유전자 알고리즘을 이용한 포워드 컨버터 제어기의 파라메터 최적화

최영규* · 우동영* · 박진현**

Parameter Optimization of Controllers for Forward Converters Using Genetic Algorithms

Young-Kiu Choi* · Dong-Young Woo* · Jin-Hyun Park**

이 논문은 부산대학교 자유학술연구비(2년)에 의하여 연구되어졌습니다.

요 약

포워드 컨버터는 광범위하게 사용되는 파워공급기 중의 하나이다. 본 논문은 부하가 다양하게 변동하는 환경에서 출력 전압의 변동을 최소화하는 포워드 컨버터의 최적 회로 소자 값을 구하기 위한 파라메터 동조방법을 제시한다. 위상여유의 개념을 사용하는 기존의 방법은 최적의 위상여유를 통해 출력 전압 응답에서 부분적인 성능 개선이 이루어지도록 확장되었다. 이를 위해서 위상여유를 동조 파라메터로 두고 유전자 알고리즘을 사용하여 최적화하였다. 다음으로 회로 소자 값들을 동조 파라메터로 직접 선택하고, 역시 유전자 알고리즘으로 최적화하여 포워드 컨버터의 출력 전압 제어에서 매우 개선된 성능을 갖도록 하였다.

ABSTRACT

The forward converter is one of power supplies used widely. This paper presents parameter tuning methods to obtain optimal circuit element values for the forward converter to minimize the output voltage variation under various load changing environments. The conventional method using the concept of the phase margin is extended to have optimal phase margin that gives slightly improved performance in the output voltage response. For this, the phase margin becomes the tuning parameter and is optimized with the genetic algorithm. Next, the circuit element values are directly chosen as the tuning parameters and also optimized using the genetic algorithm to have very improved performance in the output voltage control of the forward converter.

키워드

포워드 컨버터, 출력 전압 제어, 유전 알고리즘

Key word

forward converter, output voltage control, genetic algorithm.

* 부산대학교 공과대학 전자전기공학부

** 진주산업대학교 메카트로닉스공학과(교신저자)

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Ⅰ. Introduction

The forward converter is one of power supplies used widely. It is based on DC/DC converters that transform some DC voltages into required DC voltages. DC/DC converters are usually classified into buck, boost, buck-boost and Cúk converters. Forward converters are related to buck converters. Forward converters with rectifier stages on the AC side are used as power supplies that should maintain constant DC output voltages[1-3]. Even though the loads of forward converters often change abruptly, forward converters should keep constant output voltages with some forms of feedback control. A design method proposed by Venable[4,5] using the concept of phase margins has been widely used. It has voltage feedback controllers with error amplifiers composed of OP-Amps, resistors and capacitors. Other design methods using the root locus[6], PI control[7] and robust control[8] were also proposed for the output voltage control of power supplies. These design approaches essentially have some design parameters such as phase margins and gains. The performance of feedback controllers for output voltages is closely related to those design parameters; however, these parameters usually rely on designers' experience. So, we have optimization problems for forward converters with respect to those parameters and the problems may be efficiently solved by genetic algorithms[9].

In this paper, the conventional design method based on the phase margin[5] is extended to have optimized performances with the genetic algorithm for the forward converter; the phase margin is considered as the tuning parameter that is optimized to have some improved output voltage responses. Next, resistances and capacitances of the voltage feedback controllers are directly regarded as the tuning parameters and they are optimized using the genetic algorithm to have very improved response of output voltage in the forward converter.

Ⅱ. Control System of the Forward Converter

Since the output voltages of forward converters are directly influenced by the change of loads, voltage feedback controls are required to maintain constant output voltages. Fig.1 shows a circuit diagram of the forward converter with the voltage feedback control loop.

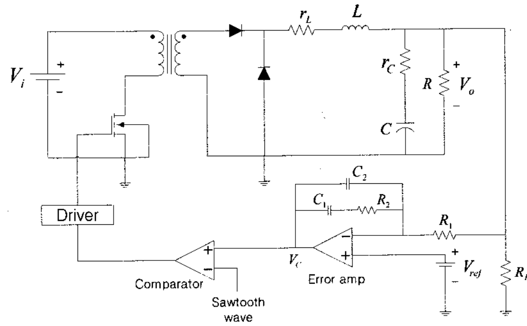

그림 1. 전압 제어 루프를 갖는 포워드 컨버터
Fig. 1. Forward converter with voltage control loop

Let $G_p(s)$ be a transfer function relating the output voltage $V_o(s)$ to the control voltage $V_c(s)$. Then we have

$$G_P(s) = \frac{V_i/V_P}{LC}\left[\frac{1+sr_cC}{s^2\left(1+\frac{r_c}{R}\right)+s\left(\frac{1}{RC}+\frac{r_c}{L}+\frac{(r_c+R)r_L}{RL}\right)+\frac{(r_L+R)}{RLC}}\right]. \tag{1}$$

where V_i is the input source voltage, V_p is the peak voltage of PWM circuits, and R is the load resistance. L is the inductance of the inductor coil, r_L is the resistance of the inductor coil, C is the capacitance of the capacitor, and r_c is the equivalent series resistance of the capacitor.

We should have proper values of circuit elements R_1, R_2, C_1 and C_2 of the error amplifier for the voltage feedback controllers in Fig. 1 to minimize the variation of the converter output voltage caused by the change of the load resistance R. The conventional procedure to select the proper values of the circuit elements is as follows[5].

i) Plot the Bode diagram of $G_P(s)$.

ii) Select a desired bandwidth $\omega_{CO}(=\omega_s/10 \sim \omega_s/5)$, where ω_s is the switching frequency. Find R_1 and R_2 such that $G_P(j\omega_{CO}) = R_1/R_2$.

iii) Choose a proper phase margin (PM) that should be usually greater than or equal to 45°. Calculate the following equations:

$$\varphi_{CO} = PM - \angle G_P(j\omega_{CO}) - 180^\circ, \tag{2}$$

$$K^2 - 2\tan(\varphi_{CO} + 90^\circ)K - 1 = 0. \tag{3}$$

iv) Find the zero frequency ω_Z and pole frequency ω_P :

$$\omega_Z = \omega_{CO}/K,\ \omega_P = K\omega_{CO}. \tag{4}$$

v) Finally, C1 and C2 are obtained as follows:

$$C_1 = 1/(R_2\,\omega_Z),\ C_2 = 1/(R_2\,\omega_P). \tag{5}$$

Ⅲ. Circuit Parameter Optimization Using Genetic Algorithms

In the conventional procedure previously stated, the phase margin should have an appropriate value to minimize the variation of the output voltage of the forward converter caused by the load change; however, the optimum value of the phase margin is not known. In this paper, the phase margin is selected as the tuning parameter and the genetic algorithm is applied to optimize the phase margin that results in optimal values of R_1, R_2, C_1 and C_2 of the error amplifier to achieve the minimum variation of the output voltage. Next, to improve further the forward converter performance beyond the conventional procedure based on the phase margin, we have R_1, R_2, C_1 and C_2 themselves as the tuning parameters, i.e., the chromosomes of the genetic algorithm. The chromosomes are encoded to be binary forms of 32 bits. The cost function J is defined as below:

$$J = \int_0^{T_f} |e(t)|dt, \tag{6}$$

where $e(t)$ is the output error voltage that is the difference between the reference voltage V_{ref} and the output voltage $V_o(t)$. T_f is the final time for evaluation of the cost function.

The cost function J is to be minimized. On the other hand, genetic algorithms need the fitness function F that is to be maximized. Hence the fitness function F has an inverse relation to the cost function J and the fitness function F is defined as

$$F = \frac{1}{1+\alpha J}, \tag{7}$$

where α is a weighting factor for the fitness value.

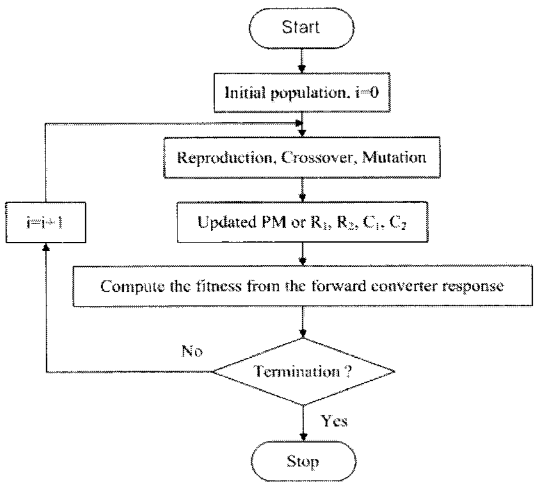

그림 2 파라메터 동조 알고리즘의 순서도
Fig. 2. Flow chart of the parameter tuning algorithm

Fig. 2 shows the total flow chart for parameter tuning procedure with the genetic algorithm. PM denotes the phase margin.

Ⅳ. Simulation Results and Discussion

Let the forward converter in Fig. 1 have the following values:

$V_i = 8V, \quad V_{ref} = 5V, \quad L = 5\mu H, \quad r_L = 20m\Omega,$
$C = 2000\mu F, \; r_c = 10m\Omega, \; \omega_{CO} = 6.66\pi \times 10^4 [rad/s]$
$V_P = 3V.$

The load resistance R is set to be 0.2Ω in the time interval between 0s to 0.6*ms*, is changed to be 0.1Ω in the time interval between 0.6*ms* to 1*ms*, and is set again to be 0.2Ω in the time interval between 1.0*ms* to 1.5ms. T_f in eqn.(6) is 1.5*ms* and α in eqn.(7) is 2×10^5.

Given the phase margin 50° that is arbitrarily chosen, the conventional procedure previously stated for the forward converter generates the following element values:

$R_1 = 20k\Omega, \quad R_2 = 800.84k\Omega, \quad C_1 = 23.184pF$ and $C_2 = 1.5332pF$

The cost function J is 3.8582×10^{-6} and the output voltage of the forward converter is shown in Fig. 3.

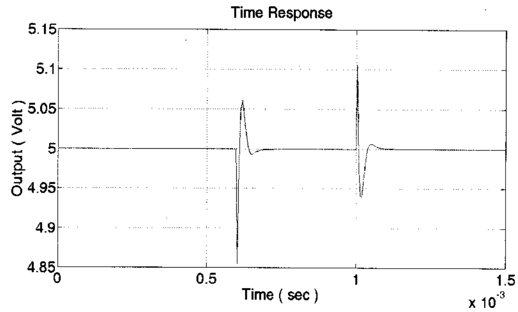

그림 3. 위상여유가 50°일 경우, 포워드 컨버터의 출력 전압

Fig. 3. Output voltage of the forward converter with the phase margin 50°

Next, the genetic algorithm is applied to optimize the phase margin. The phase margin is encoded to be 20-bit binary chromosomes, the population size is 100, the crossover rate is 0.75, and the mutation rate is 0.008. The load resistance R is changed in the same way as before. As a result, the cost function J is 3.2361×10^{-6} and the optimized phase margin is 65.41°. Fig. 4 shows the output voltage response of the forward converter that is slightly improved compared to that in the case of the phase margin 50°.

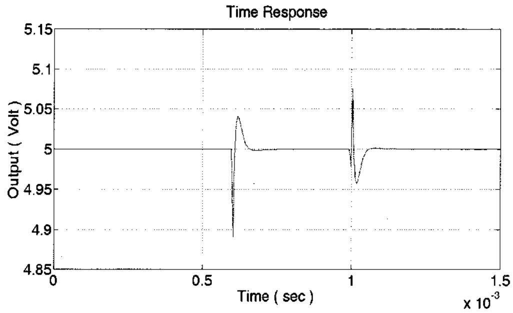

그림 4. 위상여유가 65.41°일 경우, 포워드 컨버터의 출력 전압

Fig. 4. Output voltage of the forward converter with the phase margin 65.41°

The circuit element values are also a little bit changed:

$R_1 = 20k\Omega, \; R_2 = 800.84k\Omega, \; C_1 = 50.623pF$ and $C_2 = 0.70217pF$

To improve the output voltage response further, R_1, R_2, C_1 and C_2 are directly regarded as the tuning parameters and encoded in the form of 32-bit binary chromosomes, and then the genetic algorithm is applied to tune the parameters. The population size is 100, the crossover rate is 0.75, and the mutation rate is 0.008. The load resistance R is changed in the same way as before. The cost function J is so much decreased to be 5.8164×10^{-7} and the circuit parameters are $R_1 = 1k\Omega, \; R_2 = 198.82k\Omega, \; C_1 = 117.65pF$ and $C_2 = 0.49412pF$. Fig. 5 shows the output voltage response of the forward converter that seems very improved when compared to that of the phase margin 65.41° in the sense of the magnitude and duration of the transient response: the magnitude decreased 65.8% and the duration also decreased 30.8%.

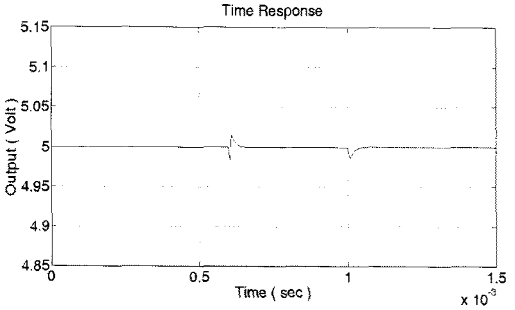

그림 5. 최종의 경우, 포워드 컨버터의 출력 전압
Fig. 5. Output voltage of the forward converter in the final case

V. Conclusions

The forward converter is one of power supplies widely used and it needs precise voltage regulation. This paper presents a parameter tuning method using the genetic algorithm to obtain circuit element values of the forward converter in order to minimize the output voltage variation under various load conditions. First, an optimal phase margin for the conventional procedure has been pursued using the genetic algorithm; however, it ensures only a little bit improvement over the phase margin 50° that was arbitrarily chosen. Next, two resistances and two capacitances of the error amplifier for the forward converter are selected as the searching parameters for the genetic algorithm; after optimization using the genetic algorithm, the optimal parameters give us very improved control performances for the output voltage of the forward converter.

감사의 글

이 논문은 부산대학교 자유학술연구비(2년)에 의하여 연구되어졌습니다.

References

[1] N. Mohan, T.M. Undeland and W.P. Robbins, *Power Electronics 3rd Edn.*, John Wiley & Sons, Inc., 2003.

[2] Y.M. Chen , Y.C. Liu and S.H. Lin, "Double-input PWM DC/DC converter for high-/low-voltage sources," *IEEE Trans. on Industrial Electronics*, vol. 53, no. 5, pp. 1538-1545, 2006.

[3] S. Wei and B. Lehman, "Current-fed dual-bridge DC-DC converter," *IEEE Trans. on Power Electronics*, vol. 22, no. 2, pp. 461-469, 2007.

[4] D. Venable, "The K factor: a new mathematical tool for stability analysis and synthesis," *Proceedings Powercon*, vol. 10, 1983.

[5] D.W. Hart, *Introduction to Power Electronics*, Prentice-Hall, 1996.

[6] L. Guo, J.Y. Hung and R.M. Nelms, "Digital controller design for buck and boost converters using root locus," *Proceedings IEEE IECON*, pp. 1864-1869, 2003.

[7] H. Guo, Y. Shiroishi and O. Ichinokura, "Digital PI controller for high frequency switching DC/DC converters based on FPGA," *Proceedings IEEE INTELEC*, pp. 536-541, 2003.

[8] K. Higuchi, K. Nakano, T. Kajikawa, E. Takegami, S. Tomioka and K. Watanabe, "Robust control of DC-DC converter by high-order approximate 2-degree-of- freedom digital controller," *Proceedings IEEE IES*, pp. 1839-1844, 2004.

[9] Z. Michalewicz, *Genetic Algorithms + Data Structures = Evolution Programs 3rd Edn.*, Springer-Verlag, New York, 1996.

저자소개

최영규(Young-Kiu Choi)

한국해양정보통신학회 논문지
제13권 제3호참조

우동영 (Dong-Young Woo)

2002년 2월 한국해양대학교
전기공학과 학사
2009년 2월 부산대학교 대학원
전자전기공학과 석사
※ 관심분야 : 신경회로망, 퍼지논리, 지능제어,

박진현 (Jin-Hyun Park)

한국해양정보통신학회 논문지
제13권 제3호참조