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Gain Scheduling Adaptive System for the Extension of Speed Domain of the FOC Drives with Asynchronous Motors

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Abstract

Electrical drives with asynchronous motors controlled by field orientation are the most widely used due to advantages in terms of dynamic behavior and of possibility to adjust speed in wide range.The drive can be considered as a nonlinear process, so that the parameters of the mathematical model obtained by linearization of its, change from an operating point to another. This requires adding an extra adaptation loop in order to update the speed PI controller parameters.

The paper presents the achievement of an adaptive system, developed by so-called gain scheduling strategy, which in adjustment functions of speed controller parameters used as input variable motor speed even. Gain scheduling functions are obtained for four different intervals covering the full range of speeds slower than the nominal. Matlab Simulink simulations show the validity of the designed system.

Key words: *speed control, gain scheduling, adaptive system, field oriented control, induction motor*

Introduction

Depending on the technological process in which they function and on the power of the motor, the automatic electric drives must accomplish a large variety of demands as follows:

- the continuous control of the speed and of the torque;
- the reduction to the minimum of the errors and diminishing the transitory process, when the controlling variables and the perturbing ones modify;
- the stability of the system;
- the maximum efficiency of the energy conversion.

These demands can be satisfied with the help of the automatic control systems of the asynchronous motors, where the electric motor is supplied with the help of the frequency converters.

Field oriented control technique (FOC), often found in control of modern drives with asynchronous motors, takes its name from the fact that it used the mathematical model of the induction motor [2], developed in a reference frame rotating synchronously and with the same phase with one of the three space phasors of the fluxes: from stator, from rotor or from air gap.

The drive improved here by an adaptive control type *gain scheduling* is controlled by the rotor flux orientation after, which is preferable to other FOC alternatives in practice, because it completely separates the fllux and torque control, the motor mechanical characteristics become linear and torque response is fastest [4, 7].

The Simulation of the Scheme of Variable Speed Electric Drive

Matlab Simulink simulation of induction motor drive system based on FOC technique, with rotor flux orientation after, is described in [6], and here, in figure 1, is presented directly the scheme of the simulated electric drive. Practical implementation of such a scheme of variable speed drive, in which the speed controller is a PI regulator, is relatively simple, but can only provide a quality control for a reduced area of speeds. For the enlargement of the speed domain it is necessary to adjust the k_p and k_i coefficients of the mentioned regulator by an extra adaptation loop, so that they become suitable for different operating points of the drive and their corresponding mathematical models.

Tuning of PI controller parameters for a specified operating point of the drive, corresponding to a certain speed, was achieved from us by identification of the mathematical model of the drive system (without the speed controller) and then by obtaining the optimal parameters of a PI regulator that satisfy the performance requirements imposed on system responses at step variation of reference speed [3]. Detailed presentation of these operations are given in [5], and here is shown the processing of the results obtained for different speeds of the motor in order to construct the adaptation subsystem called *Gain scheduling*, visible as a block in figure 1.

Gain Scheduling Adaptive Control Strategy

Gain scheduling strategy is one of the methods used to design nonlinear control systems, applied successfully to control various processes. The block diagram of an adaptive control system of this type is shown in figure 2. This strategy uses a *divide and conquer* approach by which a nonlinear system is replaced by several linear systems, equivalent to certain areas of operation with the original, but which are much easier to control. Adaptive control by *gain scheduling* is done through relationships established between the controller parameters and the parameters of the process, that can be implemented by functions or tables [8]. The idea of the method is to find auxiliary measurable variables (which can even be outputs which are used as reaction variables), that can cause changes in the dynamic of the process. In the case of the adaptive control system for adjusting the speed of the electrical drive which is simulated here, was used as variable even the motor speed.

Developing an adaptive control system with *gain scheduling* has four distinct stages, which were followed in this case too:

- identifying the linear models of the process for sets of operating conditions corresponding to various operating points chosen;
- designing linear controller for each model [1];
- developing a kind of variation (a schedule) for the controller parameters;
- implementing the controller parameters on the original nonlinear process.

The results of the first two stages are detailed in [5] and the last two below.

There are several options for scheduling the controller parameters:

- switching parameters as discrete values;
- interpolation of controller parameters using the calculated values for several operating points;
- varying the controller parameters as functions of auxiliary variables and output quantities- *this is the option used in the schedule for studied electric drive.*

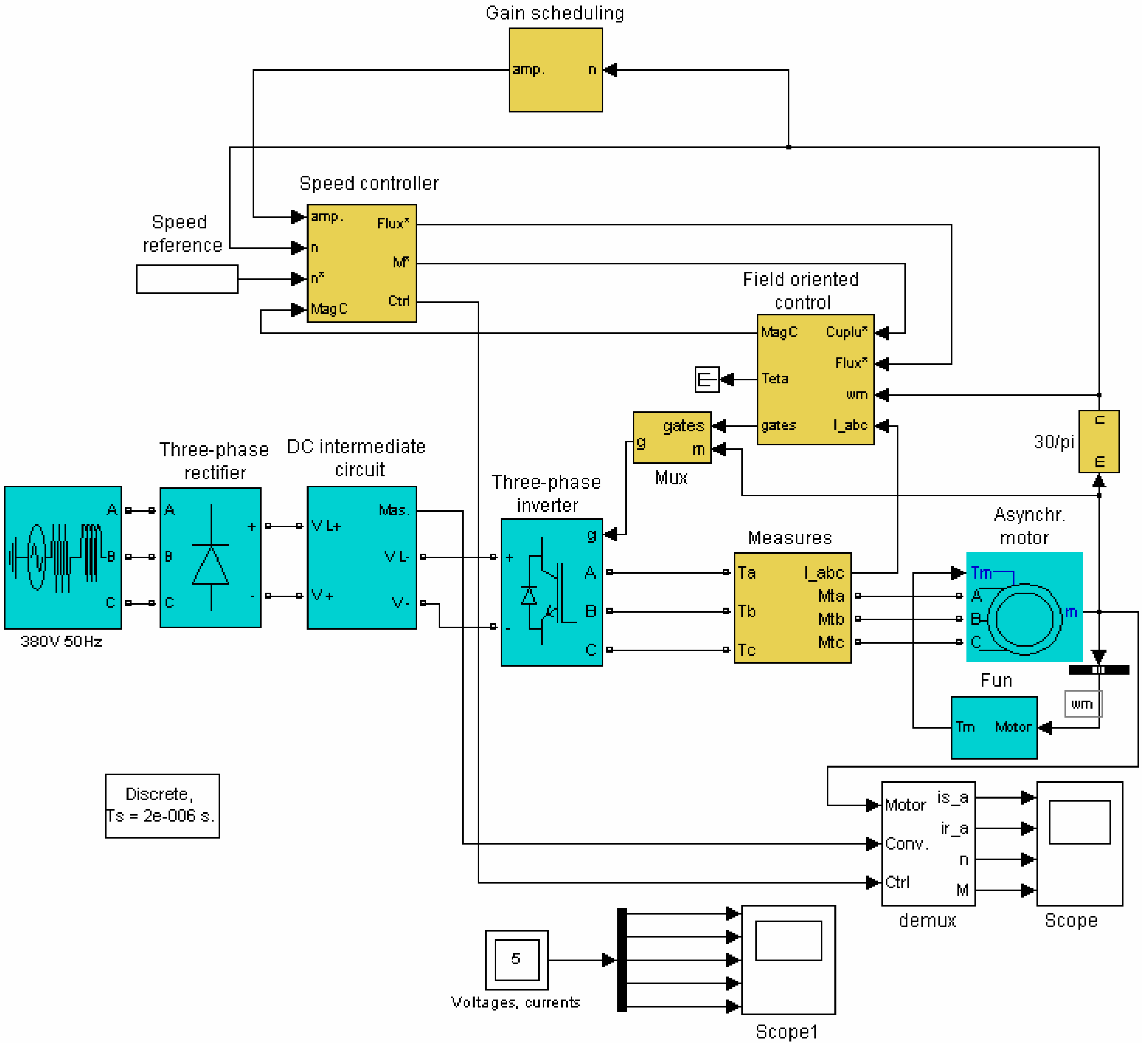


Fig. 1. The Simulink scheme of the FOC electric drive of the asynchronous motor

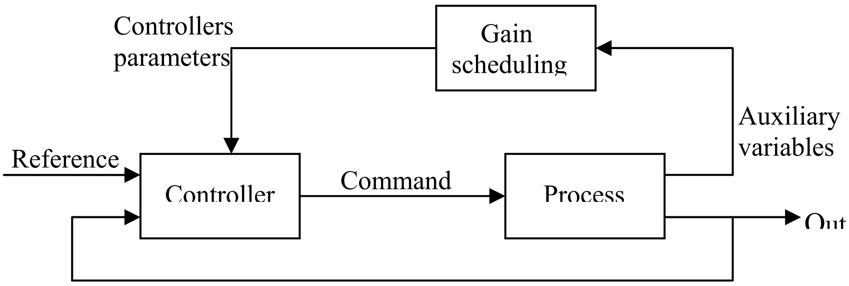


Fig. 2. The block diagram of an adaptive control system with *gain scheduling*

Development and Simulation of *Gain Scheduling* Subsystem

Were calculated the optimal coefficients of the PI speed regulator for various motor speeds distributed across the area slower than the nominal. The k_p coefficient maintained constant its value, k_p=0.787, and k_i acquired values from Table 1. After knowledge of these coefficients, the functions which adjust k_i depending on motor speed were calculated, so that they take the known values for analyzed operating points.

Table 1. The values of k_i coefficient depending on the motor speed

n(rpm)	100	200	400	600	800	1000	1200	1400	1500
k_i	1.416	2.237	3.34	4.632	6.115	7.644	9.273	10.98	11.615

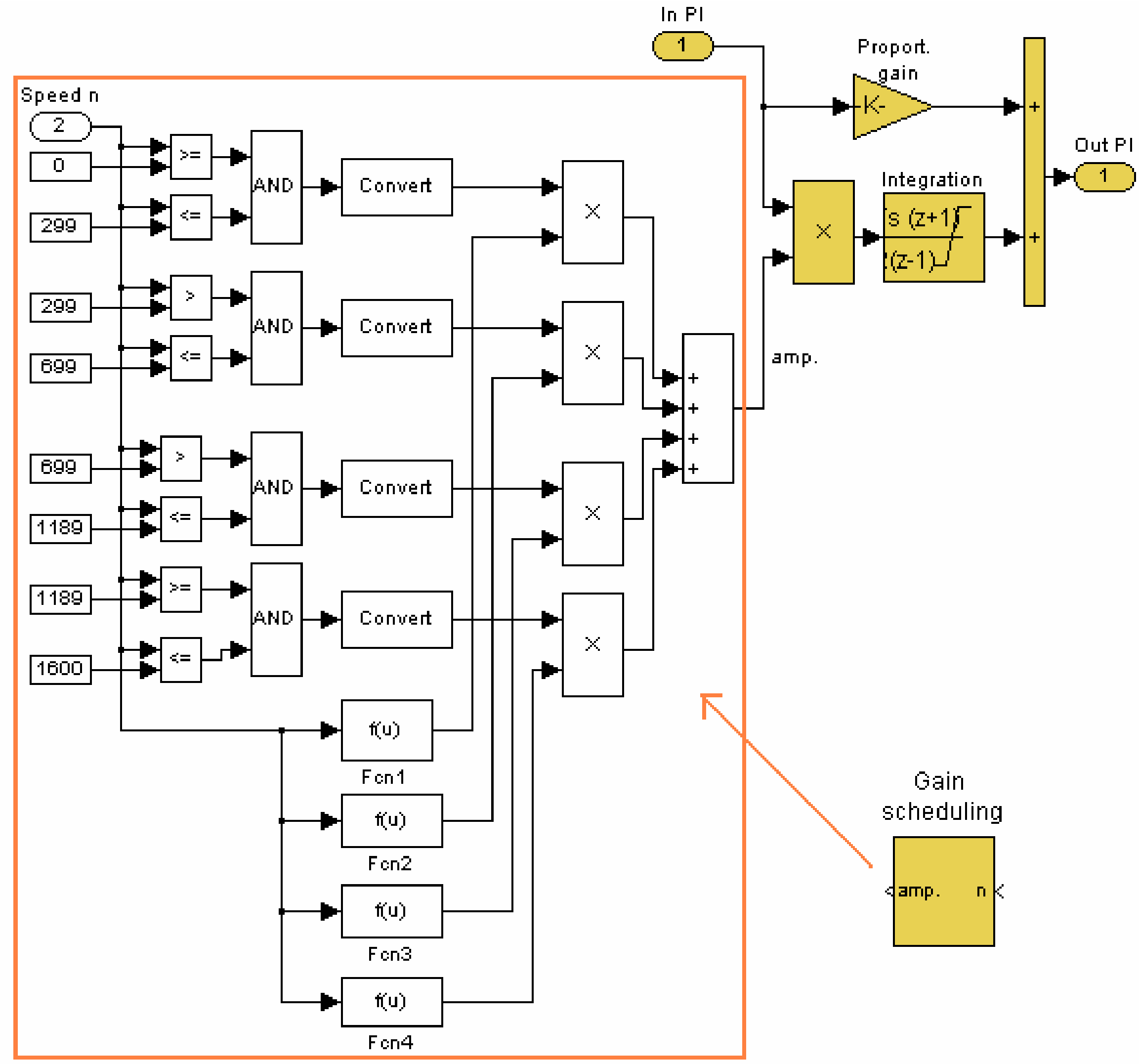


Fig. 3. The Simulink scheme of the *Gain scheduling* subsystem

It was necessary to develop four such functions, each covering a particular area of speed. In calculus of the coefficients of the four functions it was considered that, at passing from one area to another, k_i must have the same value. It was not necessary to adjustment the k_p coefficient, because it remains constant through the entire area of speeds slower than the nominal value. The four adjusting functions for the integration coefficient are:

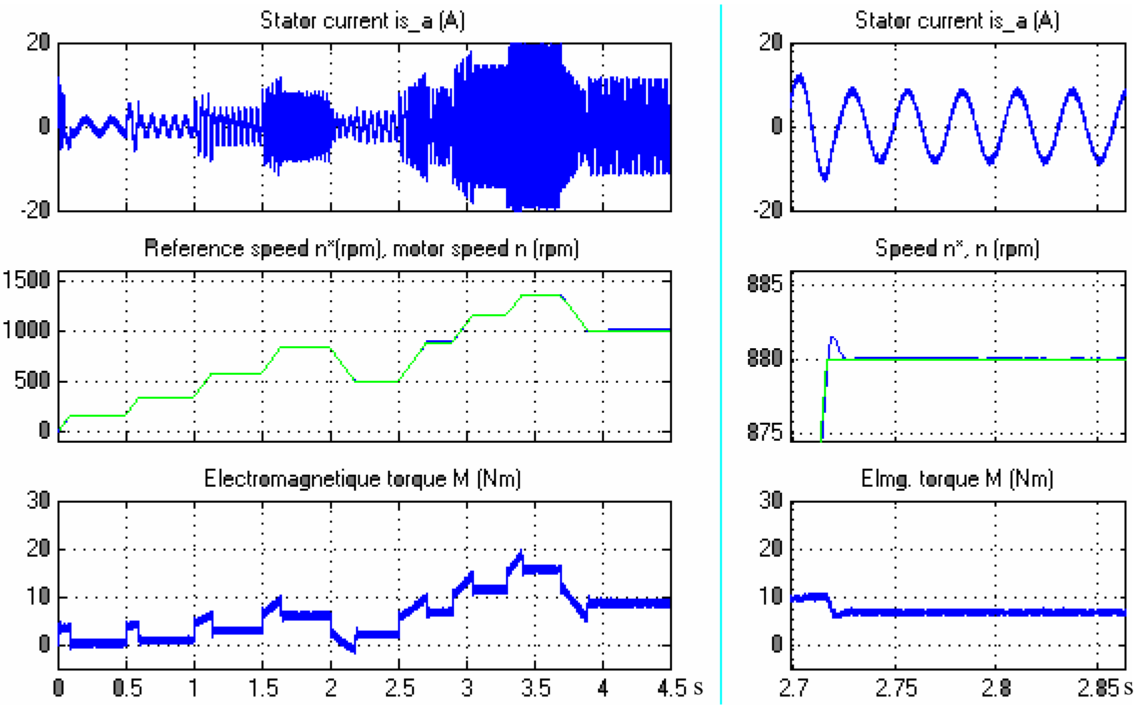
- 0 - 299 rpm: $k_i(n) = f_1(n) = 1.0424 \cdot 1.85^{\,n/200}$
- 299 - 699 rpm: $k_i(n) = f_2(n) = 2.6149 \cdot 1.45^{(n\text{-}299)/200}$
- 699 - 1189 rpm: $k_i(n) = f_3(n) = 5.4978 \cdot 1.235^{(n\text{-}699)/200}$ (1)

- 1189 - 1500 rpm: $k_i(n) = f_4(n) = 9.2209 \cdot 1.16^{(n-1189)/200}$.

In figure 3 we can see the Simulink scheme of the *Gain scheduling* block, which aims to adjust the controller parameters. One can see how the block's output interferes with the PI regulator.

The Simulation Results

It was made simulations for an asynchronous motor with squirrel-cage rotor, with following parameters: $P_n = 3$ kW, $U_n = 380$ V, $f_n = 50$ Hz, $p = 2$, $n_s = 1500$ rpm, $\cos\varphi = 0.81$. *The load torque* was introduced through relation $M_s = k\Omega^2$ (characteristic for a lot of drives), where $k = 7.74 \cdot 10^{-4}$, being calculated to obtain the nominal torque at nominal speed.



a. b.

Fig. 4. The variation of the main quantities at the drive simulation **a.** ensemble **b.** detail

Time of simulation was 4.5 s and *speed reference* was prescribed to $n^* = [150 \;\; 330 \;\; 570 \;\; 830 \;\; 490 \;\; 880 \;\; 1150 \;\; 1350 \;\; 1000]$ rpm at the moments $t = [0 \;\; 0.5 \;\; 1 \;\; 1.5 \;\; 2 \;\; 2.5 \;\; 2.9 \;\; 3.3 \;\; 3.7]$ s. It was used an acceleration/deceleration factor of 1800 rpm/s. Figure 4 presents the way of variation of the main quantities of drive and figure 5 some of corresponding transitory regimes.

One can observe that:

- *the motor speed n follows* in an accurate way *the reference speed* n^* on the stationary portions but also in the ramp zones. The fluctuations of the *n speed* until the stabilization on a new value are limited in an *oscillating damped regime* with one oscillation only, that lasts almost 0.01 s. Overshoot is extremely low, regardless of the speed step;
- at switch to a new steady state, caused by increasing or decreasing of the speed, *the electromagnetic torque M* takes also a damped oscillating regime with a single oscillation, as fast as the transitory regime of the speed.

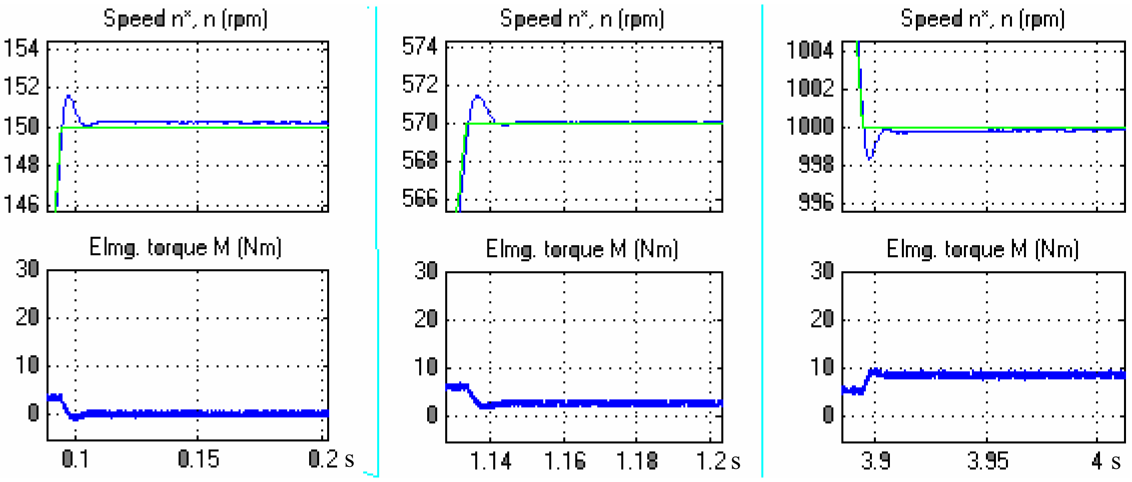


Fig. 5. Transitory regimes at different speeds

Conclusions

Extension of speed domain of the FOC electric drives with asynchronous motors could be achieved by adding an extra adaptation loop based on *gain scheduling* strategy. So, the speed controller parameters are adjusted to optimal values, through functions depending on motor speed. Simulations showed getting a quality control for speeds slower than the nominal, with very good transitory responses in speed and torque.

In this way, the advantages of FOC control technique: the decoupling of the control-circuit after *d-q* axes and linearization of the mechanical characteristics, combine successfully with the advantage of adaptive command: a quality control on an extended speed domain. These make the method advisable in precisely and wide speed range drives as there are: the driving of the tool machines with numerical command, the industrial robot driving, the synchronized position driving and others.

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Sistem adaptiv gain-scheduling pentru extinderea domeniului de turație al acționărilor cu motoare asincrone comandate FOC

Rezumat

Acționările electrice cu motoare asincrone comandate prin orientare după câmp sunt dintre cele mai utilizate datorită avantajelor în privința comportamentului dinamic şi posibilității reglării turației în domeniu larg. Sistemul de acționare poate fi asimilat cu un proces neliniar, astfel că parametrii modelului matematic obținut prin liniarizare locală a acestuia se modifică de la un punct de funcționare la altul. Aceasta impune construirea unei bucle suplimentare de adaptare care să actualizeze parametrii regulatorului PI de turație.

Articolul prezintă realizarea unui sistem adaptiv prin aşa numita strategie gain scheduling, care în funcțiile de ajustare a parametrilor regulatorului de turație foloseşte ca variabilă de intrare chiar turația motorului. Se obțin funcții gain scheduling pentru patru intervale distincte ce acoperă întreaga gamă a turațiilor subnominale. Simulările în Matlab Simulink evidențiază valabilitatea sistemului proiectat.