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Parameter Estimation by OE model of DC-DC Converter System for Operating Status Diagnosis

Jin-Hong Jeon†, **Tae-Jin Kim***, **Kwang-Su Kim*** and **Kwang-Hwa Kim***

Abstract - This paper deals with a parameter estimation of the DC-DC converter system for its diagnosis. Especially, we present the results of parameter estimation for the DC-DC converter model by the system identification method. The parameter estimation for the DC-DC converter system aims at the diagnosis of its operating status. For the operating status diagnosis of the DC-DC converter system, we assume that the DC-DC converter system is an equivalent model of the Buck converter and estimate the main parameter for on-line diagnosis. In addition, for verification of an estimated parameter, we compare a bode plot of the estimated system transfer function and measurement results of the HP4194 instrument. It is a control system analyzer for system transfer function measurement. Our results confirm that the main parameter for diagnosis of the DC-DC converter system can be estimated by the system identification method and that the aging status of the system can be predicted by these results on operating status.

Keywords: DC-DC Converter, on-line diagnosis, parameter estimation, system identification

1. Introduction

As for the DC-DC converter, it has been used by direct current power appliances such as can be found in the industrial field, household electric appliance field, and information and communication field. It has been utilized throughout various fields from large capacity such as a repeater power supply for communication systems to small capacity like a notebook computer or embedded system according to an application field. It is necessary to prevent accident occurrence because huge loss can transpire in the case of individual life and property by device fault in an electric power converter applied to various fields. To date, in order to prevent these accidents from occurring, protection circuits have been installed so that when a system fault occurred, it blocked off an electric power supply of a system, so as not to generate a problem. Because of this prevention method, no studies concerning system diagnosis to prevent an accident of a device as a result of aging have been done[1][2][3].

An aging diagnosis can prevent an accident from occurring in a power supply by diagnosing the state of the power supply in advance and securing a stable action to be taken in regards to the power because the user can decide on replacement and maintenance times. The characteristics of a technical diagnostic method of an electric power conversion device were concentrated individually on each element and on off-line measuring data. These diagnostic methods complicate a system because every element requires numerous sensors, raising the price of the system. Little consideration has been concentrated on individual elements and off-line measuring data, but recent study has been given to systematic diagnosis during on-line status and the changes or trends by signal processing of measured data[4][5].

Therefore, for systemic diagnosis during on-line status, this paper deals with parameter estimation of the DC-DC converter system. In particular, we present the results of parameter estimation for the DC-DC converter model by the system identification method. The parameter estimation for the DC-DC converter system aims at the diagnosis of its operating status. For the operating status diagnosis of the DC-DC converter system, we assume that it is an equivalent model of the Buck converter and estimate the main parameter for on-line diagnosis. Furthermore, for verification of estimated parameters, we compare the bode plot of estimated system transfer function and measurement results of the HP4194 instrument, which is a control system analyzer for system transfer function measurement. Our results confirm that the main parameter for diagnosis of the DC-DC converter system can be estimated by the system identification method and that the aging status of the system can be estimated by these results on the operating status.

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2. System Identification

It is the system identification that determines which mathematical model can operate to be identical to an unknown target system, including the input and output data. As a conception, system identification is a mapping to a model space from a space of observed input and output data. A process used to decide on a dynamic model from measured input - output data includes the following three basic sections[6].

1. Input data and output data
2. Model structure
3. A method to select the model that specified information with base data in this meeting (an identification method)

An identification process selects the model structure repeatedly, calculates the best model and examines the properties of this model until the structure is satisfactory. These processes can be summarized as follows.

1. Collect input and output data via experiments in order to distinguish an unknown target system.
2. Apply a filtering method in order to select a useful section of data and to emphasize important frequency range.
3. Select a model structure and define its parameter.
4. Calculate the best model in the model structure according to input - output data and a matching rate basis.
5. Validate the properties of an estimated model.
6. If an approximate model is sufficient, this process is stopped. But if not, using another model structure, repeat from Step 3 again, or attempt a possible alternate way (Step 4) or work the input - output data again.

3. Transfer Function of Buck Converter

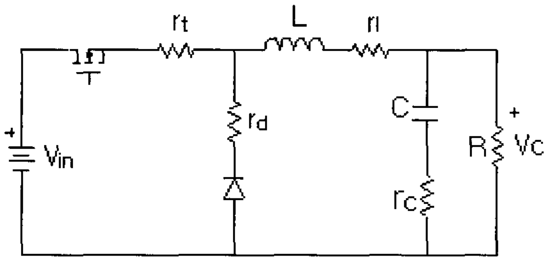

Fig. 1 An equivalent Circuit of Buck Converter with parasitic resistance.

A DC-DC converter is composed of a semiconductor device for electric power, capacitors, inductors and any other elements. Aging is proceeded according to use of these elements for a long term period, and it increases the parasitic (series or parallel) equivalent resistance of each element. For that reason, its increasing equivalent resistance puts a diagnosis index on aging. Fig. 1 is an equivalence circuit that included a parasitic resistance component of each element in a buck converter[2].

Equation 1 can be defined as a transfer function and an aging index of Fig. 1.

$$G(s)=\frac{\delta V_c}{\delta D}=V_{in}\frac{(1+sCr_c)(1+\xi_2)}{\frac{LCs^2}{1+\xi_1}+\frac{s}{1+\xi_1}(\frac{L}{R}+CR\xi_1)+1} \qquad (1)$$

$$\xi_1=\frac{r_l+r_c+r_tD+r_d(1-D)}{R},\quad \xi_2=\xi_1-\frac{(Dr_t-Dr_d)}{R}$$

where, $V_o=DV_{in}$, $D_1=1-D$

V_o : output voltage, V_{in} : input voltage, D : duty ratio, L : inductance, C : capacitance, R : load resistance, r_l : parasitic resistance of inductor, r_c : parasitic resistance of capacitor, r_t : parasitic resistance of switch, r_d : parasitic resistance of diode.

As in the above equation (1), ξ_1 and ξ_2 are made from a combination of converter internal resistance, and a change in the internal resistance caused by aging has a direct influence on ξ_1 and ξ_2 values. It is virtually impossible to measure the complete internal resistance of each element, but it can be possible to observe a change in ξ_1 and ξ_2 values. Therefore, it is a desirable method that observes a change of ξ_1 and ξ_2 values for an aging of the target system[5]. A mathematical model and a transfer function of a measured equivalent model can be simply shown as in the following Fig..

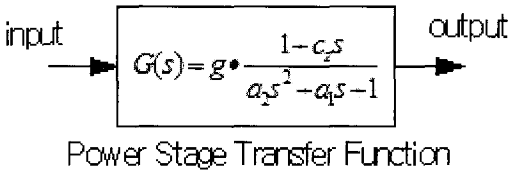

Fig. 2 A transfer function of DC-DC converter equivalent model.

The parameters (g, a1, a2,cz) of transfer function in Fig 2 are simply represented in the parameters of equation 1. These parameters are composed of ξ_1 and ξ_2, which are a combination of input voltage, duty ratio, load resistance, inductance, capacitance and internal resistance. Therefore, as in the following Fig. 3, an identity can be defined between the measured results and the mathematical analysis. We can solve the equation of parameters and then calculate ξ_1 and ξ_2 values. As mentioned above, it can be simply shown as in the following Fig.

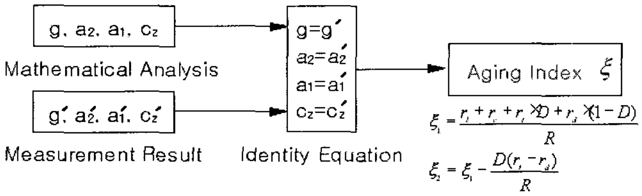

Fig. 3 A method of calculating an aging index

In this study, the major parameters of a buck converter are listed in Table 1 and in this case, the coefficients of a transfer function are listed in Table 2.

Table 1 The major parameters of a buck converter.

Parameters	Values
D	0.24±0.04
V_{in}	24 [V]
C	470 [μF]
L	1.017 [mH]
R	10.5 [Ω]
r_t	10.7[mΩ]
r_d	6.1[mΩ]
r_l	1.20223[Ω]
r_c(ESR)	157.474[mΩ]

Table 2 The coefficients of a transfer function.

Coefficients	Values
g	20.878162
C_z	7.4013e-005
a_2	4.216844e-007
a_1	6.538932e-004
ξ_1	0.130182
ξ_2	-0.130077

4. Estimation of Transfer Function by OE Model

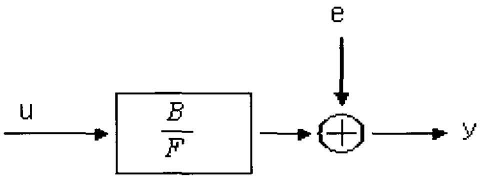

Fig. 4 The output error model structure

As estimate coefficients of the transfer function, we applied the OE (output-error) model in this study. The structure of the OE model is like as in the following equation 2 and Fig. 4.

$$y(t) = \frac{B(q)}{F(q)} u(t) + e(t) \qquad (2)$$

As a transfer function of the DC-DC converter equivalent model in Fig. 2, if the order of the numerator is one and the order of the denominator is two, we can make a transfer function by the OE model, as indicated in the following equation.

$$y(t) = \frac{b_1 q + b_2}{q^2 + f_1 q + f_2} u(t) + e(t) \qquad (3)$$

A method of system identification is as follows by using the OE model that is mentioned above. Fig. 5 is an experimental block diagram to measure data for system identification[6].

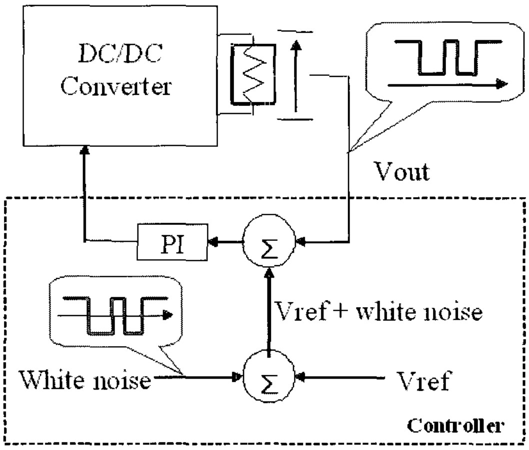

Fig. 5 An experimental block diagram for system identification

For measuring system identification data, a white noise component is added to the reference input signal of a controller. The input of the PI controller is a comparing value of the output voltage and the reference input with white noise component. The output of the PI controller is a gate-on duration time of switch and then the output voltage of the DC-DC converter is a result of the reference input with white noise components. As in equation 1, the ratio of the white noise components of reference input (δD) and the voltage output components of input white noise (δV_c) is a transfer function. Therefore, for system identification, we can extract the input white noise components and their output voltage components from the experimental results. In this study, we estimate the major parameter of the DC-DC converter by using the system identification toolbox of MATLAB from extracted input and output data. The results

Table 3 The theoretical values and the estimated values

Coefficients	Theoretical Values	Estimated Values
g	20.8781	20.6754
C_z	7.4013e-005	7.4937e-005
a_2	4.2168e-007	4.2192e-007
a_1	6.5389e-004	6.4438e-004

comparing the estimated values with the calculated theoretical values are listed in Table 3.

As a list of Table 3, the results of system identification by using an OE model are reasonable from comparing the theoretical values with the estimated values.

5. The Verification of an Estimated Transfer Function

In this study, we compose the test system displayed in Fig. 6 in order to verify an estimated transfer function that used an OE model to measure a frequency response of the DC-DC converter that was used in the experiment by utilizing an HP4194 control system measuring instrument.

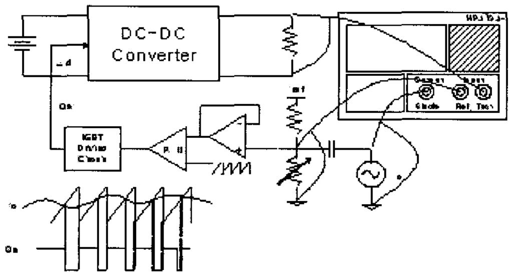

Fig. 6 A test system for a frequency response of the DC-DC converter

As in Fig. 6, we connect an output of HP4194 to the reference input of a converter and connect an output of a converter to an input of HP4194. As a connection between HP4194 and the DC-DC converter in Fig. 6, HP4194 adds up a specific frequency input to a DC-DC converter reference input and then measures a magnitude and a phase angle of specific frequency of the DC-DC converter output voltage. It is possible to calculate the frequency response of a converter experimentally by this method. The results, which are compared to the measured frequency response by HP4194 with the frequency response of the estimated transfer function, are shown in Fig. 7.

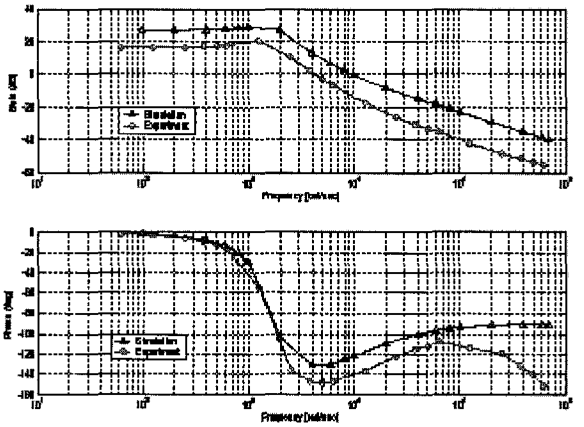

Fig. 7 The results of measured and estimated frequency response

As a bode plot of Fig. 7, the results of system identification by using an OE model are reasonable from comparing the measured transfer function with the estimated transfer function, in which the loop gain and the phase characteristics of the two transfer functions are similar.

6. Conclusion

In this paper, we present the parameter estimation results of the DC-DC converter system by using an OE model for its diagnosis and verify its estimated results by comparing measured frequency response with HP4194. From these results, this paper comes up with the possibility of on-line diagnosis for power conversion devices by a system identification method. Hereafter, study will involve another applicable model for system identification and on-line diagnosis.

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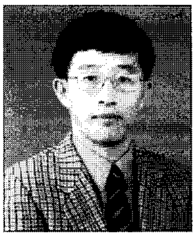

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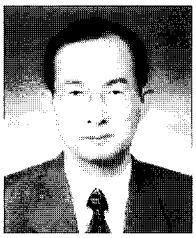

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