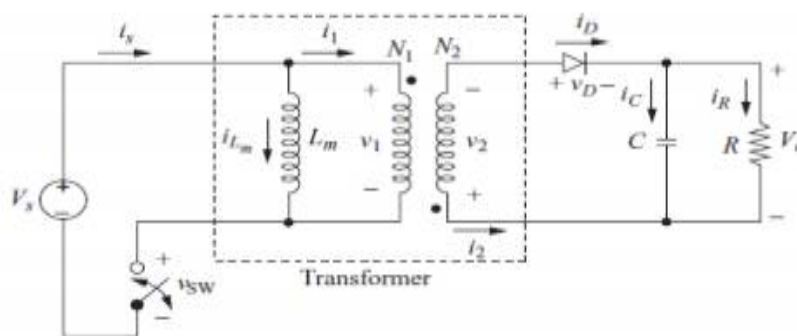


Figure 1: Equivalent circuit of Flyback Converter

A. Difference between continuous and discontinuous conduction Mode Flyback Converter

Continuous conduction mode (CCM)	Discontinues conduction mode (DCM)
<ul style="list-style-type: none"> ➤ In CCM the diodes are not operated at zero current. 	DCM provides better switching conditions for the rectifier diodes, since the diodes are operating at zero current just before becoming reverse biased.
<ul style="list-style-type: none"> ➤ The transformer size can't be reduced using CCM because the average energy storage is high. 	The transformer size can be reduced using DCM because the average energy storage is low.
<ul style="list-style-type: none"> ➤ CCM is preferred for low voltage and high current output applications, because the RMS current is low, which decreases conduction loss of MOSFET and the current stress on the output capacitor. 	DCM is recommended for high voltage and low current output applications, because the RMS current is high, which increases conduction loss of MOSFET and the current stress on the output capacitor.
<ul style="list-style-type: none"> ➤ In CCM fly-back converter, the design process is straight forward since the input-to-output voltage gain depends only on the duty cycle. 	The input to output voltage gain of a DCM fly-back converter depends not only on the duty cycle but also on the load condition, which causes the circuit design to be somewhat complicated.

The main reason for using DCM Flyback converter is that, the stability is easier to achieve because at frequencies less than one half the switching frequency has no net inductance reflected to the transformer secondary, hence no second pole in the input to output transfer function and no right half-plane (RHP) zero appears as no energy is delivered to the output in each cycle which is directly proportional to the switching device on time in DCM case.

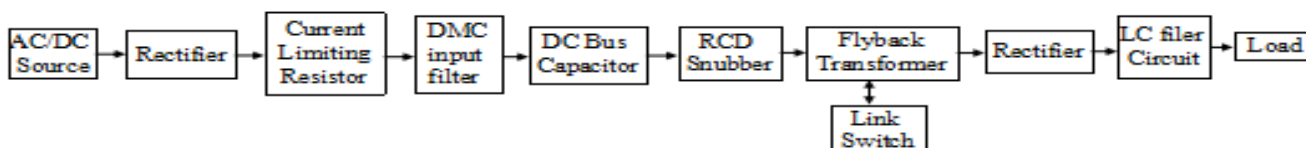


Figure 2. General block diagram

B. Proposed converter general block diagram

The proposed converter general block diagram is shown in Figure 2. AC input of 230V can be taken directly from mains or a DC input is given from a DC jig. A rectifier converts AC input to DC which is an uncontrolled diode rectifier with RC snubber built in a single silicon chip. A fusible current limiting resistor is used to avoid the high

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inrush current during start. Differential mode choke (DMC) input filter is used to neglect the differential noise present in the circuit, these differential noises are usually the commentary signals which cancel out each other and this circuit provides a known impedance at the input. The RCD snubber circuit is used to provide a path for leakage current produced due to leakage inductance usually used to avoid high dv/dt . A Transformer provides electrical isolation between primary and secondary winding. The flyback transformer is designed for an input of 120V to 400V dc with three secondary outputs of 18V, 7V and 7V. The Link switch (LNK6667E) is a digital controller which is an IC integrated with MOSFET as switching device and PWM controller on a single silicon chip. The output rectifier is used to convert the high frequency DC to a constant DC output voltage. A LC low pass Filter is used to filter high frequency components such as ripple and passes low frequency components (DC). The DC outputs are used to supply the load as per the application requirement.

II. MULTIPLE OUTPUT FLYBACK TOPOLOGY

The proposed converter as shown in Figure 3 has a similar operation as that of a conventional flyback converter during ON time of the switch, the energy is stored in the transformer and during OFF time the stored energy is transferred to the secondary circuit. A PWM signal is given to the MOSFET where both MOSFET and PWM controller are integrated on a single chip. This Single chip IC is called Link Switch (LNK6667E) which operates at the switching frequency of 132 kHz. The FEEDBACK pin in the Link switch is used to sense input and output voltage by sensing the auxiliary winding. During MOSFET ON-time the current out of FEEDBACK pin is used to sense the input voltage. During the OFF-time the FEEDBACK voltage is proportional to the output voltage through the turns ratio between the secondary outputs and the FEEDBACK winding. The proposed converter is aimed at output voltages of 18V, 7V and 7V.

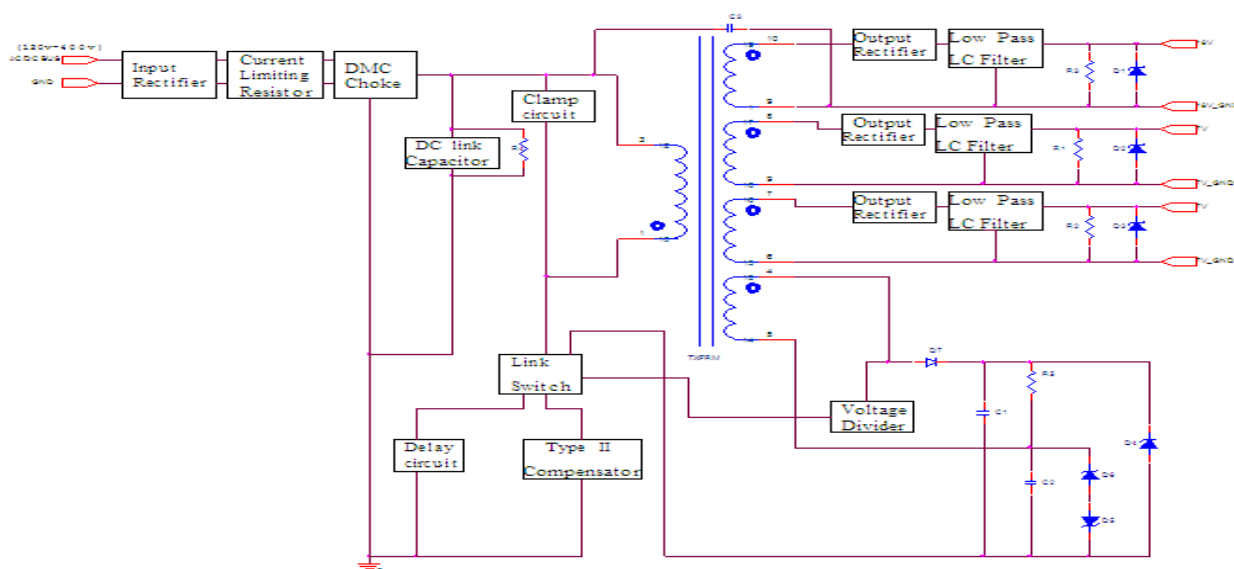


Figure 3: Block diagram of the proposed prototype

III. DESIGN CONSIDERATIONS

Specifications of Flyback converter is provided in Table I. the converter is designed to operate in wide input voltage range of 120V-400V. It has one output of 18V and two outputs of 7V. The digital controller used here is linkswitch LNK6667E. Once the converter operates in the steady state the generated 5.6V output will take care of required bias supply for the controller IC. Thus the output power limited to 30W.

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A. Flyback Converter

Sl.No	Description	Specifications
1	Output power rating	30W
2	Input voltage range	120-400Vdc
3	Switching frequency	132kHz
4	Vout1	18V
5	Vout2	7V (2 no's)
6	Voltage consideration for bias voltage	12V

TABLE I: Flyback converter Parameters

C. Flyback Transformer

Table II Shows the Flyback transformer parameter considered for the designed converter circuit. The transformer design is carried out. During Flyback converter operation, when the switch is on, input dc voltage appears across the transformer primary winding. When the switch is off reflection voltage (V1) can be seen across primary winding of the transformer.

Sl. No	Description	Specifications
1	Primary turns (N ₁)	60
2	Vout1 winding turns (N ₂)	11
3	Vout2 winding turns (N ₃)	4
4	Vout3 winding turns (N ₄)	4
5	Bias winding turns	7
6	Transformer core (EE)	EE 25/13/7

TABLE II: Flyback Transformer Parameters

C. Current Mode Digital Controller

Linkswitch (LNK6667E) Current mode controller mainly used to obtain regulated output voltage with peak current limit capability in offline DC-DC Converter. This is a digital controller switch with combination of MOSFET and PWM controller which gives extensive protection like auto-restart during overload faults, output short circuit protection, accurate thermal shutdown, line over voltage shutdown extends line surge withstanding line brown-in/out protection and in addition to this it has a feedback winding which is used to sense output and input voltage by sensing the auxiliary winding voltage.

$$\text{Conductionloss} = R_{DSon} \times I_{in}^2$$

$$\text{Switchingloss} = V_{DC} \times I_{pk} \times f_{sw} \times T_{fall}$$

$$\text{Totalloss} = \text{Conductionloss} + \text{Switchingloss}$$

D. RCD Clamp Circuit

RCD clamp circuit is a combination of R_{clamp}, C_{clamp} and Diode connected across the primary winding of the transformer. It is used to reduce the high dv/dt across the link switch. Lesser the value of resistor will reduce the spike voltage across the MOSFET but will lead to increase of power loss. But higher value of resistor will reduce voltage spike. Hence the proper selection of resistor is an important criterion. Capacitor value is selected in order to limit the



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rise in voltage by suitably absorbing leakage energy. The voltage rating of diode should be greater than the DC bus voltage.

E. Rectifier Diode and Capacitor Selection

Rectifier diode selection depends on the peak inverse voltage (V_R) across it and output current.

$$V_R \geq 1.25 \times PIV_S$$

Where I_D is the diode rated DC current is the average output current which depends on the thermal rise in duration of peak load condition.

$$I_D \geq 3 \times I_o$$

$$I_o = \frac{P_o}{V_o}$$

Output capacitor selection depends on the ripple current.

$$I_{ripple} = \sqrt{(I_{rms}^2 - I_{av}^2)}$$

With low ESR an electrolytic capacitor is selected.

Output ripple voltage is $I_{SP} \times ESR$ the capacitor rating is increased on the basis of measured capacitor temperature rise under worst case loading and ambient temperature. ESR of the capacitor is multiplied with the secondary peak current to give the switching ripple voltage. Therefore it is important to select the low ESR capacitor to reduce the ripple voltage. Usually, selecting a high ripple current rated capacitor results in a acceptable value of ESR.

IV. SIMULATION

The triple output flyback converter topology is simulated using Orcad Pspice software.

The simulation parameter is shown in the Table III. The simulation model includes linear transformer, VDC Source, Vpulse and SBreak (ideal switch) at the input side. D1, D2 and D3 are the rectifier diodes. C1, C2 and C3 are the output capacitor across the regulated output of Vout1, Vout2 and Vout3 for an DC input of 120V. The PWM pulse required for SBreak is given by the Vpulse with the required duty cycle for the given switching frequency. The simulation circuit is shown in Figure 4 and Simulation results are shown in Figure 5.

Sl. No	Description	Specifications
1	Primary inductance (L1)	60uH
2	Output inductance Vout1 (L2)	11.1uH
3	Output inductance Vout2 (L2)	1.55uH
4	Output inductance Vout3 (L2)	1.6uH
5	VDC Voltage	120V
6	Output Capacitor of Vout1 and ESR	10000uF, 96mE

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7	Output Capacitor of Vout2 and ESR	1000uF, 9.4mE
8	Output Capacitor of Vout3 and ESR	1000uF, 9.4mE
9	Rload for Vout1	32.6E
10	Rload for Vout2	3.2E
11	Rload for Vout3	3.2E
12	Switching Frequency (fsw)	132kHz

TABLE III: Simulation Parameters

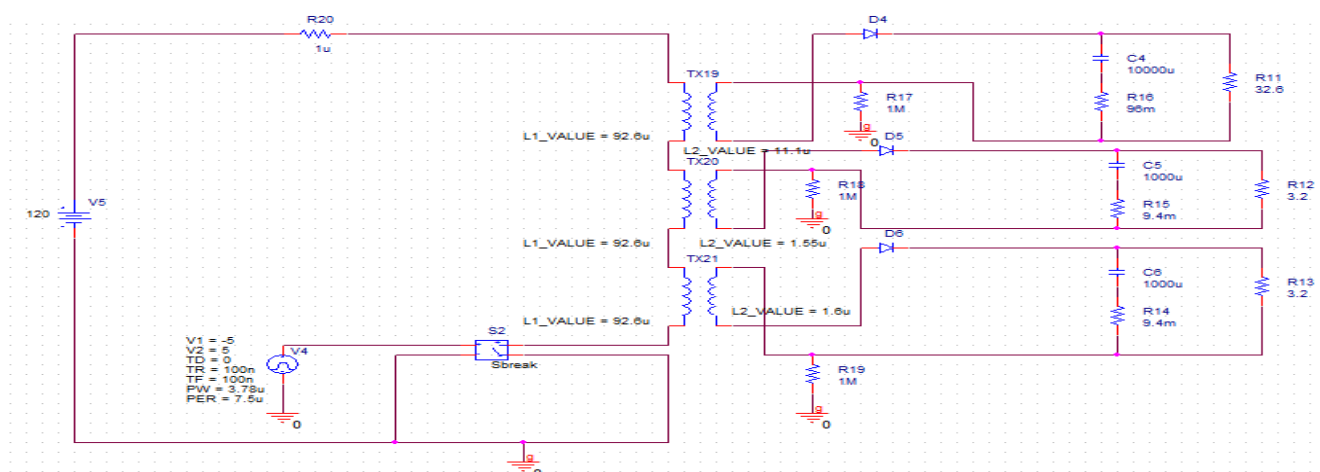


Figure 4: Simulation circuit

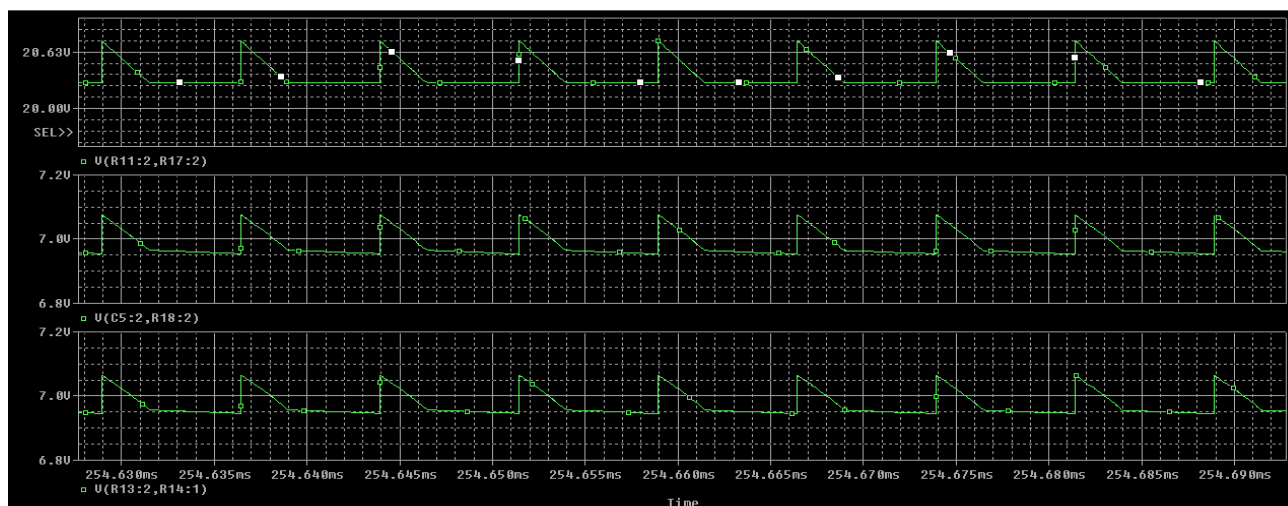


Figure 5: Simulation output Vout1 (20V), Vout2 (7V), Vout3 (7V)

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V. HARDWARE IMPLEMENTATION AND RESULTS

The proposed converter is implemented in the hardware as discussed in earlier section; the hardware setup is shown in Figure 6 and Figure 7. Controller generates initial PWM signal. Thus by switching action flyback converter provides 18V and two 7V outputs for input voltage ranging from 120V to 400 V with switching frequency of 132 kHz and output power rating of 30W. A separate feedback winding is used to provide 5.6V as bias supply for the controller. Protection circuit such as snubber is used.

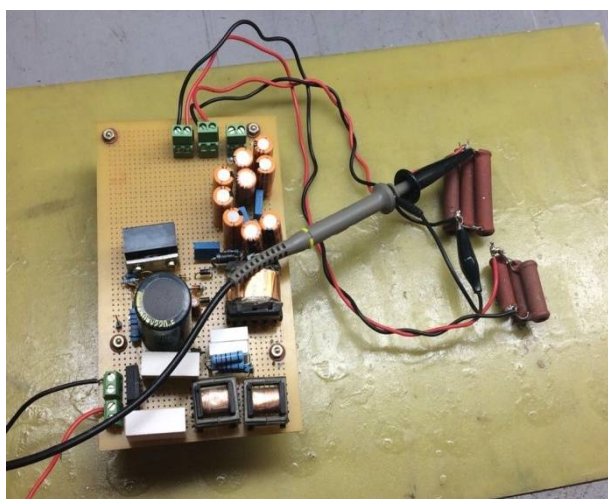


Figure 6: Hardware built on GPCB



Figure 7: Hardware Setup

The experiment was carried out for DC input voltage of 300V with R_{load} ($R_{load1} = 33\Omega$, $R_{load2} = 3.3\Omega$ and $R_{load3} = 3.3\Omega$). The hardware results are shown in Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12.



Figure 8: Reflecting Voltage across snubber circuit



Figure 9: Secondary output voltage 1(Vout1) of 18V

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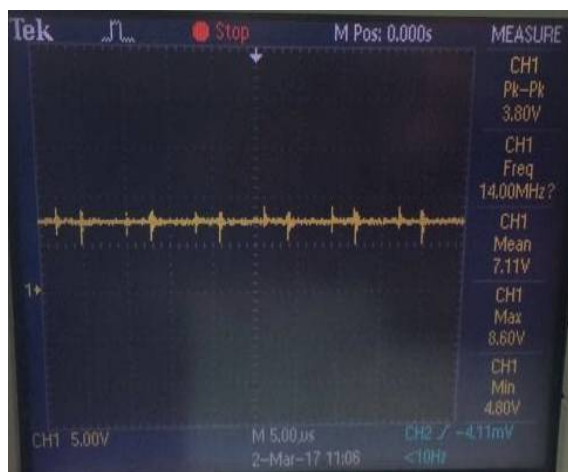


Figure 10: Secondary output voltage 2(V_{out2}) of 7.11V

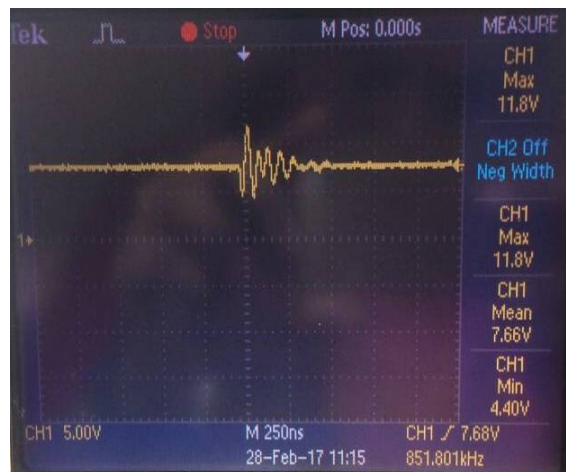


Figure 11: Secondary output voltage 3(V_{out3}) of 7.66V

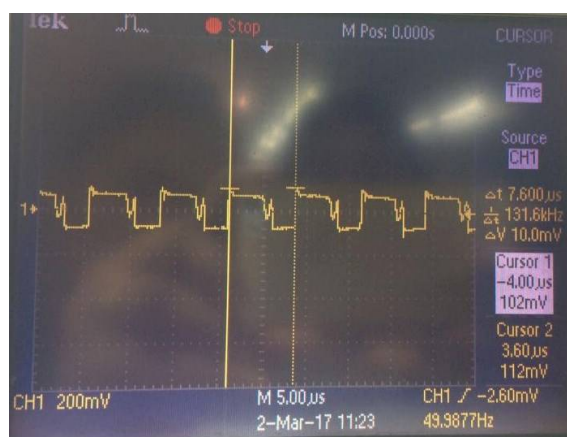


Figure 12: Duty cycle and switching frequency

VI. CONCLUSION

The multiple output flyback converter is designed to operate in the wide input range of 120V to 400V. The hardware prototype is build and the results are captured. The converter is observed to have ripple voltage less than 1% with good output regulation.

The use of link switch in the circuit reduces conduction and switching losses, reduction is component count. Thus, resulted in higher efficiency for lower input voltage and higher reliability.

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