http://dx.doi.org/10.11142/jicems.2014.3.3.282
282 *Journal of International Conference on Electrical Machines and Systems vol. 3, no. 3, pp. 282~288, 2014*

Simulation Analysis of Control Methods for Parallel Multi-Operating System constructed by the Same Output Power Converters

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Abstract – A large capacity power conversion system constructed by using two or more existing power converters has a lot of flexibility in how the power converters are used. However, at the same time, it has a problem of cross current flows between power converters. The cross current must be suppressed by controlling the system while miniaturizing the combination reactor. This paper focuses on two current control methods of a power conversion system constructed by using two power converters connected in parallel supplying the same power. In order to elucidate the control performance of cross current, each control method which are aimed at controlling cross current and not directly controlling it are examined in simulations.

Keywords: Power converter, Cross current, Combination reactor, Current Control

1. Introduction

Parallel multi-operating systems constructed by parallel connected power converters have the advantage of being able to be constructed by combining existing power converters quickly and inexpensively. Additionally, most parallel operation systems have been considered to have a structure in which each power converter provides the same output current [1]-[2].

However, recently, in order to increase the flexibility of system construction, a method has been proposed that enables the combination of power converters supplying different output current [3]-[5].

In order to improve the parallel conversion system, we have to consider the suppression of cross current. The cross current is suppressed by using a large capacity combination reactor. However, it is necessary to accept large loss and make a large space.

One control method for this system is an individual current control method that independently controls each current of each power converter. This method can decrease the rate of utilization of motor current since it does not directly control cross current flowing between power converters connected in parallel.

Therefore, motor current and cross current control method has been developed that independently controls both motor current and cross current. This method is intended to improve the suppression of cross current and the rate of utilization of motor current [1]. In addition, it is intended to miniaturize the combination reactor.

In the proposed method, control performance can be deteriorated by various disturbances. If we can find out how much these disturbances degrade control performance, things that we should consider become clear in the case of combining different outputs or odd power converters.

Therefore, in this paper, we focus on a current control method for a power conversion system in which two existing power converters are connected in parallel. In particular, we elucidate the suppression performance of cross current, power efficiency, and the effect of the disturbances in simulations.

2. Current Control of Power Conversion System Connected Two Converters in Parallel

2.1 Overall Structure of Power Conversion System

Fig.1 shows the overall system of the power conversion system using the individual current control method. Two power converters INV1 and INV2 are supplied from DC

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Received 18 April 2014; Accepted 25 May 2014

source. Each of them is allotted output currents I1 and I2 in such a way that I1 equals I2. The input current of a motor is sum current I1 + I2 added through a combination reactor CR.

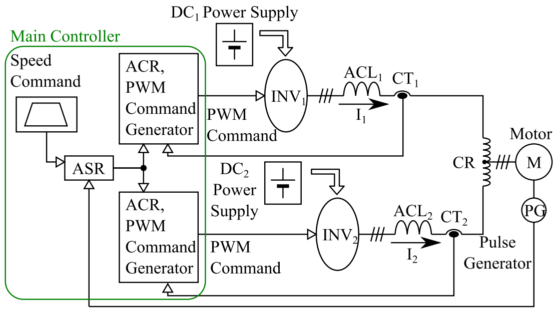

Fig. 1. Overall schematic diagram of system using the individual current control method

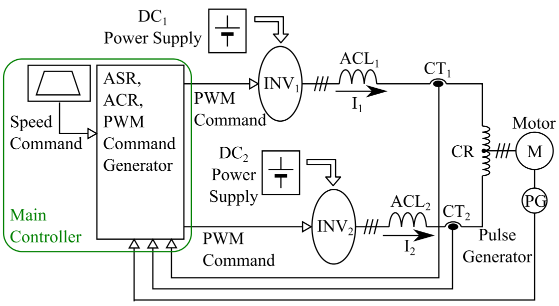

Fig. 2. Overall schematic diagram of system using the motor current and cross current control method

This has the effect of passive suppression on cross current. Motor speed is measured with a pulse generator PG. Output currents I1 and I2 are measured with current detectors CT1 and CT2. The information obtained from them is processed in the main controller, which contains the function of speed control (ASR), two sets of current control (ACR), and a PWM command generator provided for each power converter. PWM command generator provides PWM signals to control the output voltage of a power converter.

Fig.2 shows the overall system of the power conversion system using the motor current and cross current control method. One major difference between the two methods is that, unlike the individual current control method, the motor current and cross current control method controls the currents separated into two components from I1 and I2 in a main controller that has the functions of ASR, ACR, and PWM command generator.

2.2 The Individual Current Control Method

Fig.3 shows a block diagram of the individual current control method used in simulations. This method evenly divides current command calculated from speed control (ASR) into current control (ACR) of two power converters INV1 and INV2. In addition, each q-axis ACR is inputted with signals of a half current command from ASR and a feedback signal of output current of one of two power converters. PWM signals provided to INV1 and INV2 are calculated from ACR and control the output voltage of each power converter. The individual current control method does not directly control the cross current.

2.3 The Motor Current and Cross Current Control Method

Fig.4 shows a block diagram of the motor current and cross current control method used in simulations. This method controls two power converters by separating feedback signals of output current i_1 and i_2 into motor current component $i_m(=i_1+i_2)$ and cross current component $i_c(=i_1-i_2)$, respectively. Therefore, the motor current component and cross current component can be independently controlled. Cross current component i_c is controlled so as to be $i_c = 0$. Moreover, voltage commands from ACR_1 and ACR_2 are assigned to the two power converters by the allotted current ratio.

3. Simulation Results of Both Methods

A parallel operation system using both current control methods was simulated by using a software package called

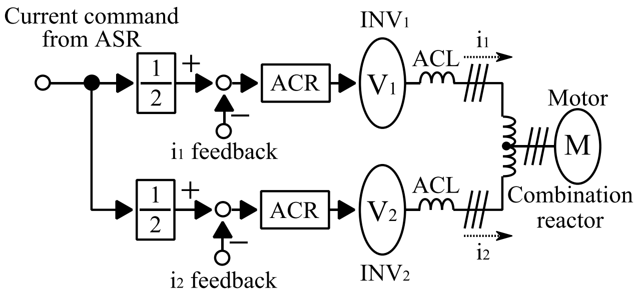

Fig. 3. Block diagram of the individual current control method

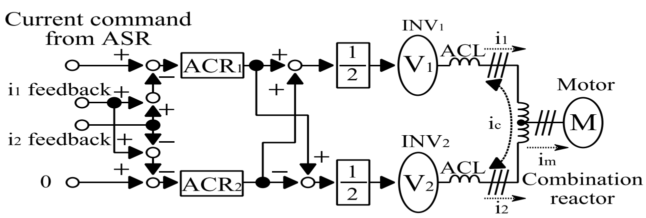

Fig. 4. Block diagram of the motor current and cross current control method

PSIM by Powersim Inc. A control block of the individual current control method is shown in Fig.5. The frequency of

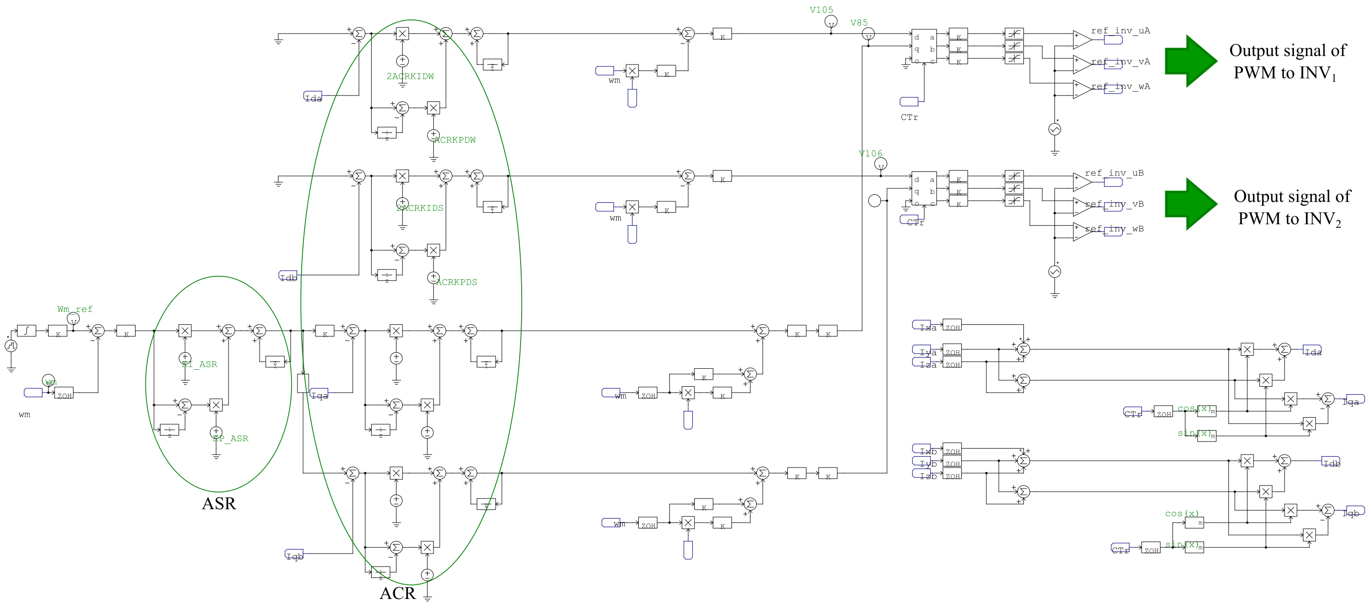

Fig. 5. Control Block of individual current control method used in simulations

the carrier of power converters is 8kHz in simulations. Sharing ratio of the output current of each power converter is equal. Speed command used the trapezoidal speed pattern.

A combination reactor that plays a role in adding i_1 and i_2 in Fig.3 uses a coupled inductor of subtractive polarity as an equivalent circuit model. A control block of the motor current and cross current control methods is shown in Fig.6. The frequency of the carrier of converters is 8kHz, the same as in Fig.4. Sharing ratio of the output current of each converter is equal. A combination reactor that plays a role in adding i_1 and i_2 in Fig.4 uses a coupled inductor of subtractive polarity as an equivalent circuit model.

In order to compare how well each method suppresses the cross current, in the case of the individual current control method, each time constant of ACR that controls motor current is equivalent to that of the motor current and cross current control method. In addition, the suppression effect of the combination reactor on cross current is intentionally weakened in simulations.

3.1 Simulation under Ideal Condition

In the case of a simulation under ideal conditions in which each power converter condition is equal, cross current does not flow between power converters, and output currents of them are equal. However, in the case of an actual circuit, the voltage potential differs between DC power supplies commutated by each converter. This potentially affects the suppression of cross current of the system. Therefore, the changes in the voltage potential are examined by altering the voltage of DC power supply of INV2 to INV1 in simulations.

In the case of controlling parallel connected power converters, a micro controller outputs switching signals of each power converter. However, plural micro controllers are potentially needed due to the limited number of I/O ports. In this case, if they cannot do clock synchronization, phase difference occurs between the carriers used in each PWM control that produces switching signals.

This also potentially affects the suppression of cross current. Therefore, the changes in the phase difference are examined by delaying the phase of the carrier of INV2 to INV1 in simulations, on cross current is intentionally weakened in simulations.

3.2 Effects on Suppression of Cross Current due to Voltage Potential Difference

Fig.7 shows the simulation results of cross current and power efficiency in the case of altering the voltage of DC power supply of INV2 to INV1. Power efficiency does not differ much between two methods. However, the motor current and cross current control method can suppress cross current caused by the difference in the output voltage of each power converter. In contrast, the individual current control method cannot suppress cross current. Fig.8 shows non-overlap time periods of positive phase of each power converter under the condition of DC source voltage error of INV2 to INV1 in the case of using the individual current control method. Fig.9 shows non-overlap time periods of positive phase of each power converter under the condition of occurring DC source voltage error of INV2 to INV1 in the case of using the motor current and cross current control method.

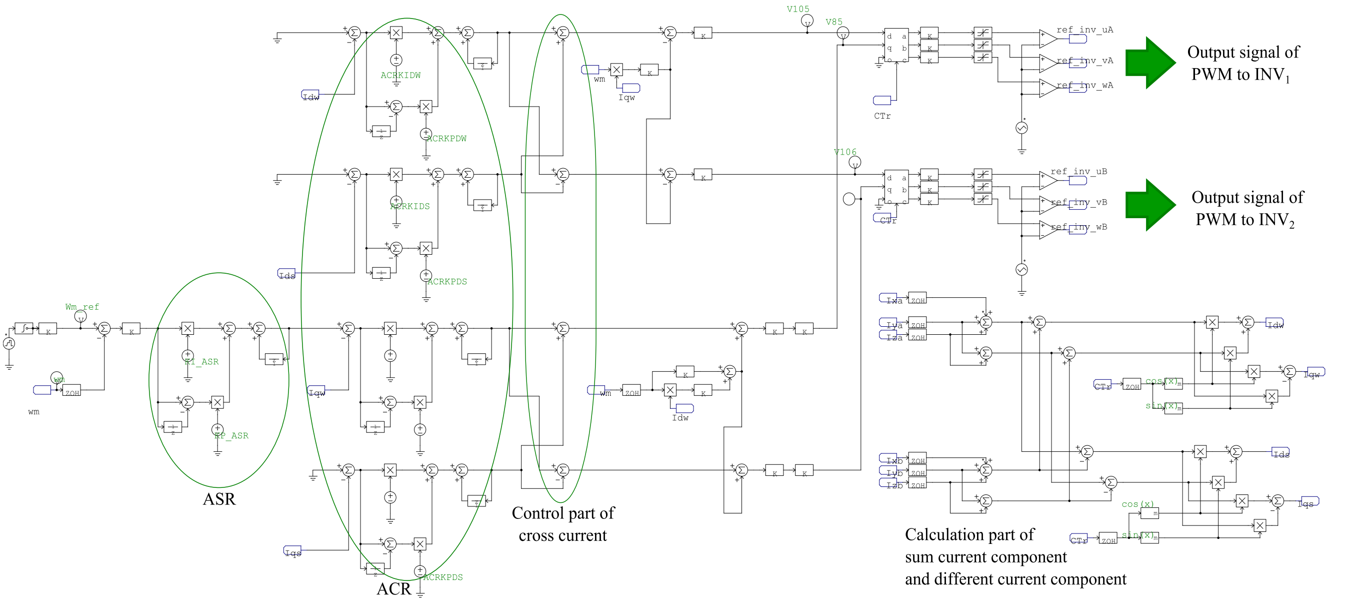

Fig. 6. Control Block of motor current and cross current control method used in simulations

In the case of the individual current control method, pulse width of switching signals of each power converter is independently varied. As a result, one voltage command exchanges magnitude relation with another every calculation cycle. Therefore, non-overlapping time periods of positive phase increase. Then, cross current also increases.

On the other hand, in the case of the motor current and cross current control method, non-overlapping time periods of positive phase increase less than in the case of the individual current control method. This decreasing is due to the modulation wave to control one power converter using a lower DC source voltage is constantly bigger than that of the other power converter using the higher one. It is considered that the decrease in non-overlapping time periods is related to suppressing cross current flowing between power converters.

3.3 Effects on Suppression of Cross Current due to Phase Difference between Carriers

Fig.10 shows the simulation results of cross current and power efficiency in the case of delaying the phase of the carrier of INV2 to INV1 in simulations. Power efficiency does not differ much between the two methods. However, neither method can suppress cross current flowing between power converters. Fig.11 shows non-overlap time periods of positive phase of each power converter under the condition of carrier phase delay of INV2 to INV1 in the case of using the individual current control method. Fig.12 shows non-overlap time periods of positive phase of each power converter under the condition of carrier phase delay of INV2 to INV1 in the case of using the motor current and cross current control method. There is no voltage potential difference between DC power supplies commutated by either converter in these simulations.

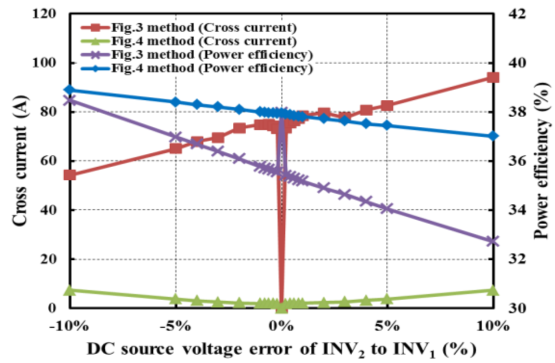

Fig. 7. The effect of voltage potential difference occurring between DC power supplies commutated by each converter

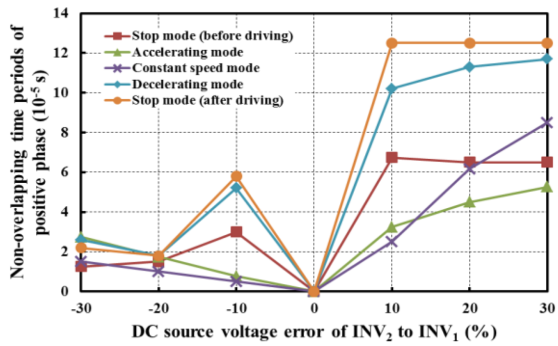

Fig. 8. The relationship between non-overlapping time periods of individual current control method and voltage potential difference

Nevertheless, non-overlapping time periods are long. This is due to the timing of the switching of PWM control of one power converter being delayed relative to the other with phase lag. In the case of the individual current control method, the output current of each power converter is controlled independently. For this reason, regardless of modes, non-overlapping time periods separately increase. In contrast, in the case of using the motor current and cross current control method, non-overlap time periods of positive phase similarly increase in each mode. This means that each modulation wave used in the PWM control of two power converters overlaps. That is, if the timing of the switching of each power converter cannot match, the effect of suppressing cross current becomes small.

Neither method can suppress cross current caused by the phase difference between the carriers.

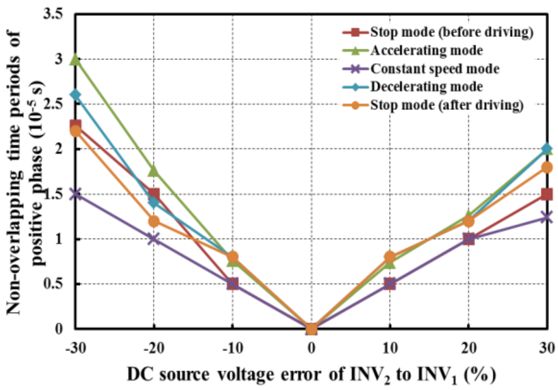

Fig. 9. The relationship between non-overlapping time periods of motor current and cross current control method and voltage potential difference

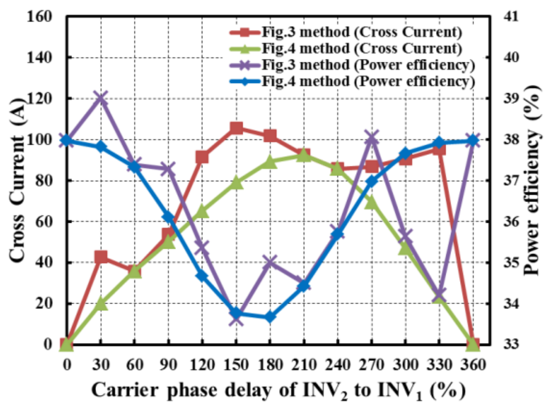

Fig. 10. The effect of the phase difference between the carriers used for PWM control

3.4 Effects on disturbance torque

In the case of driving a motor used in an elevator by a power conversion system, a rapid increase or decrease in the load to the motor rapidly is anticipated. Based on this situation, a load torque of step pattern is given as the disturbance in simulations. As a condition of simulations, the voltage potential difference is caused by lowering the DC source voltage of one power converter to 90% that of the other power converter. Figs.13 and 14 show simulation results of power conversion systems using the individual current control method and the motor current and cross current control method, respectively. Regardless of control methods, the output current flowing in the motor is controlled by current command calculated from ASR. The motor speed is controlled to be 0 rpm. In the case of the individual current control method, the output current value of each power converter becomes imbalanced. Therefore, cross current flowing between power converters increases in this simulation.

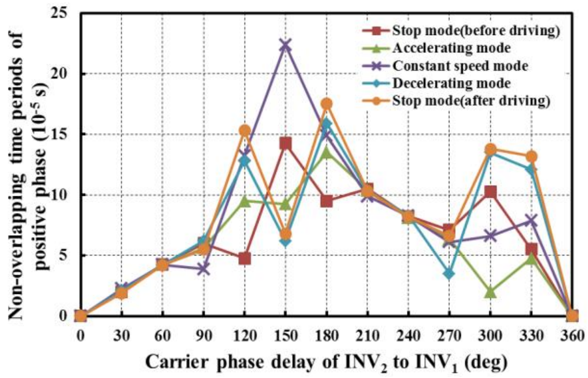

Fig. 11. The relationship between non-overlapping time periods of individual current control method and phase difference

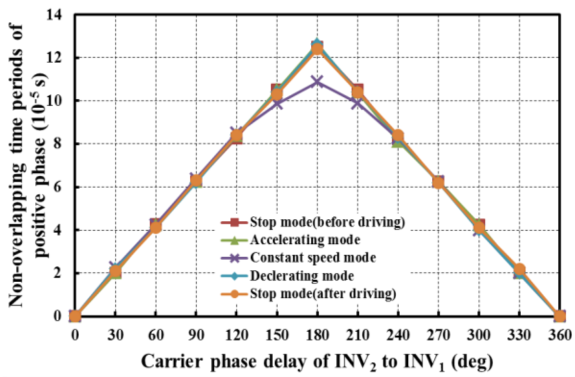

Fig. 12. The relationship between non-overlapping time periods of motor current and cross current control method and phase difference

On the other hand, in the case of the motor current and cross current control method, only a small imbalance between the output current of each power converter was caused by the suppression control of cross current. Therefore, the cross current is suppressed in this simulation. In addition, as for transient changes, the individual current control method is inferior to the motor current and cross current control method at keeping cross current at a constant value. Therefore, in the case of being given a load torque, in the motor current and cross current control method, cross current has little effect on the power conversion system.

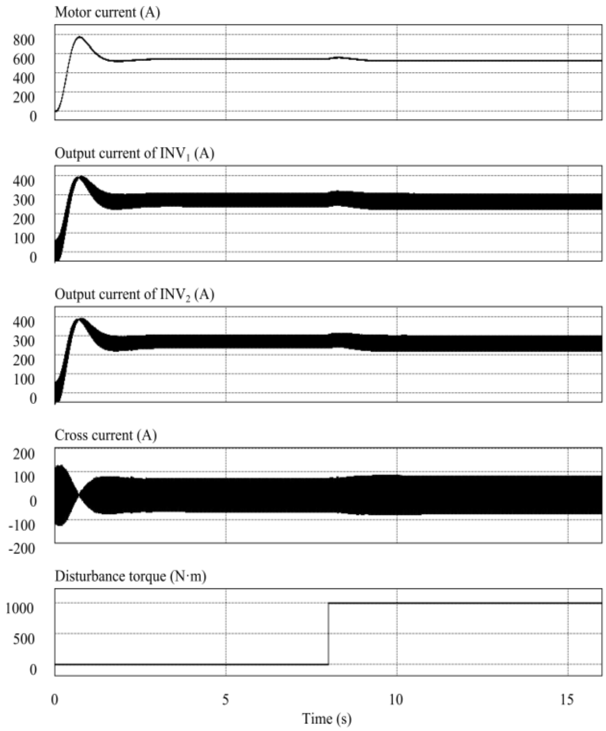

Fig. 13. The effect of disturbance torque of step pattern in the case of individual current control method

4. Conclusion

Simulation analysis of two current control methods elucidated suppression performances of cross current for a parallel operation system constructed by using two power converters. The cross current generated by the voltage potential difference between DC power supplies commutated by each converter is suppressed more efficiently by using the motor current and cross current control method than by using an individual current control method. However, the cross current generated by phase difference between the carriers used for PWM control that produces switching signals cannot be suppressed either current control methods. Therefore, the phase difference between the carriers of converters must be eliminated. In other words, decreasing non-overlap time periods as much as possible will lead to the suppression of cross current. As for disturbance torque, the motor current and cross current control method suppresses large transient change less than the individual current control method. Thus, it is concluded that the motor current and cross current control method is superior to the individual current control method at controlling cross current.

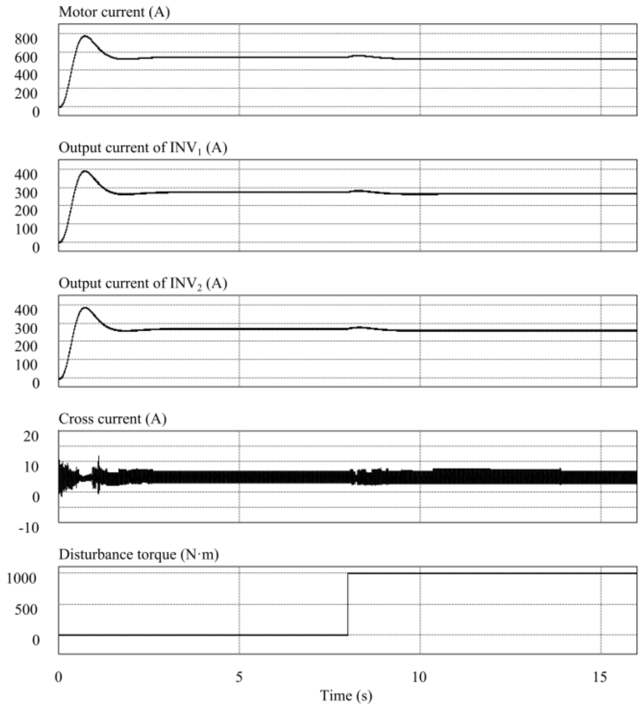

Fig. 14. The effect of disturbance torque of step pattern in the case of motor current and cross control method

Acknowledgements

The authors thank H. Ayano of Tokyo National College of Technology and T. Yoshikawa of Hitachi, Ltd. for their helpful discussions and suggestions. This work was partly supported by JSPS KAKENHI Grant Number 23560333.

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