Parameter Estimation for Digital Current Control of PWM Converters

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ABSTRACT - From the viewpoint of model-based current control, it is indispensable to use the accurate system parameters for the high control performance. This paper adopts the Least-Squares algorithm as a parameter estimation scheme because it has the fast convergence rate and the low sensitivity to noises. In case of the intelligent current controller with delay compensator, the simulation results show that the adopted estimation scheme can be successfully applied to PWM converters and also show the improved control performance in the estimated parameters.

1. INTRODUCTION

The current control in three phase power conversion systems is one of the most important areas and has long been studied in many papers. The system parameters are used in the design of the predictive current controllers [1-2] and some other control schemes [3]. The author also has been studied the predictive current controller [2] which dealt with the varying bounds of control voltages in PWM converters and the computational delay. From the viewpoint of model-based current control like the predictive control, it is indispensable to use the accurate system parameters for the high control performance. But this issue has hardly been studied in papers.

This paper focuses on parameter uncertainties and adopts the Least-Squares algorithm as a parameter estimation scheme because it has the fast convergence rate and the low sensitivity to noises. First, this paper deals with the modeling of PWM converter and the intelligent predictive current controller with delay compensator. Then the application of estimation scheme is described and also the whole system is modeled and simulated by SIMULINK/MATLAB. The simulation results are presented to show that the adopted estimation scheme can be successfully applied to PWM converters and also to show the improved control performance in the estimated parameters.

2. MODELING OF PWM CONVERTER [2]

In the synchronous dq reference frame and under the balanced source voltages, the ac input part of PWM converter can be modeled as shown in (1).

$$\begin{aligned} L\frac{di_d}{dt} &= -R\cdot i_d + \omega L\cdot i_q + V_{ds} - e_d \\ L\frac{di_q}{dt} &= -R\cdot i_q - \omega L\cdot i_d + V_{qs} - e_q \end{aligned} \qquad (1)$$

In (1), i_d and i_q are converter input currents, e_d and e_q, converter output voltages, V_{ds} and V_{qs}, source voltages, ω, the source angular frequency, L and R, the inductance and the resistance of an input reactor, respectively.

Let's design converter output voltages such as shown in (2).

$$\begin{aligned} e_d &= \omega L\cdot i_q + V_{ds} - u_d \\ e_q &= -\omega L\cdot i_d + V_{qs} - u_q \end{aligned} \qquad (2)$$

where the ideal conditions are assumed and u_d & u_q are feedback control voltages.

From (1) and (2), the following very simple system is obtained.

$$\begin{aligned} \frac{di_d}{dt} &= -\frac{R}{L}i_d + \frac{1}{L}u_d \\ \frac{di_q}{dt} &= -\frac{R}{L}i_q + \frac{1}{L}u_q \end{aligned} \qquad (3)$$

3. DIGITAL CURRENT CONTROLLER [2]

The intelligent digital current controller with delay compensator is shown in Fig. 1. Fig. 1(a) shows the proportional controller and the conditional integrator where the Mag_BPW functions like the internal graph of the block. The gains of controller are as follows.

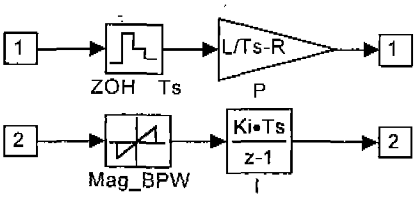
$$Kp = L/T_S - R \qquad (4)$$

$$Ki = L\cdot(2\cdot\zeta\cdot T_S)^{-2} \qquad (5)$$

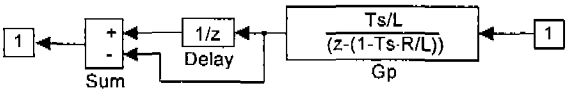
where Kp is the proportional gain, Ki is the integral gain, ζ is the damping factor, T_S is the sampling time, respectively.

Fig. 1(b) shows the Smith-Predictor block diagram where the block of Gp is the corresponding discrete system of (3) and it is assumed the delay to be one sampling time.

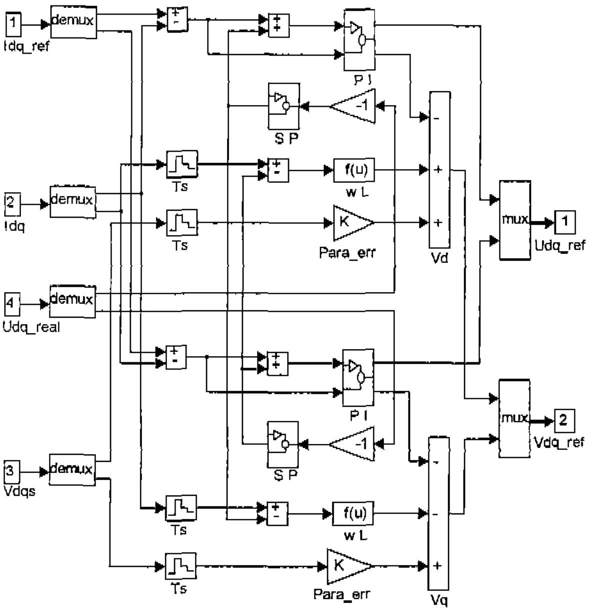
This controller uses the system parameters for the design of the proportional and integral gains and for the Smith-Predictor. Therefore it needs accurate parameters for the designed high control performance.



(a) Internal block diagram of PI block



(b) Internal block diagram of SP block



(c) The whole block diagram

Fig. 1. SIMULINK block diagram of an intelligent current controller

4. PARAMETER ESTIMATION

Equation (1) can be transformed into the stationary DQ reference frame as follows.

$$L\frac{di_D}{dt} = -R\cdot i_D + V_{DS} - e_D$$
$$L\frac{di_Q}{dt} = -R\cdot i_Q + V_{QS} - e_Q \qquad (6)$$

Equation (6) can be treated as a single input and single output system without coupling terms, which represents the ac input part of PWM converters. Therefore this is a suitable system model for the parameter estimation algorithm.

Each of (6) can be represented in a discrete ARMA model as shown in (7), in which two parameters consists of system parameters and the known sampling time. Therefor it is possible to calculate the estimated inductance and resistance by using two estimated parameters and the known sampling time.

$$i(k) = -(R\cdot Ts/L-1)i(k-1) + (Ts/L)\{V(k-1) - e(k-1)\} \qquad (7)$$

where the suffixes of variables are omitted for simplicity.

This paper adopts the Least-Squares algorithm as a parameter estimation scheme because it has the fast convergence rate and the low sensitivity to noises [4]. If the values of variables such as source current, source voltage and converter output voltage are accurate, then the adopted estimation scheme can give the very accurate parameter estimates.

5. SIMULATION RESULTS

The SIMULINK block diagram of the whole system is shown in Fig. 2, where there are four major parts; a current controller shown in Fig. 1, a space vector PWM modulator with the vector over-modulation scheme, a dynamic system based on Eq. (1), and a Least-Squares estimation algorithm. The dc-link part is modeled to be an ideal dc source.

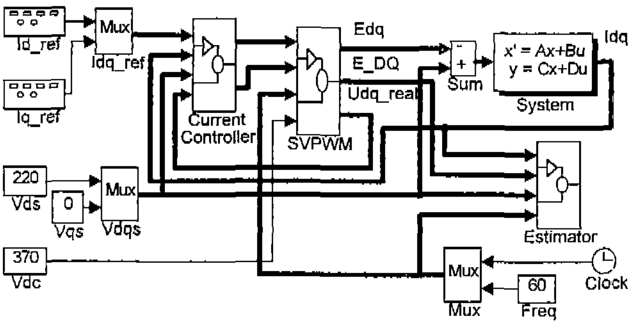


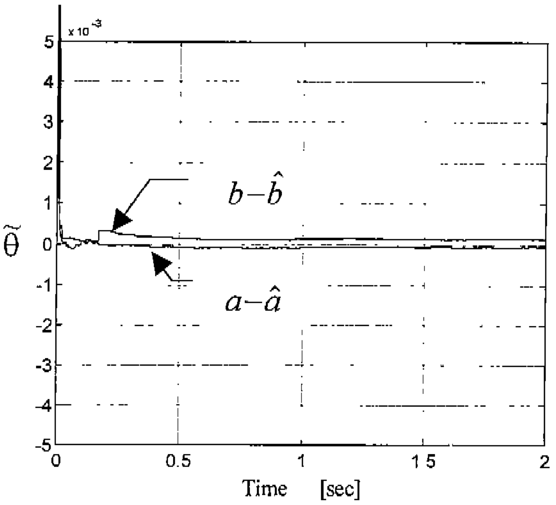
Fig. 2. SIMULINK block diagram of a whole system

Table 1 shows the nominal values of system parameters in the PWM converter, where the designed damping factor is also shown. The error limit of the conditional integrator is designed to be 5[A].

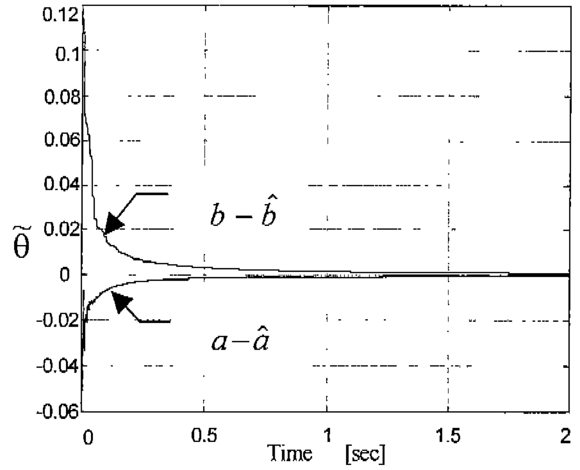
Table 1. System Parameters

Vll = 220 [V]	L = 1.7 [mH]	fsw = 2.5[kHz]
Vdc = 370 [V]	R = 5.6 [mΩ]	$\zeta = \sqrt{2}$

The estimator consists of two Least-Squares estimators that use d-axis and q-axis variables respectively for comparisons. Fig. 3 shows the simulated parameter estimation errors for both estimators with the initial inductance of 1.2 times the nominal value. It tells that both



(a) d-axis variables



(b) q-axis variables

Fig. 3. Simulated parameter estimation errors using different variables (a = R•Ts/L - 1, b = Ts/L)

estimators give very good estimates and then the estimator using d-axis variables shows much better parameter convergence performance. Therefore Fig. 3 validates that the adopted estimator can be successfully applied to PWM converters and also it is recommended to use the estimator using d-axis variables.

Fig. 4 and Fig. 5 show the simulated current waveforms by using the 1.2 times nominal inductance and the estimated inductance, respectively. The estimated system parameters are calculated by using the estimates of the estimator using d-axis variables. Fig. 5 shows better control performance of q-axis current component and much better control performance of d-axis current component in transient state than the control performance of Fig. 4. Therefore it is possible to obtain the designed high control performance by using the estimated accurate system parameters. This parameter estimation method would be useful if it is exploited in the tuning process for mass production or in the initial parameter-tuning mode

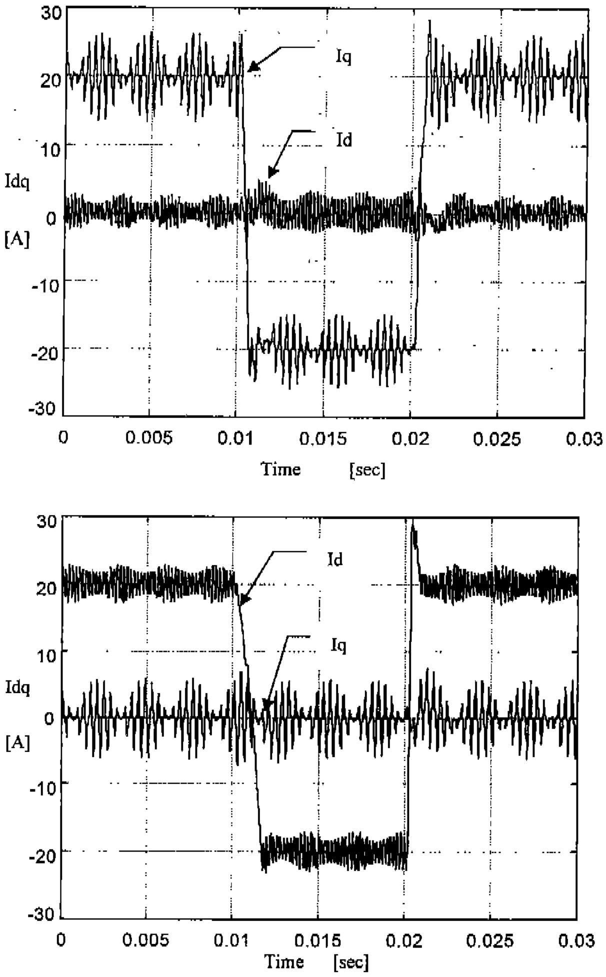


Fig. 4. Simulated current waveforms by using the 1.2 times nominal inductance (one step reference current : 20[A] ↔ -20[A], the other reference current : 0[A])

before normal operations.

6. CONCLUSIONS

As a solution against parameter uncertainties, this paper adopted the Least-Squares algorithm as an estimation scheme. In case of the intelligent current controller with delay compensator, the simulation results have shown that the adopted estimation scheme can be successfully applied to PWM converters and also have shown the improved control performance by using the estimated parameters. It is recommended to use the estimator using d-axis variables from the simulation results. This method would be useful in the prior tuning stage.

7. REFERENCES

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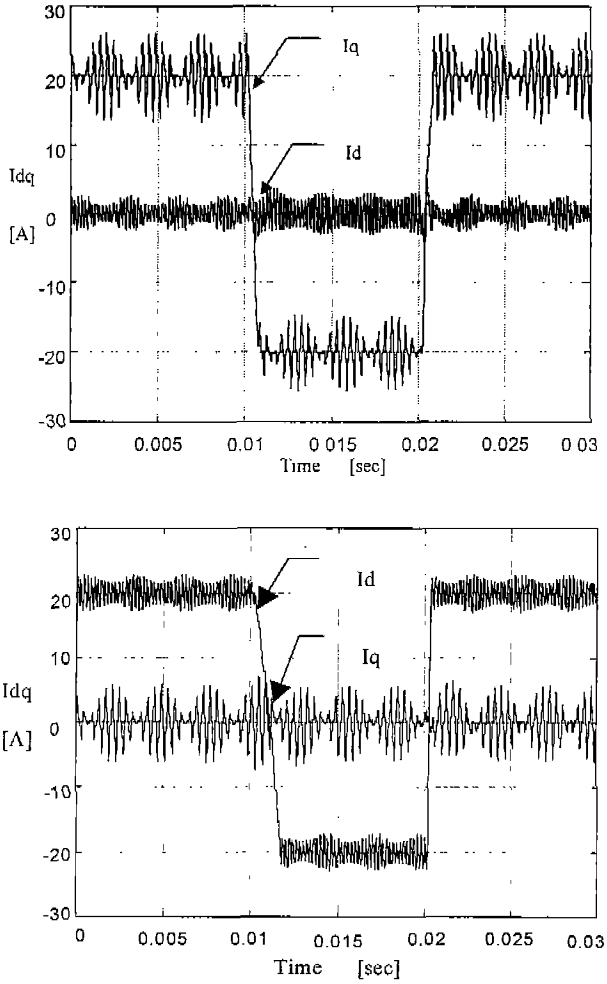

Fig. 5. Simulated current waveforms by using the estimated inductance (one step reference current : 20[A] ↔ -20[A], the other reference current : 0[A])