Development of SMPS for Medium Voltage Electrical Drives

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Abstract

In this paper, an effort has been made to develop a compact multiple output SMPS for control circuitry and driver section of Medium Voltage Medium Power Electrical Drives. SMPS generates multiple outputs regulated and isolated +5 V, +24 V, +/-15 V and five +24 V isolated output voltages. Continuous Conduction Mode and Discontinuous Conduction Mode are described. The SMPS is developed using Fly-back converter and performance of SMPS is observed in terms of Line, Load and Cross regulation.
Keywords: Switched Mode Power Supply (SMPS), Output Voltage Regulation, Multiple Output SMPS, Flyback Converter

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I. Introduction

Now-a-days, SMPS are rapidly replacing linear regulated power supplies in most of the consumer electronic applications due to their advantages like higher efficiency, better output voltage regulation, compact size and capability to provide isolation between multiple outputs. [1-2] Multiple outputs are used in almost all consumer electronic equipment and electrical drives where all the outputs are to be regulated and isolated from each other. SMPS typically uses switching frequencies of the order of a few tens of kHz and hence the size of associated filtering components and the transformer is reduced drastically. Personal Computers and embedded system based control applications require power supplies with multiple outputs delivering stiffly regulated and isolated DC voltages at different levels such as ±5 V, +3.3 V and ± 12 V. If there are 'n' outputs in an SMPS, it normally uses 'n+1' dc-dc converters to obtain individual control of all the outputs. [3-4] In this paper, multiple output SMPS is developed for electrical drive. This SMPS generates multiple output for control circuitry and driver section and these are isolated from each other too. This SMPS generates regulated multiple outputs +5 V, +24 V, +/-15 V for control circuitry, and four +24 V isolated for driver section and +24 V for fan power supply. The effects of various magnetic structures of high frequency transformers on cross regulation and the comparison of transformer winding arrangements that effect the cross regulation in a multiple-output flyback converter are presented in [5[and [6]. In [7], three methods of transformer winding arrangements are presented in comparison. Each winding arrangement is reasonably performed in such a way to control leakage inductance in order to improve cross regulation in a multiple output fly back converter.

From the experimental results, it was concluded in paper [7] that amongst all the three methods, sandwich type winding is having a very tight coupling between windings and have better cross regulation than other two methods.

II. System working

A fly-back converter is basically an isolated version of the buck-boost converter in which the inductor has been replaced by a fly-back transformer. A fly-back converter operates by first storing energy from an input source into the transformer while the primary power switch is on. When the switch turns off, the transformer voltage reverses, forward-biasing the output side diodes and delivering energy to the outputs. With a fly-back topology, an output can be positive or negative (defined by a transformer polarity dot). This fly-back transformer is basically a coupled inductor which may have more than one secondary. The input dc source Vs and switch S are connected in series with the primary transformer winding. The diode D and the R-C output circuit are connected in series with the secondary of the fly-back transformer. A simple block diagram showing components used in fly-back converter is shown in figure 1.

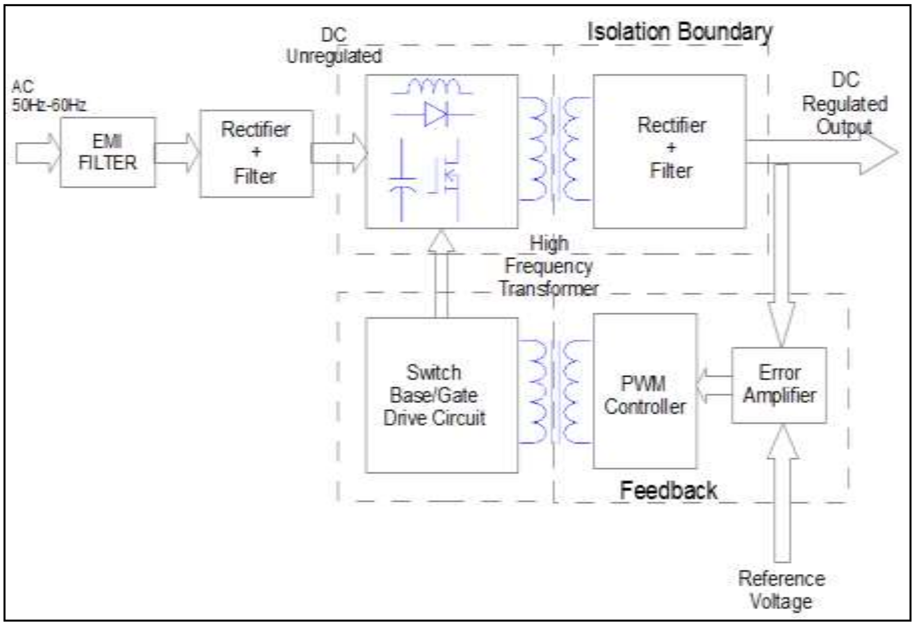


Fig. 1: Block Diagram of Fly-back Converter

Depending on the switching, there may be two modes of operation; Continuous Conduction Mode (CCM) and Dis-continuous Conduction Mode (DCM).

A. Continuous Conduction Mode

In CCM mode of operation, when switch turns ON, primary current flows through primary winding of fly-back transformer and energy is stored in primary inductor. At this time, there is no secondary current, and hence the output current is supplied through output filter capacitor. In second mode, when switch is turned OFF, the energy stored is transferred to the secondary side, while primary current free-wheels through clamp circuit. Clamp circuit is used to reduce the voltage-spike during turn-off condition. In third mode, when all the energy stored in primary winding is transferred to secondary side the secondary winding will charge the output filter capacitor as well as supply current to the output also. Fig. 2(a) shows modes of operation in CCM, while Fig. 2(b) shows current waveforms, flux in the core and voltage across MOSFET during this mode of operation.

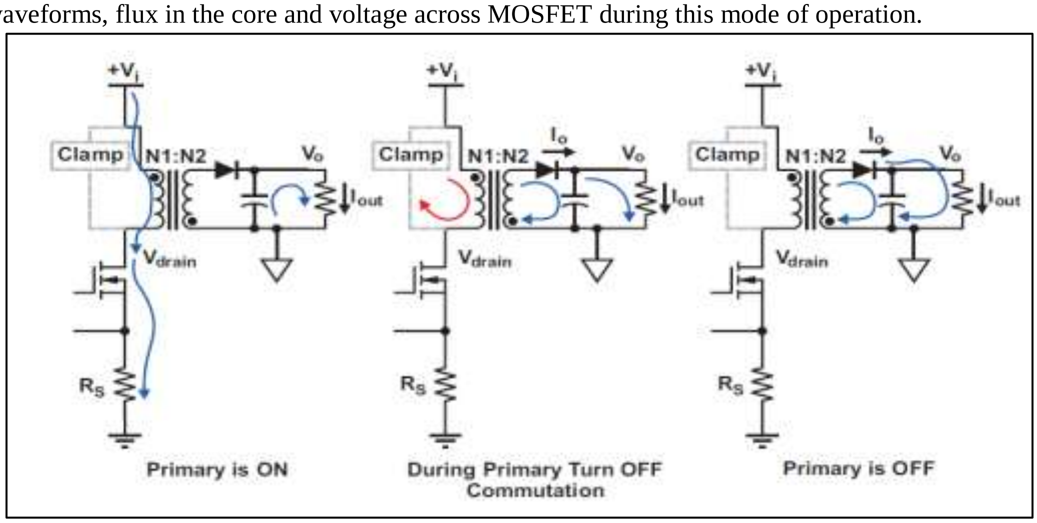


Fig. 2 (a): Continuous Conduction Mode operating modes

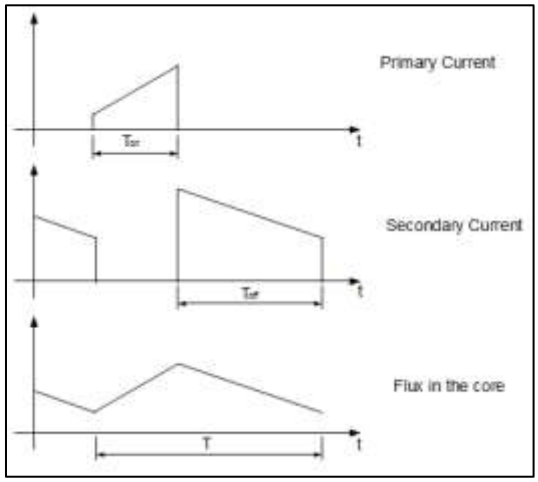


Fig. 2(b): Continuous Conduction Mode waveforms

B. *Discontinuous Conduction Mode*

In this mode of operation, the current gets reduced to zero before the switch again turns on, the flux also gets reduced to zero at the end of the cycle. Here, when the switch is in OFF state the energy stored during the on state of the switch is transferred to secondary and hence this mode of operation is also called Complete Energy Transfer Mode. The figure 3(a) given below shows various stages of DCM and figure 3(b) shows current waveforms, flux in the core and voltage across MOSFET during this mode of operation.

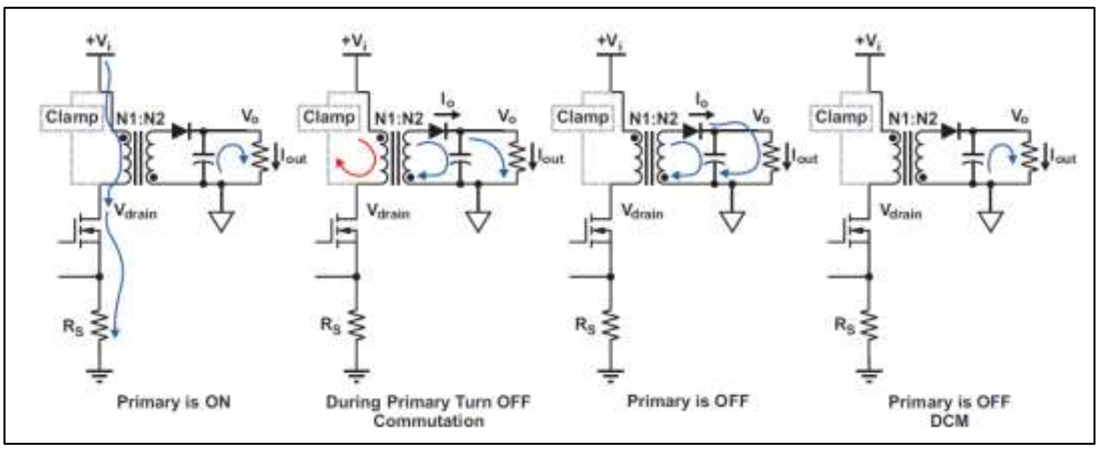


Fig. 3 (a) Discontinuous Conduction Mode operating modes

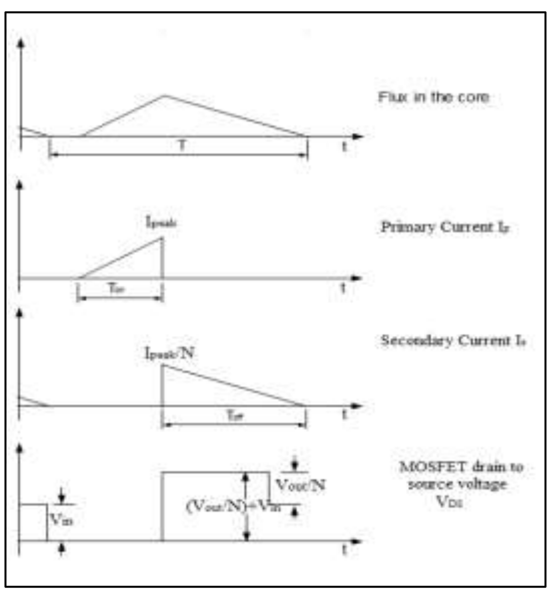


Fig. 3 (b): Discontinuous Conduction Mode waveforms

III. MULTIPLE OUTPUT SMPS DESIGN

The design of multiple output SMPS has been done such that the output voltages obtained are at the required levels even if the power supply is delivering full load over the full range of input voltage. Closed loop control is employed using Discontinuous Conduction Mode and Current Mode Control is employed in prototype development. The multiple output SMPS considered here is rated approximately at 24 W having the following specifications.

General Specifications

- Input Voltage Range : 85 VAC to 265 VAC
- Switching Frequency : 50 kHz
- Maximum Duty Cycle : 50 %
- Maximum Output Power : 24 W
- Expected Efficiency : 80 %

Output Specifications

- Output 1 : +24 V / 285 mA
- Output 2 : +24 V / 130.2 mA
- Output 3 : +15 V / 288 mA
- Output 4 : -15 V / 48 mA
- Output 5 : +5 V / 523.8 mA
- Output 6 to 9 : +24 V / 50 mA
- Auxiliary Winding : +15 V / 70 mA

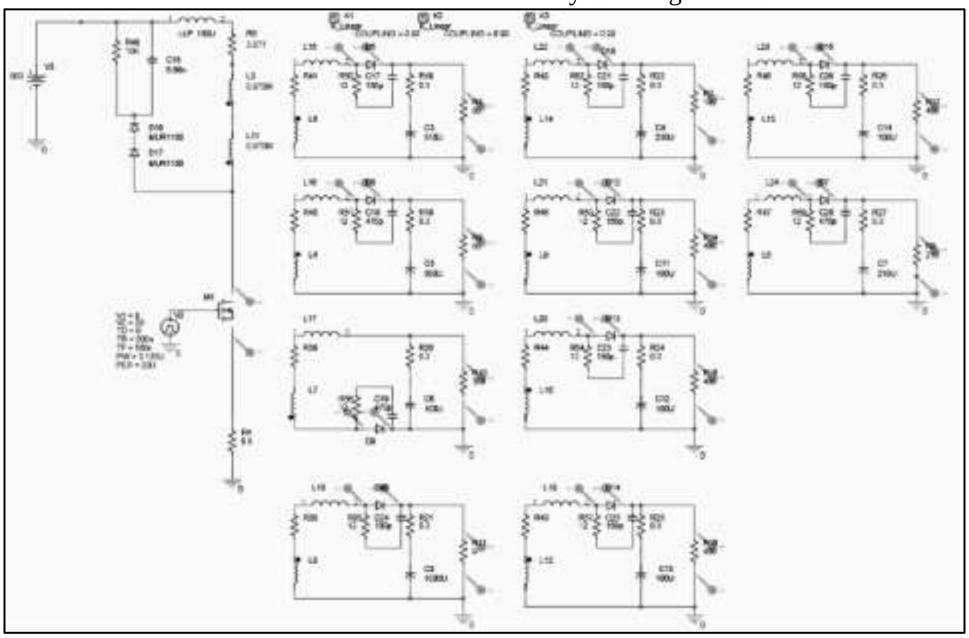


Fig. 4: Open loop simulation circuit in PSpice software

Open loop simulation circuit and simulation results are shown in figures 4 and 5, respectively. Fig. 5 shows the simulation results of SMPS output voltages at 500 V and 22% duty cycle.

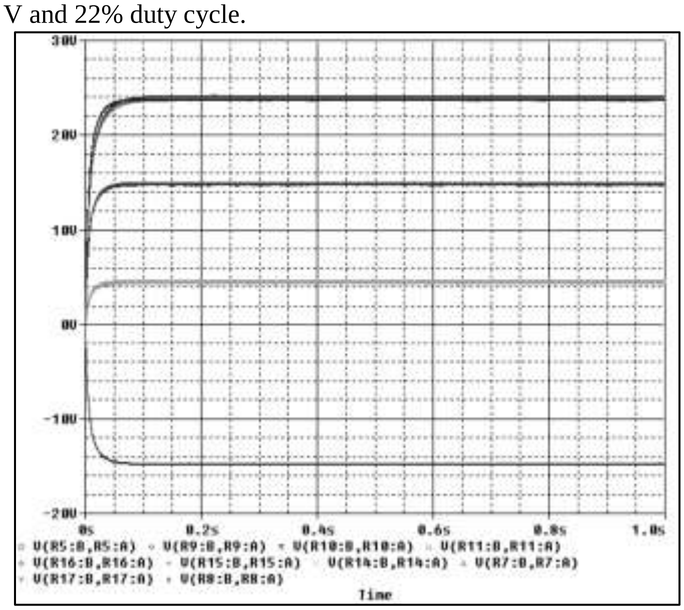
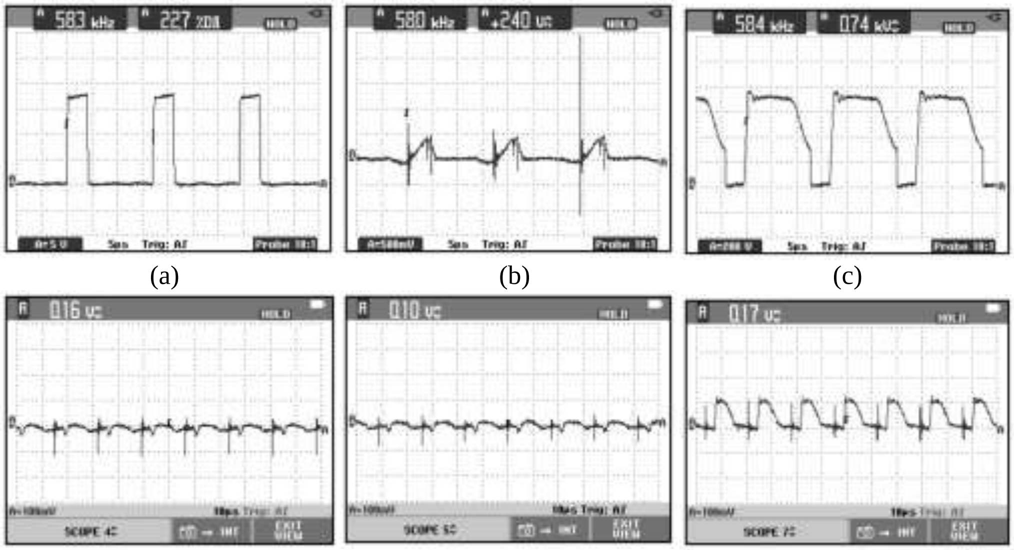


Fig. 5: Simulated Output Voltages at V_{in} = 500 V and 22% duty cycle; X-axis : 1 div = 0.2 sec; Y-axis : 1 div = 10 V

IV. EXPERIMENTAL RESULTS

Fig. 6 (a) shows the waveform of duty cycle when maximum input voltage of 500 V DC is given, duty cycle is 22.7%. Fig. 6 (b) shows the waveform of current (approx. 500 mA) passing through primary winding which was measured across sensing resistor R_{SENSE}, hence the waveform shown here is of voltage across R_{SENSE}. From Fig. 6 (d), (e) and (f), it can be seen that the output voltages have ripples less than 1 % with respective to that output voltages.



(a) (b) (c)

(d) (e) (f)

Fig. 6 (a) Experimental results of Duty Cycle at 500 V input; X-axis : 1 div = 5 μ sec; Y-axis : 1 div = 5 V
Fig. 6 (b) Experimental results of Current from Primary Winding at 500 V input;
X-axis : 1 div = 5 μsec; Y-axis : 1div = 500 mV
Fig. 6 (c) Experimental results of Voltage Spike at 500 V input; X-axis : 1 div = 5 μsec; Y-axis : 1 div = 200 V
Fig. 6 (d) Experimental results of Ripple waveforms in +15 V output voltage;
X-axis : 1 div = 10 μsec; Y-axis : 1 div = 100 mV
Fig. 6 (e) Experimental results of Ripple waveforms in +5 V output voltage;
X-axis : 1 div = 10 μsec; Y-axis : 1 div = 100 mV
Fig. 6 (f) Experimental results of Ripple waveforms in +24 V output voltage;
X-axis : 1 div = 10 μsec; Y-axis : 1 div = 100 mV

Also, other tests like Polarity Test, High Voltage Test, Line Regulation, Load Regulation, Cross Regulation, Heat Run Test and Short Circuit Test were carried out and observed and found to be well within the specific limits.

Fig. 7 shows the outputs of driver circuitry which is given the output of SMPS developed here. These pulses, can directly be given to IGBTs for turning ON and OFF, are derived from the secondary output voltages of SMPS and don't need any isolation circuitry.

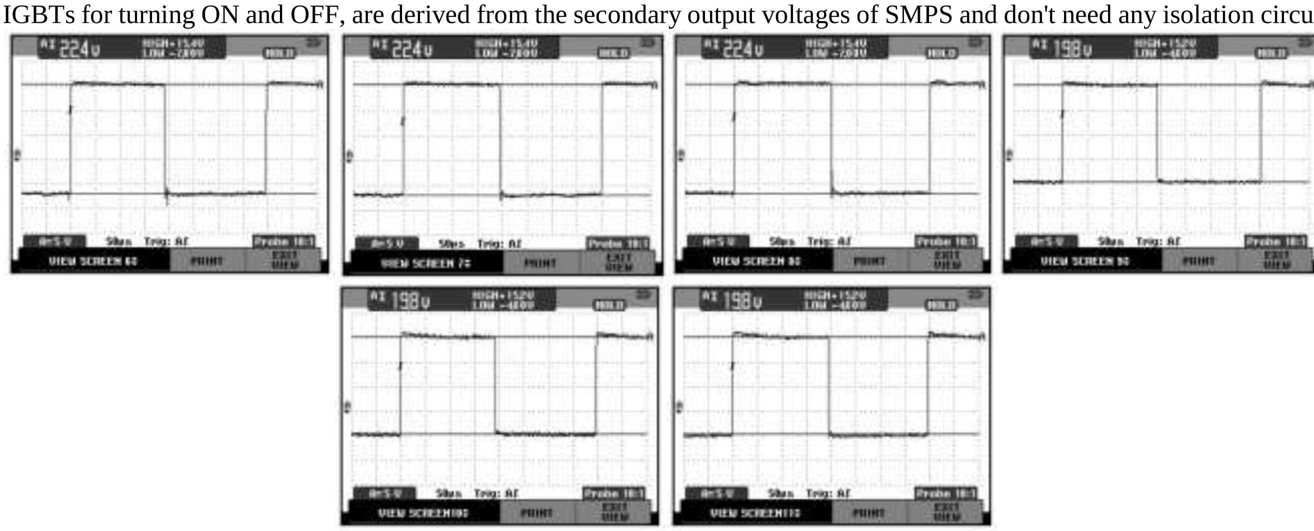


Fig. 7 Gate Pulses for Switches: on left side (S1, S3, S5), on right side (S2, S4, S6);
X-axis : 1 div = 50 μsec; Y-axis : 1 div = 5 V

V. CONCLUSION

Fly-back converter topology was selected for developing multiple output SMPS for the need of power supply section of an electrical drive. Developed SMPS can be used for supplying power to control circuitry and driver section with high voltage isolation. Experimental results for MOSFET pulses, MOSFET drain-to-source voltage, primary current and ripple in output voltages are shown and discussed. Line and load regulation are less than 5 % and Cross regulation is less than 3 %.

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