MATHEMATICAL MODEL-BASED SMART CONTROL SYSTEMS FOR ELECTRIC DRIVES

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Abstract

This article focuses on enhancing the efficiency of regulating combined systems of asynchronous motors in multi-link electric drives with power ratings ranging from 0.25 to 400 kW. A key approach to achieving this is the development of an intelligent control system, which is optimally suited for asynchronous motors operating at voltages up to 440 V. This advanced control system is adaptable for use in multi-link motor applications within manufacturing plants, including integration into existing machine tools and tracking systems. The significant improvement in operational performance for interconnected multi-link electric drives can be realized through the implementation of dynamic models and the synthesis of control laws that account for the complex interactions and movements within these systems. Furthermore, optimizing the intelligent control system in such multi-link drives not only enhances system responsiveness but also contributes to a substantial reduction in energy consumption—up to 12%. This makes the proposed approach highly beneficial for energy-efficient industrial operations.

Keywords: Asynchronous motor, integrated system, multi-communication motor, adaptive control, associative memory, coordinates DQ control unit.

Introduction

The increasing demand for high-performance, energy-efficient electric drives in industrial and manufacturing processes has driven the need for more advanced control systems. Traditional control methods often fall short in optimizing the performance of multi-link electric drives, especially when faced with complex dynamic interactions between interconnected components. To address these challenges, intelligent control systems, grounded in robust mathematical models, have emerged as a promising solution [1].

Electric drives, particularly asynchronous motors, are widely used across industries due to their reliability and flexibility. However, their efficient operation, especially in multi-link systems with power ratings from 0.25 to 400 kW, requires precise regulation. The integration of smart control systems, utilizing mathematical models, provides a method for enhancing the performance of such motors. These systems can adapt to changing load conditions, improve response times, and reduce wear on mechanical components, all while maintaining optimal energy use [2].

Mathematical models allow for the simulation and analysis of complex drive systems, enabling control algorithms to anticipate and react to variations in system behavior. By using these models, intelligent control systems can dynamically adjust to multiple variables such as voltage, current, and torque, offering an efficient means of controlling asynchronous motors operating at voltages up to 440 V . This approach is particularly beneficial in manufacturing plants, where it supports the use of multi-link motors in existing machine tools, automation processes, and tracking systems [3].

Moreover, the adoption of these model-based smart control systems contributes to significant improvements in energy efficiency. By synthesizing control laws that account for the dynamic nature of multi-link systems, energy consumption can be reduced by up to 12%. This reduction not only lowers operational costs but also supports sustainability efforts in energy-intensive industries.

It is known that [1-3] control should be addressed when the complexity of the controlled process reaches a level at which it is necessary to take into account the influence of uncertainty on the conditions of the system functioning. According to the definition of control processes, adaptive control systems are divided into self-regulating systems, adaptive systems in special phase cases, and learning systems.

In the control of electric drives available at manufacturing enterprises, the intelligent control system is distinguished by the following indicators and features:

- improvement of indicators of speed control in the frequency range;
- reduction of energy consumption of electric drives;

Improving the regulation of variable parameters of electric drives by combining 3 or more motors;

- significantly expanded interface functions and increased efficiency;

- create an opportunity to analyse the basic principles of building intelligent control systems, methods and problems of implementing the technology of associative memory;

You can use the Matlab Simulink program to improve an existing control system. An important stage in the organization of a mathematical model is the consideration of variable dynamic equations in the electric drive.

Determine the frequency value generated by the oscillation using the following expression.

$$\omega_P = \sqrt{\frac{c(J_1+J_2+J_3)}{J_1J_2J_3} - \left(\frac{b(J_1+J_2+J_3)}{3J_1J_2J_3}\right)^2} \qquad (1.1)$$

In this case a and b are variable coefficients, $J_1J_2J_3$ moments of inertia of the combined electric motor.

Results

The variable part of the mathematical model of a single-engine system is as follows (Fig. 1.2).

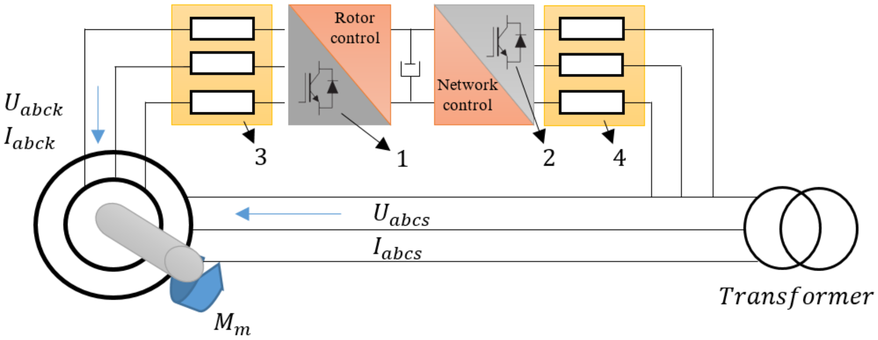

Fig.1. General power and double acting AC motor control.
1- Rotor-side VSC, 2- Grid-side VSC, 3- Rotor filter, 4- Grid filter

Using mathematical expressions 1.1. according to the figure (Fig. 1.2), you can build the following model.

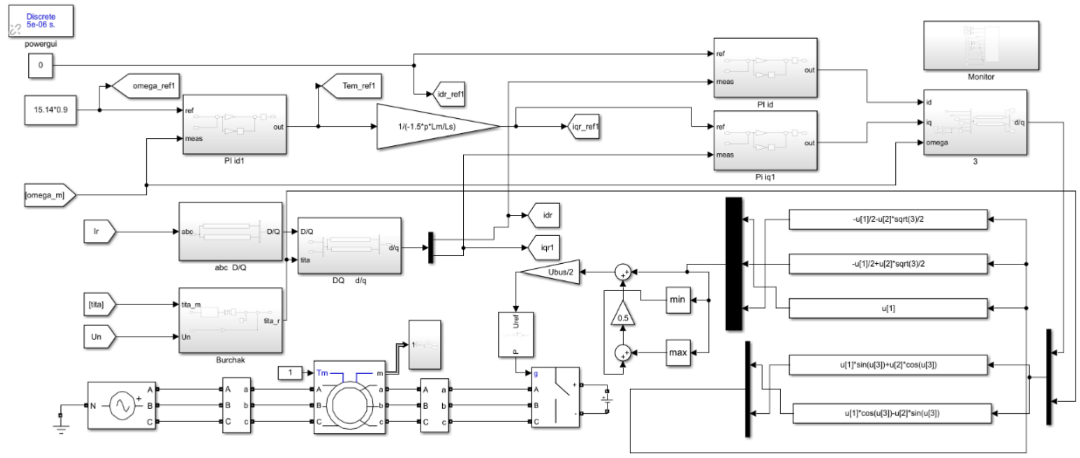

Fig. 2. Matlab Simulink software is an AC motor control model and control box

$$v_s = R_s i_s + \frac{d\psi_s}{dt} \Rightarrow \begin{cases} v_{as} = R_s i_{as} + \dfrac{d\psi_{as}}{dt} \\ v_{Bs} = R_s i_{Bs} + \dfrac{d\psi_{Bs}}{dt} \end{cases} \tag{1.2}$$

From Equation (1.2), for example, if the voltage drop across the stator resistor is small, the stator current will be constant because the stator is connected directly to the mains at a constant AC voltage; hence d ‖→ ψ$^{\to}$ equals zero. The last two equations show that it is possible to control the rotor currents dq using a regulator for each current component, as shown in fig. 1.3.

By relating DQ to mains voltage, we can construct a mathematical expression given the following equation.

$$\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\dfrac{1}{2} & \dfrac{\sqrt{3}}{2} \\ -\dfrac{1}{2} & -\dfrac{\sqrt{3}}{2} \end{bmatrix} \tag{1.3}$$

To help the controller in the program, the inverse conditions of equation (1.3) can be included in the output signal of each controller. The stator current and ω_p must be calculated according to the conditions of interaction, but this is simple and does not lead to an increase in additional difficulties. The check must be made in dq coordinates, but then the rotor voltages and currents must be converted to DQ coordinates. First, you can get the angle of the phase vector of the stator voltage, then subtract 90∘ from this calculated angle and thus get θs. In the control block diagram shown in fig. 1.3, the current rings operate with the rotor currents corresponding to the stator side and the conversion to the values shown on the rotor is done during the current measurement phase and before the generation of pulses. Using the above model (Fig. 1.3,1.4,1.5), the following characteristics can be obtained.

This, in turn, shows that the control systems are chosen correctly and the expression of the variable parameters in them has changed.

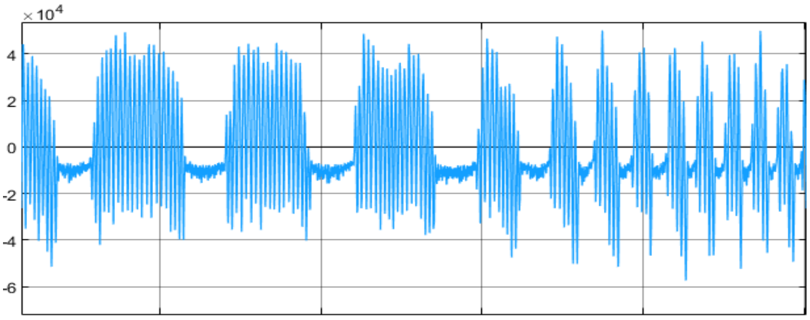

Fig. 3. Changing the current Idr through the control unit

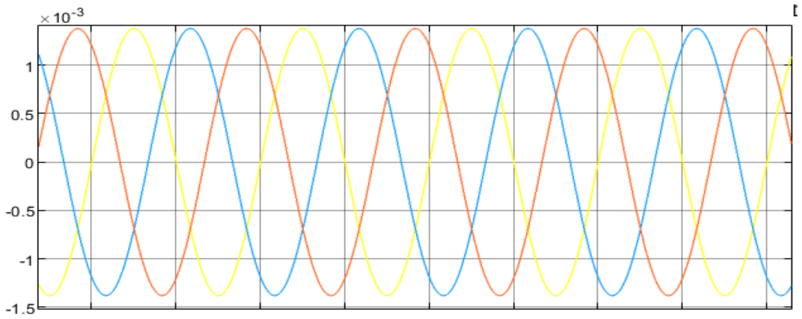

Fig. 4. Un voltage change via control

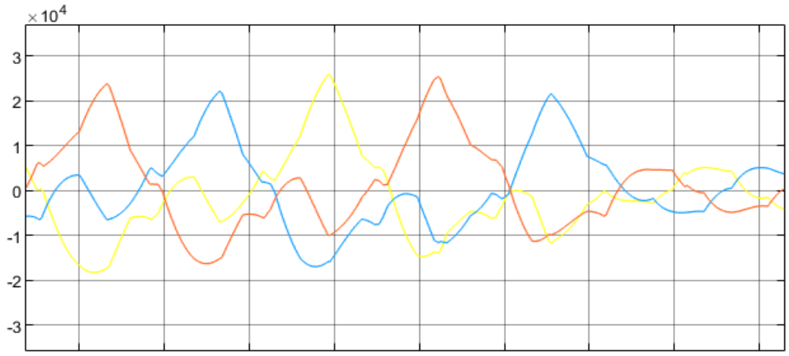

Fig. 5. Changing the current through the control unit

The main feature of the control of a multi-link motor drive system is the interaction of mobility levels at high speeds of the working body [1-5].
When building intelligent control systems, an increase in the speed of generating control signals is achieved through the use and processing of knowledge in the process of generating control signals [10]. By using the knowledge embedded in the control system, it will be possible to significantly increase the speed of calculating the control law, since the results necessary for this are not calculated in the control process, but are taken from the knowledge base. For example, in contrast to adaptive control systems, where the parameters of a controller with a certain motion trajectory must be calculated during operation, in intelligent systems, a set of controller settings can be included in the knowledge base and this knowledge can be used.

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