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A Study of Output Instability in the Current-Mode Controlled DC-DC Buck-Boost Converter

Ryota NAKASHIMA†, Takayuki KIMURA‡, and Yoichi ISHIZUKA†

†Graduate School of Science and Technology, Nagasaki University
Bunkyo-machi 1-14, Nagasaki City, Nagasaki, 852-8521 Japan
‡Department of Electrical and Electronic Engineering, Nippon Institute of Technology
Gakuendai 4-1-1, Miyashiro, Saitama, 345-8501 Japan
E-mail: †bb52111233@cc.nagasaki-u.ac.jp, ‡tkimura@nit.ac.jp, †isy2@nagasaki-u. ac. jp

Abstract– Because of technical advantages and diversifications of electronic devices, power supplies with high-efficiency and low noise are required to realize energy-saving society. As one of the key technologies to reduce loss of energy in the circuit, switching power supplies are proposed. Although the switching power supply which is controlled by semiconductor switching devices regulates the output voltage to use various loads efficiency, it behaves like chaotic oscillation if particular parameters are introduced into the circuit. Then, the switching power supply becomes unstable. To inspect such a behavior, we have done some experiments and evaluate it in this paper. From the results, the oscillatory phenomena can be found in the system and also the chaotic phenomena can be found in the specified condition.

1. Introduction

Because of global heating and exhaustion of fossil fuels, electric power supplies for renewable power generation pay much attention recently. As one of the research filed to apply those electric power supplies, DC power supply system is proposed and many researches are being done [5]. In general, the electric power by the renewable power generation systems is supplied to each load using power supply circuits aimed to use the loads safety and efficiently. In those power supplied circuits, a DC-DC converter is the one of which outputs an arbitrary DC voltage from a DC power supply[3], and is important to produce the stable electric power; the electric power could not be changed depending on the input voltage or output current. For designing the system in stable, the stability of the system is evaluated with the averaged and linearized model, generally. Thus, by using such analyzing methods and the small signal analysis, discontinuity of the circuit composition by the timing of the switching is neglected [6]. However, it is reported that, with specified circuit parameters, the system behavior becomes complicated oscillatory phenomena like chaotic one [1, 2].

In this paper, we investigate the influence of the circuits parameters which gives the behavior of the output power in the power supplied systems by numerical simulations and demonstrated experiments. Obtain results show that in demonstrated experiments, oscillation of multiple period begins when input voltage is lower than 30[V]. However, in numerical simulations, we could be confirmed that the circuit happen complex oscillatory phenomena when input voltage is lower than 50[V].

2. Techniques of the Circuit Analysis

Conventionally, the switching power supplies are designed that the fluctuation of the input power is within 10% of the rated value by a steady power transmission and distribution. However, because of the use of the renewable energy which fluctuates depending on the weather conditions as the input power for the power supplied system, the situation has changed; we should consider the behavior of the input power on the power supplied systems for efficient use of each load. In addition, one of the possibilities to efficient use the power supplied systems with renewable energy is to implement a buck-boost typed DC-DC converter in real energy conversion systems. Then, we analyzed the behavior of the output power on the buck-boost typed DC-DC converter in this paper.

2.1 Small Signal Analysis and Large Signal Analysis

Generally, analysis of the switching power supply is broadly divided into two types. The first one is a small-signal analysis and the second one is the large -signal analysis. The static characteristics and the dynamic characteristic of the power supply are analyzed by the small-signal analysis with average model. The characteristic of the near operating points is sufficiently investigated if the circuit is designed under stable power transmission and distribution. Then, the averaging equation state of the buck-boost DC-DC converter is

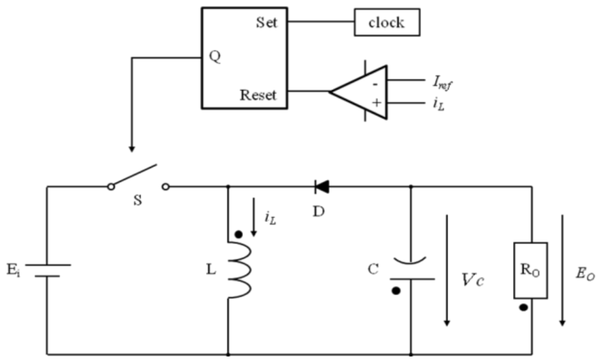


Fig. 1 Buck-boost DC-DC converter

defined as follows[7]; each parameter of the above equation show that $\bar{x}(t)$ is averaging state vector, A and b is coefficient matrix, D is duty ration, and $d\bar{x}(t)/dt$ is the averaging equation state. What can we know from this is led state equation analysis of steady state is possible by placing the right-hand side with 0, this thing called DC analysis. To examine the dynamic characteristics is possible if causing

$$\frac{d\bar{x}(t)}{dt} = A\bar{x}(t) + bE_i \, , \tag{1}$$

$$\begin{cases} \bar{x}(t) = [i_L(t) \quad E_o(t)]^t \\ A = \begin{bmatrix} 0 & -\frac{D'}{L} \\ \frac{D'}{C} & -\frac{1}{R_o C} \end{bmatrix} \\ b = \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix} \\ D + D' = 1 \end{cases} .$$

the right-hand side is small variation, this is called the small-signal analysis.

On the other hand, although the circuit equation becomes complicated, we can analyze the state of the circuit without linearization by the large-signal analysis. In addition, the large-signal is a powerful tool for investigating the behavior of the operating point in which large fluctuation is added, and the large-signal analysis may have possibility for verifying the bifurcation phenomenon on the switching circuits.

3. Control system

In this study, we use the current-mode controlled DC-DC buck-boost converter. Shown in equation (2) input and output characteristics;

$$E_i = \frac{D}{1-D} E_o \, . \tag{2}$$

When the switch S is turned ON that clock pulse is input to the RS flip-flop, inductor current i_L rises until it reaches the reference current i_{ref}. Also, be ignored even if the clock pulse is input during this period (Fig.2). ON state equation can be shown to the following equation:

$$\frac{di_L}{dt} = \frac{E_i}{L} \, . \tag{3}$$

$$\frac{dE_o}{dt} = -\frac{1}{R_o C} E_o \, . \tag{4}$$

When the switch S is turned OFF state that inductor current i_L reaches the reference current i_{ref}, and switch S remains OFF state until next clock pulse is inputted. OFF state equation can be shown to the following equation:

$$\frac{di_L}{dt} = -\frac{1}{L} E_o \, . \tag{5}$$

$$\frac{dE_o}{dt} = \frac{1}{C} i_L - \frac{1}{R_o C} E_o \, . \tag{6}$$

From the equation (2), ON time t_n of switch S can be shown to the following equation:

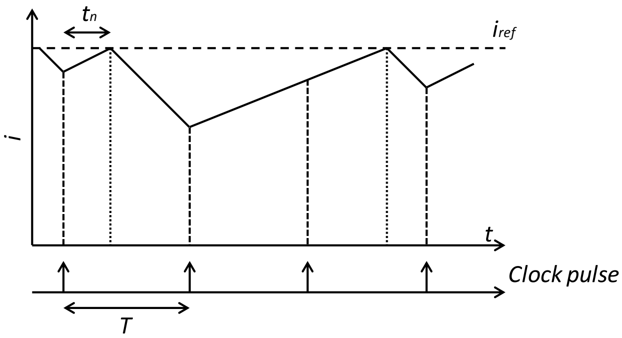


Fig.2 Peak current control.

$$t_n = \frac{L}{E_o}(I_{ref} - I_L). \tag{7}$$

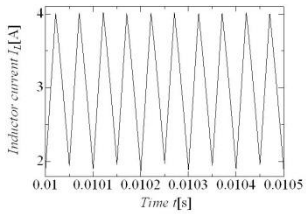
Also, capacitor voltage when t equal t_n can be shown to the following equation:

$$E_o(t_n) = E_{on} e^{-\frac{1}{R_o C} t_n} \, . \tag{8}$$

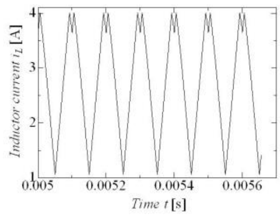
4. Stability by the current control mode

The main purpose of the switching power supply is to supply a stable DC voltage to the load using a negative feedback circuits. Because the DC-DC converter consists of an inductor *L* and a capacitor *C*, we carefully consider the phase compensation of the negative feedback circuits. The negative feedback circuit has two types of operation mode; a current control mode and a voltage control mode. In the case of the voltage control mode, speed of response to output fluctuations is sacrificed because of compensating any fluctuations in the output voltage for phase compensation in a feedback loop that is detected by the error amplifier. On the other hand, the current control mode quick responses speeds because of returning to fast reactor current by feedback. Also phase reversal does not occur because from input supply to the output portion of the reactor can be approximated to a constant current source. The output stage becomes the primary delay of RC circuit. That is, it is stability that the DC-DC converter using the current control mode. However, the peak current control of the current control mode is stable if the duty ratio is less than 0.5 but inductor current becomes unstable when the duty ratio is more than 0.5 [8].

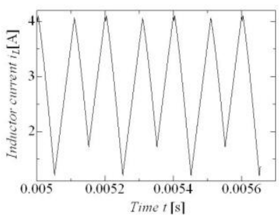
Because of the use of the renewable energy which fluctuates depending on the weather conditions as the input power for the power supplied system, the situation has changed; we should consider the behavior of the input power on the power supplied systems for efficient use of each load. In order to stabilize this output, whatever duty ratio may be higher than 0.5. However, when the circuit is performed by the current control, we cannot raise the ratio of duty. Therefore, we performed numerical simulations and demonstrated experiments as a basic experiment; whether how to behave which the output of the current-mode controlled DC-DC buck-boost converter was powered by solar power.



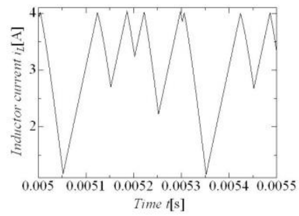
(a) Reactor current waveform



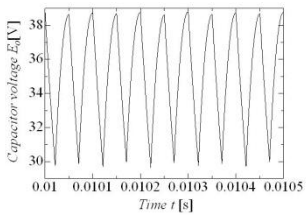
(a) Reactor current waveform



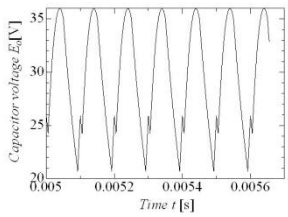
(a) Reactor current waveform



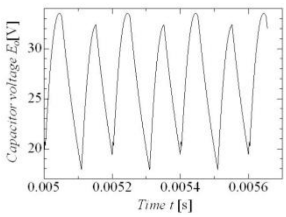
(a) Reactor current waveform



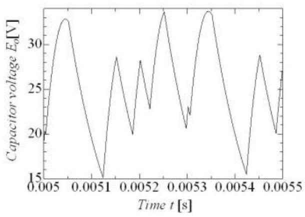
(b) Output voltage waveform



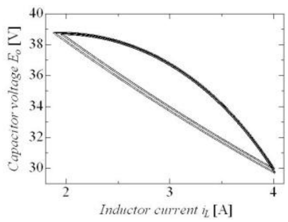
(b) Output voltage waveform



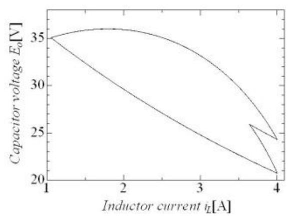
(b) Output voltage waveform



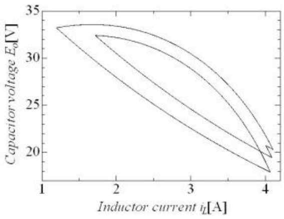
(b) Output voltage waveform



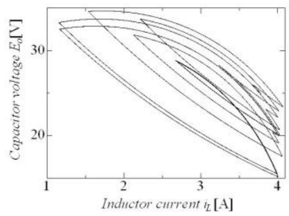
(c) Lissajous figure
50V input voltage



(c) Lissajous figure
35V input voltage



(c) Lissajous figure
25V input voltage



(c) Lissajous figure
20V input voltage

Fig.3 Numerical simulations

5 Numerical simulations and Demonstrated experiments

In this chapter, the oscillatory phenomena of the current-mode controlled DC-DC buck-boost converter are described. Numerical simulations and demonstrated experiments have been done.

5.1 Numerical simulations

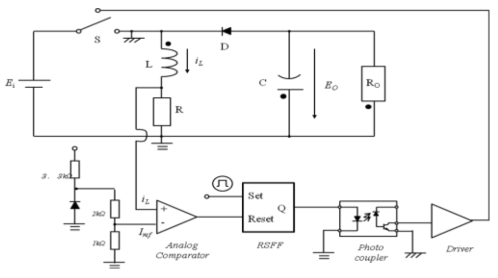
Numerical simulations have been done using the circuit parameter values shown in [3]. In this simulation, the input voltage is varied from 0 V to 50 V and confirmed the oscillatory phenomena of the reactor current and the output voltage in the circuit.

Figure 3 shows the results of numerical simulations when the input voltage is 50 V. From Fig. 3, it is seen that the reactor current waveform and the output voltage waveform are a vibration in the rule between switching of the switching element. Also the period of the reactor current and output voltage is one period. Figure 4 shows the results of numerical simulations when the input voltage has 35V. Unlike the case of input voltage 50 V (Fig.3), when the input voltage is 35V, the period of the reactor current and output voltage is two period. Each figures in Fig. 5 shows the results of experimental results when the input voltage is 25 V and 20 V. When input voltage is lower than 25 V, the reactor current and the output voltage showed a complex behavior, and the oscillation of multiple period is confirmed. In this condition, it is confirmed that the reactor current and the output voltage are both in a chaotic behavior.

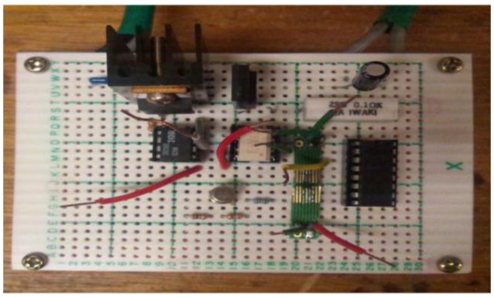
5.2 Demonstrated experiments

We have done some experiments to confirm the oscillatory phenomena in the current-mode controlled DC-DC buck-boost converter. Figure 7 shows the circuit diagram and photographs used in the experiment. The circuit parameters are show in Table 1 as well as numerical simulations [3]. Figure 8 shows the experimental results. It is confirmed that when the input voltage is lower than 30 V, the reactor current and the output voltage showed a complex behavior. In addition, when input voltage is 10V, it is confirmed that the circuit loses periodicity has been a complex vibration. Also we can be confirmed that the circuit operates periodically when the input voltage is 20V.

Comparing the results that obtained from numerical simulations and demonstrated experiments, in either experiment, we could be confirmed that the reactor current and the output voltage is becoming in the complex behavior with the lower input voltage. In addition, in the demonstrated experiments, oscillation of the multiple periods begins when input voltage is lower than 30V. However, in the numerical simulations, we could be confirmed that the circuit happens complex oscillatory phenomena when the input voltage is lower than 50V.

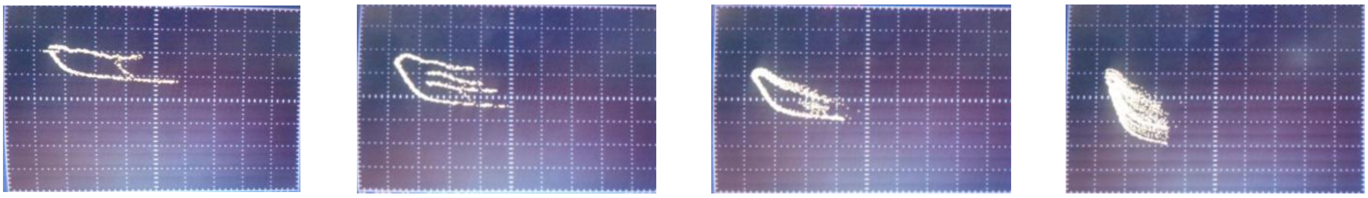


(a) Schematic

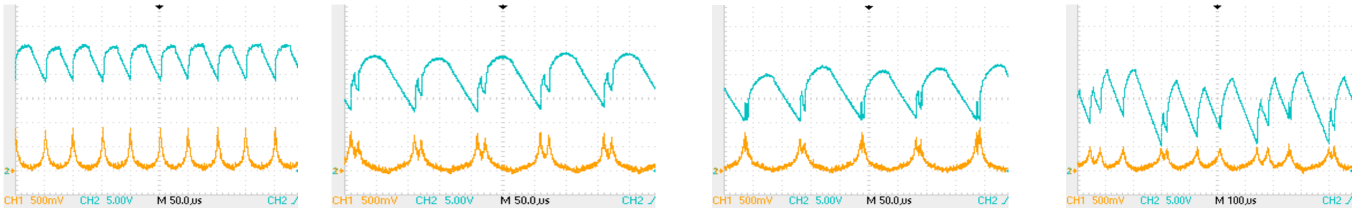


(b) Circuit photo

Fig.4 The experimental circuit



(a) E_i=30V (b) E_i =25V (c) E_i =20V (d) E_i =10V



(e) E_i =30V (f) E_i =25V (g) E_i =20V (h) E_i =10V

Fig.5 Result of demonstrated experiments:

(a)-(d) Lissajous figure (H:200mV/div. V:5V/div.), (e)-(h)i_L(CH1) and E_o(CH2) waveform.

6.Conclusion

In this paper, some numerical simulations and experiments has been done with the current-mode controlled DC-DC buck-boost converter to confirm the chaotic behavior. From the results, it could be confirmed that the reactor current and the output voltage oscillation do not show the complex behavior when the input voltage fluctuated.

As the future works, it will be evaluated that circuit model that subjected to setting more realistic in numerical simulations. Also, in this demonstrated experiments, a peak current of the reactor current couldn't be controlled when input voltage increased. Therefore, we will improve the demonstrated experiments of the circuit and compare numerical simulations and demonstrated experiments in the current-mode controlled DC-DC buck-boost converter. In addition, based on the evaluation of these, we will examine about output stabilization for chaotic phenomena appearing in the circuit. Last, The research of T.K. was partially supported by a Grant-in-Aid for Young Scientists (B) from JSPS (No.23700180).

References

[1] K.W.E.Cheng, M.Liu and J.Wu, "Chaos study and parameter-space analysis of the DC-DC buck-boost converter," *IEE Pro.-Power Appl*. Vol.150, No2, 2003.

[2] Chi Kong Tse, "Complex Behavior of Switching Power Conveters," *CRC Press*, 2004.

[3] NINOMIYA Tamotsu, "Fundamentals of Switching Converters," CORONA PUBLISHING CO.LTD, Tokyo, 1992.

[4] SUETOMI Masayuki and MATSUO Hirofumi, "A Bidirectional AC-DC Converter with High Power Efficiency and High Power Factor Using Novel FPGA Control Circuit," *IEE-SPC* 2011(121), 91-95, 2011-07-28.

[5] SUETOMI Masayuki and MATSUO Hirofumi, "High Frequency Isolation Circuit with High Efficiency for the High DC Voltage Power Feeding System," *IEICE-EE*, vol. 111, no. 305, EE2011-29, pp. 31-35, 2011.

[6] Hikihara Takashi, Konaka Masaki and Ueda Yoshisuke, "A Study on Bifurcation and Chaotic Phenomenon in Output of a Convertor Circuit", *IEICE*, Technical Repert, pp. 9-16, 1998.

[7] Ryota NAKASHIMA, Takayuki KIMURA and Yoichi ISHIZUKA, "A Study of Chaos in A Current-mode Controlled DC-DC Buck-boost Converter", *IEICE Technical Report*, Vol.111, No.498, 2012.

[8] SERTARO Baba, "Design techniques for SMPS," CQ Publishing Co.Ltd, 2009.