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OPTIMIZATION OF OUTPUT RIPPLE VOLTAGE IN 11 KW SWITCH MODE POWER SUPPLY (SMPS)

Avinash Kumar[*1] & Dr. Shailja Shukla[2]
[*1&2]Jabalpur Engineering College, Jabalpur

ABSTRACT

In this paper, the analysis and design of voltage feedback loop for phase-shifted full-bridge series resonant converter are presented. The effect of input ripple of dc-dc converter at output ripple is also presented. In order to achieve low ripple, proper structure of feedback controllers and output filter are identified. The effect of output capacitor value on output ripple voltage of closed loop system is also presented

Keywords: *Phase-shifted full-bridge series resonant converter, feedback loop, output filter.*

I. INTRODUCTION

Switch mode power supply (SMPS) has wide application and has replaced the linear power supply because of its high performance parameters like high efficiency, small size. SMPS have become an important part of modern electronic systems. The operational success or failure of these modern devices is strongly dependent on a quality of the voltage provided by their power supplies. SMPS have been used in high-energy physics research laboratories and medical institution for particle beam excitation and control [1]. In certain applications (loads), ripple factor (or peak to peak ripple voltage) at the output of SMPS needs to be reduced to minimum possible. Such requirement demands optimization of power supply control loop which is load specific. One such example is copper vapor laser (CVL) which is a nonlinear load and that needs very low ripple power supplies to obtain low jitter. The major difficulty facing switch mode power supplies for such application is the large harmonics generated high-frequency switching modulation. Therefore, choosing a proper feedback control loop for good harmonic reduction as well as fast dynamic response becomes an important design issue [1]-[3]. The objectives of SMPS feedback control design are to yield the output voltage that is stable and well regulated, and responds sensibly fast to disturbances such as a sudden load change [2]-[7].

In the past decades, modelling of SMPS power stages has been a subject of research with the results leading to transfer functions that accurately model small-signal behaviour of the circuits [2]. In [8-10] the small-signal equivalent circuit modelling of full-bridge series resonant converter based on the extended describing function concept and generalized state space averaging concept has been reported. The use of these transfer function is primarily in feedback compensation design to give a power supply desired performance.

II. SELECTION OF INPUT FILTER

In this paper phase-shifted full-bridge series resonant switch mode power supply shown in figure 1 is studied.

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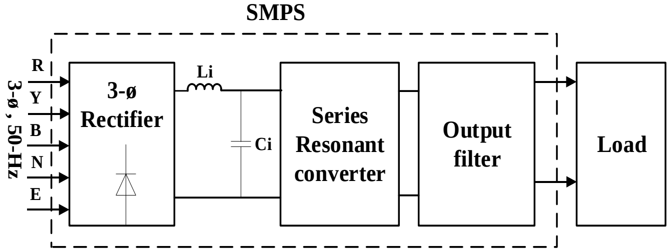

Figure 1:Phase-shifted full-bridge series resonant SMPS

In figure 1 an input filter (Li-Ci) is used to block the switching current from flowing back to the AC source and to reduce input harmonics and disturbances. The filter at the output is design primarily for reducing switching harmonics. It can be noted from figure 1 that load voltage or voltage ripple levels are affected by input source harmonics (Low-order) from the diode bridge conversion, switching harmonics (high-order) from high frequency pulse width modulation, and possible AC line fluctuation [1]-[3].

To get low output ripple, the input harmonics (peak to peak ripple voltage) at the series resonant converter input should be minimum. Since the output of 3-phase rectifier contains considerable amount of peak to peak ripple, hence it cannot be applied to series resonant converter directly. Therefore, a proper L-C filter is used to reduce the peak to peak ripple voltage. The value of Li and Ci as shown in figure 1 is selected so that it reduces the peak to peak ripple about 1% [2]-[7].

III. SELECTION OF FEEDBACK CONTROLLER

From the control system point of view, SMPS are a voltage regulator, consisting of a plant, Gp(s), which includes power circuit and PWM modulator, and a controller, Gc(s), as shown in figure 2. The transfer function of Gp(s) is known from the chosen topology, while the transfer function of Gc(s) is dependent on the compensation circuit configuration used. Thegiven Gp(s), Gc(s) should be designed to yield the open-loop transfer function, Gp(s)Gc(s) for following characteristics:

1) A gain at low frequencies should be high. This is required for good output voltage regulation.
2) A gain crossover frequency, f_{gc}should be high. This indicates the increase in system bandwidth, which is required for fast output voltage response.
3) A phase margin should be more than 45° to ensure an adequate stability margin [1]-[3].

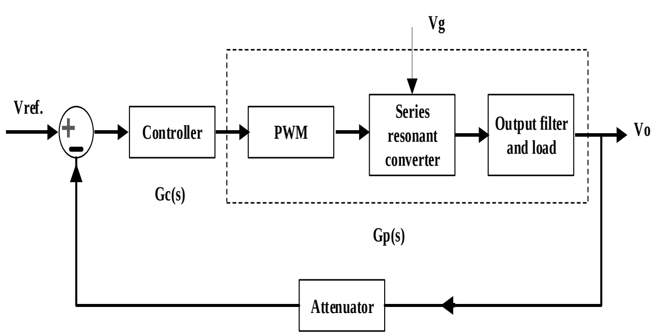

Figure 2: A control block diagram of SMPS

The most commonly used controller in SMPS to achieve above mention characteristics is PI controller [1]-[3].

$$G_c(s) = k\frac{1+s\tau}{s\tau} \quad (1)$$

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IV. SELECTION OF OUTPUT FILTER

In the phase shifted series resonant converter, the output rectifier is driven by the nearly sinusoidal tank output current. A large capacitor is placed at the dc output, so that the output voltage contains negligible harmonics of the switching frequency.

V. SIMULATION RESULTS

The small signal model of the resonant converter are used to calculate the open loop gain and closed loop gain. This model is exemplified with illustrative calculation in this section for a converter whose parameters are listed in table 1.

Table 1: Parameters of converter for illustrative calculations

Parameters	Values	Parameters	Values
DC input	560	Duty ratio (D)	0.2-0.9
Transformer turns ratio	1:1	Output filter capacitance (Co)	0.7 mH
Resonant frequency (fr)	17.8 kHz.	Load resistance (R_L)	22 Ω
Switching frequency(fs)	22 kHz.	Output DC voltage (Vo)	(340-550) V
Resonant inductance (Lr)	100 µH	Output DC current (Io)	20 A (max.)
Resonant capacitance (Cr)	0.8 µF	Voltage divider ratio	1:73

MATLAB is used for the calculation of the transfer function with the parameter given in table 1.

- Calculate Gp(s)
- Calculate Gc(s)
- Calculate H(s)

The open loop transfer function of series resonant power circuit (Gp) of prototype SMPS is calculated using MATLAB is given below

$$G_p(s) = \frac{2.57x10^9 s^3 + 2.44x10^{14} s^2 + 0.81x10^{19} s + 0.59x10^{25}}{s^5 + 1.32x10^5 s^4 + 6.32x10^{10} s^3 + 4.17x10^{15} s^2 + 4.4x10^{19} s + 3.2x10^{22}} \tag{2}$$

PI controller is most commonly used in SMPS, in frequency domain the transfer function of PI controller for following values$R_1 = 8.2\ \mathrm{k\Omega}, R_2 = 91\ \mathrm{k\Omega}, C = 0.1\ \mu\mathrm{F}$ is given by

$$G_c(s) = \frac{V_c(s)}{V_e(s)} = 11\left(\frac{1+9.1x10^{-3}s}{9.1x10^{-3}s}\right) \tag{3}$$

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The output of power circuit is high voltage (370 V DC) as compare to the control circuit elements operating range, hence the output is attenuated using potential divider network. The transfer function of attenuator using the value listed in table 1 is given by:

$$H(s) = \frac{1}{73} \tag{4}$$

Simulation of closed-loop system response

The close loop transfer function is given by equation 5

$$G(s)H(s) = G_p(s)G_c(s)H(s) \tag{5}$$

The value of the different transfer functions obtained in equations 2 to 4 are substituted in equation 5, the close loop transfer function $G(s)H(s)$for series resonant converteris obtained using MATLAB and is given by equation 6.

$$G(s)H(s) = \frac{3.21x10^5 s^4 + 3.05x10^{10} s^3 + 1.02x10^{16} s^2 + 7.32x10^{20} s + 8.03x10^{22}}{82x10^{-5} s^6 + 108.2s^5 + 5.18x10^7 s^4 + 3.42x10^{12} s^3 + 3.63x10^{16} s^2 + 2.62x10^{19} s} \tag{6}$$

The close loop response of series resonant converter is shown in figure 3. The close loop GM and PM of the system is 30.5 dB and 40.4° respectively. Simulation shows that system is stable and has bandwidth of ~ 2.23 kHz which is sufficient for fast output voltage response ,but the PM of system is 40.4° which is not enough for a stable system, Phase margin should be more than 45° to ensure an adequate stability margin.

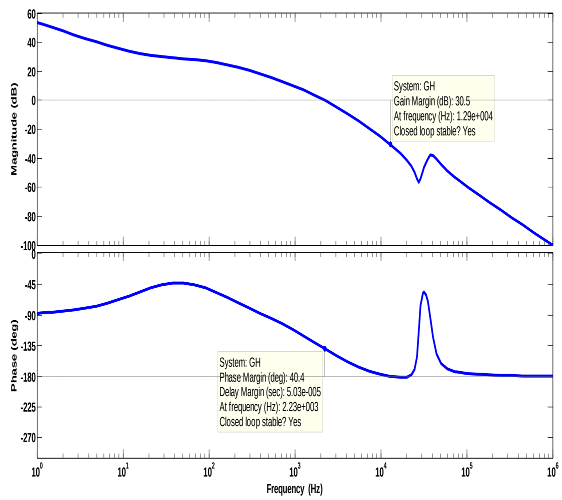

Figure 3: Closed loop response of series resonant converter

Effect of output capacitor on closed-loop response

The effect of output capacitor on GM, PM and bandwidth (BW) is simulated in MATLAB for three different values and tabulated in table 2 for the fixed value of controller gain i.e. $R_1 = 8.2$ kΩand$R_2 = 91$ kΩ.

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Table 2: GM, PM and BW for different values of Co.

Co in (mF)	GM in dB	PM in Degrees	BW in kHz.
Co = 0.7	30	40°	2.23
Co = 1.3	36	53°	1.45
Co = 2.5	41	67°	0.85

The simulated data shown in figure 4 shows that as the value of Co is increased from 0.7 mF to 2.5 mF, the GM is increased from 30 dB to 41 dB, PM is increased from 40° to 67°, but bandwidth of the system decreased from 2.23 kHz to 0.85 kHz

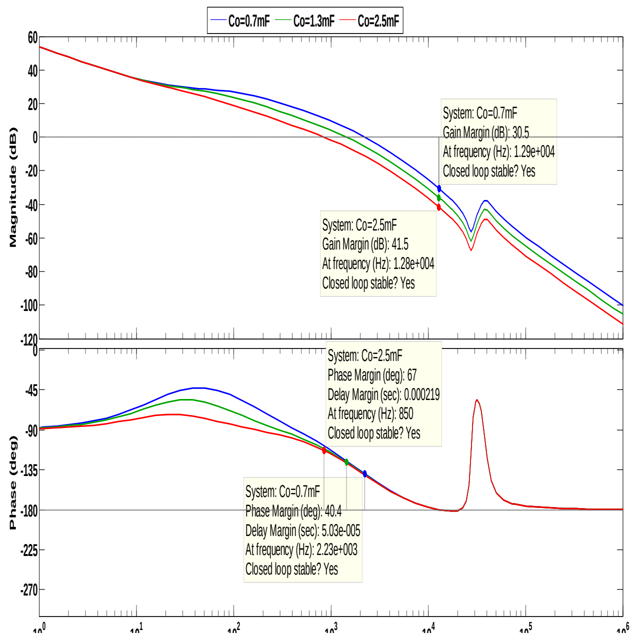

Figure 4: Closed loop response for Co = 0.7 mF, 1.3 mF and 2.5 mF

Effect of controller gain on closed-loop response

Bandwidth of the system is decreased to 850 Hz asthe output capacitance increased to 2.5 mF. To see the effect of variation in controller gain the feedback loop is modified for fixed value of output capacitor 2.5 mF and controller resistor R_1 = 8.2 kΩ . The controller gain is charged by charging the value of R_2resistor only.

Table 3: GM, PM and BW for different values of R2.

PI controller R_2 value in kΩ	GM in dB	PM in Degrees	BW in kHz.
R_2= 91	41	67°	0.85
R_2= 180	35.6	52°	1.47
R_2= 47	47	76°	0.46

The simulated data shown in figure 5 shows that as the value of R_2 is increased from 91 kΩ (gain ~11) to 180 kΩ (gain ~22), the GM is decreased from 41 dB to 35.6 dB, PM is decreased from 67° to 52°, but bandwidth of the system is increased from 0.85 kHz to 1.47 kHz. If the value of R_2 is decreased to 47 kΩ (gain ~ 5.7), the GM is increased to 47 dB, PM increased to 76° but the bandwidth decreased to 0.46 kHz.Therefore, a trade-off between stability (GM &PM) and fast response (BW) has to be made. The value of parameters is so selected that GM and

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PM are about 30 dB and 45° respectively and the bandwidth of the system is about 10% of switching frequency (f_s) i.e. ~2 kHz in my case (f_s = 22 kHz). Hence the value of R_2= 180 kΩ is good option when Co= 2.5 mF is selected.

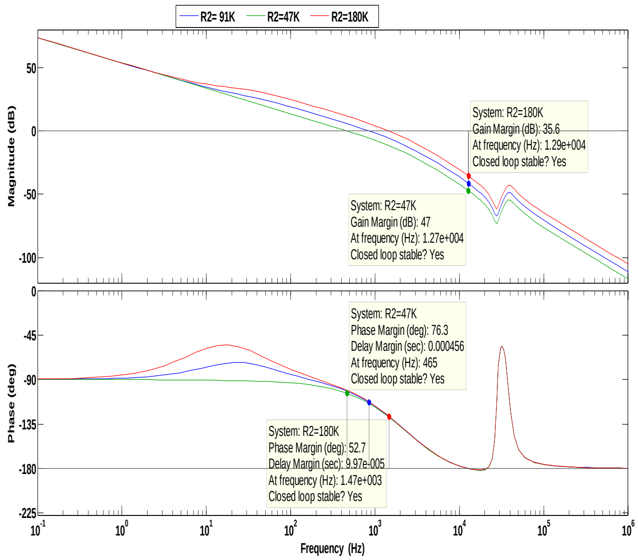

Figure 5: Closed loop response for different controller gain

VI. EFFECT ON OUTPUT RIPPLE VOLTAGE

The output ripple voltage for given prototype SMPS (parameters mention in table 1) at pulsed load (copper vapor LASER) are measured and tabulated in table 4 and table 5 for output capacitor value 0.7 mF and 2.5 mF respectively. The peak to peak output ripple was ~0.5 % initially (Co = 0.7 mF) which is reduced to ~0.2 % when the output capacitor value increased to 2.5 mF.

Table 4: output ripple (P-P) and % output ripple (P-P) .at Co=0.7 mF

SMPS DC voltage (V)	Output ripple voltage (P-P) (V)	% Output ripple voltage (P-P)
340	1.33	0.39
350	1.44	0.41
360	1.58	0.44
370	1.70	0.46
380	1.79	0.47

Table 5: output ripple (P-P) and % output ripple (P-P) .at Co=2.5 mF

SMPS DC voltage (V)	Output ripple voltage (P-P) (V)	% Output ripple voltage (P-P)
340	0.61	0.18
350	0.63	0.18
360	0.65	0.18
370	0.67	0.18
380	0.68	0.18

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VII. RESULTS AND CONCLUSION

The studies were carried out to reduce theoutput ripple voltage (peak to peak) to ~ 0.2 %. When the Phase-Shifted Full Bridge Series Resonant SMPS is tested at pulsed load (high voltage pulse power supply driving CVL), it was observed that the peak to peak output ripple voltage is 0.5 % when output capacitor value is 0.7 mf, which is not suitable for copper vapor LASER (CVL) to operate in master oscillator power amplifier (MOPA) chain. The effect of output capacitance and PI controller gain on system response is simulated using MATLAB. Simulation shows that the phase margin of 67°, gain margin of 41 dB and bandwidth of 0.85 kHz for output capacitor filter 2.5 mF, In order to improve the response time the PI controller gain is modified (Gain 22). The bandwidth of system is improved from 0.85 kHz to 1.47 kHz.

REFERENCES

1. *K. Kittipeerachon C. Bunlaksananusorn "Practical Compensation circuit design of Switch Mode Power Supply" IEEE 2003.*
2. *K. Kittipeerachon, C. Bunlaksananusorn "Feedback Compensation Design For Switched Mode Power Supplies With A Right-Half-Plane (RHP) Zero" KMITI 2004.*
3. *H. Jin, S.B. Dewan, J.D. Lavers "Voltage loop design for a low ripple fast-response AC/DC switch mode magnet power supply" IEEE 1992.*
4. *Yu-Kang Lo, Chung-Yi Lin, Min-Tsong Hsieh, and Chien-Yu Lin, "Phase-Shifted Full-Bridge Series-Resonant DC-DC Converters for Wide Load Variations", IEEE 2011.*
5. *Hangseok Choi, "Practical feedback loop design consideration for Switch Mode Power Supplies", Fairchild Semiconductor power seminar 2010-2011.*
6. *Bingjian Yang, Jorgen L. Duarte, Wuhua Li, Kai Yin, Xiangning He, Yang Deng "Phase-Shifted Full-Bridge Converter Featuring ZVS over the Full Load Range" IEEE 2010.*
7. *J.A. Sabate, V. Vlatkovic, R.B. Ridley, F.C. Lee, B. Il. Cho, "Design Considerations For High Voltage High Power Fill-Bridge Zero-Voltage-Switched PWM Converter", IEEE 1990.*
8. *Ping Wang, Can Liu, Lin Guo, "Modeling and Simulation of Full-bridge Series Resonant Converter Based on Generalized State Space Averaging", ICCSEE 2013.*
9. *Shuilin Tian, Fred C. Lee, Qiang Li and Bin Li, "Small-signal Equivalent Circuit Model of Series Resonant Converter", IEEE 2015.*
10. *Eric X. Yang, Fred C. Lee, and Milan M. Jovanovic, "Small-Signal Modeling of Series and Parallel Resonant Converters", IEEE 1992.*
11. *Richard Redl, Laszlo Balogh, David W. Edwards, "Optimum ZVS Full-Bridge DC/DC Converter with PWM Phase-Shifted Control: Analysis, Design Considerations, and Experimental Results" IEEE 1994.*