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Research Article

Synchronization controller design of two coupling permanent magnet synchronous motors system with nonlinear constraints

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ABSTRACT

In this paper, two coupling permanent magnet synchronous motors system with nonlinear constraints is studied. First of all, the mathematical model of the system is established according to the engineering practices, in which the dynamic model of motor and the nonlinear coupling effect between two motors are considered. In order to keep the two motors synchronization, a synchronization controller based on load observer is designed via cross-coupling idea and interval matrix. Moreover, speed, position and current signals of two motor all are taken as self-feedback signal as well as cross-feedback signal in the proposed controller, which is conducive to improving the dynamical performance and the synchronization performance of the system. The proposed control strategy is verified by simulation via Matlab/Simulink program. The simulation results show that the proposed control method has a better control performance, especially synchronization performance, than that of the conventional PI controller.

1. Introduction

An increasing number of coupling multi-motor systems (CMMSs) appear in the industry, agriculture, and transportation. In order to get good production quality, reduce contouring error and improve the operation security of system, usually, synchronization is the basic requirement in many coupling multi-motor systems. In recent decades, many synchronization control strategies have been designed for multi-motor system. Zhang et al. [1] have developed chaotic speed synchronization controller for multiple induction motors by using stator flux regulation. Based on Takagi–Sugeno–Kang-type fuzzy neural network estimator, Lin et al. [2] have proposed cross-coupled intelligent complementary sliding mode control for a dual linear motor servo system, while in order to simplify control structure, Zhao et al. [3] have studied an adjacent cross-coupling control architecture incorporating sliding mode control method for multiple induction motors. Barton and Alleyne [4] have achieved precision motion control by combining individual axis iterative learning control (ILC) and cross-coupled ILC (CCILC) into a single control input. For the sake of tracking different desired trajectories, Xiao et al. [5] have exploited a generalized synchronization controller for multi-axis motion systems by integrating cross-coupling technology into optimal control architecture, and optimal synchronization controller for high-precision motion system has been designed in [6] by introducing the coupling and synchronization factors into the synchronization error. Besides, many other control strategies have been adopted in this fields, such as adaptive control [7–9], fuzzy control [10,11], electronic line-shafting control [12,13], robust control [14–19], neural network control [20], gain-scheduled control [21] and model-free control [22].

Permanent magnet synchronous motors (PMSMs) have been widely used in many engineering applications owning to theirs features of high power, high torque-to-current ratio and large power-to-weight ratio [23–25]. So far, many control methods have been developed for PMSMs, e.g., robust control [26,27], adaptive control [28,29], optimal control [30], fuzzy control [31], sliding mode control [32,33], model reference adaptive control [34] and predictive control [35–38].

Because of the above advantages, PMSMs have become irreplaceable in many fields including the coupling multi-motors system. Usually, the dynamic model of driving device is seldom considered or do not be taken into account in the CMMSs when

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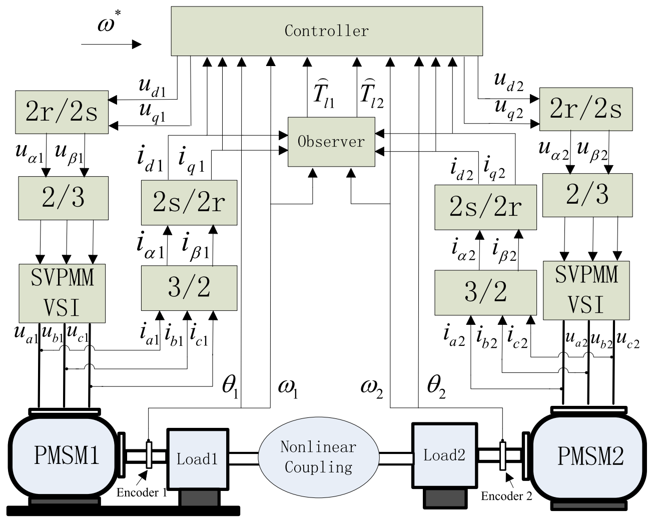

Fig. 1. Control configuration of two coupling PMSMs system with nonlinear constraints.

controller is designed, such as [2,5,12,13,16–21]. If the dynamic model of driving device is taken fully into account, the dynamic performance of system will be improved. Besides this, because of the coupling between motors, the motors will influence each other when their rotor angular positions are different. Therefore, the coupling between motors should be considered when the model of CMMSs is established. Moreover, the linear coupling is a special case of the nonlinear coupling and two coupling motors system is one of typical applications in engineering [39]. Therefore, in this paper, two coupling PMSMs system with nonlinear constraints is studied. First, the mathematical model of the system is developed based on the engineering practices, in which the dynamic model of PMSMs and the coupling between motors are taken into account to get good dynamic performance and synchronization performance. Then based on the model, a synchronization controller is designed.

Cross-coupling control idea is widely used to design the synchronization controller, which can be seen in literatures [2–8,11,13–17,20,22]. Only the speed error signal and/or position error signal are taken as cross feedback signal in most synchronization controllers like [1–6,15–17,20]. If the current signal is considered, together with speed error signal and position error signal, the system will have better dynamic performance and better synchronization performance than before since electromagnetic time constant is far less than the mechanical time constant, i.e., the dynamic response of current is faster than the response of the speed and position. Therefore, in this paper, speed, position and current signals all are taken as self-feedback signal as well as cross-feedback signal. Interval matrix theory is often used to cope with bounded parameters [40–43]. Limited by voltage supply, protection equipment and rated parameter, the speed and the current of a given PMSM change in the certain range likes rated range [44]. Therefore, they can be viewed as interval variables. In this paper, based on interval matrix, cross coupling control idea and the characteristic of system, a synchronization controller is designed. Simulation results show compared with convention PI controller, the proposed controller has a better dynamic performance and synchronization performance.

This paper is organized as follows. In Section 2, the mathematical model of two coupling PMSMs system with nonlinear constraints is established. Section 3 develops a synchronization speed controller and a load torque observer for the system. In order to verify the effectiveness of the synchronization controller and the load torque observer, in Section 4, simulation is carried out via Matlab/Simulink soft, and simulation results are analyzed. Finally, conclusions and future works are presented in Section 5.

2. Mathematical model of two coupling PMSMs system with nonlinear constraints

The following notations will be used throughout the paper. I is the identity matrix with appropriate dimension and e_i is the ith column of matrix I. 0_{ij} stands for the zero matrix with $i \times j$ dimensions.

According to literatures [45,46], the model of PMSMs is described as follows by means of a change of coordinates, which transforms the AC three-phase system into an equivalent DC bi-phase system

$$\frac{di_d}{dt} = -\frac{R_s}{L_{sd}} i_d + \frac{L_{sq}}{L_{sd}} \omega i_q + \frac{1}{L_{sd}} u_d, \tag{1a}$$

$$\frac{di_q}{dt} = -\frac{L_{sd}}{L_{sq}} \omega i_d - \frac{R_s}{L_{sq}} i_q - \frac{1}{L_{sq}} \omega \psi_r + \frac{1}{L_{sq}} u_q, \tag{1b}$$

$$\frac{d\omega}{dt} = \frac{n_p^2}{J}(L_{sd} - L_{sq}) i_d i_q + \frac{n_p^2}{J} \psi_r i_q - \frac{n_p}{J} T_l - \frac{B}{J} \omega, \tag{1c}$$

where L_{sd} and L_{sq} respectively are d- and q-axis inductances; R_s is the stator resistance; Ψ_r is the permanent magnet flux linkage; n_p is the number of pole pairs; B is the frictional coefficient; J is the inertia moment; i_d and i_q respectively are d- and q-axis stator currents; ω is the rotor speed; u_d and u_q respectively are d- and q-axis voltages; and T_l is the load torque.

The connection model of two coupling PMSMs system with nonlinear constraints is depicted in Fig. 1. If the rotor angular positions of two PMSMs are same, i.e., synchronization condition is satisfied, coupling force between the two PMSMs do not exist. When one of the loads of two motors changes, it is difficult to keep the speed of two motor synchronization, which will lead to mutual influence of two PMSMs, and further, the system may be left in an unstable state. Therefore, synchronization controller must be designed.

In order to get good control performance, the dynamical model of PMSMs and the coupling between two motors are taken into