Robust MRAS-Based Algorithm for Stator Resistance and Rotor Speed Identification

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Abstract: This letter proposes a model reference adaptive system (MRAS)-based algorithm for simultaneous stator resistance (R_s) and rotor speed (ω) identification of position sensorless induction motor to accurately estimate ω at low speeds without affecting drive performance. The R_s has to be estimated concurrently with the ω estimation to compensate for the fluctuation in R_s. The reference model and adjustable model are interchangeable for concurrent ω and R_s estimation. For stator resistance identification, the two models switch roles. Extensive computer simulation and experimental investigation prove the effectiveness of the proposed solution.

Keywords: Parallel model reference adaptive system, identification, sensorless control.

Introduction: Induction motors have been widely used in high-performance ac drives, requiring ω information. Introducing a shaft speed sensor decreases system reliability, and different solutions for sensorless ac drives have been proposed. The MRAS speed estimators are the most attractive approaches [1], [2], due to their design simplicity. The disadvantage of the estimators is that R_s detuning causes ω and torque response to deteriorate in the low speed range [2]. Therefore, simultaneous estimation of ω and R_s is required.

In [3], ω is estimated using a full order adaptive observer and R_s or R_r [4] are identified simultaneously. Kubota [4] uses an auxiliary test signal for simultaneous ω estimation and rotor time constant identification. The same performance index in [5] is applied on ω or R_s identification mechanisms. The criterion function chosen in [5] is robust on stator leakage inductance but these two identification algorithms are not simultaneous. Furthermore, during the R_s identification time interval the drive is without speed information. The steady state condition is required for R_s estimation. References [1]-[5] contributed to solving MRAS-based ω estimation problems. In spite of all this work, low-speed operation of sensorless induction motor drive with robustness against R_s variation still remains an unsolved problem.

This letter presents a new parallel MRAS observer. It contains a reference and an adjustable model and it is proposed to implement ω control of sensorless induction motor drives. This parallel MRAS observer includes two adaptive mechanisms, one for ω estimation and the other for R_s estimation. In the proposed structure $u_s - i_s$ rotor flux estimator serves as the reference model for ω estimation with $i_s - \omega$ estimator as the adjustable model, while in R_s estimation the former and latter models switch their roles. The functions of the two models used in the parallel MRAS observer are interchangeable. The essence of the parallel MRAS observer is to compensate for the thermal variation of R_s in the speed reference model by a second adaptation mechanism. Newly proposed adaptive mechanisms for R_s identification-based parallel MRAS observers offer superior performance and do not require steady state conditions. Moreover, that adaptation mechanism may be active in steady state and during transient response. The pulsation character of the torque command does not interfere with the estimation mechanism and does not require dedicated sensors, special tests, or injection of test signals and modification of motor windings. Up to now, other on-line R_s identification algorithms did not meet these requirements. The proposed algorithm can be readily implemented in a vector controlled sensorless induction motor. Experimental results show the effectiveness of the parallel MRAS observer.

Parallel MRAS Estimation of Rotor Speed and Stator Resistance: The system block diagram of a conventional MRAS speed observer is shown in Figure 1a and includes a reference model (1), an adjustable model (2), and an adaptive ω mechanism (3). Both models are excited by measured stator voltages and/or currents. The reference model specifies a given rotor flux $\hat{\underline{\psi}}^s_{rV}$. The difference of phase angle between outputs of these two models is used by the adaptive mechanism to converge the estimated ω to its true value. The second piece of information of the vector product (3) is unused. Therefore, in order to allow the continuous tracking of nonpredictable thermal R_s changes, there is a basis for using $\hat{\underline{\psi}}^s_{rV}$ and $\hat{\underline{\psi}}^s_{rI}$ in added adaptation mechanisms (Figure 1b). The adaptation mechanism for the on-line tuning of R_s (4), proposed in this letter, is derived by hyperstability theory.

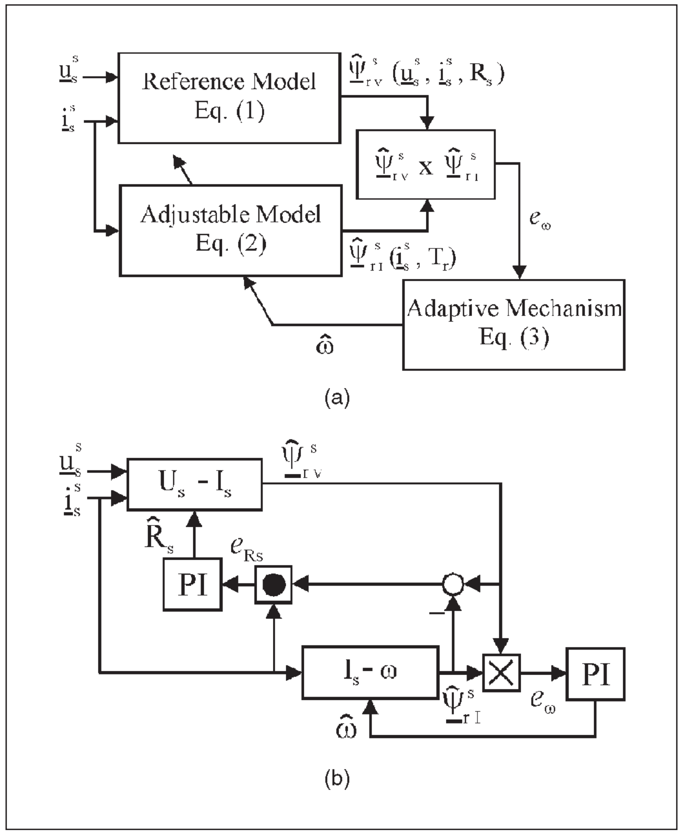

Figure 1. The MRAS speed observer; (a) the basic configuration, (b) configuration for parallel rotor speed and stator resistance estimation

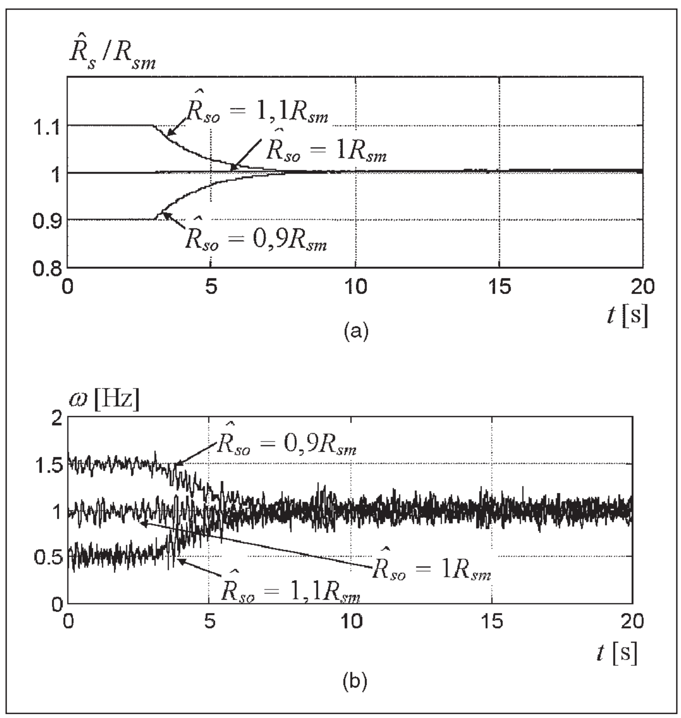

Figure 2. Identification by the parallel MRAS observer with 4 Hz as ω reference value; (a) the stator resistance identification, (b) the rotor speed

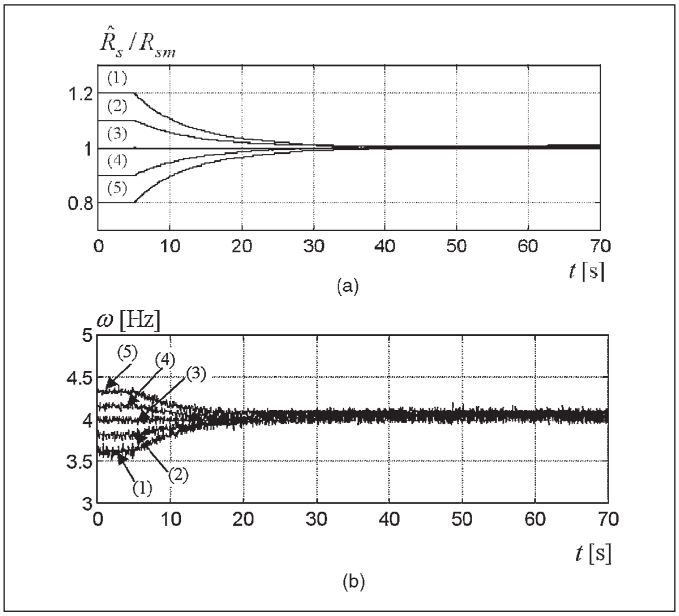

Figure 3. Identification by the parallel MRAS observer with 4 Hz of ω reference value. Initial value of R_S estimate: (1) $\hat{R}_{so} = 1.2R_{sm}$, (2) $\hat{R}_{so} = 1.1R_{sm}$, (3) $\hat{R}_{so} = R_{sm}$, (4) $\hat{R}_{so} = 0.9R_{sm}$, (5) $\hat{R}_{so} = 0.8R_{sm}$; (a) the stator resistance identification, (b) the rotor speed

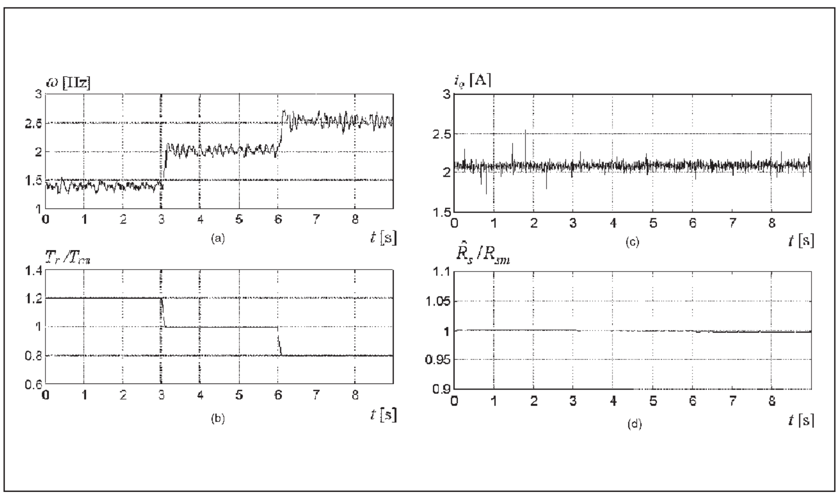

Figure 4. Influence of T_r detuning on ω and R_s estimation by parallel MRAS observer; (a) the rotor speed , (b) the rotor time constant, T_{rm} value in motor, (c) the q- current component, (d) the stator resistance estimate

The parallel MRAS observer operates in the stationary reference frame (α, β) and it is described with the following space vector equations. The symbol ^ is used to indicate estimated value.

Reference model or voltage estimator ($u_s - i_s$) of rotor flux ($\sigma = 1 - L_m^2 / (L_s L_r)$) is

$$p\underline{\hat{\psi}}^s_{rV} = \frac{L_r}{L_m}\left[\underline{u}^s_s - \left(\hat{R}_s + \sigma L_s p\right)\underline{i}^s_s\right]. \tag{1}$$

The adjustable model or current estimator ($i_s - \omega$) of rotor flux is

$$p\underline{\hat{\psi}}^s_{rI} = \frac{L_m}{T_r}\underline{i}^s_s - \left(\frac{1}{T_r} - j\hat{\omega}\right)\underline{\hat{\psi}}^s_{rI}. \tag{2}$$

The adaptive mechanism for ω

$$\hat{\omega} = \left(K_{p\omega} + \frac{K_{I\omega}}{p}\right)e_\omega;\; e_\omega = \underline{\hat{\psi}}^s_{rI} \times \underline{\hat{\psi}}^s_{rV} = \hat{\psi}_{\alpha rI}\hat{\psi}_{\beta rV} - \hat{\psi}_{\beta rI}\hat{\psi}_{\alpha rV} \tag{3}$$

and for R_s estimation

$$\hat{R}_s = \left(K_{pR_s} + \frac{K_{IR_s}}{p}\right)e_{R_s};$$
$$e_{R_s} = \mathbf{i}^s_s \cdot \left(\underline{\hat{\psi}}_{rV} - \underline{\hat{\psi}}_{rI}\right) = i_{\alpha s} \cdot \left(\hat{\psi}_{\alpha rV} - \hat{\psi}_{\alpha rI}\right) + i_{\beta s} \cdot \left(\hat{\psi}_{\beta rV} - \hat{\psi}_{\beta rI}\right) \tag{4}$$

are proposed by Popov's hyperstability theory.

Results: The results shown in Figures 2 and 4 are obtained for a sensorless FOC system using the newly proposed parallel MRAS observer. The DSP system based on the DS1102 controller board from dSPACE GmbH is used for experimental investigation of efficiency of the proposed parallel ω and R_s estimations. The motor terminal currents are sensed by current sensors. The stator voltages are reconstructed from the PWM pattern and dc-bus voltage.

Figure 2 shows the results of R_s identification using the parallel MRAS observer and ω performance. The drive is at first started with R_s detuned in the MRAS observer (Figure 2a) and without R_s – estimation. As can be seen, by switching on the R_s identification mechanism at $t = 3s$ the parallel MRAS observer is able to identify R_s successfully. The initial value of the R_s estimate ($\hat{R}_{so}$) is indicated in Figure 2a. The reference speed is 1 Hz. The ω shown in Figure 2b is slightly higher than the reference value for the first 3 s period, because R_s in the MRAS is detuned. The value of ω returns back to the reference value as the estimate of R_s converges to the actual value (R_{sm}).

In Figure 3 same experiment is shown as in Figure 2, but with 4 Hz of reference speed.

Figure 4 shows the parallel MRAS observer performance when the rotor time constant T_r in the observer is varied (Figure 3b). The drive is loaded with nominal torque. It is clear from Figure 3d that the on-line R_s identification is insensitive to T_r detuning.

Conclusions: A study of behavior of a sensorless FOC induction motor drive with new parallel ω and R_s MRAS observer in the presence of parameter detuning is presented. The parallel adaptive approach is used to identify R_s to enhance the robustness of the sensorless induction motor drive in the range of low speed (around 1 Hz). If T_r is detuned, the suggested parallel MRAS observer estimates R_s well. The straightforward design procedure is proposed by Popov's hyperstability theory. The effectiveness of the proposed parallel MRAS algorithm is verified by extensive experimental investigation.

References:

[1] J. Holtz, "Methods for speed sensorless control of ac drives," in *Sensorless Control of AC Motors,* K. Rajashekara, Ed. Piscataway, NJ: IEEE Press, 1996.

[2] Z. Peng and T. Fukao, "Robust speed identification for speed sensorless vector control of induction motors," *IEEE Trans. Ind. Applicat.*, vol. 30, pp. 1234-1240, Sept./Oct. 1994.

[3] G. Yang and T.H. Chin, "Adaptive speed identification scheme for a vector-controlled speed sensorless inverter-induction motor drive," *IEEE Trans. Ind. Appl.*, vol. 29, pp. 820-825, July/Aug. 1993.

[4] H. Kubota and K. Matsuse, "Speed sensorless field-oriented control of induction motor with rotor resistance adoption," *IEEE Trans. Ind. Appl.,* vol. 30, pp. 1219-1224, Sept./Oct. 1994.

Induction Motor Data:								
U_n [V]	I_n [A]	P_n [W]	T_n [Nm]	L_s [H]	L_r [H]	M_n [H]	R_{sm} [Ω]	R_{rm} [Ω]
380	2.1	750	5	0.464	0.461	0.421	10	6.3

[5] L. Zhen and L. Xu, “Sensorless field orientation control of induction machines based on a mutual MRAS scheme,” *IEEE Trans. Ind. Electron.*, vol. 45, pp. 824-831, Oct. 1998.

2002 FACTS Award

Call for Nominations

Deadline: 31 January 2002

The IEEE Power Engineering Society (PES) calls for nomination of outstanding individuals to receive the 2002 Flexible AC Transmission System (FACTS) Award.

Description: Power electronics and other static controllers are making a major impact on future power systems through application in transmission, distribution, and small generation. Applications in transmission include HVDC and FACTS. Since the introduction of the FACTS concept, the technology has been moving ahead at an increasing pace. Very significant near to long term benefits of FACTS technology are now recognized in the industry. The FACTS Award is for individuals who have made a major contribution to the state of the art of FACTS technology and its applications. The IEEE definition of FACTS is: “Alternating current transmission systems incorporating power electronics-based and other static controllers to enhance controllability and power transfer capability.” By this definition, the FACTS concept, in addition to the hardware, software and applications work carried out since its introduction, incorporates considerable prior work done on Static VAR Compensators and other static Controllers.

Eligibility: Individuals who have made a major contribution to the state of the art of FACTS technology and its applications.

Selection: Factors to be considered in selecting the FACTS Award recipient include:

- The candidates contribution(s) to FACTS technology
- Originality or innovative nature of the contribution(s)
- Impact of the contribution(s) on FACTS technology and its applications
- List of significant publications in FACTS
- Candidate’s stature in FACTS
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Nomination Procedure: A nomination (2 copies) written in English on behalf of each candidate along with at least four and no more than five supporting recommendations must be received as a package by the Chairman of the FACTS Award Committee on or before 31 January 2002. These nominations will be considered for the award planned to be made during the 2002 IEEE PES Summer Meeting. The above listed selection factors should be carefully considered during preparation of nominations and recommendations. They must be complete and provide sufficient information to establish the candidate’s contribution(s) and role in FACTS. Nominators are encouraged to format the nomination package in sections addressing each of the factors. Each supporting letter of recommendation should not exceed two pages

The Award: The FACTS Award consists of a plaque and an honorarium of one thousand dollars. PES administers this award. The 2002 Award would be the fourth FACTS Award.

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Series FACTS Devices in Financial Transmission Rights Auction for Congestion Management

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Abstract: Financial transmission rights (FTR) auction is an important method for allocating the network transmission capabilities to the market participants who value them most. In this letter, series flexible ac transmission systems (FACTS) devices are modeled as additional power injection at buses in the presented linear optimization problem of FTR auction, which is based on a dc power flow model. The impacts of controlling different FACTS devices on auction results are shown by detailed studies of an eight-bus test system.

Keywords: FTR, FACTS, electricity markets.

Introduction: The concept of FTR, also known as transmission congestion contracts (TCC) or fixed transmission rights, is introduced by W. Hogan into power markets as a pure financial instrument to hedge unexpected high-congestion charges on constrained transmission lines. Market participants can submit their bids for purchase and sale of FTRs in a separated auction market conducted by the independent system operator (ISO), whose objective is to maximize revenues from FTRs while keeping all the FTRs simultaneously feasible [1]-[2]. An FTR auction has been put into practice at PJM since May 1999 and has been running efficiently.

Since the concept of FACTS was first proposed in 1988, many various FACTS devices have been utilized to meet a growing demand of transfer capabilities due to increasing wheeling transactions in the deregulation environment. In addition to all the well-known advantages brought by FACTS devices, they can offer new opportunities for the ISO to run a more efficient FTR auction to make the full use of the existing power grid.

A method is proposed to incorporate some FACTS devices into the FTR optimal auction model. Since the FTR auction usually runs monthly and only concerns active power, the dc power flow model is used here. Two types of series FACTS devices, which are thyristor controlled series compensators (TCSCs) and thyristor controlled phase shifters (TCPSs), are modeled into the FTR auction with the so-called power injection model (PIM). The solution of this FTR optimal auction consists of the feasible sold FTRs and the optimal control parameters of FACTS devices. An eight-bus test system is studied to illustrate the proposed method.

Description of FTR: According to the PJM definition, FTR is *a financial instrument that entitles holder to receive compensation for transmission congestion charges that arise when the transmission grid is congested in the day-ahead market and differences in day-ahead locational marginal prices (LMPs) results from the dispatch of generators out of merit order to relieve the congestion.* The holder of the FTR is not required to deliver energy in order to receive a congestion credit. If a constraint exists on the grid, the holders of FTRs receive a credit based on the FTR MW reservation, and the LMP difference between point of delivery and point of receipt.

It is natural to have an auction for allocating part or all of the FTRs to provide open access to the grid through a market mechanism. An OPF model can be adopted to provide a formulation of an FTR auction model for selecting the long-term capacity awards based on the willing-to-pay principle. The power flow equations embedded into the FTR auction make it straightforward to identify which FTRs are available by characterizing all possible rights and selecting a set of feasible rights that would provide the highest valued use of the network. The revenue from the FTR auction will be allocated to the transmission owners (TO) to compensate their investment on improving the power grid. A secondary market provides a contractual mechanism for long-term pricing of transmission grid. Figure 1 shows that FTR is a market-based approach to network congestion management.