MRAS METHODS FOR ROTOR RESISTANCE IDENTIFICATION

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ABSTRACT

This article describes several methods of MRAS identification using rotor flux-linkage and their derivatives. These methods are compared in various conditions and analyzed to determine their suitability for identification of rotor resistance.

1. INTRODUCTION

Classical DC motors are gradually replaced by synchronous and asynchronous motors. These motor can be used for almost all needs, simply by selecting the appropriate AC motor, frequency inverter, sensors and control method. During the development of motors, the efficient control evolved and higher knowledge of controlled engines parameters was demanded. If parameters are accurate, we can achieve more efficient control with higher performance. These parameters can be determined analytically or by analysis of the magnetic field during the machine design. These calculations are usually performed in laboratory conditions, sometimes it is necessary to know the exact characteristics of the machine or the appropriate conditions for identification parameter must be arranged (eg. locked rotor). However, these methods do not respond to changing conditions during engine operation. These are the so-called off-line methods that are unsuitable for effective control. One of the parameters which need to be identified for effective control is the rotor resistance R_r that raises its value to 130% during engine operation mainly due to the heating coil. In following article, we deal with several types of on-line identification MRAS (Model Reference Adaptive Systems) for asynchronous motor and we detect their effectiveness in identifying the rotor resistance R_r.

2. MRAS

The MRAS method is not fast method, but for identification of rotor resistance R_r, where the changes caused by the heating are not so fast it is sufficient. This method is based on two models of redundant induction motor. One of them is the so-called reference voltage model, which does not contain an identified parameter. Its stator equations are used for correcting the adjustable current model. Identified parameter is then obtained using variations e_R of these two model outputs $D, \widehat{D}$. See figure 1

The induction machine model is used to derive rotor resistance R_r estimation schemes that are independent of the motor control method. The $\alpha\beta$ stator and rotor voltage equations (1)-(4) and the flux linkage equation (5)-(8) of 3-phase squirrel-cage induction machine in the stationary reference frame are used for creating the reference and adjustable model.

$$u_{s\alpha} = R_s i_{s\alpha} + p\Psi_{s\alpha} \quad (1)$$

$$u_{s\beta} = R_s i_{s\beta} + p\Psi_{s\beta} \quad (2)$$

$$0 = R_r i_{r\alpha} + p\Psi_{r\alpha} + \omega_r \Psi_{r\beta} \quad (3)$$

$$0 = R_r i_{r\beta} + p\Psi_{r\beta} - \omega_r \Psi_{r\alpha} \quad (4)$$

$$\Psi_{s\alpha} = L_s i_{s\alpha} + L_m i_{r\alpha} \quad (5)$$

$$\Psi_{s\beta} = L_s i_{s\beta} + L_m i_{r\beta} \quad (6)$$

$$\Psi_{r\alpha} = L_r i_{r\alpha} + L_m i_{s\alpha} \quad (7)$$

$$\Psi_{r\beta} = L_r i_{r\beta} + L_m i_{s\beta} \quad (8)$$

Where $u_{s\alpha\beta}$ is the stator voltage vector, $i_{s\alpha\beta}, \mathrm{i}_{\mathrm{r}\alpha\beta}$ are the stator and rotor current vector, and $\Psi_{s\alpha\beta}, \Psi_{r\alpha\beta}$ are stator and rotor flux linkage vector. The speed is donated by ω_r, and L_m, L_s and L_r are the magnetizing, stator and rotor self-inductances, respectively.The proposed method is derived using (1)-(8) under the assumption that the rotor resistance is varying slowly compared to the electrical or mechanical dynamics of the system. It is also assumed that stator voltage, $u_{s\alpha\beta}$, current, $i_{s\alpha\beta}$, and speed, ω_r, measurements are made.[2]

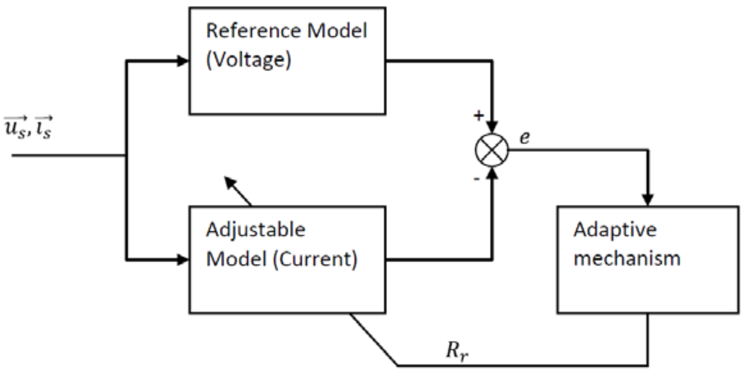

Figure 1: MRAS

After adjusting these equations we get the equations for the reference voltage model

$$\frac{L_m}{L_r} p\Psi_{r\alpha V} = u_{s\alpha} - R_s i_{s\alpha} - \sigma L_s p i_{s\alpha} \quad (9)$$

$$\frac{L_m}{L_r} p\Psi_{r\beta V} = u_{s\beta} - R_s i_{s\beta} - \sigma L_s p i_{s\beta} \quad (20)$$

and the equation for adjustable current model

$$\frac{L_m}{L_r} p\Psi_{r\alpha I} = \frac{L_m}{L_r}\left(-\frac{\hat{R}_r}{L_r}\Psi_{r\alpha I} - \omega_r \Psi_{r\beta I} + L_m \frac{\hat{R}_r}{L_r} i_{s\alpha}\right) \quad (11)$$

$$\frac{L_m}{L_r} p\Psi_{r\beta I} = \frac{L_m}{L_r}\left(-\frac{\hat{R}_r}{L_r}\Psi_{r\beta I} + \omega_r \Psi_{r\alpha I} + L_m \frac{\hat{R}_r}{L_r} i_{s\beta}\right) \quad (12)$$

The MRAS method which is applied to the identification of rotor resistance can be divided into two types. The first type uses only rotor flux-linkage and the second type uses rotor flux-linkage and its derivatives.

2.1. METHODS WORKING WITH ROTOR FLUXES

As it is shown in the previous section, model num.1 can estimate the rotor resistance by using two estimators (a reference-model-based estimator and an adaptive-model based one), which independently estimate the rotor flux-linkage components in the stator reference frame ($\Psi_{\alpha r}, \Psi_{\beta r}$), and by using the difference between these flux-linkage estimates to drive the rotor resistance of the adaptive model to that of the actual resistance.[3]

$$e_{R1} = Im(\Psi_{rV}\Psi_{rI}) = \Psi_{r\alpha I}\Psi_{r\beta V} - \Psi_{r\beta I}\Psi_{r\alpha V} \tag{13}$$

Next method num. 2 is similar the previous one. The same components of flux deducted voltage and current model are multiplied by the currents $i_{s\alpha\beta}$

$$e_{R2} = i_{s\alpha}(\Psi_{r\alpha V} - \Psi_{r\alpha I}) + i_{s\beta}\left(\Psi_{r\beta V} - \Psi_{r\beta I}\right) \tag{14}$$

2.2. METHODS WORKING WITH ROTOR FLUXES AND THEIR DERIVATIONS

In order to obtain a method num.3 for estimating R_r which is independent of R_s a reference model that only consists of measured or known variables or parameters, and an adjustable model in which the only unknown quantity is R_r, are required. It is also required to eliminate R_s in both models so that R_r estimation is independent of R_s. The stator resistance can be eliminated by multiplying (9) by $i_{s\beta}$ and (10) by $i_{s\alpha}$ and taking the difference.

$$e_{R3} = Im(\Delta\bar{e}\bar{\iota_s}) = \bar{\iota_s} \times \bar{e} - \bar{\iota_s} \times \hat{\bar{e}} = D - \widehat{D} \tag{15}$$

$$e_{R3} = \frac{L_m}{L_r}\left(p\Psi_{r\beta V}i_{s\alpha} - p\Psi_{r\alpha V}i_{s\beta}\right) - \frac{L_m}{L_r}\left(p\Psi_{r\beta I}i_{s\alpha} - p\Psi_{r\alpha I}i_{s\beta}\right) \tag{16}$$

$$D = \left(u_{s\beta}i_{s\alpha} - u_{s\alpha}i_{s\beta}\right) + \sigma L_s(i_{s\beta}pi_{s\alpha} - i_{s\alpha}pi_{s\beta}) \tag{17}$$

An equation equivalent to (17), that is expressed using the rotor equations, can be obtained by performing multiplication of equation (11) with $i_{s\alpha}$and subtracting equation (12) multiplied with $i_{s\beta}$.

$$\widehat{D} = \frac{L_m}{L_r}\left(\frac{\hat{R}_r}{L_r}\left(\Psi_{r\alpha I}i_{s\beta} - \Psi_{r\beta I}i_{s\alpha}\right) + \omega_r\left(\Psi_{r\alpha I}i_{s\alpha} + \Psi_{r\beta I}i_{s\beta}\right)\right) \tag{18}$$

Equations (17) and (18) can then be used in a final implementation of the rotor speed observer. When this observer is used in a vector controlled drive, it is possible to obtain satisfactory performance even at very low speeds. PI controller gains should be as large as possible. The scheme is insensitive to stator resistance [3].

Next we treated the method num. 4. The presence of the stator transient inductance (σL_s) is undesirable. A goal for the purposes of the present scheme is to eliminate the need for using the stator transient inductance. The stator transient inductance can be eliminated by multiplying $pi_{s\alpha\beta}$.[3]

$$e_{R4} = Im(\Delta\bar{e}p\bar{\iota_s}) = D - \widehat{D} \tag{19}$$

$$e_{R4} = \frac{L_m}{L_r}\left(p\Psi_{r\beta V}pi_{s\alpha} - p\Psi_{r\alpha V}pi_{s\beta}\right) - \frac{L_m}{L_r}\left(p\Psi_{r\beta I}pi_{s\alpha} - p\Psi_{r\alpha I}pi_{s\beta}\right) \tag{20}$$

$$D = \left(u_{s\beta}pi_{s\alpha} - u_{s\alpha}pi_{s\beta}\right) - R_s(i_{s\beta}pi_{s\alpha} - i_{s\alpha}pi_{s\beta}) \tag{21}$$

$$\widehat{D} = \frac{L_m}{L_r}\left(\frac{\hat{R}_r}{L_r}\left(\Psi_{r\alpha I}pi_{s\beta} - \Psi_{r\beta I}pi_{s\alpha}\right) + \omega_r\left(\Psi_{r\alpha I}pi_{s\alpha} + \Psi_{r\beta I}pi_{s\beta}\right) + L_m\frac{\hat{R}_r}{L_r}\left(i_{s\beta}pi_{s\alpha} - i_{s\alpha}pi_{s\beta}\right)\right) \tag{22}$$

Adaptive mechanism is $\hat{R}_r = K_p e_r + K_i \int e_r dt$ where K_p and K_i are gain constants.

2.3. SIMULATION RESULTS

This section tries to compare methods described in previous section in simulation in Matlab Simulink environment. Identifications were carried out on an asynchronous motor model with parameters $U_n = 300V, R_s = 0.894\Omega, \mathrm{R_r} = 0.85\Omega, \mathrm{L_s} = 0.1192\mathrm{H}, \mathrm{L_r} = 0.1181, \mathrm{L_m} = 0.112\mathrm{H}, \mathrm{p} = 3$. Simulations also included variation of the rotor resistance value so as to emulate the influence of heating the engine. Rotor resistance has been identified for various conditions. The methods were tested by varying engine load and with different noise power spectral densities. Simulation results are shown in Table 1 and Table 2.

PSD	U[V]	f[Hz]	M[Nm]	$\delta_{R_{r1}}$[%]	$\delta_{R_{r2}}$[%]	$\delta_{R_{r3}}$[%]	$\delta_{R_{r4}}$[%]
0	300	50	20	1.1	0.95	0.05	0.78
0	300	50	10	1.2	1	0.04	0.6
0	300	50	0	+0.1$\frac{\%}{s}$	+0.01$\frac{\%}{s}$	+0.007$\frac{\%}{s}$	+0.001$\frac{\%}{s}$
0	24	4	20	0.14	0.12	0.02	0.65
0	24	4	10	0.13	0.2	0.06	0.07
0	24	4	0	+0.02$\frac{\%}{s}$	+0.02$\frac{\%}{s}$	+0.03$\frac{\%}{s}$	+0.025$\frac{\%}{s}$

Table 1: Maximum error of method without noise

PSD	U[V]	f[Hz]	M[Nm]	$\delta_{R_{r1}}$[%]	$\delta_{R_{r2}}$[%]	$\delta_{R_{r3}}$[%]	$\delta_{R_{r4}}$[%]
1e-9	300	50	20	1.1	0.95	10	-
1e-9	300	50	10	1.2	0.9	10	-
1e-9	300	50	0	+0.25$\frac{\%}{s}$	+0.025$\frac{\%}{s}$	10	-
1e-9	24	4	20	0.15	0.13	10	-
1e-9	24	4	10	0.15	0.21	9	3
1e-9	24	4	0	+0.02$\frac{\%}{s}$	+0.02$\frac{\%}{s}$	11	14

Table 2: Maximum error of method with noise

Maximal methods errors are in Table 1 and 2. The methods are tested for different supply voltage and frequency, load and noise. For each of these combinations method error is shown. When the method is tested on nominal load and half nominal load, the error is indicated as a percentage but when the load is zero, tables show error change in percentage per second only when the signal is too noisy the error is indicated as a percentage.

One of the most important properties of described methods is their convergence speed. These convergence speeds are considerably different for these methods. Rotor resistance identification waveform is shown for $U_m = 150V, f = 25Hz, M = 18Nm$ and no noise in Figure2.

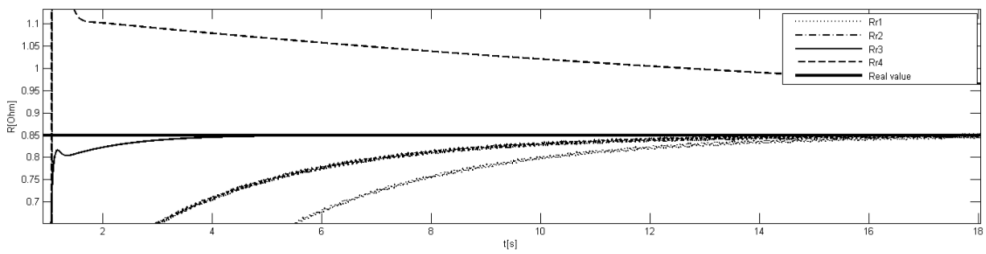

Figure 2: Speed of identification

3. CONCLUSION

As the figure 1 shows the method num.4 which works with derivatives of currents it is apparent that it is not suitable for rotor resistance identification. This method achieved very good results under ideal conditions but it is very slow and even unusable for noisy signals. On the other hand, method num.3 is very fast, but useless for noisy signal again, because it has an error up to 10%. The best results are achieved with methods (num.1, num. 2) which are based on working with rotor flux-linkage. Their accuracy does not change with the noise. Finally the best method for rotor resistance identification is the method num.2 because its accuracy does not change in various conditions and it is also faster than the method num.1 because it includes the currents.

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