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Flyback Switching Power Supply Very Wide Input Voltage Range

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***Abstract* - One of the many problems be setting the power supply designer today is being able to design a switching power supply that is able to operate in all the power systems within their international marketplaces. Forward−mode switching power supplies typically operate over a single power system's range of voltage, that is, 90 to 130 VAC or 200 to 270 VAC. Boost−mode converters can just make the range of 90 to 270 VAC. Any higher input voltages would then require a different design. Very Wide Input Voltage Rang Flyback Switching Power Supply is designed using standard topology, and commercially available application specific Integrated circuit. The design is simulated on MATLAB software and tested.The above design has been successfully tested on the hardware and waveforms at various points have been measured practically.**

Index Terms - Brush-less DC motor; Grey theory; Grey PID Control

I. Introduction

Over the years as the portable electronics industry progressed, different requirements evolved such as increased battery lifetime, small and cheap systems, brighter, full-color displays and a demand for increased talk-time in cellular phones. An ever increasing demand from power systems has placed power consumption at a premium. To keep up with these demands engineers have worked towards developing efficient conversion techniques and also have resulted in the subsequent formal growth of an interdisciplinary field of Power Electronics. However it com One of the many problems be setting the power supply designer today is being able to design a switching power supply that is able to operate in all the power systems within their international marketplaces. Forward−mode switching power supplies typically operate over a single power system's range of voltage, that is, 90 to 130 VAC or 200 to 270 VAC. Boost−mode converters can just make the range of 90 to 270 VAC. Any higher input voltages would then require a different design.

This leads companies to create products targeted at specific marketplaces, which can be costly, or to have their customers arrange jumpers to accommodate their power system which can be annoying or lead to costly errors. Added to this are those industrial companies which may not only have their products reside on residential power systems but also have the varied international industrial power systems. This means that a single product family might have to operate from an input voltage of 90 to 600 VAC, well beyond the residential limits of 90 to 270 VAC.

This paper reviews one method of enabling a flyback converter to operate beyond its traditional range of input voltage of 3:1 to a range of more than 6.6:1 without affecting the reliability of its operation. This is done by changing its mode of operation and the use of recently available power MOSFETs with breakdown voltage ratings of 1200 V.

II. Topology of Flyback Converter

A. Flyback Converter

Fig 1 shows the basic topology of a fly-back circuit. Input to the circuit may be unregulated dc voltage derived from the utility ac supply after rectification and some filtering. Since the SMPS circuit is operated at much higher frequency (in the range of 100 khz) the input voltage, in spite of being unregulated, may be considered to have a constant magnitude during any high frequency cycle. A fast switching device ('S'), like a MOSFET, is used with fast dynamic control over switch duty ratio (ratio of ON time to switching time-period) to maintain the desired output voltage. The transformer, in Fig 1, is used for voltage isolation as well as for better matching between input and output voltage and current requirements. Primary and secondary windings of the transformer are wound to have good coupling so that they are linked by nearly same magnetic flux. The fly-back transformer works differently from a normal transformer. The output section of the fly-back transformer, which consists of voltage rectification and filtering, is considerably simple than in most other switched mode power supply circuits. The secondary winding voltage is rectified and filtered using just a diode and a capacitor. Voltage across this filter capacitor is the SMPS output voltage. A more practical circuit will have provisions for output voltage and current feedback and a controller for modulating the duty ratio of the switch. It is quite common to have multiple secondary windings for generating multiple isolated voltages.

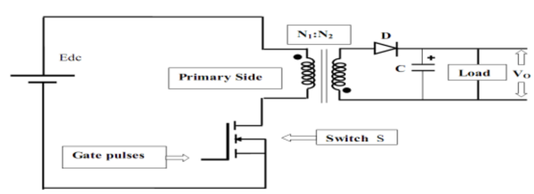

Fig1 : Flyback Converter

B. Circuit Equations under Continuous flux operation

The waveforms in Fig2.4 correspond to steady state operation of fly back converter. 'TON' denotes the time for which the fly-back switch is ON during each switching cycle. 'T' stands for the time period of the switching cycle. The ratio (tON/T) is known as the duty cycle (α) of the switch. The primary winding current rises from Io to Ip in ' αT ' time.

$$(I_P - I_0) = (E_{dc} / L_{Pri})\, \delta T$$

Under steady state the energy input to primary winding during each ON duration equals:

$$0.5E_{dc}\,(I_P + I_0)\,\delta = V_0\, I_{Load}$$

The mean (dc) voltage across both primary and secondary windings must be zero under every steady state. When the switch is ON, the primary voltage equals input supply voltage and when switch is OFF the reflected secondary voltage appears across the primary winding. Under the assumption of ideal switch and diode.

$$E_{dc}\ \delta = (N_1 / N_2)\ V_0\ (1\text{-}\delta)$$

where N_1 and N_2 are the number of turns in primary and secondary windings and $(N_1/N_2)V_0$ is the reflected secondary voltage across the primary winding (dotted end of the windings at lower potential) during mode-2 of circuit operation.

One needs to know the required ratings for the switch and the diode used in the converter. When the switch is OFF, it has to block a voltage (V_{switch}) that equals to the sum of input voltage and the reflected secondary voltage during mode-2.

Thus, $\mathbf{V_{switch} = E_{dc} + (N_1 / N_2)\ V_0}$

When the switch in ON, the diode has to block a voltage (V_{diode}) that equals to the sum of output voltage and reflected primary voltage during mode-1, i.e.,

$V_{diode} = V_0 + E_{dc}\ (N_2 / N_1)$

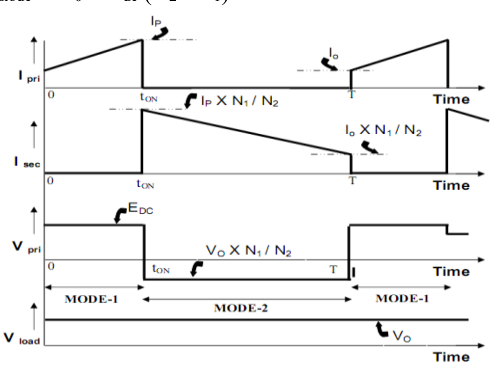

Figure.2. Waveforms of fly back converter under continuous magnetic flux

Since the intended switching frequency for SMPS circuits is generally in the range of 100 kHz, the switch and the diode used in the fly-back circuit must be capable of operating at high frequency. The switch and the transformer primary winding must be rated to carry a repetitive peak current equal to IP (related to maximum output power as given by Eqns. above). Similarly the secondary winding and the diode put in the secondary circuit must be rated to carry a repetitive peak current equal to the maximum expected load current. The magnetic core of the high frequency inductor - transformer must be chosen properly such that the core does not saturate even when the primary winding carries the maximum expected current. Also, the transformer core (made of ferrite material) must have low hysteresis loss even at high frequency operation. Since the ferrite cores have very low conductivity, the eddy current related loss in the core is generally insignificant.

C. Circuit Equations under Discontinuous flux operation

Fig1.5 shows some of the important voltage and current waveforms of the fly-back circuit when it is operating in the discontinuous flux mode. During mode-3 of the circuit operation, primary and secondary winding currents as well as voltages are zero. The load, however, continues to get a reasonably steady voltage due to the relatively large output filter capacitor.

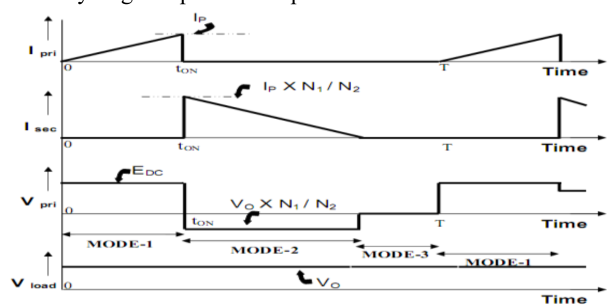

Figure 3. Waveforms for Discontinuous Flux Operation

With the turning ON of the switch, the primary winding current starts building up linearly from zero and at the end of mode-1 the magnetic field energy due to primary winding current rises to12 $L_{pri}\ I_P^2$. This entire energy is transferred to the output at the end of mode-2 of circuit operation. Under the assumption of loss-less operation the output power (P_o) can be expressed as:

$$P_o = \frac{1}{2} L_{pri} I_P^2\, f_{switch}$$

Where f_{switch} (=1/T) is the switching frequency of the converter. It may be noted that output power Po is same as '$V_0\ I_{Load}$' used in above equations. The volt-time area equation as given in Eqn.(22.5) gets modified under discontinuous flux mode of operation as follows:

$$E_{dc}\ \ \delta \leq (N_1 / N_2)\ V_0\ (1\text{-}\delta)$$

Average voltage across windings over a switching cycle is still zero. The inequality sign of Eqn. is due to the fact that during part of the OFF period of the switch [= (1-δ)T], the winding voltages are zero. This zero voltage duration had been identified earlier as mode-3 of the circuit operation. The equality sign in Eqn will correspond to just-continuous case, which is the boundary between continuous and discontinuous mode of operation. The expression for V_{switch} and V_{diode}, as given in Eqns, will hold good in discontinuous mode also.

III. METHODOLOGY OF FLYBACK CONVERTER

By a very simple modification to the traditional fixed frequency current−mode controlled flyback converter design, one can greatly extend its operational input voltage range. The modifications make the control method one of variable on−time, and variable frequency. Figure illustrates the newly added and redefined functional blocks of this new method of control.

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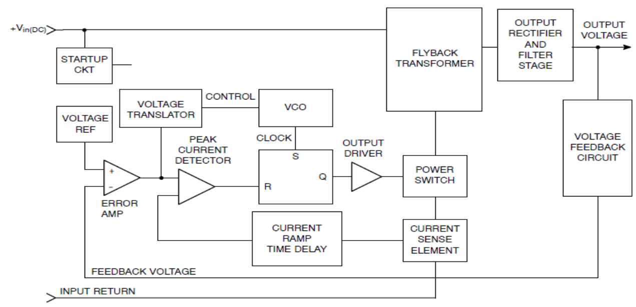

Figure 4. Block Diagram of the Wide Input Range, Flyback Converter

A VCO (voltage−controlled oscillator) is created by removing the timing capacitor's charging circuit from a fixed voltage or current source and placing it under the control of the error voltage. In the design example shown later, it means simply removing the timing resistor from the voltage reference and wiring it to a variable voltage created by the output of the error amplifier. A voltage translator is placed between the output of the error amplifier and the control input to the VCO. It consists of a simple biased 3.3 V zener diode so that the error amplifier may make use of its entire output voltage swing. The other new block is really a redefinition of an old familiar function − the leading edge spike filter from the current sensing element. Here, the formerly annoying parasitic of time lag serves an important function within the control algorithm. It now delays the actual current ramp prior to being sensed by the control IC. It allows the actual peak current to increase with increasing input voltages while the controller sees a lowering peak current needed by this control strategy. This will be discussed later.

The ultimate goal of the new control methodology is to force the on−time of the power switch to be greater than this minimum effective on−time over the power supply's entire line/load operating range. Its operation can be best understood by examining equation 3. The error amplifier/VCO section of the circuit lowers the operating frequency as the input voltage is increased. This requires the energy stored per conduction period to increase to meet the short−term power requirement of the output. This is done by extending the on−time of the power switch. If the key component parameters such as maximum operating flux density (Bmax) of the transformer, the avalanche ratings of the diodes and power switch, and the current ratings of the output rectifiers are adequate, then no degradation in the reliable operation of the supply is experienced.

Its operation can be better defined by rearranging equation and neglecting any power loss due to the inefficiency of the supply one gets:

$$i_{pk} = \sqrt{\frac{2\,P_{out}}{L_{pri} \cdot f_{(f(Ve))}}}$$

where f(f(Ve)) is the controlled frequency of the power supply.

As one can see, the peak current is inversely proportional to the square root of the frequency of operation, since all the other terms are fixed in the short−term operation and by the circuit design.

By substituting equation 1 into equation 4 one further gets

$$t_{on} = \frac{1}{V_{in}} \cdot \sqrt{\frac{2\,P_{out} \cdot L_{pri}}{f_{(f(Ve))}}}$$

There are more unknowns than there are independent equations, but at the low input line voltage and at the rated output load, one can solve equation. The input voltage is known to be 325 VDC (230 VAC), the frequency will be at its highest point as designated by the designer, the on−time will be one−half of the entire operating period and the peak current will be calculated as it is in a common fixed−frequency flyback converter. This will allow us to determine the appropriate value for the primary inductance.

In the sample design, the frequency of operation at the highest input voltage will drop to one−half from that at the lowest input voltage. Equation then indictates:

$$i_{pk(hi)} \approx \sqrt{2}\, i_{pk(lo)}$$

If the desired maximum operating flux density (Bmax) is one−half the core material's saturation flux density at 100°C and at the high input line, then the operating flux density at the low input voltage should be:

$$B_{max(lo)} \approx \frac{B_{sat(min)}}{2\sqrt{2}}$$

For most common ferrite materials such as 3C8, N27, or F, the operating flux density at low line will be at approximately 1,300 gauss. The Bmax at the high input voltage will be no more than one−half the saturation flux density at 100°C.

The inductance can now be calculated by using equation 1 at the low input voltage, and an air gap calculated using any one of the common methods.

It is important to determine the secondary inductance such that the core's energy can be emptied as close to 50 percent duty−cycle (1/fop(hi)) as possible. This will minimize the RMS currents to their lowest possible point over the entire operating range. The output peak current at any operating point is described as:

$$i_{pk(out)} \approx 2 \cdot I_{out(av)} \cdot T_{disch} \cdot f_{op}$$

This would describe both the peak currents flowing through the output rectifiers and the peak ripple currents flowing into and out of the output filter capacitors. Within the sample design with one ampere rated outputs, at low line the peak−to−peak rectifier currents would be four times the average output current. At the high line, the peak−to−peak currents would be eight times the average output current for the rated output current.

V. RESULTS AND DISCUSSIONS

The diagram represents the simulation diagram of the very wide range input voltage Flyback Converter. The simulation of this project is done using Matlab software. This software does not provide IC's (UC3845B). So, we used a simple pulse generator to generate the pulses. With the help of this pulses we can ON and OFF the MOSFET through gate signal. The output voltages is obtain at the filter capacitors i.e. C12 and C14 so that we get the output as a+5Vdc at C14 and +12Vdc at C12by converting the 325Vdc to 12Vdc and 5Vdc with the help of transformer.

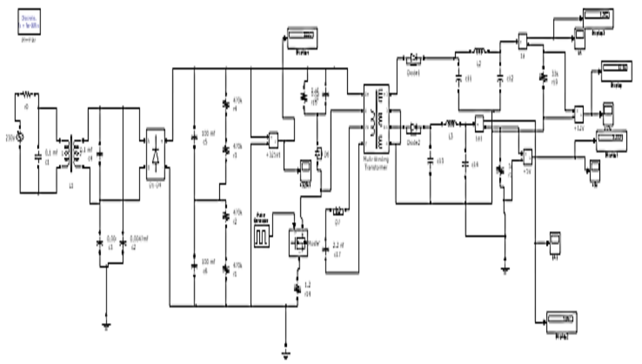

Figure 5. Simulation Circuit of Flyback Converter

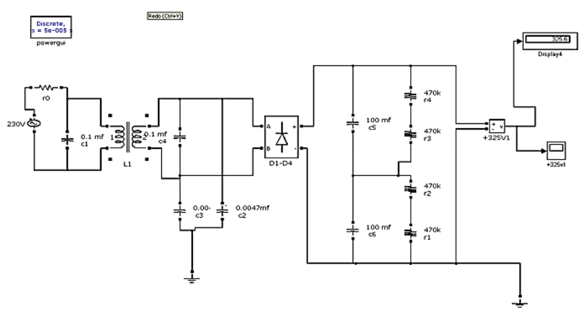

Figure 6. 325Vdc Input voltage waveform

A. Simulation Results

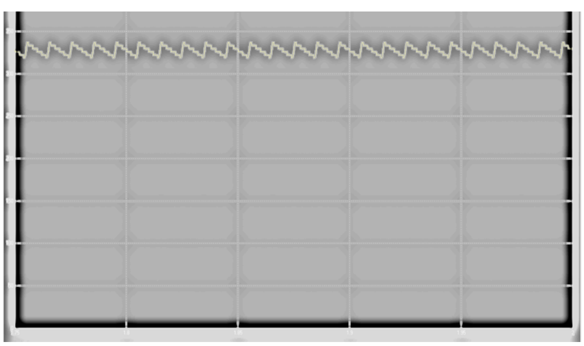

Figure 7. 325Vdc Input voltage waveform

Figure 8: DC output voltage +12Vdc waveform

Figure 9: DC output current 1Amps waveform

The circuit is simulated in MATLAB - Simulink software. After the output in the simulation has been verified, this circuit is implemented on a Printed Circuit Board (PCB).It is checked whether it has got proper routing. It is to be noted that proper spacing should be given between the holes to be made on the bare PCB. We have listed out, what are the components needed to connect the hardware. We connected components on the PCB, given the input supply (DC) to circuit and checked output across load at various testing points. We are using the resistor as a load and the output waveforms are observed for different values of input in CRO.The below figure shows Bare PCB Board of Fly back Converter.

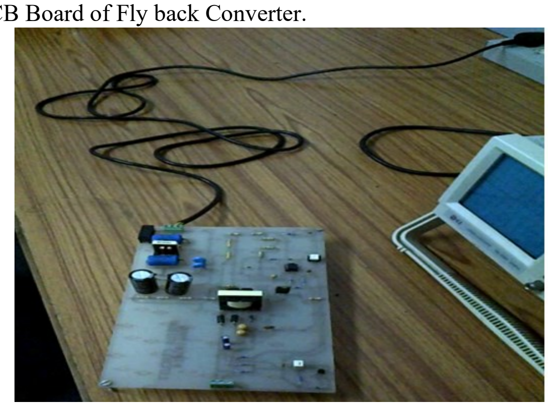

Figure 10: Mounted General PCB Board of Flyback Converter

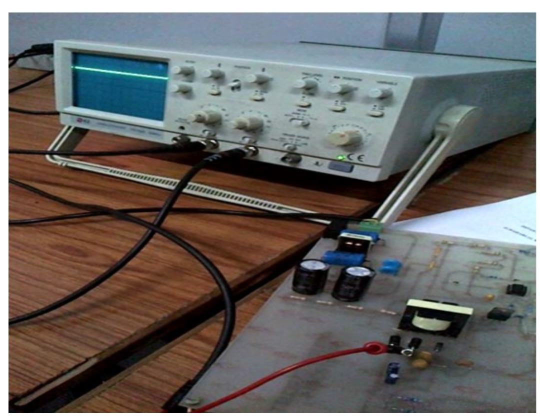

Figure 11: +5Vdc output voltage in CRO

VI. CONCLUSION

Very Wide Input Voltage Range Flyback Switching Power Supply is an efficient step-down DC-DC converter used in numerous Electronic devices. It is modeled and simulated using Matlab. A closed loop model is developed and used successfully for simulation. This converter has advantages like reduced hardware, high performance, less weight and accuracy. The simulation results are in line with the predictions.

The same was implemented as a hardware project and output voltages of +12V and +5V was obtained with an input of 230V AC supply. Also the waveforms across various test points were obtained, studied and compared with the theoretical waveforms. The waveforms were found to be in precise proximity of theoretical waveforms

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