Design and Simulation of Isolated Forward Buck Converter Based Switched Mode Power Supply

C. Subba Rami Reddy, P. Chandrababu, K. Rayudu, A. Murali

Abstract: In this paper, design and implementation of Switched mode power supply is analysed for various alterations of the supply voltage. Proper components were selected and its functionality was verified in NI-MULTISIM as a simulator. At first open loop configuration was designed, implemented and its functionality was examined in NI-MULTISIM. To examine the performance of the proposed system, PI controller is embedded using PWM based feedback network, and successfully verified in NI-MULTISIM.
Index Terms: Switched mode power supply, Pulse width modulation, PI Controller.

I. INTRODUCTION

Many electronic and digital circuits such as integrated circuits and pc hard disk drive etc require standard regulated dc supply at voltage levels of 3.3v, 5v, 12v etc for their proper operation. Unfortunately, the power supply available at our homes, offices, educational institutes and IT companies etc is not such a standard dc supply instead it is ac supply and more over it is not a regulated power supply. So in order to convert the available unregulated ac supply into regulated dc supply, an electronic circuit is required; such an electronic circuit is known as regulated power supply. There are two types of regulated dc supplies, one is linear regulated dc power supplies and the other one is switched mode regulated dc power supplies. From the past two and half decades the energy scarcity is a problem in several Asian countries like India, and which have been under pressure from energy prices made a slogan that "energy saving is energy generation". Therefore energy scarcity, increase in the energy prices motivates the development of high efficient electrical circuits [1]. The efficiency of switched mode power supply is high compared to linear regulated power supply particularly when the fluctuations in available unregulated power supply are large [2].

II. LINEAR REGULATED POWER SUPPLY VS SWITCHED MODE POWER SUPPLY

The objective of regulated power supply is to provide the desired constant output voltage at its output terminals even though there is a fluctuation in input available unregulated supply at its input terminals. The available unregulated power supply voltage is generally higher than the required regulated voltage [3]. In case of linear regulated power supply, the excess voltage in the available unregulated voltage is dropped across the series element of regulated power supply so that, power loss in the linear power supply [4] is more and hence its efficiency is poor where as in case of switched mode power supply(SMPS), the excess voltage in the available unregulated voltage is controlled by controlling the duty ratio i.e. the ON time period of switching device in switched mode power supply so that the efficiency of switch mode power supply is high. The SMPS is compact when compared to linear power supply. The control of linear regulated power supply is simple where as the control of SMPS is complex[5] as it requires the feedback network to generate the control voltage which decides the on time period of switching device [6] in the SMPS. So from the above discussion, it can be concluded that for most compact and most efficient applications [7],[8] the SMPS is preferable than the linear power supply.

III. BLOCK DIAGRAM OF SMPS

The block diagram of the proposed SMPS is shown in fig.1. The unregulated available AC supply is first given to a transformer that scales the available voltage into required voltage level and also provides the isolation [9]. The output from the scaling and isolation transformer is given to the diode bridge rectifier which converts the ac output from the transformer into pulsating dc voltage [10]. The pulsating dc output voltage from the diode bridge is given to capacitor filter to reduce the ripple content. This unregulated dc voltage from the capacitor filter is applied as the input to forward buck converter [11],[12]. By controlling the duty ratio of the switching device in the forward buck converter the output voltage is maintained at desired constant value [13], [14], [15].
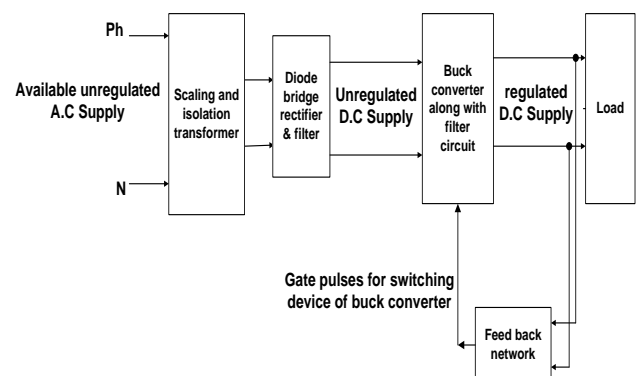

Fig.1. Block diagram of isolated forward buck converter based SMPS

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The ripple content in the output regulated voltage can be minimized by providing L-C filter circuit. The output voltage is maintained at required constant level even though the unregulated input voltage is fluctuated by controlling the duty ratio of the switching device in the SMPS. To control the switch duty ratio, we need actual output as a feedback signal. In feedback network actual output is compared with desired voltage command, and as a result an error signal is generated, the error signal is shaped as a control voltage by a controller. The control voltage signal is given to pulse generating unit where it is compared with high frequency triangular carrier signal to generate gate pulses to switching device of SMPS to control its duty ratio according to actual output voltage.

IV. BLOCK DIAGRAM OF FEEDBACK NETWORK

The block diagram of the feedback network of the proposed SMPS is shown in fig.2. The desired reference voltage and actual output voltages are given as a inputs to error generator where they are compared and an error signal is generated.
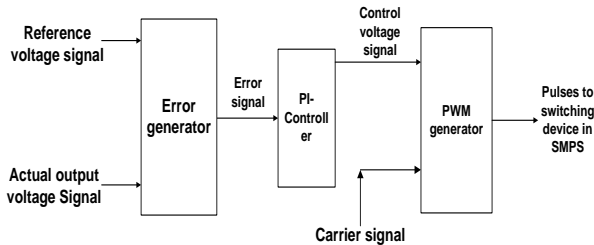

Fig.2. Block diagram of feedback network of SMPS

The error signal is given as input to PI controller. The output of the PI controller is control voltage signal. The control voltage signal is given as an input to pulse width modulation (PWM) generator. The control voltage signal is compared with high frequency triangular carrier wave in the PWM generator and hence the pulses of desired width are generated which are given to gate terminal of the switching device used in the SMPS to control its ON time period.

V. DESIGNING OF OUTPUT FILTER

As we know that the output of the buck converter is not pure dc instead it is a train of pulses i.e. when the chopper switch is ON then the output is dc input to the chopper and the output is zero when the chopper switch is OFF. So in order convert the chopped dc into pure dc we need an output filter which averages the converter output voltage. The fig.3 shows the simple second order output filter.
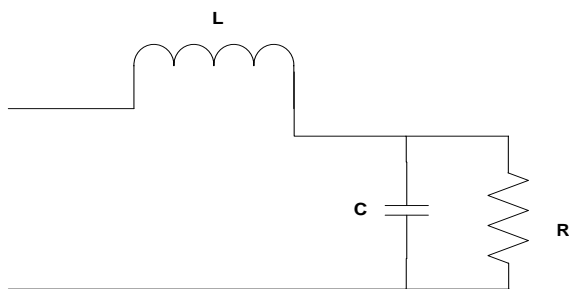

Fig.3. Output LC Filter

The transfer funtion of the above simple second order filter is given as

$$G_f(s) = \frac{R}{RLCS^2 + LS + R} \qquad (1)$$

$$G_f(s) = \frac{1/LC}{S^2 + (1/RC)S + 1/LC} \qquad (2)$$

Where

$$\omega_n = 1/\sqrt{LC} =$$

$$Un\ damped\ natural\ frequency\ of\ the\ filter$$

$$\alpha = 1/2RC = \text{Damping Ratio of the filter}$$

The calculation of inductor and capacitor values are based on the trial and error method. It should be noted that, the inductor should be chosen that it should carry the maximum load current with factor of safety. Based on the 10-20% of the output ripple current as a rule of thumb, first we have to choose the inductor value and then find the value of capacitor based on the break frequency of the filter i.e.

$$f_r = 1/2\pi\sqrt{LC} \qquad (3)$$

In order to get the low output ripple, the switching frequency of the converter should be far high from the break frequency of the output filter.

VI. DESIGN OF THE PI CONTROLLER

To design the PI Controller we need the plant transfer function. In our SMPS the plant is nothing but a modulator along with the second order filter as shown in the figure.4.

The transfer function of the second order output filter has been given in the equation (2). So it is necessary to develop the modulator transfer function to get the overall transfer function of plant. As the converter used is the buck converter, the output voltage is given as
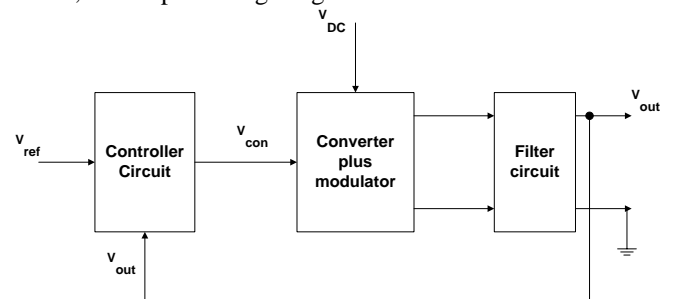

Fig.4. Block diagram of PI Controller Design

$$V_0 = \delta\,V_{in} \qquad (4)$$

Where δ = Duty cycle = $\frac{T_{on}}{T}$

V_{in} = converter input dc voltage

In modulator, the rectangular control voltage is compared with high frequency triangular carrier wave. When control voltage is more than the triangular wave, the modulator output is high and vice-versa. As the output of the modulator decides the duty ratio of the converter, the duty ratio can also be written as

$$\delta = \text{Duty cycle} = \frac{V_{con}}{V_{tri}}$$

Therefore the overall transfer function can be defined as

$$G_m(s) = \frac{\Delta V_o}{\Delta V_{con}}$$

$$= \frac{d(\delta V_{in})}{dV_{con}} = \frac{d(\frac{V_{con}}{V_{tri}})V_{in}}{dV_{con}}$$

$$G_m(s) = K = \frac{V_{in}}{V_{tri}} \qquad (5)$$

From equation (5), it can be concluded that, the transfer function of the modulator is a constant. From equation (5) and (6), the overall transfer function of the plant is given by

$$G_p(s) = \frac{K/LC}{S^2 + (1/RC)S + 1/LC} \qquad (6)$$

The transfer function shown in above equation (6) is a second order model. But to design a PI controller using a pole assignment technique, first order model is needed. By properly choosing the values of R, L & C, we can convert the above second order system into first order system by using dominant pole concept and it can be represented like.

$$G_p(s) = \frac{b}{S+a}$$

The reduced block diagram to determine the proportional gain and integral time constants of the controller is shown below fig.5.
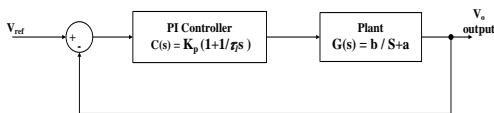

Fig.5. Reduced block diagram of PI Controller Design

Upon simplifying the above block diagram, the values of proportional gain and integral time constants of the controller can determined as

$$K_p = \frac{2\xi\omega_n - a}{b} \qquad (7)$$

$$\tau_I = \frac{2\xi\omega_n - a}{\omega_n^2} \qquad (8)$$

So from the equations (7) and (8), if we know the plant parameters a and b, the PI controller parameters are calculated by properly choosing the values of ξ (damping ratio) and ω_n (natural frequency) of desired stable closed loop characteristic polynomial.

VII. RESULTS

The open loop configuration of SMPS is shown in fig.6 and the corresponding output voltage and PWM generating unit output are shown in fig.7.In case of open loop configuration, if the unregulated input ac voltage is changed, then there is a corresponding change in the output dc voltage i.e. if input voltage is more than the nominal 230V r.m.s, then the output is also more than desired 12V and vice versa.
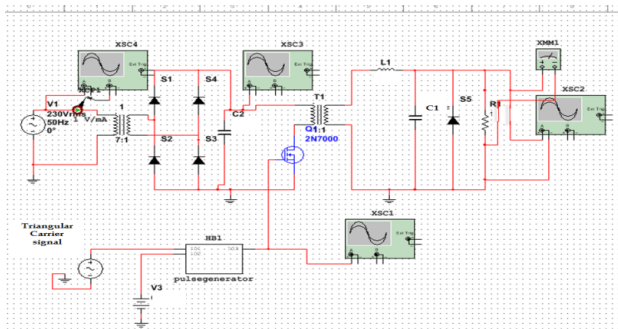

Fig.6 Implementation diagram of open loop configuration of SMPS
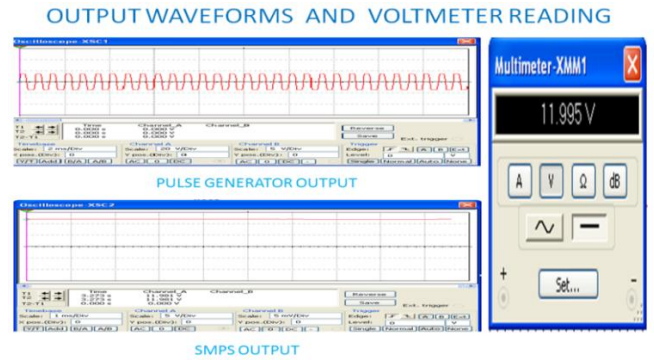

Fig.7 Pulse generator output, output voltage and its voltmeter reading of open loop configuration of SMPS

In case of closed loop configuration, even though the unregulated input ac voltage is changed above or below the nominal 230V, the output dc voltage is maintained at its desired value i.e. at 12V. The closed loop implementation diagram of SMPS is shown in fig.8 and the corresponding output voltage and PWM generating unit output when the nominal voltage of 230v r.m.s is given as input to SMPS are shown in the fig.9.
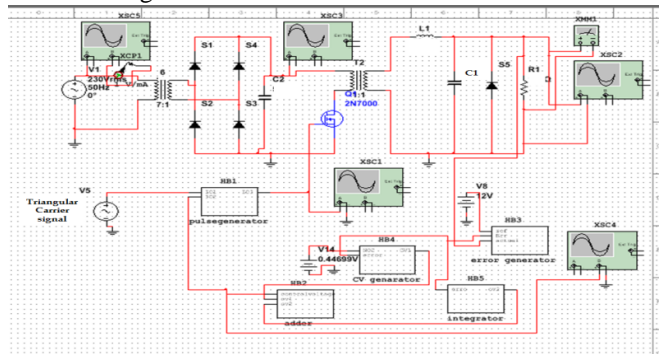

Fig.8 Implementation diagram of closed loop configuration of SMPS when input voltage at 230V r.m.s
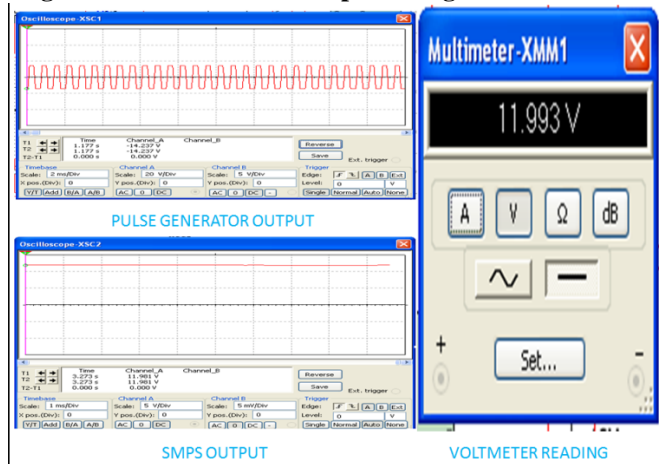

Fig.9 Pulse generator output, output voltage and volt meter reading of output voltage when input voltage is at 230V r.m.s

Fig.10 shows the closed loop implementation diagram of SMPS when the input voltage is changed to 275V r.m.s and the corresponding output voltage and PWM generating unit outputare shown in the fig.11.

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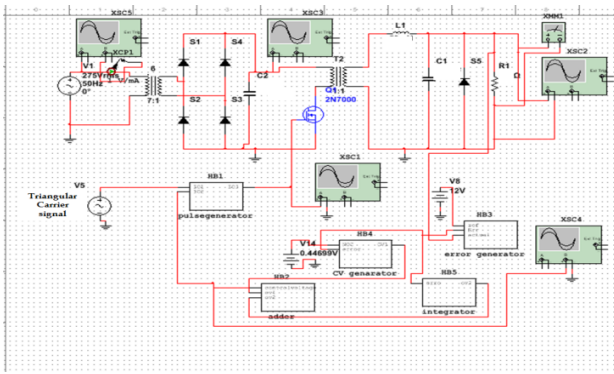

Fig.10 Implementation diagram of closed loop configuration of SMPS when input voltage at 275V r.m.s
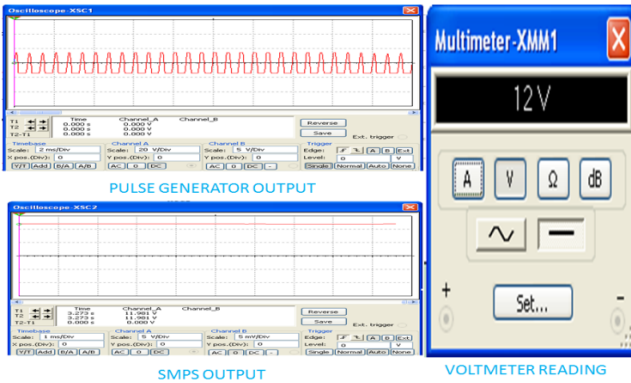

Fig.11 Pulse generator output, output voltage and volt meter reading of output voltage when input voltage is at 275V r.m.s

From the above figure it is observed that even though the input voltage is changed to 275V r.ms i.e. the input voltage is increased 45V above the nominal voltage of 230V, the output voltage is maintained at the desired voltage of 12V. It can be observer from the pulse generating unit output that when the input voltage is increased from 230V r.m.s to 275V r.m.s the width of the gate pulses is reduced i.e. the ON time period of the switching device of SMPS is reduced due to the controller action and hence the output voltage is maintained at its desired value of 12V.

Fig.12 shows the closed loop implementation diagram of SMPS when the input voltage is changed to 195V r.m.s and the corresponding output voltage and PWM generating unit output are shown in the fig.13.
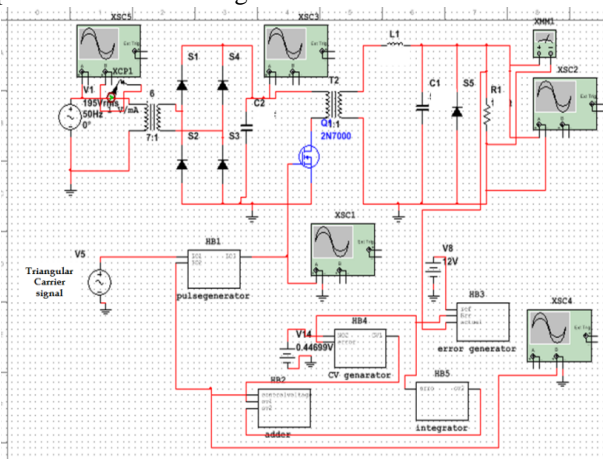

Fig.12 Implementation diagram of closed loop configuration of SMPS when input voltage at 195V r.m.s

From the above figure it is observed that even though the input voltage is changed to 195V r.ms i.e. the input voltage is decreased 35V below the nominal voltage of 230V, the output voltage is maintained at the desired voltage of 12V.
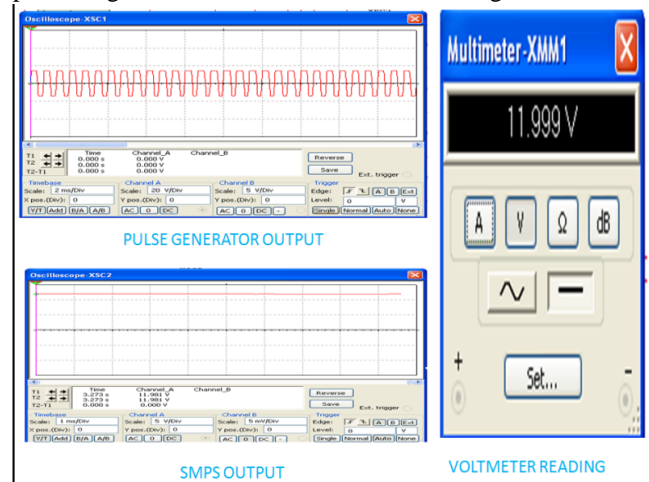

Fig.13 Pulse generator output, output voltage and volt meter reading of output voltage when input voltage is at 195V r.m.s

It can be observer from the pulse generating unit output that when the input voltage is decreased from 230V r.m.s to 195V r.m.s the width of the gate pulses is increased i.e. the ON time period of the switching device of SMPS is increased due to the controller action and hence the output voltage is maintained at its desired value of 12V.

VIII. CONCLUSION

Proper components were selected and open loop configuration was implemented and its functionality was verified in NI-MULTISIM as a simulator. Then a PWM based feedback network using PI Controller has been designed and it was built and its functionality was verified in NI-MULTISIM as a simulator. The results prove that the proposed design withstand for various alterations in the supply voltages.

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