Approach for the Rapid Characterization and Control of an Induction Machine

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***Abstract*—Induction machines are commonly used in traction applications due to their robustness and lower production costs when compared to the Permanent Magnet Synchronous Motor (PMSM). In such traction applications, the induction machines are mainly operated by field oriented control. This control technique requires an accurate knowledge of the machine's parameters. The accuracy of the parameters influence the precision of the calculated rotor flux and its angle and the decoupling of the machine's equation into the direct and quadrature coordinate system (dq-components). Furthermore, the parameters can be used to configure the controllers of the field-oriented control system and therefore have an influence on the dynamic behavior and stability of the control. In this paper we will discuss, analyze and compare different methods to calculate the machine's parameters in an automated and rapid procedure with minimal measuring expenditure. Moreover, a method to configure a control that reduces the overall Ohmic losses of the machine in every point of operation will be presented and analyzed.**

Keywords*—induction machine; parameter identification; analytic machine models; equivalent circuits, field-oriented control.

I. INTRODUCTION

An approach for the rapid characterization and control of an induction machine for traction applications is described and assessed in this paper. This approach is separated into two parts: The identification of the machine's parameters and the control of the machine using the identified parameters. The structure of the introduced rapid characterization and control approach for an induction machine is described in Fig. 1.

The identification procedure uses the measured stator current, stator voltage, and speed information during a low-voltage and no-load start-up with a constant stator voltage and constant synchronous frequency to calculate the parameters of the fundamental equivalent circuit diagram of the machine. The machine's data are measured with a dSPACE controller board ds1103 (Fig. 2) and the Yokogawa power analyzer WT1800. On a computer, the measured values are used to numerically calculate the equivalent circuit diagram parameters. For this purpose, three methods are introduced, discussed and analyzed. First, a Particle Swarm Optimization Method [1]; second, a R-X-Method [2], which relies on the measured overall machine reactance and resistance; and third, an evolutionary strategy [3,4].

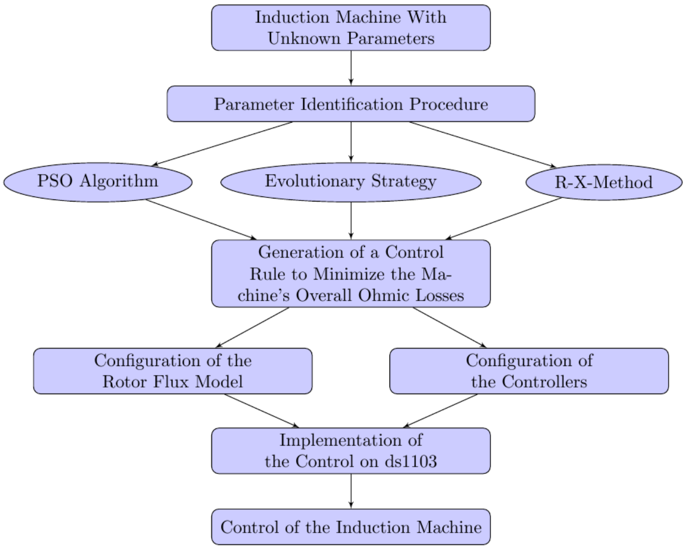

Fig. 1: Procedure for the rapid characterization and control of an induction machine with a given inverter.

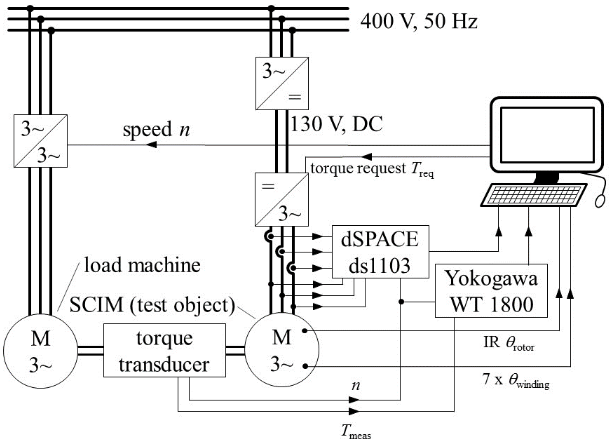

Fig. 2: Test-bench set-up for the automated parameter identification and control.

II. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization is a computational method analogous to biological swarm behavior [1]. A swarm of, in this case, parameter sets $\widehat{\Theta}^m$ is moved through a search area to get the best solution. The direction of movement relies on the quality of the individual set and the overall best set. The quality is determined by the mean square error of the measured and recalculated stator currents in dq-components (1). For the calculation of the currents the measured stator voltages and the individual parameter set is considered.

$$\mathbf{FIT}(\hat{\mathbf{\Theta}}^{\mathbf{m}}) = \frac{1}{N}\sum_{i=1}^{N}\left(||i_{1,q,i}^{m} - \hat{\mathbf{i}}_{1,q,i}^{m}||^2 - ||i_{1,d,i}^{m} - \hat{\mathbf{i}}_{1,d,i}^{m}||^2\right) \qquad (1)$$

Simulations show that this method can find the correct parameters under certain conditions. First, the parameters of the method must be set correctly, which is extremely difficult without any knowledge about the machine parameter range. Second, satisfactory results are only reached with good initial machine parameters. Without a good approximation of these initial values the method can get stuck in a local minimum. Overall, this method turns out to be unpractical for an automated and rapid parameter identification.

III. R-X-METHOD

The R-X-Method is based on the calculated overall machine resistance R and reactance X. With (2) and (3) and a minimization technique the equivalent circuit diagram parameters can be calculated from the measured resistance and reactance [2].

$$R = R_1 + \frac{X_{\mathrm{h}}^2 \frac{R_2'}{s}}{\left(\frac{R_2'}{s}\right)^2 + \left(X_{\mathrm{h}} + X_{2,\sigma}'\right)^2} \qquad (2)$$

$$X \approx X_{2,\sigma}' + X_{\mathrm{h}} - \frac{s^2 X_{\mathrm{h}}^2\left(X_{\mathrm{h}} + X_{2,\sigma}'\right)}{R_2'^{\,2} + s^2\left(X_{\mathrm{h}} + X_{2,\sigma}'\right)^2} \qquad (3)$$

The used minimization techniques considered are a gradient method and an evolutionary strategy. The gradient method turns out to be impractical due to the presence of ill-conditioned matrices or too few measurement values. The minimization with the evolutionary strategy produces satisfactory results under some conditions. First, the synchronous frequency must be constant. Second, because the method is not highly robust to noise, the measured values must have a low noise or be filtered.

IV. EVOLUTIONARY STRATEGY

The evolutionary strategy is a metaheuristic optimization algorithm based on the theory of evolution and related mechanisms such as mutation, selection, and inheritance. The use of the theory of evolution to solve technical problems was described by Rechenberg and Schwefel [3,4] in the 1990's. In this method, the mean squared error (1) is used as a quality characteristic or fitness function. In a (μ, λ)-strategy, the λ descendant parameter sets are compared due to their fitness (1). The best μ of these sets will be selected, will survive the current generation, and will pass into the next generation. The new parent parameter sets will undergo stochastic mutation and reproduction processes to generate new progenies. This procedure is convergent and will soon reach the optimal solution as shown in Fig. 3.

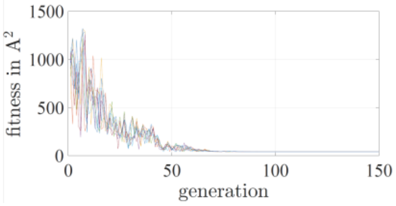

Fig. 3: Mean squared error (fitness) of an evolutionary strategy for the parameter identification (Simulation).

V. RESULTS

The evolutionary strategy is tested in simulations performed with Matlab/Simulink and on the machine test-bench. To validate the method, the deviation of the estimated parameters relative to the given ones are calculated for the rotor flux oriented circuit. The simulations are done with different sampling times t_s and different white noise amplitudes N_w. The noise amplitudes are added to the simulated stator voltage, stator current, and speed. The results demonstrate close agreement with the given parameters (Tab. 1). The simulated and with the estimated parameters calculated current also match closely (Fig. 4).

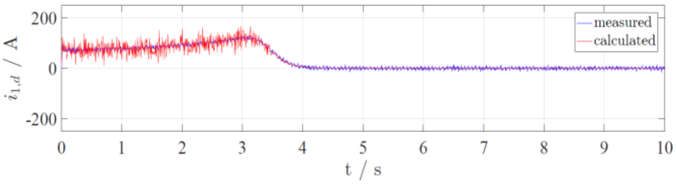

Fig. 4: Measured and with the identified parameter calculated stator currents in dq-components (Simulation).

VI. CONCLUSIONS

Three rapid approaches to identify the equivalent circuit diagram parameters of an induction machine are presented in this abstract. Their benefits and drawbacks are briefly outlined. The full paper will present a detailed description of these identification processes. The control rules and configuration of the controllers, which are both based on the identified parameters, will be given in the full paper.

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Tab. 1: Deviation of given and identified machine parameters in the rotor flux oriented equivalent circuit diagram under different noise and sampling times.

	#1	#2	#3	#4	#5	#6	#7	#8	#9
$\Delta\hat{R}_2^+$ in %	-0,24	0,02	3,13	0,13	0,47	3,59	1,23	1,78	4,83
$\Delta\hat{L}_{1,\sigma}^+$ in %	0,5	0,18	-0,44	0,72	0,27	-0,71	1,39	0,66	-1,07
$\Delta\hat{L}_{\mathrm{M}}^+$ in %	-0,28	-0,16	-12,5	-0,03	0,12	-11,86	0,71	0,91	-10,34

#1 t_s = 1 µs; N_w = ±3 V/A/rpm
#2 t_s = 6.25 ms; N_w = ±3 V/A/rpm
#3 t_s = 56 ms; N_w = ±3 V/A/rpm
#4 t_s = 1 µs; N_w = ±6 V/A/rpm
#5 t_s = 6.25 ms; N_w = ±6 V/A/rpm
#6 t_s = 56 ms; N_w = ±6 V/A/rpm
#7 t_s = 1 µs; N_w = ±10 V/A/rpm
#8 t_s = 6.25 ms; N_w = ±10 V/A/rpm
#9 t_s = 56 ms; N_w = ±10 V/A/rpm