# System Identification Method를 이용한 DC/DC 컨버터 상태진단

論 文
56-4-12

## A Operating Status Diagnosis of DC/DC Converter by System Identification

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**Abstract** - In this paper, we propose a new diagnosis method of DC/DC converter aging. The method is based on variations of the parasitic resistor for the aging process. We apply an on-line diagnosis of the DC/DC converter because the observation is not a device, but a system. This study proposes a method of DC/DC converter diagnosis by analyzing the variations of model on the variations of parasitic resistor.

**Key Words** : DC/DC converter, diagnosis, parasitic resistor, System identification

## 1. INTRODUCTION

The power converter system supplies power to the fields of industry, home, information and communication. It requires specialized protection equipment to prevent an accident from occurring with the power converter because it could bring a great loss of human life and operations, communication troubles, and accident treatment costs.

Generally, the power converter system has a protection circuit to prevent an immediate accident from the states of emergency, such as over voltage and current, and temperature increment, and it cuts off the power in these emergency situations. However, there are still few studies that have been performed on diagnosis systems that will help prevent the occurrence of an accident to a system caused by the aging of semiconductor elements, inductors, capacitors, drive and control circuits. Diagnosis of aging and deterioration is used to prevent an accident in a power system by making a diagnosis of the conditions of the system, thereby making it possible to ensure the stable operation of the power system because it determines the times of change and maintenance.

The main feature of the diagnosis of a power converter system all this while depends on the secondary symptoms of parts, off-line, field measured data, temperature, and noise. The simplest methods of diagnosis for each part are to measure the voltage, current, and temperature, but this makes for a complicated system and higher cost because all of the parts are required to install an individual sensor for each part. The most desirable method for a diagnosis of part aging is the individual measurement for each part. It, however, is not a proper method because the power converter system consists of many parts, and each part has a different extent of lifetime for the conditions of operation. In addition, a malfunction of the system is expected to occur due to the interferences of measured noise. Furthermore, it shows inefficiency because it is not an on-line method but an off-line method. In addition, it is mainly focused on the absolute values of voltage and current based on the fields of measured data and is defined as a judgment guideline for a diagnosis of the secondary symptoms of a power converter system, such as noise and temperature.

The recent trends of research and development are not the individual measurement but the aspects of systematic and on-line diagnosis. In addition, studies have been carried out not only for the simple physical quantity of measured data, but also the examination of the variations and progresses using a signal processing method [1,2,3,4].

This study presents an indicator for the aging of a power converter system and demonstrates a diagnosis method of a power converter system using this study. This study proposes a method of DC/DC converter diagnosis by analyzing the variations of model against the variations of parasitic resistor.

## 2. Diagnosis method for DC/DC converter aging

### 2.1 Diagnosis indicator of DC/DC converter aging

A DC/DC converter consists of the power semiconductors, condensers, inductors, and so on. These

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接受日字 : 2006年 10月 11日
最終完了 : 2007年 3月 8日

parts are aged by long-term usage, and the equivalent resistors of the series and parallel connections for each part are increased.

These increased resistors are defined as a diagnosis indicator of aging. Fig. 1 shows an equivalent circuit included in the property of the parasitic resistor for each part of the Buck converter from the power converter system.

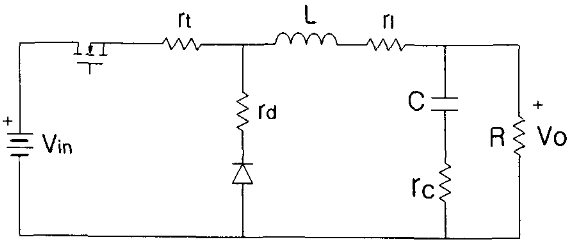

**Fig. 1** Buck converter considered in the parasitic resistor

The mathematical model of the Buck converter considered in the parasitic resistors can be expressed as shown in Eq. (1). The transfer function G(s) and diagnosis indicators ξ of aging can be defined as Eq. (1).

$$G(s) = \frac{\hat{v}_o}{\hat{d}} = V_{\in} \bullet \frac{(1+sC \bullet r_s)(1+\xi_2)}{\frac{LCs^2}{1+\xi_1} + \frac{s}{1+\xi_1}\left(\frac{L}{R}+CR\xi_1\right)+1} \qquad \text{------------------ (1)}$$

$$\xi_1 = \frac{r_l + r_c + r_t D + r_d(1-D)}{R},$$

$$\xi_2 = \xi_1 - \frac{(Dr_t - Dr_d)}{R}$$

Where DC is the output voltage (assumed by the constant current flow of inductor: CCM). Vin : Input voltage, D : Dutycycle, D1 = 1-D, L : Inductor, C: Capacitor, R: Load resistor, rl : Internal resistor of inductor, rc : Internal resistor of capacitor(=ESR), rt : Internal resistor of switch, and rd : Internal resistor of diode. From the mention edequation, it is known that these a remade of the combination of the parasitic resistors of the DC/DC converter, and the parasitic resistor produced by the aging is directly affected by the diagnosis indicator ξ1, ξ2.

Therefore, it is not actually possible to measure the internal resistor for all of the parts. It is then desirable to judge for the aging by means of the variations of the values of the diagnosis indicator ξ1, ξ2.

## 2.2 System Identification

The system identification is used to define a mathematical model, which is to act as the same operation, using measured input and output data from the unknown system. In the aspect of an ideal viewpoint, it is a kind of mapping onto the model space from the space of measured input and output data. The processes for defining a dynamic model from the measured input and output data include the three basic items as follows.

1. Input-output data
2. Model set (Model structure)
3. A method to select a specific model based
on the data from the set (Identification method)

The identification process selects a model structure repeatedly and calculates the most desirable model. If this model is satisfied, the property of the model will be investigated as follows.

1. Input and output data from the process will be collected for the identification.

2. Useful parts of data will be selected, and filtering is applied to focus on the major ranges of frequency.

3. A model structure will be selected and defined.

4. The most desirable model will be calculated by the input and output data and given standard of the conformity rates from the model structure.

5. Investigate the property of the acquired model.

If the model is good enough, the process will be stopped. Otherwise, the process will start from step 3 with the other model set. Another possible estimation method (Step 4) will be attempted, but it will restart from the input and output data (Steps 1 and 2).

## 2.3 Diagnosis algorithm of DC/DC converter

The transfer function of an equivalent model constructed by the mathematical equivalent model and experimental measurement can be expressed as shown in Fig. 2.

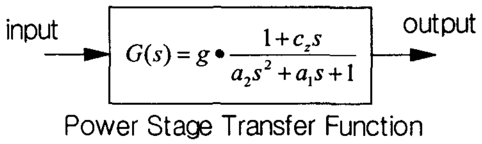

**Fig. 2** Transfer function of the equivalent model of converter

where g, cz, a2 and a1present the simple expression of the coefficients shown in Eq. (1).

Therefore, the identity can be realized by the equation produced by the mathematical modeling and actual values measured by the experiments as presented in Fig. 3, and the diagnosis indicators and can be calculated by the expansion of an equation.

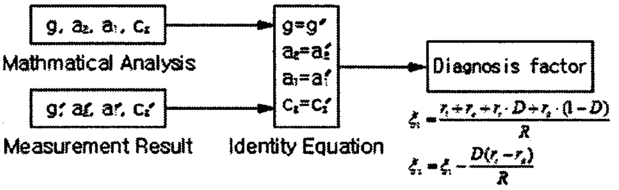

Fig. 3 Defining of the diagnosis indicators

### 2.4 Boost and Buck-Boost converter modeling

The Boost and Buck-Boost converter can be produced by using the mentioned methods as follows. Fig. 4 illustrates the Boost converter circuit considered in the parasitic resistor.

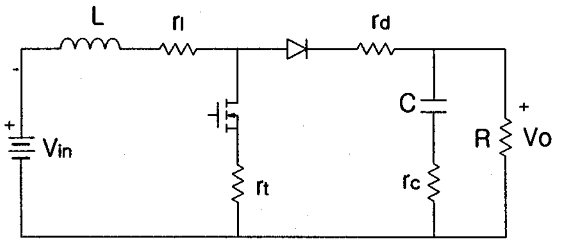

Fig. 4 Boost converter considered in the parasitic resistor

$$G(s) = \frac{\hat{v}_o}{\hat{d}} = \frac{V_{in}(D_1^2 - \xi_2)}{(D_1^2 + \xi_1)^2} \bullet \frac{1 - \dfrac{Ls}{R(D_1^2 - \xi_2)}}{\dfrac{LCs^2}{D_1^2 + \xi_1} + \dfrac{s}{D_1^2 + \xi_1}(\dfrac{L}{R} + CR\xi_1) + 1}$$

$$\xi_1 = \frac{r_l + r_t \cdot D + (r_c + r_d)(1-D)}{R}, \quad \xi_2 = (r_l + r_t)/R \qquad \text{------------(2)}$$

In order to produce an equivalent model, the mathematical model of the Boost converter that has the property of parasitic resistor applied by the state space average method from some kind of method can be expressed as follows.

Where the DC output voltage is assumed by the constant current flow of inductor: CCM. Fig. 5 presents the Buck-Boost converter circuit considered in the parasitic resistor.

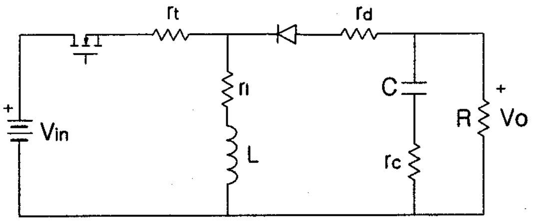

Fig. 5 Buck-Boost converter considered in the parasitic resistor

The mathematical model of the Buck-Boost converter considered in the internal resistor can be expressed as shown in Eq. (3) in order to produce an equivalent model as well as the Boost converter using the Spate Space Average method.

$$G(s) = \frac{\hat{v}_o}{\hat{d}} = \frac{V_{in}(D_1^2 + \xi_2)}{(D_1^2 + \xi_1)^2} \bullet \frac{1 - \dfrac{LDs}{R(D_1^2 + \xi_2)}}{\dfrac{LCs^2}{D_1^2 + \xi_1} + \dfrac{s}{D_1^2 + \xi_1}(\dfrac{L}{R} + CR\xi_1) + 1}$$

$$\xi_1 = \frac{r_l + r_t \cdot D + (r_c + r_d)(1-D)}{R}, \quad \xi_2 = \xi_1(1-2D) + \frac{(r_c + r_d - r_t)DD_1}{R} \qquad \text{--------------------------------(3)}$$

## 3. Measurement of the diagnosis indicator

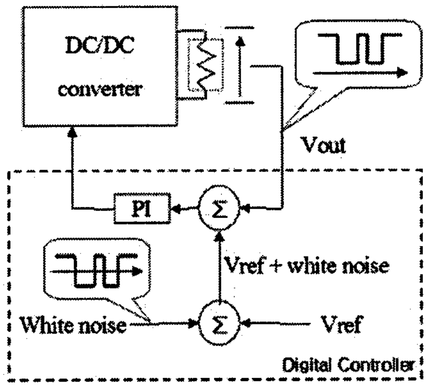

Fig. 6 Block diagram for the diagnosis indicator measurement

Fig. 6 presents a diagram for the measurement of the diagnosis indicator. The input of the controller is the input of the digital controller added by the white noise. This output is applied to the input of the PI controller as compared with the output voltage Vout. The output of the PI controller is to define the width of gate for the power converter system, and then the final output voltage added by the noise property will be obtained. It is a method so that the output can be obtained by the input added by the comparison between the white noise and the output response.

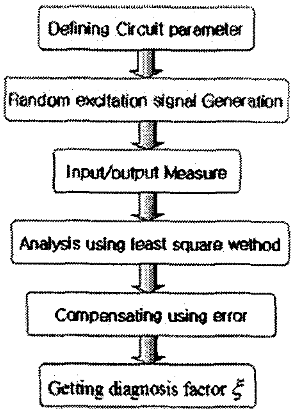

**Fig. 7** Diagnosis algorithm and implementation flow chart

Fig. 7 shows a flow chart for implementing the diagnosis algorithm. The system identification is implemented by using the library introduced by the Matlab after converting the AD sampled data that is stored in the data buffer into the data file by using the DSP320C32 emulator in order to perform the mentioned diagnosis algorithm.

Fig. 8 shows the property of white noise and its response characteristics added in the input signal.

Fig. 9 presents the results of the system identification according to the response characteristics and verifies the diagnosis algorithm using the comparison between the experimental analysis and the simulation results as a similar result by means of the simulation of the transfer function with the circuit parameters.

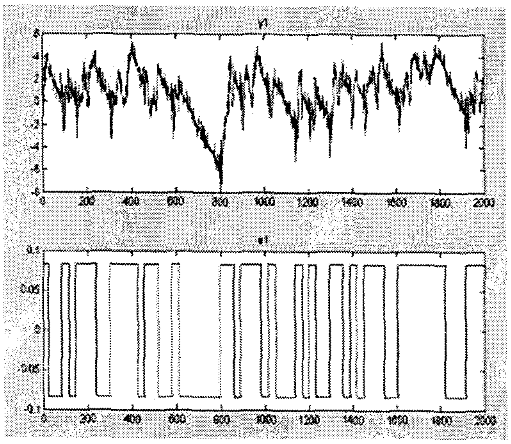

**Fig. 8** White noise and its response characteristics added in the input signal

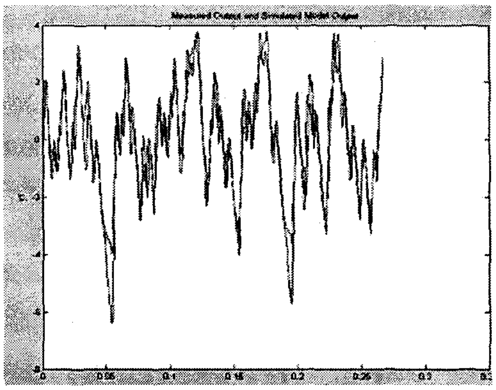

**Fig. 9** *Verification of system identification* ($\xi1$ = 0.12)

## 4. Experimental Result

**Table 1** Circuit Parameters

| | |
|---|---|
| Input voltage Vin | 24[V] |
| Output voltage Vout | 5[V] |
| Load resistor Ro | 10.6[Ω] |
| Inductor parasitic resistor rl | 1.2 [mΩ] |
| Condenser series resistor rc | 12.5[mΩ] |
| Switching series resistor rt | 10.7[mΩ] |
| Diode series resistor rd | 6.1[mΩ] |
| Condenser C | 470[uF] |

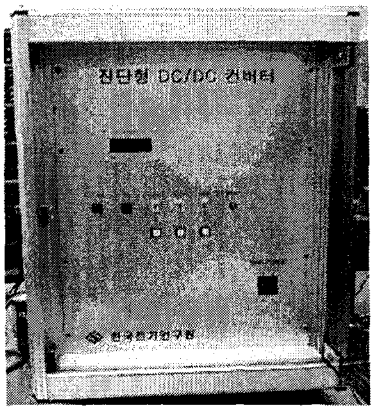

**Fig. 10** Diagnosis DC/DC converter prototypes

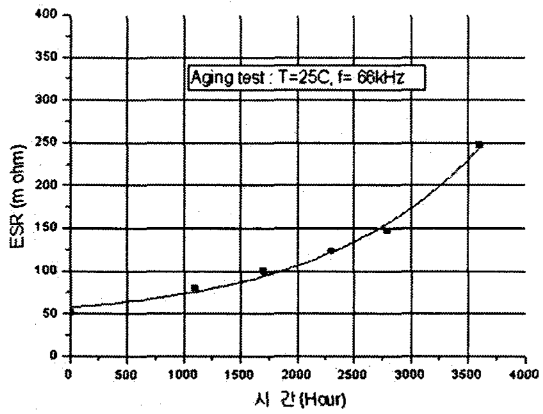

**Fig. 11** Variations of the equivalent resistor of electrolytic condenser due to the aging increment

Fig. 10 presents diagnosis DC/DC converter prototypes. Table 1 is the circuit parameter of the prototype. Fig. 11 presents the variations of the equivalent resistor of the electrolytic condenser due to the aging increment [4]. It shows the variations of about 500% after applying 4,000 hours compared with the initial times 0 for the variations of ESR according to the operation times of the electrolytic condenser under the switching frequency of 66 kHz and 25℃.

Table 2 presents the results of the diagnosis results by experiment and theoretical results under the two conditions. Condition 1 shown in Table 1 pertains to the circuit parameters and is the diagnosis results according to the experiment of the Buck converter. The circuit parameters a2,a1,g,cz, and $\xi_1$ are produced by the method mentioned in clause 2.1, and it shows the results compared with the theoretical values of Eq. (1). Condition 2 presents the comparison between the condition that a series resistor 208[mΩ] is connected to the output condenser with a serial connection and the theoretical results under the same conditions as those in condition 1. Here, the error means the diagnosis indicator $\xi_1$ of experimental error for the theoretical results. It still shows a significant error comparatively under 5~8%, but it is relatively regarded as a closed result for the diagnosis technology as considering the errors of the modeling or measuring process. In addition, it is expected that the comparison and consideration of the absolute values and variations is to compensate the errors.

Fig. 12, 13, and 14 present the variations of $\xi_1$, a1anda2accordingtothevariationsofload from 2[mΩ] to 10[mΩ] and verify the diagnosis algorithm by using the agreement between the experimental values and the theoretical values.

Fig. 15 presents the condenser equivalent series resistor according to the variations of aging level and verifies the diagnosis algorithm by using the agreement between the diagnosis values and the real values. Aging level means state of condition 1 in Table 2 adding serial connection resistors, which is 12[mΩ], 79[mΩ], 112[mΩ], and 208 [mΩ].

**Table 2** Diagnosis results

| | Condition 1 | | Condition 2<br>(Condition1 + 208[mΩ] series connection) | |
|---|---|---|---|---|
| | Diagnosis values | Theoretical values | Diagnosis values | Theoretical values |
| Fitting rate | 60.8% | - | 69.6% | - |
| a2 | 9.44E-07 | 4.22E-07 | 8.72E-07 | 4.14E-07 |
| a1 | 6.20E-04 | 6.54E-04 | 6.87E-04 | 7.28E-04 |
| g | 17.5428 | 20.90761 | 17.5571 | 20.40273 |
| $\xi_1$ | 0.120133 | 0.128954 | 0.13756 | 0.149991 |
| $\xi_2$ | -0.26905 | -0.12885 | -0.26845 | -0.14989 |
| Error | 6.84% | - | 8.23% | - |

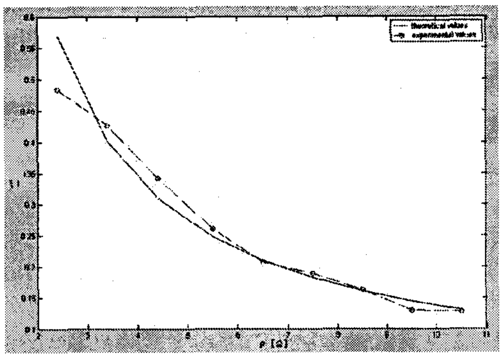

**Fig. 12** Variations according to the variations of load (o Diagnosis values, - Theoretical values)

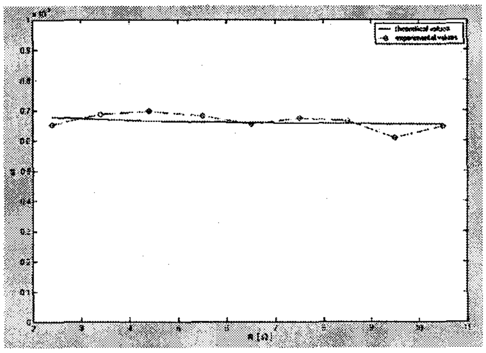

**Fig. 13** Variations of a1accordingtothevariationsofload (o Diagnosis values, - Theoretical values)

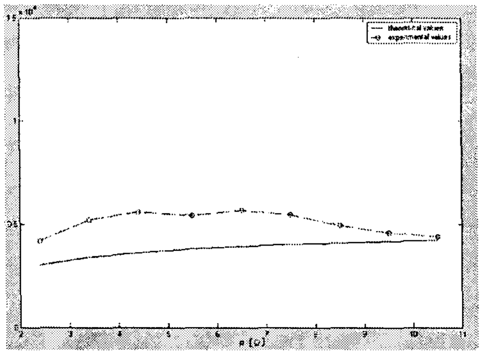

**Fig. 14** Variations of a2accordingtothevariationsofload (o Diagnosis values, - Theoretical values)

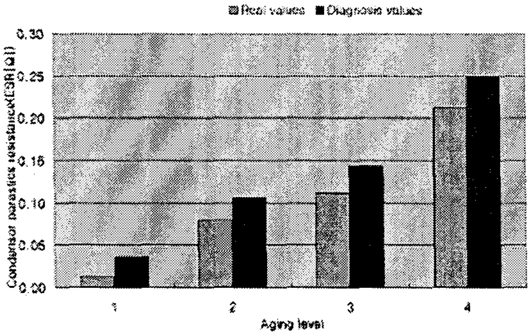

**Fig. 15** Real value and diagnosis values

## 5. Conclusions

This paper comes to the following conclusions.

1) A new algorithm is proposed to diagnose for the DC/DC converter of a power converter system.

2) The diagnosis indicators are defined not to diagnose each individual element, but for the entire system.

3) The diagnosis indicator $\xi$ of parasitic property for each element is defined as a diagnosis indicator of the diagnosis.

4) The system identification of the power converter system can be used to produce the indicator $\xi$.

5) The diagnosis algorithm can be verified by the analysis and simulation by using the agreement between the experimental results and the simulation results through the manufactured sample of the DC/DC converter.

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