REPRESENTATION OF AN INDUCTION MOTOR IN FIELD-ORIENTED STEERING ALGORITHM FOR INDUSTRIAL CONVERTER DRIVE SYSTEMS

ABSTRACT The article presents the results of research and the actual simulation of an induction motor operation cooperating with a vector control converter system, for different steering configurations and control algorithms. This particular control system uses different equivalent models of the motor. The advantages and drawbacks of the investigated drive system are shown and the results of measured parameters for different algorithms of steering, are compared with calculations.

Keywords: modelling of induction motor, field-oriented drive system
1. INTRODUCTION

At present the majority of all the engineering machines are equipped with drive systems containing induction motors. It happens so, due to the advantages of the induction motor itself, as well as thanks to the application of the most modern drive systems controlled with the help of signal processors and modern steering algorithms. These algorithms allow very precise regulation of the rotating speed and the driving moment. The application of the newest methods of steering, based on the field-oriented motor description (Fig. 1), enforces the need of knowing the parameters of the equivalent induction motor scheme. In the realization of steering algorithms, vector control captures its strategy on the dynamic states of the whole drive system, where mainly control signals and the signals from closed-loop can be improved by the choice of shorter times for computational cycles. These methods at present are standard in the sphere of electrical drives with speed regulation for induction motors and are characterized with better reaction of the steering object to the change of the set value and lower powers, starting torques and currents in comparison to scalar algorithms – Fig. 1.

The development of digital electronics and energy-electronics also enabled the implementation of the newest methods of parameters identification. It has given rise to the application of the new algorithms, which allowed also the engineers and researchers to define the required motor parameters, tuning controllers and the diagnostics of the whole steering system. The drives in practice, work in frequently changing electromechanical conditions, both from the side of load and supply. Higher technical requirements are put against these systems in the field of dynamics and efficiency. In the stage of designing it is therefore necessary to take into account the dynamic characteristics, a useful tool in that area is modeling study and simulation of the transient electromagnetic processes. Nowadays drives give us completely new possibilities of analysis of parameters and dynamic states of the investigated induction motors cooperating with the inverter drive system: $U/f$ (scalar), VC (vector control) and DTC (direct torque control), [4], [6].
Fig. 1. Comparison of starting curves of induction motor for different steering algorithms, [2], [3]
2. MOTOR MODEL AND IDENTIFICATION OF PARAMETERS

The induction motor itself is a nonlinear, multidimensional object with couplings of controlling signals with internal controlled signals occurring inside, such as coupled fluxes or electromagnetic torque. The difficulties in controlling such an object could be overcome with the use of spatial vector theory, in a properly chosen coordinate system, for describing the dynamics of the motor. The motor model used allows the researchers to execute introductory and in progress calculations carried out for the actual conditions, [2], [5].

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\begin{align*}
U_r &= R_r I_r + \frac{d\Psi_r}{dt} + j\Psi_s \Omega_g \\
0 &= R_s I_s + \frac{d\Psi_s}{dt} + j\Psi_r (\Omega_g - \Omega) \\
\Psi_s &= L_s I_s + L_m I_r \\
\Psi_r &= L_r I_r + L_m I_s \\
M &= \frac{3}{2} \frac{L_m}{L_r} \text{Im}(\Psi^* I_s) - M_o
\end{align*}
\]

(1)

Here, the applied motor model is the key to use the implemented technology of the field-oriented steering. The mathematical model of the induction motor, is lead out from the classical equations with the regard of universal, practical simplifications. The model is described by parameters expressed in the system of coordinates connected with the stator, the equivalent schema is presented in Fig. 2.

The investigated drive system uses modern methods of identification of the motor parameters and control software tools, all of these is done automatically. The parameters of an induction motor can be obtained in the starting "identification run" process that is used to identify the classical equivalent scheme of an induction motor – Fig. 2. On the basis of this "run" we get a lot of precious information to describe the drive: parameters of the equivalent scheme and the settings of the controllers. This “run” consists of several tests, depending on the selected kind of control (U/f or vector) and the feedback used: measurement of parameters in standstill state, measurement of parameters in no-load state and optimization of controllers (e.g. speed controller, etc.).
Depending on the utilization of the examined drive system there is access to the parameters adjusting the dynamics of the supplied induction motor (these parameters are shown on the functional block diagrams of the inverter, [2], [3]).

![Diagram of an induction motor](image)

**Fig. 2. Equivalent schema of induction motor implemented in the examined SIEMENS drive system SIMOVERT MASTERDRIVES VC, [3]**

Where: $R_s$ – resistance of stator windings, $R'_r$ – resistance of rotor windings recalculated to the stator side, $X_{so}$ – leakage reactance of stator, $X_s$ – own reactance of stator windings, $X_{ro}$ – leakage reactance of rotor recalculated to the stator side, $X_r$ – own reactance of rotor windings recalculated to the stator side, $X_m$ – reactance of magnetization, $s$ – slip, $I_s$ – phase current of stator, $I'_r$ – phase current of rotor recalculated to the stator side, $I_m$ – current of magnetization, $n_1$ – synchronous speed, $n$ – rotor speed, $f_1$ – frequency of stator EMF, $f_2$ – frequency of rotor EMF, $p$ – pair of poles, $U_{ph}$, $E_{ph}$ – phase voltage and EMF

In the described drive system, the identified parameters are based on the results of measurements executed in the system working only for the need of test. Identification takes place on the ground of registered curves of magnitude, which are the answer to the given input. The drive system before starting its duty has to be exactly recognized and parameterized. The properly, well-chosen by the producer procedure of parameterization serves to achieve this target. Right after inputting the quantities from the rating plate of the motor the „automation parameterization“ is executed, which calculates the basic parameters for the steering algorithms in open loop and closed loop regulation and steering system, taking into account, among other, the pulse frequency. Parameters of the longitudinal branch of the equivalent schema are calculated on the ground of results of measurements executed at standstill (motionless rotor) – Fig. 3. This dictates requirements for the exploitation, since it is really necessary that rotor of motor stays motionless during the tests. Parameters of the transverse branch of the equivalent schema are identified instead during the no-load tests of the motor, in the state without load (idle-run measurement).
3. STEERING ALGORITHMS OF THE DRIVE AND ITS MOTOR MODELS

The SIMOVERT MASTERDRIVES (made by SIEMENS) machine is a frequency converter for very precise drives with controlled speed and torque. It is a module-based drive, which can cooperate with a wide range of motors and other devices, thanks to its abilities to parameterize. The regulation process itself and connected with it the processing of particular signals is carried out digitally by the means of the microprocessor system (DSP). On the other hand, all the other available components of the signal route, according to which the steering takes place, are presented in the drive documentation in the form of

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**Fig. 3.** The curves obtained during identification of parameters in “stand still” state:  

a) motor 1.5 kW, b) motor 55 kW
many pages illustrating block diagrams of the particular parts completing certain tasks in the whole process of steering – Fig. 4.

Fig. 4. Function diagram of sensorless steering algorithm and equivalent motor models, [3]

For the benefit of the users implementing the drive, a new graphic system has been used of representing the very sophisticated steering structure. This is to accelerate and simplify the operation of this device. This facility has originated from the use of the so-called BICO technology (Fig. 4), which until now has been the most optimal representation of the logical connection/linking of signals. The documentation [3] contains the normalized numeration of the input / output signals (the so-called connectors) as well as the parameters of the given block. Thanks to this data, there exists a possibility of modeling the way, in which the steering is accomplished to meet all the requirements of the user. This is possible after linking particular block connectors with one another, or after setting all the parameters of these particular blocks. The tool software DriveMonitor, installed on the PC, is usually used to configure and set the parameters of the drive and enable the communication with the drives by
means of the typical serial interface. There is also a possibility of choosing the methods of examination or archivization of the time curves obtained from the convector (ex: output current, motor torque, steering error signal, speed of the motor). The selected kind of control is applied in every case where the quality of control influences the quality of the technological process. The field oriented control method relies on determining the components of the motor’s stator current: component $I_{sd}$ (responsible for flux generation) and component $I_{sq}$ (responsible for generating torque). Additionally it is necessary to measure or evaluate the angular position of the coupled flux vector in the machine, where the information is required about the status variables and inaccessible by measurement (or hardly accessible) information such as, i.e. the flux in the induction motor’s rotor. Therefore methods were developed, in relation to the algorithms reproducing the inaccessible by measurement status variables, which make it possible to replace an actual measurement of a physical quantity with an indirect method based on easily measured variables. Every switching of the power section is directly dependent on the electromagnetic condition of the motor and is determined from the calculations of the stator flux and motor torque. In Fig. 5a) the zoom of function diagram is presented, executed in BICO technology for realization of steering algorithms in the range of operation with incorporation of equivalent models. The current model acts to 10 % of the set value (measurement of speed necessary) or the arrangement of given current (the sensorless arrangement), however above this value switches in the EMF model (does not require the measurement of rotary speed). In Fig. b) area B is marked, in which the process of switching both equivalent models occurs.

The phenomena of electromagnetic process occurring during starting the drives with vector-control steering is the most crucial element of functioning of many industrial processes. The time duration of the process of establishing the electromagnetic state depends on the rated power of applied motor. For example for motor of rated power $P_N = 1.5$ kW this process is over in about total 0.3 s, and for a motor of rated power $P_N = 100$ kW it lasts almost about 1.8 s (this time is calculated from the moment the start signal for the application "the start take-off" was set to the time of detecting speed $n > 0$) – region A on Fig. 5b). Some relatively large delays occur in the starting process after applying “the start take-off” signal, what for example, in case of the cranes application can make up large technical problem, [1], [2].
Fig. 5. Equivalent schema of induction motor:
  a) and starting curves b) for selected sensorless steering algorithm
4. THE INFLUENCE OF EQUIVALENT PARAMETERS OF THE MODEL ON THE PERFORMANCE OF THE STEERING ALGORITHM

In case of vector control, the element of large meaning is the accuracy of determining the value of winding stator resistance. When the actual value of resistance is smaller than the one introduced to the model, the control system is adapting the parameters of the initial stage of starting to the given conditions, suitably enlarges the tension in order to compensate the voltage drop on the resistance of windings. In consequence, the speed of the rotor in the time, when it begins its calculation on basis of phase currents, shows larger than the process of steering needs at this point. The effect of this is the negative impulse, appearance of component Isq and in consequence negative driving torque. The situation, in which the resistance in the model is understated generate the opposite result, but in courses of speed less unfavorable. Therefore in case of impulse change of load torque for motor SzJe -24a, the fluctuations of speed are significantly restricted and establish in comparatively short time.

![Graph showing the influence of equivalent parameters of the model on the performance of the steering algorithm.](image-url)

**Fig. 6.** Starting curves of 1.5 kW induction motor:
a),c) starting process in vector control algorithm with the parameters calculated in classical method; b),d) starting process in vector control algorithm with the parameters from identification, [2]
The experiment was executed depending on introducing to the memory of the converter two sets of parameters to describe the equivalent model of the motor in the algorithm of control. These were the following parameters: calculated with the classic method procedures – Fig. 6 a) i c) and obtained from identification – Fig. 6 b) i d). In Fig. 6, for example, are shown the curves acquired during starting the converter with motor SzJe-24a, with parameters counted with the classic method as well as measured during the starting procedure with parameters got from identification. Essential differences come out in the values and time of establishing of the magnetic flux. Differences occur also in the transient processes in the motor during switching current and voltage models, this means the utilization of the sensorless vector control algorithm. In settled state however, the acquired curves are very similar to each other. If the change of schema parameters has the essential influence on dynamics (what we notice in shape and time, for example, of creating the current component of stator $I_{sq}$ - in consequence the torque of the motor) then it does not cause essential changes in operation of the speed controller.

5. CONCLUSIONS

The considerations concerning the work of a drive arrangement with vector control steering algorithm give rise to the following conclusion: the vector control is preferable due to the improved control characteristics e.g. accelerating along the current limit and also due to the improved immunity to stalling. Usually the vector control is also possible, even when several motors are connected to a single drive converter, as normally, the motors are similarly loaded. On the basis of investigations of the model with constant parameters of induction motor in dynamic states we can see, that its behavior is similar to the response of a real motor despite acceptance in modeling such simplifications, as the omission of hysteresis, acceptance of permanent saturation of magnetic circuit as well as omission of current displacement in rotor windings for the motor Sg-90L4 (differences in relation to measurements of initial value of dynamic torque amount to about 28 % - difference in time of duration of the process is near to 0,27 s). It is good to underline that the area of incompatibility of initial torque amplitudes from the point of view of drive performance has no larger meaning because it is outside the area of limitations specified by the settings of functional parameters, and also it results from different – subordinated parameters of the drive steering, forming the electromagnetic phenomena in
motor. These effects are not considered in case of starting a motor supplied from network with full voltage. The proportion of actual value of the windings resistance of the motor and the value of resistance introduced to the equivalent model has large influence on the course of the starting process. Introduction, to model of the motor, of new settings of the parameters of leakage reactance $X_k$ ($X_k = X_s + X_{r'}$), magnetizing reactance $X_m$ and magnetizing current $I_m$, influences the change of calculated value of the torque and change of the point of work of the motor. The conception of EMF model does not require the measurement of rotary speed of the motor shaft. This model is also less "sensitive" to the change of temperature, particularly to the change of rotor resistance under changing temperature of the motor. The performance of the EMF model strongly depends however on changes of the stator resistance of motor in the range of low frequencies. Utilization of this model in this case of arrangement with closed-loop speed control ensures the more precise identification of parameters of the machine and the possibility of generating maximum driving torque already practically at zero rotary speed (for ex: lifts application).

\section*{LITERATURE}


PRZEMYSŁOWYCH PRZETWORNIKOWYCH SYSTEMÓW NAPĘDOWYCH

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STRESZCZENIE Praca omawia wyniki badań i symulację pracy silnika indukcyjnego współpracującego z przetwornikowym systemem sterowania wektorowego dla różnych konfiguracji sterowania i algorytmów sterowania. Ten układ sterowania stosuje różne równoważne modele silnika. Zalety i wady badanego układu napędowego zostały przedstawione i wyniki mierzonych parametrów dla różnych algorytmów sterowania porównano z obliczeniami.