Minimum Power Capacity of the Auxiliary Circuit for a Parallel Connected Multiple PMSM Drive System

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Abstract:- This paper discusses a multi-parallel drive system for permanent magnet synchronous motors (PMSMs) using an auxiliary inverter and windings. The auxiliary inverter suppresses the vibration of the motor. The power capacity of the auxiliary circuit depends on the speed response. Thus, this paper investigates the transfer function from the speed command to rotational speed of the V/f control for PMSM because speed response dominates the power converter capacity of the auxiliary inverter. As a result, the output power of the auxiliary inverter is suppressed to 10 % of the main inverter power capacity in the speed response of lower than 13 rad/s in the prototype of 1500-W PMSM drive system.

Keywords : Permanent magnet synchronous motor , Parallel operation , Damping control

1. Introduction

Recently, parallel connected multiple induction motor drive systems are applied to industry in terms of cost reduction and simplify of the system, because this system only uses large power capacity inverter to multiple induction motors [1]. However, it is difficult to drive the parallel connected PMSMs by using only one inverter because the torque vibration occurs due to the resonance between a synchronous reactance and the inertia moment.

There are some literatures which two PMSMs are driven by one power converters [2-3]. However, it is difficult to apply those converters to several motors. So, the authors have proposed a drive system for multi-parallel connected PMSMs by the auxiliary inverter and windings [4]. It is important to use small power capacity of the auxiliary inverter in terms of the practical system. However, the power capacity of the auxiliary inverter depends on the speed response of the system.

In this paper, the minimum power capacity of the auxiliary inverter is clarified from frequency characteristics of the transfer function from the speed command to the output power of the auxiliary inverter depends on the speed response of system.

2. Proposed system and control strategy

Fig. 1 shows the configuration of the proposed system. In PMSMs, the auxiliary windings which are used in the damping control (with the auxiliary inverter) are placed in the slots together with the main windings. The proposed system uses two different power rating inverters. The first one is the large power capacity inverter for the main windings to control the speed of the parallel connected PMSMs. The second one is a 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.

Fig. 2 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 field-oriented control and the damping control. Each of the auxiliary inverter controls the current in auxiliary windings of the PMSM in order to suppress the torque and speed vibrations. Since these vibrations

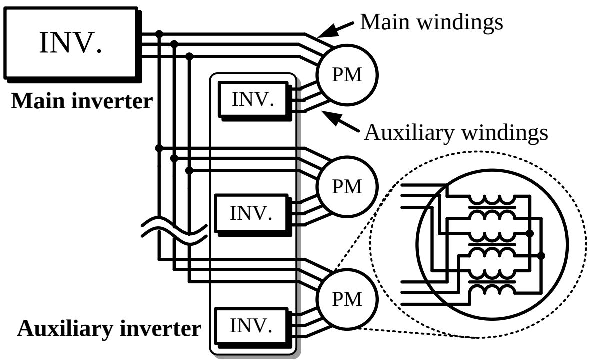


Fig. 1. Configuration of the proposed system.

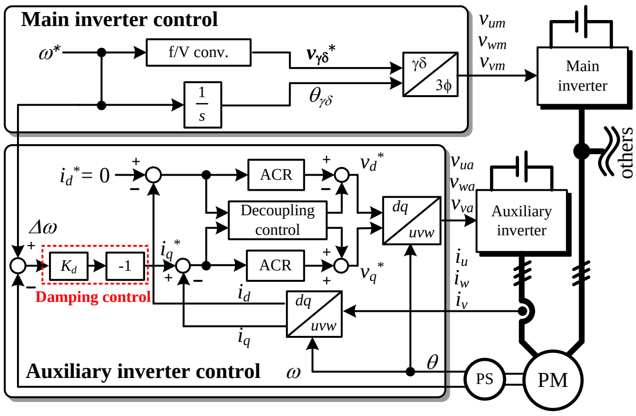


Fig. 2. Control block diagram of the proposed system.

are caused by the phase difference between the rotational coordinates of the inverter and of the PMSM, it can be suppressed by the damping control in the auxiliary inverter.

3. Minimum power capacity of auxiliary inverter

3.1 Analysis model

Fig. 3 shows the simplified system in order to confirm the operation of the damping control. The proposed system uses the PMSM placed the auxiliary windings in the slots together with the main (conventional) windings, and so the mutual magnetic interference occurs between the main and the auxiliary windings. Due to the above reason, the control for the auxiliary inverter becomes complicated. Therefore, as the first step, 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 is neglected. This model is used in the simulation and the experiment.

3.2 Frequency characteristic of the speed transfer function

Fig. 4 shows the frequency characteristic of the transfer function from the speed command to rotational speed of the V/f control from the main motor. Table 1 shows the analysis and experimental conditions. In Fig. 4, the magnitude becomes lower at the resonance frequency ω_n by applying the damping control in comparison to the proposed system without the damping control. It means that the suppression effect becomes higher. In SPMSM, the damping factor ζ and the natural angular frequency ω_n are given by

$$\zeta = \sqrt{\frac{3}{2}}\frac{P_{fM} K_d}{2}\sqrt{\frac{L_M}{J}} \quad \text{(1)}$$

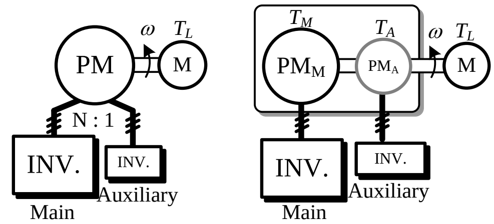
$$\omega_n = \sqrt{\frac{3}{2}}\frac{P_{fM} \Psi_{mM}}{\sqrt{J L_M}} \quad \text{(2)}$$

where K_d is the damping gain, L is the synchronous reactance, P_f is pairs of the pole, Ψ_m is the magnet flux linkage, and J is the inertia moment of motors, Suffix 'A' represents the parameter of the motor that is connected to the auxiliary inverter, 'M' represents the parameter of the motor that is connected to the main inverter.

Without the damping control (ζ = 0), the magnitude at the resonance frequency rises. By contrast, by applying the damping control (ζ = 0.3), the magnitude at the resonance frequency decreases to 5 dB.

3.3 Frequency characteristic of each output power transfer function

Fig. 5 shows the frequency characteristic of the transfer function from speed command to output power of the main inverter, the auxiliary inverter, and the sum of the inverters in the proposed system. In the proposed system, the main torque cannot be controlled directly due to the V/f control. However, by calculating the torque transfer function from the speed one, the frequency characteristic of each output power is derived [4]. In Fig. 5, the output power of the auxiliary inverter rises near the resonance frequency. On the other hand, when the frequency components into the speed command are lower and lower, the output power of the auxiliary inverter is suppressed more. In other words, the auxiliary inverter does not contribute steady state i.e. constant speed. Nevertheless, although the output power of the main inverter is constant because the main inverter drives the motor. In the experiment, each output power is a little higher or lower than simulation in high frequency region due to the vibration because the transfer function is derived as the load angle in stationary state δ_0 is 0 deg, the current in the stationary state is 0 A in the simulation. Note that the damping factor is designed by the equations which are derived by the authors [4]. For example, when the frequency component included in the speed command is lower than 13 rad/s, the output power of the auxiliary inverter can become lower than 10% of the main inverter. Therefore, the results show that, if the application that is required a slow speed response is applied to the proposed system such as fan applications, the power capacity of the auxiliary inverter can be designed to nearly several percent of the main inverter.



(a) Connection diagram (b) Simplification model

Fig. 3. Simplified model of the PMSM in addition the auxiliary windings.

Table 1. Analysis and experimental conditions

	PM_M	PM_A		PM_M	PM_A
Rated power [W]	1500	750	d-axis inductance [mH]	11.5	15.2
Rated speed [min^{-1}]	1800		q-axis inductance [mH]	23	33.2
Rated current [A]	8.2	4	Electro-motive force constant [Vs/rad]	0.368	0.338
Number of pole pairs	3	3	Inertia moment [kgm^2]	0.0051	0.0026
Armature resistance [Ω]	1.55	1.98	Rotational speed in stationary state [rad/s]	900	

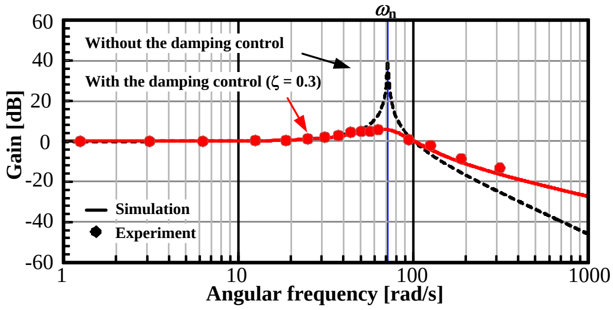


Fig. 4. Frequency characteristics of the speed command to the rotational speed in the proposed system.

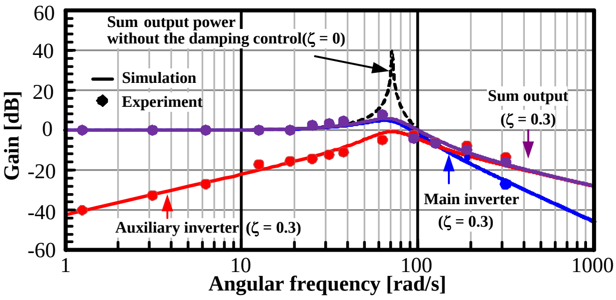


Fig. 5. Frequency characteristics of output power of each inverter in the proposed system.

4. Conclusion

In this paper, the frequency characteristics of the proposed system are discussed. The output power of the auxiliary inverter is suppressed to 10% of the main inverter power capacity in the speed response of lower than 13 rad/s in the prototype of 1500-W PMSM drive system. In the future work, the proposed drive method will be evaluated for several motors in the experiment.

References

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