# Design of Multi-Parallel Drive Technique for System with Numbers of Permanent Magnet Synchronous Motors

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***Abstract*— This paper discusses a multi-parallel drive system, which uses two types of inverters; A main inverter with V/f control and numbers of auxiliary inverter with vector control and damping control to control multiple numbers of Permanent Magnet Synchronous Motors (PMSMs). In addition, in PMSMs, the auxiliary windings are placed in the slots together with the conventional windings. The auxiliary windings are used in the auxiliary inverter with damping control to suppress the torque vibration when the motor speed is converged. From the simulation and experimental results, the proposed system achieves a stable operation with two parallel connected PMSMs. Furthermore, the experimental results demonstrate the effectiveness of the proposed system even if the output power of the auxiliary inverter is less than 10% of the main inverter. Moreover, the relationship among the response of the damping control, the overshoot of the motor speed and the power capacity of the auxiliary inverter are investigated in simulation and experiments. From the results, it can be confirmed that if the application requires a slow response of the motor speed, the smaller power capacity of the auxiliary inverter can be designed to be 10% compared with the main inverter capacity.**

## I. Introduction

Recently, driving multiple motors at a time shows good interests in community. One of the techniques to drive multiple motors in parallel is to employ one large power capacity inverter. One of the advantages of parallel motor drive by one large power capacity inverter is to be able to reduce the numbers of the inverter and system cost. Multiple numbers of parallel connected induction motor can be driven by one large power capacity inverter. However, in the case of PMSMs, since each pole position of the motor is different to each other, the motor current cannot be controlled to match the rotational coordinates by only one inverter. Therefore, it is difficult to drive the parallel connected PMSMs by using only one inverter. Due to the difference of each pole position, phase differences between the rotational coordinates of the inverter and each of motor will occur eventually. In that case, the torque vibration occurs due to the resonance between a synchronous reactance and the inertia moment of the motor. Therefore, the torque vibration needs to be suppressed in order to drive the PMSMs in parallel.

On the other hand, in order to drive two PMSMs, two parallel drive systems with a five-leg inverter [1-2] and a nine switches inverter [3] have been proposed and studied [4-7]. However, the numbers of parallel units are limited by the number of legs in the inverter. Especially, it is not practical to drive several ten units of PMSMs at the same time.

In this paper, in order to drive PMSMs in parallel efficiently, multi-parallel drive system of PMSMs based on V/f control is proposed [8]. The V/f control is suitable for multi-parallel drive for PMSM because the controller does not require the information of the rotor position in the PMSM. In addition, each of the PMSM is added with auxiliary windings [9]. The auxiliary windings, which are connected to a small power capacity inverter, suppress the torque vibration. The power capacity of the auxiliary inverter is much smaller than that of the main inverter because the power capacity of the auxiliary windings is required as much as the vibration for suppression. Note that the application of this proposed system is aiming for the constant speed drive system such as belt conveyers, fans, process line control and so on. Variable speed drive systems such as the electric train and electric vehicles are not considered in this paper because the motor speed in each motor is different in these applications.

This paper is organized as follows; first, the configuration of the proposed parallel drive system is introduced. Next, the control method of the main inverter with V/f control and the auxiliary inverter with vector control is described. Next, the simulation and experimental results demonstrate that the proposed system can drive multiple of parallel connected PMSMs efficiently by suppressing the torque vibration. Finally, the relationships among the response of the damping control and the overshoot of the motor speed and the power capacity of the auxiliary inverter are clarified.

## II. PROPOSED SYSTEM AND CONTROL

Fig. 1 shows the configuration of the proposed system. In PMSMs, the auxiliary windings which are used for the damping control (with the auxiliary inverter) are placed in the slots together with the main windings as shown in Fig. 2. The proposed system uses two different power rating inverters. The first one is the large power capacity inverter for the main windings to drive the motor. The second one is the small power capacity inverter for the auxiliary windings to suppress the torque vibration. In term of the effectiveness of the proposed system, it is very important that the power capacity of the auxiliary inverter is enough small. In other words, the damping power for the PMSM is much smaller than that of the main drive power.

Fig. 3 shows the control block diagram of the proposed system. In the proposed system, the main inverter is applied with the V/f control and the auxiliary inverter is applied with the vector control and the damping control. Each of the auxiliary inverter can control the current in auxiliary windings in order to suppress the torque and speed vibration.

Figs. 4 (a) and (b) show the control block diagrams of damping control which is implemented to the vector control in the auxiliary inverter control. The torque vibration results from the fluctuation of the pole position. The fluctuation is then intended to be suppressed by the damping control in the auxiliary inverter. The structure of Fig. 4 (a) is generally used to suppress the fluctuation of the pole position. After the fluctuation is only extracted by a high pass filter, this fluctuation is multiplied by a damping gain $K_d$ where the product is the q-axis current command. However, there are problems that it is influenced by the noise which is caused due to differentiate the pole position error and that the frequency bandwidth of the controller is limited. On the other hand, taking account of the velocity, the error between the rotational speed command and the detection value is multiplied by the damping gain as shown in Fig 4 (b). The structure of controller is similar to the velocity controller. Therefore, there are not these problems essentially.

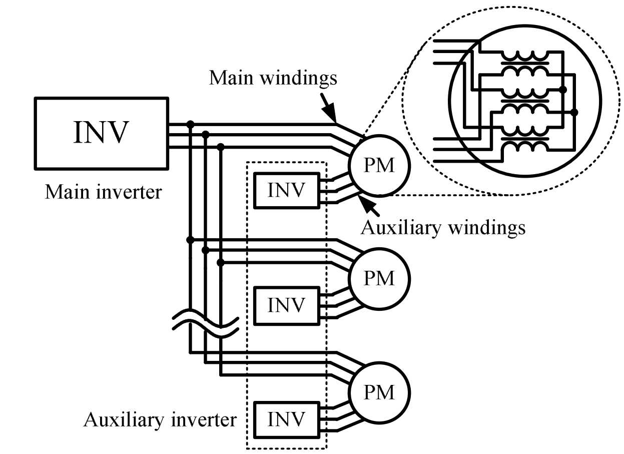



Fig. 1.Configuration of the proposed system.The proposed system uses two different power rating inverters, the large power capacity inverter for the main windings to drive the motor and the small power capacity inverter for

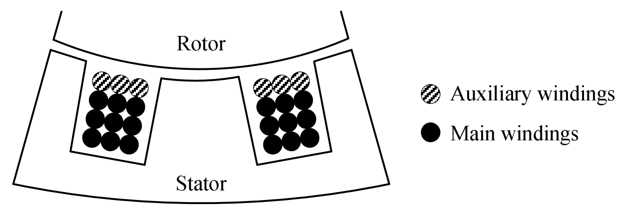
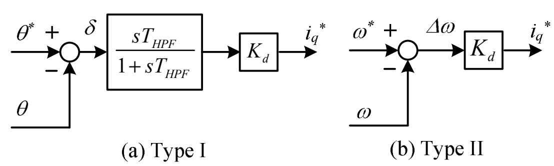



Fig. 2. Main windings and auxiliary windings. The number of the auxiliary winding is less than the numbers of the main windings.




Figs. 4.Damping control block diagram for the torque current command. Type I is generally used to suppress the fluctuation of the pole position. However, Type II is better than in term of the noise and the frequency bandwidth.

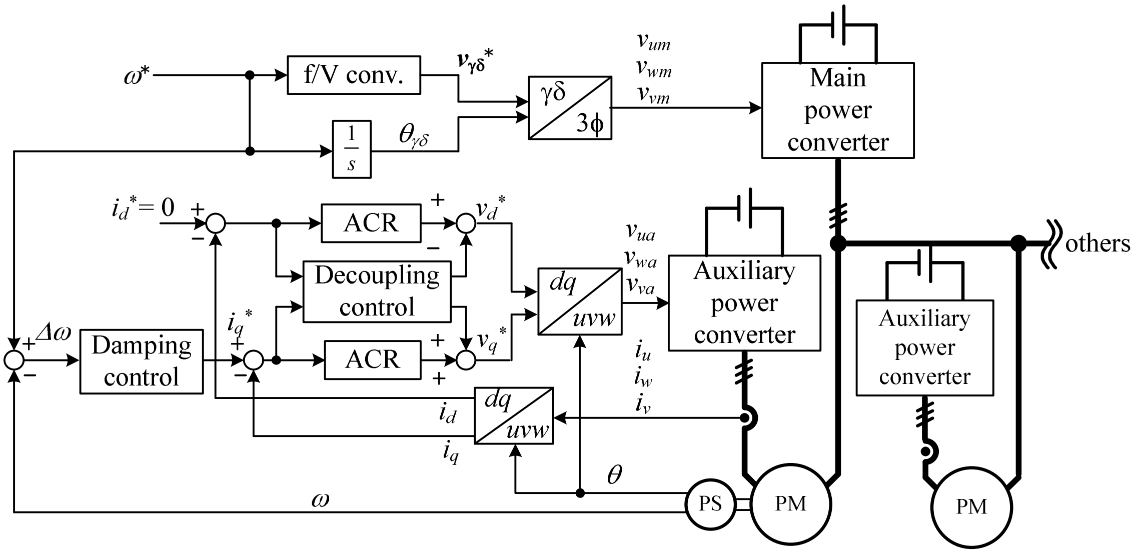
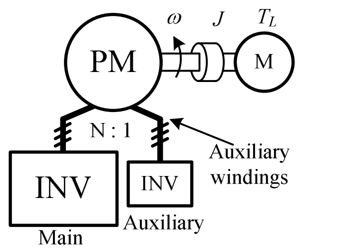
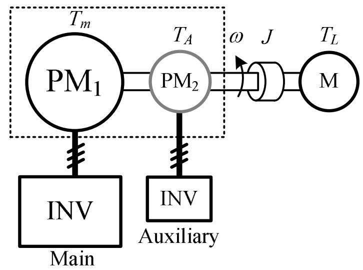



Fig. 3.Control block diagram of the proposed system. The V/f control is applied to the main inverter and the auxiliary inverters uses the vector control for the damping control.




(a) Connection diagram




(b) Simplification model

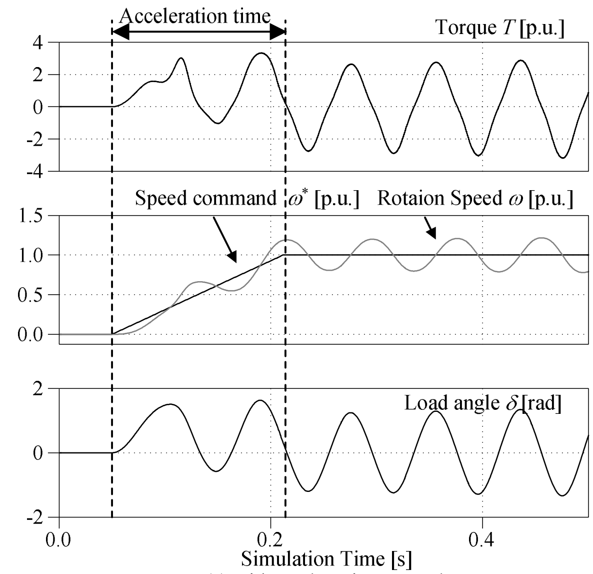
Figs. 5. Simulation and experimental model of the PMSM in addition auxiliary windings for damping control. In order to neglect the magnetic coupling in the simulation and the experiment, the proposed system is validated using (b)

## III. SIMULATION RESULTS

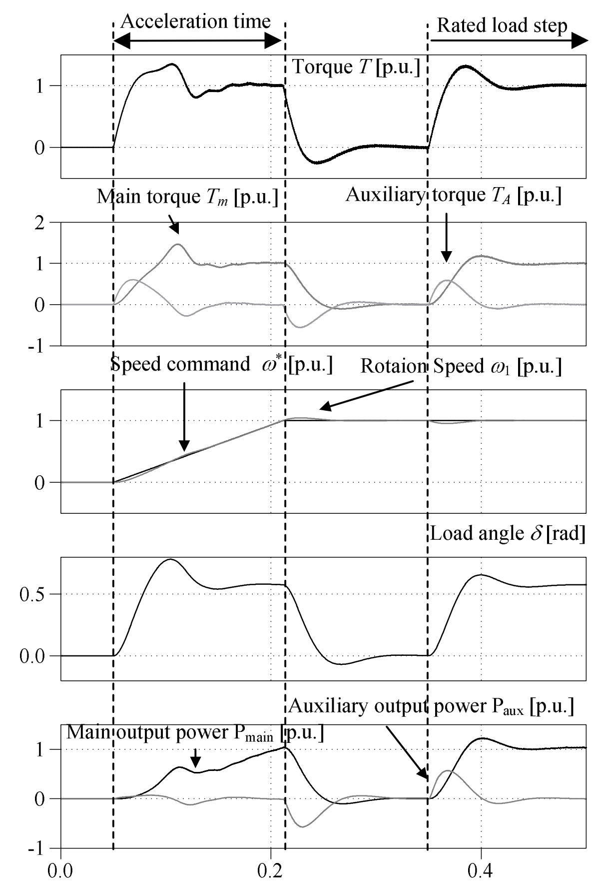
### A. Single motor drive with auxiliary windings

Figs. 5 (a) and (b) show the simulation and experimental models that are used to verify the operation of the proposed system on the simulation. Due to the reason that the mutual magnetic interference occurs between the main and the auxiliary windings, as a result the control for the auxiliary inverter becomes complicated. Therefore, the proposed system is validated using a model where two PMSMs are connected in series via single shaft. Then, the rear end of the main PMSM is connected to the load machine. It means that the magnetic coupling was neglected in the simulation and the experiment. Table 1 shows the details of the simulation condition.

Figs. 6 (a) and (b) show the simulation results when the proposed control is applied (a) without and (b) with damping control. In Fig. 6 (a), the vibration occurs in the torque and the rotational speed during the acceleration. After the acceleration, the vibration is maintained. The vibration of the load angle is also maintained. On the other hand, in Fig. 6 (b), the vibrations in the torque and the rotational speed and the load angle are suppressed by the auxiliary inverter by occurring the auxiliary torque to neutralize the vibration of the load angle. Besides, it can be confirmed that the rotational speed is well following to the rotational speed command. Moreover, even when the load fluctuation occurs after the acceleration, the effectiveness of auxiliary torque can be realized, as the vibration in the main torque can be suppressed also. Looking at the output power of each inverter, the output power of the main inverter is nearly 1.0 p.u., however, the largest power produced from the auxiliary inverter is only 0.5 p.u.. From the results, the power capacity of the auxiliary inverter is shown smaller than that of the main inverter. Moreover, the auxiliary inverter only operates when the torque vibration occurs. Note that the power capacity of the auxiliary inverter is dominated by the response time of the torque vibration suppression.




(a) without damping control.




(b) with damping control.

Figs. 6. Simulation results for a single motor drive without and with damping control. (a) The vibration of torque and rotational speed occur during the acceleration. (b) It can be confirmed that the rotational speed is well following to the rotational speed command owing to the damping control. The vibrations in the torque and the rotational speed are suppressed by the auxiliary inverter. Besides, it can be confirmed that the rotational speed is well following to the rotational speed command.

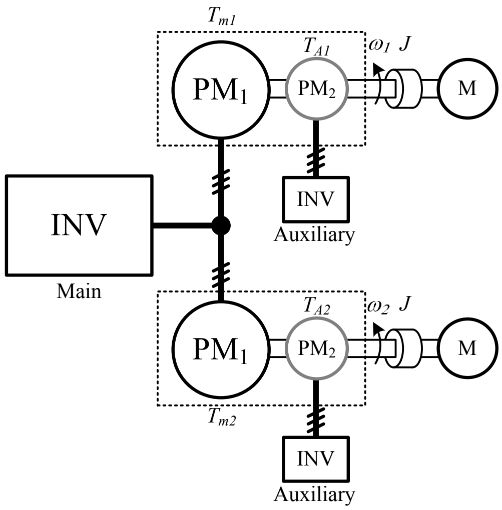



Fig. 7. Simulation model for parallel connected dual motor drive. In order to neglect the magnetic coupling in the simulation and the experiment, two parallel drive of the proposed system is validated using Fig. 7 as shown in Fig. 5(b).

### B. *Parallel motor drive with auxiliary windings*

Fig. 7 shows the simulation models that are used to verify the operation of two sets of parallel connected PMSM. As mentioned above, in order to neglect the magnetic coupling in the simulation, the model where two PMSMs are connected in series via single shaft is used in the simulation.

Fig. 8 shows the simulation results when two sets of parallel connected PMSMs are driven by the proposed system with the damping control as shown in Fig. 7. Smooth acceleration progresses are confirmed in the two set of parallel connected PMSMs. Besides, when the rated motor speed, load step applies to PMSM1 at 0.38s, and later also applies to PMSM2 at 0.42s, the operation of the two auxiliary inverters can be observed from the output power. The maximum output power of the auxiliary inverter is approximately 0.25 p.u. of the rated power of the main inverter. Although the power capacity of main inverter increases with the increase of parallel units, the power capacity of auxiliary inverter does not change to the numbers of parallel units.

## IV. EXPERIMENTAL RESULTS

In previous section, the simulation results demonstrate the effectiveness of damping control and stable parallel driving operations. In this section, in order to confirm the effectiveness of the damping control, the experiments are conducted with a motor –generator set.

Figs. 9 show the relationship between the simulation model and the motor-generator set in this paper. Since the model is constructed from two PMSMs that are connected in series via single shaft as shown in Fig. 4 (b), if the load machine is removed as shown in Fig. 9 (a), then it is equal to the motor- generator set as shown in Fig. 9 (b).

Fig. 10 shows the experimental configuration to confirm the effectiveness of the damping control in the proposed system. As mentioned above, the effectiveness of the proposed system can be verified with the motor-generator set as shown Fig. 10. Therefore, in order to confirm the effectiveness of the proposed damping control, the experiment is performed with the motor-generator set as shown in Fig. 10.

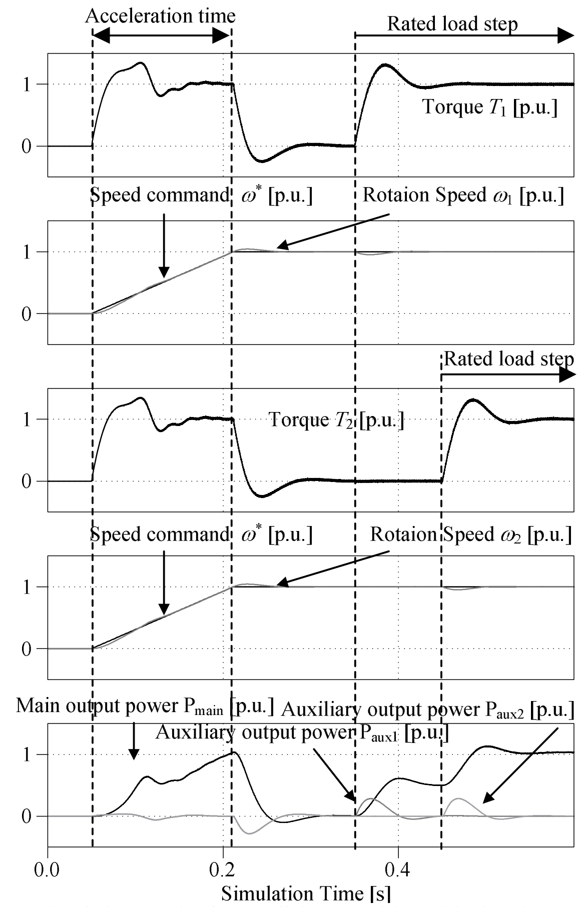
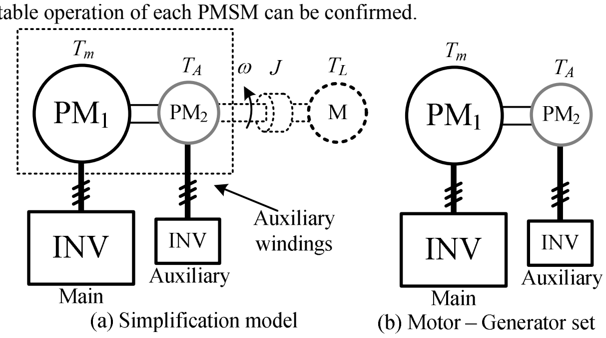
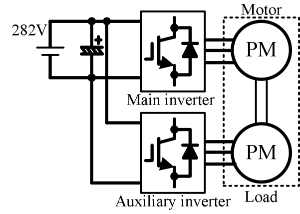



Fig. 8. Simulation results for parallel motor drive with damping control. Smooth acceleration progresses are confirmed in the two parallel connected PMSMs. After the rated motor speed, load step applies to each PMSM, stable operation of each PMSM can be confirmed.

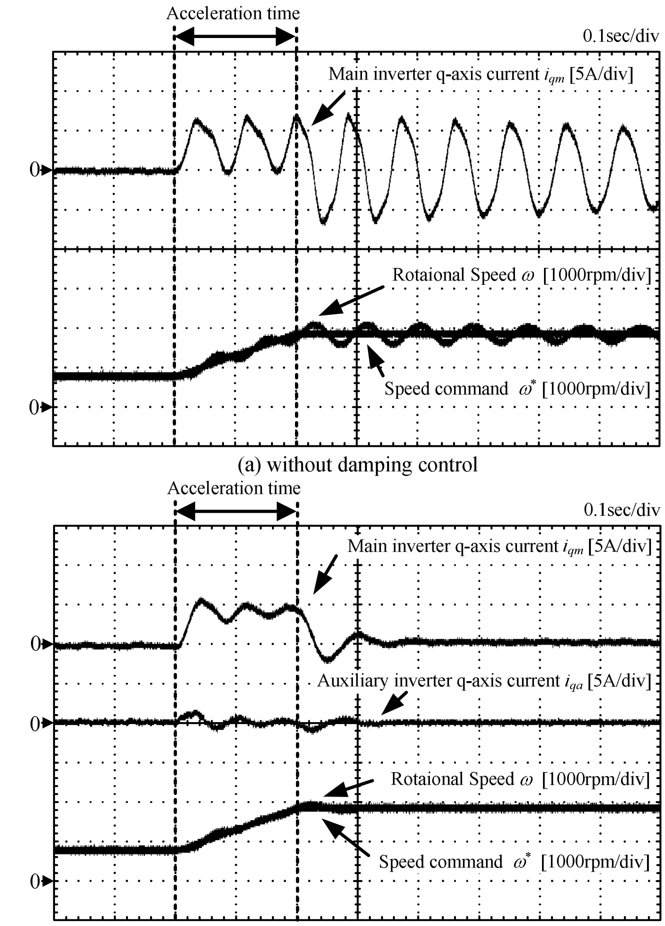



Figs. 9. Simulation model and motor-generator set. If the load machine is removed from (a), then it is equal to the motor-generator set as shown (b).




| | Motor | Load |
|---|---|---|
| Rated power | : 1.5 kW | 750 W |
| Rated speed | :1800 r/min | 1800 r/min |
| Rated current | : 6.1 A | 3 A |
| Number of pole | : 3 | 3 |
| d-axis inductance | : 11.5mH | 15.2mH |
| q-axis inductance | : 23mH | 33.2mH |
| Armature resistance | : 0.522Ω | 1.975Ω |
| Flux-linkage | : 0.368Wb | 0.338Wb |

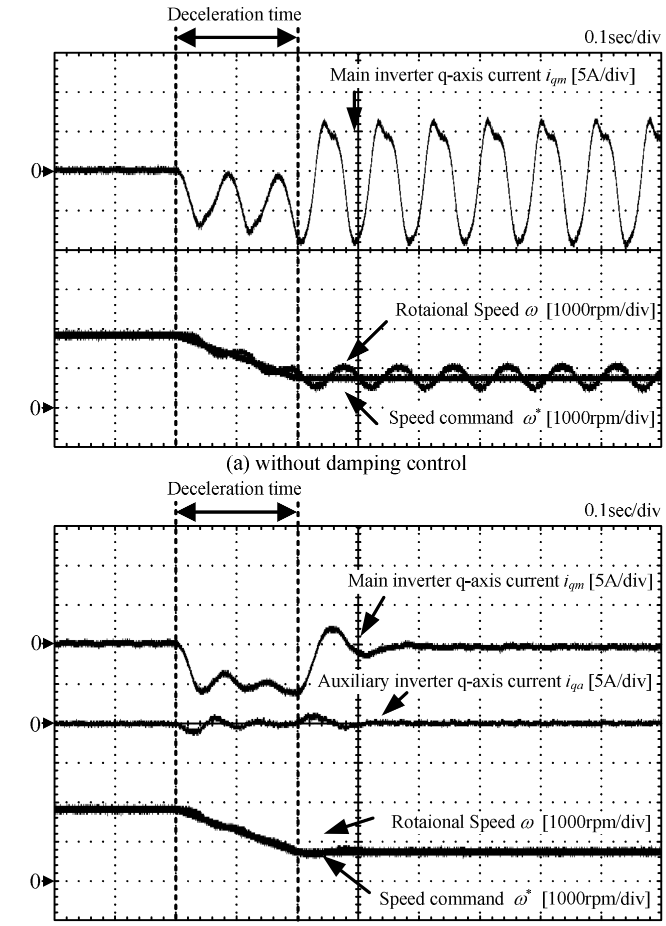
Fig. 10. Experimental configuration and condition




(a) without damping control

(b) with damping control

Fig. 11. Acceleration test without/with damping control in motor-generator set. (a) After the acceleration, the 400 r/min - speed vibration is maintained. (b) The speed vibration is reduced from 400 r/min to nearly 0 r/min in compared with (a)




(a) without damping control

(b) with damping control

Fig. 12. Deceleration test without/with damping control in motor-generator set. (a) After the deceleration, the 500 r/min - speed vibration is maintained. (b) The speed vibration is reduced from 500 r/min to nearly 0 r/min in compared with (a)

Figs. 11 show the experimental results that illustrate the motor speed vibration when the proposed system is applied (a) without the damping control and (b) with the damping control in acceleration test. In this experiment, it is difficult to measure the torque response directly. Therefore, the speed vibration is evaluated instead of the torque response. In Fig. 11 (a), the proposed system is implemented without damping control. The speed vibration can be noticed during the acceleration. After the acceleration, a 400 r/min of speed vibration and the 10 Ap-p of current vibration in q-axis of the main inverter are maintained. On the other hand, Fig. 11 (b) demonstrates the experimental results, where the proposed system is implemented with the damping control. The effectiveness of the auxiliary inverter can be noticed from the result that the speed vibration is reduced from 400 r/min to nearly 0 r/min in compared with Fig. 11 (a). The 10 Ap-p of current vibration in the q-axis of the main inverter as shown Fig. 11 (a) is suppressed as well.

Figs. 12 show the experimental results that illustrate the motor speed vibration when the proposed system is applied (a) without the damping control and (b) with the damping control in deceleration test. In the same way as Fig. 11(a), after the deceleration, a 500 r/min of speed vibration and the 15 Ap-p of current vibration in q-axis of the main inverter are maintained as shown in Fig. 12 (a). By contrast, it is confirmed that, as shown Fig.12 (b), the speed vibration is reduced from 500 r/8min to nearly 0 r/min and the current vibration is reduced from 15 Ap-p to 0 Ap-p in compared with Fig. 12 (a) in the same way as acceleration test.

Nevertheless, it is confirmed that the q-axis current of the auxiliary inverter flows only during acceleration and deceleration. Moreover, the maximum q-axis current of the auxiliary inverter is 20% of the q-axis current of the main inverter. Therefore, it is confirmed that the auxiliary inverter can suppress the speed vibration via auxiliary windings with a small q-axis current of the auxiliary inverter even if in the acceleration and deceleration test.

## V. Relationship between the Power Capacity and the Suppression Response

The fundamental operation and the parallel drive of the proposed system are discussed in the previous section. In order to confirm the relationship among the output power of the auxiliary inverter and the suppression effect of the speed vibration, various tests on different instantaneous output power are examined in simulation and experimented similarly to Fig. 6 (b).

Fig. 13 shows the relationship among the output power of the auxiliary inverter and the suppression response and the overshoot value of the speed under the same condition. Note that 1p.u. of the output power of the auxiliary inverter is 1500W. The suppression response is evaluated in terms of the natural angular frequency of the damping control. The power capacity of the auxiliary inverter is evaluated with the output power. And lastly, the suppression effect is evaluated with the overshoot of the motor speed. From the results in Fig. 13, when the output power of the auxiliary inverter is larger, the response of the damping control becomes faster. Besides, it is confirmed that decreasing the output power of the auxiliary inverter results the overshoot of the speed becomes larger. In other words, when the demand of the response in the speed control is not so fast, the power capacity of the auxiliary inverter can be reduced. Even if the auxiliary output power is only 10% of the main inverter, the overshoot is possible to suppress less than 10% (180 r/min) as shown Fig. 13. Therefore, it is confirmed that the proposed system is useful to fan and conveyor applications.

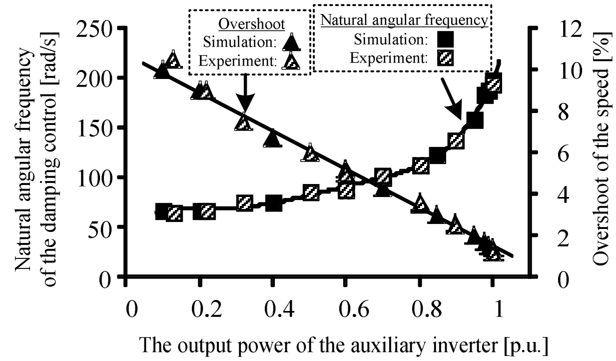



Fig. 13. Influence of the output power on the suppression effect and the suppression response. When the output power of the auxiliary inverter is larger, the response of the damping control becomes faster. The output power of the auxiliary inverter decrease, the overshoot of the speed becomes larger. In other words, when the demand of the response of the speed control is not so fast, the power capacity of the auxiliary inverter can be reduced due to the small output .power of it.

## CONCLUSION

This paper proposes a control technique to dive multiple numbers of parallel connected PMSMs. The features of the proposed system are following;

- The proposed system is composed by two different inverters, which are the main inverter for parallel drive and the small power capacity auxiliary inverter for damping control.
- In addition to the conventional windings (main windings) for the motor drive, each of the PMSM is added with auxiliary windings to suppress the torque vibration.
- The power capacity of the auxiliary inverter is small because the auxiliary inverter is operated when the torque vibration needs to be suppressed.

The simulation and experimental results demonstrated that, the proposed system can drive parallel connected PMSMs efficiently by suppressing the torque vibration by applying damping control to each of the auxiliary inverter. Moreover, the experimental results demonstrated that the proposed system can reduce the speed vibration from 400r/min to nearly 0 r/min in spite of small q-axis current.

In addition, from the simulation and experimental results, the relationship among the response of the damping control, the overshoot of the motor speed and the auxiliary inverter capacity are investigated. The results show that, if the application requires slow response, the power capacity of the auxiliary inverter can be designed to be 10% of the main inverter. Therefore, it is confirmed that the proposed system is useful in fan and conveyor applications.

In the future work, the internal structure of the auxiliary windings in PMSM of the proposed system will be considered. Secondly, driving several units of motor-generator in parallel with the proposed system drives will be considered.

## ACKNOWLEDGMENT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