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Simulation studies on model reference adaptive controller based speed estimation technique for the vector controlled permanent magnet synchronous motor drive

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ABSTRACT

This paper presents a speed estimation technique for the permanent magnet synchronous motor drive. A Model Reference Adaptive System (MRAS) has been formed using the instantaneous and steady-state reactive powers to estimate the speed. It has been shown that such unique MRAS offers several desirable features. The proposed technique is completely independent of stator resistance and is less parameter sensitive, as the estimation-algorithm is only dependent on q-axis stator inductance. Also, the method requires less computational effort as the simplified expressions are used in the MRAS. The stability of the proposed system is achieved through Popov's Hyperstability criteria. Extensive simulation results are presented to validate the proposed technique. The system is tested at different speeds including zero speed and a very satisfactory performance has been achieved.

1. Introduction

Recently Permanent Magnet Synchronous Motor (PMSM) drives have received increased attention due to having several desirable features, such as, higher efficiency, higher power density, higher torque to inertia ratio etc. Vector controlled PMSM drive [1] has very high dynamic performance and are widely used in applications like machine tools, electric vehicles etc. Indirect vector controlled system requires the information of the speed: either from the speed encoder or from an estimator/observer [2–4]. Elimination of the speed encoder is highly encouraged to increase the mechanical robustness of the system and to make the drive cheaper. Moreover, there are some applications, where there is no room to put the speed sensor or the nature of the environment (such as explosive environment in some chemical industries) does not allow the use of any additional speed sensor. This has made speed sensorless PMSM drive very attractive. Many speed estimation techniques have been reported in literature [5–17]. They are broadly categorized as:

1.1. Back-emf based method [5,6]

Use of back-emf to estimate the rotor speed has been reported [5,6]. This method offers satisfactory performance at higher speed. However, at zero or very low speed the back-emf becomes negligible. This makes the speed estimation at lower speed very difficult. Also, the method is highly sensitive to machine parameters.

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1.2. Signal injection based method [7]

Some techniques exploited the saliency in the machine to extract the speed information. Note that the phase inductance varies for different rotor positions due to the saliency present in the rotor side. To extract the position from inductance profile, a high frequency voltage signal is fed to the motor phases. The merit of this method is that the technique is reliable at zero speed. A combination of signal injection based and the back-emf based methods for speed estimation is reported in literature, where the former is used at zero or very low speed and the later for high speed. However, the accuracy of this method is highly influenced by the geometry of the rotor (i.e., positioning of the permanent magnets). This makes the technique unsuitable for the surface mounted PMSM. The main drawbacks of signal injection based methods are the adverse effect of injecting signal on motor dynamics and the requirement of extra hardwire for the purpose of signal injection.

1.3. State observer-based method [8,9]

Reported estimation method also includes Extended Kalman Filter (EKF), Extended Luenburger observer (ELO), sliding mode observer, etc. The computational complexity, parameter sensitivity and the need of initial conditions degrade the superiority of the EKF based speed estimation technique. However, one good side is that the parameter can also be treated as the state and that can be estimated along with the speed. The sliding mode observer based technique is available in [9]. The method is simple and robust against parameter variation. However, it has the demerit of the chattering phenomenon. In [9], a low pass filter (LPF) has been used to overcome the problem. However, this is at the cost of system dynamics.

1.4. Model reference adaptive system (MRAS) based techniques [10–14]

Theoretically MRAS computes a desired state (called as the functional candidate) using two different models (i.e. reference and adjustable models). The error between the two models is used to estimate an unknown parameter (here speed is the unknown parameter). A condition to form the MRAS is that the adjustable model should only depend on the unknown parameter. Here, the reference model is independent of rotor speed, whereas the adjustable model is dependent on the same. The error signal is fed to the adaptation mechanism. The output of the adaptation mechanism is the estimated quantity ($\omega_{r,\text{est}}$), which is used for the tuning in adjustable model and also for feedback. The stability of such closed loop estimator is achieved through Popov's Hyperstability criterion [17]. The method is simple and requires less computation.

Depending on the quantity (i.e. the functional candidate) used to formulate the error signal, various kinds of MRAS are possible. In [10], an MRAS is developed with *d*- and *q*-components of flux. However, the method is heavily dependent on stator resistance variation and suffers from the integrator related problems like drift and saturation. To overcome the first problem, an MRAS with on-line stator resistance estimation is reported in [11]. Reactive power-based MRAS are presented in [12,13]. In [14], Neural Network (NN) based MRAS is also reported. Among all of these methods, reactive power based MRAS is more popular for speed estimation as it is independent of stator resistance.

1.5. Other methods [15,16]

Several other approaches such as variable structure-based technique, passivity based technique, etc. are also reported to estimate the speed of a PMSM drive. The more recent approach based on Artificial Intelligence (AI) are the Artificial Neural Networks (ANN) [15] and Fuzzy Logic [16,17] for speed estimation. But, the AI-based methods require huge memory and involve computational complexity.

Out of all the techniques discussed so far, MRAS is widely accepted for speed estimation due to its simplicity and good stability. Also the method does not require any extra hardwire or signal injection or huge memory like EKF or ELO. Within the available MRAS-based methods, reactive power-based scheme [13] is not dependant on stator resistance and has definite advantages over the other methods.

This paper deals with an MRAS, where the reference model utilizes instantaneous reactive power and the adjustable model uses steady-state reactive power. This means that the two different versions of the same quantity are used to formulate error signal. This type of approach rewards a speed estimator that depends only on L_q. A mechanism for on-line estimation of L_q will make the drive parameter independent. Such MRAS with instantaneous and steady-state reactive power was reported in [12] for the speed and parameter estimation of induction motor drive. This work applies the concept to PMSM drive for the first time.

The scheme is simulated in MATLAB/SIMULINK. It is observed that the proposed technique is working well with different possible situations under load and speed variation. Extensive simulation results are presented to highlight the performance of the estimation algorithm.

2. MRAS-based speed estimation

Fig. 1 shows the MRAS based speed estimation scheme. It uses the outputs of two models: one independent of rotor speed (Reference Model) and the other dependant on rotor speed (Adjustable Model), to form an error signal. A PI controller is used in the adaptation mechanism for the convergence in the system.