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# SOFTWARE FOR INDUCTION MOTOR CONTROL BY ADVANCED ALGORITHMS WITH MINING EXTRACTION MACHINE APPLICATION

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**ABSTRACT**

In this paper the ways to control the induction motor with application to mining extraction machine are considered. For this reason, first there are analyzed the open loop and closed loop control algorithms, which are simulated in MatLab-Simulink. Then are determined the automation conditions for the extraction machine. At the end of the paper is presented the control software written in assembly language.

**KEY WORDS:** software, control, simulation, advanced algorithms.

## 1. INTRODUCTION

Nowadays the most of control systems for induction motor are hardware oriented. This means they have too much electronics for drive control, like: logic and analogical devices, discrete components, microcontrollers and DSP, power electronics etc. The control program is reduced at minimum to be implemented on microcontrollers and/or DSP for real-time reason.

In many cases the electronic equipment reduces the reliability and the adaptability of the entire system. Other disadvantages are: no hardware in-the-loop simulation is possible, no advanced algorithms are implemented like multi-linear and nonlinear, no friendly graphics simulation and measurement. On the other hand this control system is together with power electronics bigger in volume and price in compare with the electrical drive itself.

The objective of this paper is to design a real-time controller-system and to develop a software for intelligent control of induction motor. So it has large possibilities of control algorithms implementation, a minimum electronics, a friendly graphic and measurement interface, high reliability and stability. This method of control also permits a hardware in-the-loop (HIL) simulation and reduces the time to bring into operation the new drive system.

A very good application of advanced algorithms for induction motor is mining extraction machine control. The extraction-mining machine makes all the transport works between surface and underground. It transports coal, equipment, personnel etc. Because of this it must have high reliability in order to respond properly to the emergencies that could lead to material damages or even make human victims. The automation of extraction-mining machine eliminates the human operator, increasing functioning safety and working security. There are increased also the technical-economical parameters.

## 2. ADVANCED ALGORITHM CONTROL PRINCIPLE

### *2.1. Movement trajectories*

We consider that an induction motor drives the extraction machine. The induction motor must be control in order to position precisely the skips. An important problem is to reduce the mechanical inertia that can be done by reducing the speed when the skips are close to the ramps. To protect the transmission mechanisms of the machine, the motor must start with low speed. After this it must achieve the trajectory in the imposed time and with the proper precision.

There are several different types of possible trajectories, as follows:

- linear speed trajectory (minimum time);
- parabolic speed trajectory (constant shock during the movement);
- sinusoidal speed trajectory (variable shock during the movement).

#### *2.1.1. Linear speed trajectory*

This type of trajectory has the advantage of minimum movement time. The acceleration is constant and the maximum possible value, but are several point with high shock. The movement space for linear trajectory is determined by the formula:

$$x=\begin{cases} a_{max}\cdot\frac{t^2}{2} & ;0\le t\le T_1 \\ a_{max}\cdot T_1\cdot\left(t-\frac{T_1}{2}\right) & ;T_1<t\le T_2 \\ a_{max}\cdot\frac{(t+T_1-T_2)^2}{2}+a_{max}\cdot T_1\cdot(T_2-T_1) & ;T_2<t\le T_3 \\ v_{max}\cdot t+\frac{v_{max}}{2}\cdot(-T_3+T_1-T_2)+a_{max}\cdot T_1\cdot(T_2-T_1) & ;T_3<t\le T_4 \\ -\frac{a_{max}}{2}\cdot(T_{max}-t+T_1-T_2)^2+v_{max}\cdot(T_4+T_1-T_2)+a_{max}\cdot T_1\cdot(T_2-T_1) & ;T_4<t\le T_5 \\ \frac{a_{max}}{2}\cdot T_1\cdot(2\cdot t-2\cdot T_5+2\cdot T_2-3\cdot T_1)+v_{max}\cdot(T_4+T_1-T_2) & ;T_5<t\le T_6 \\ x_{max}-\frac{a_{max}}{2}\cdot(T_{max}-t)^2 & ;T_6<t\le T_{max} \end{cases}$$

In fig.1.a is presented the movement space, speed, acceleration and shock for the linear speed trajectory.

Fig.1. a) Linear trajectory; b) Parabolic trajectory; c) Sinusoidal trajectory

#### *2.1.2. Parabolic speed trajectory*

This type of trajectory has the advantage of constant shock. The acceleration is linear decreasing.

The movement space for parabolic trajectory is determined by the formula:

$$x = -\frac{v_{max} \cdot T}{2} \cdot \left[ \left(1 - 2 \cdot \frac{t}{T}\right) - \frac{1}{3} \cdot \left(1 - 2 \cdot \frac{t}{T}\right)^3 \right] + \frac{v_{max} \cdot T}{3}$$

In fig.1.b is presented the movement space, speed, acceleration and shock for the parabolic speed trajectory.

*2.1.3. Sinusoidal speed trajectory*

This type of trajectory has the advantage of being smooth. The acceleration is sinusoidal and the shock cosinusoidal.

The movement space for sinusoidal trajectory is determined by the formula:

$$x = x_{max} \cdot \left[ \frac{t}{T} - \frac{1}{2 \cdot \pi} \cdot \sin\left( \frac{2 \cdot \pi}{T} \cdot t \right) \right]$$

In fig.1.c is presented the movement space, speed, acceleration and shock for the sinusoidal speed trajectory.

*2.2. Open-loop control (constant V/Hz) principle*

The most common principle of induction motor control is the constant V/Hz principle, which requires that the magnitude and frequency of the voltage applied to the stator of a motor maintain a constant ratio. By doing this, the magnitude of the magnetic field in the stator is kept at an approximately constant level throughout the operating range. Thus, constant torque producing capability is maintained.

The most used way to control the speed of an AC induction motor, implemented based on the constant V/Hz principle, is the open-loop control, shown in fig.2.

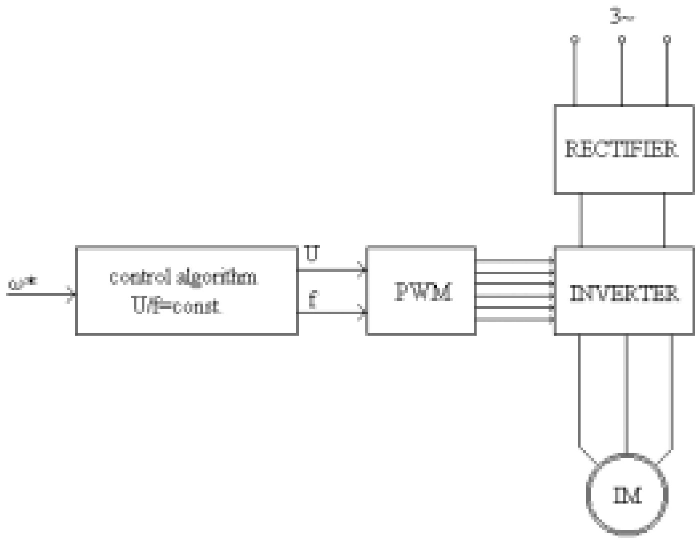


Fig.2. Open-loop control block diagram

In this case, the supply frequency is determined based on the desired speed and the assumption that the motor will roughly follow its synchronous speed. The error in speed resulted from slip of the motor is considered acceptable.

*2.3. Closed-loop control (field-oriented) principle*

The basis of the new theory of AC induction machine is Vector control also known as transvector, decoupling or orthogonal control. Vector control techniques can be as indirect or feed-forward method, and direct or feedback-method. Also is possible with rotor flux ($\Psi_r$) or stator flux ($\Psi_s$).

Fig.3 shows the indirect vector control block diagram with stator flux orientation. The feedback flux can be estimated from machine terminal voltages and currents (voltage model) or from currents and speed (current model).

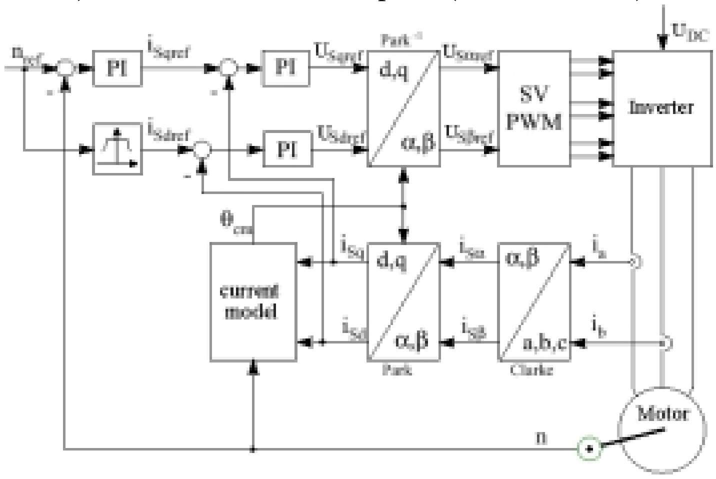


Fig.3. Field oriented closed-loop control block diagram

## 3. ADVANCED ALGORITHM CONTROL SIMULATION

In this section we'll do the simulation for the two control methods presented above, using the program MatLab-Simulink. For these there are implemented the block diagrams and there are considered each the three trajectory analyzed in section 2.1. In fig.4 are shown the simulation results for the scalar control method and in fig.5 for the field oriented control method.

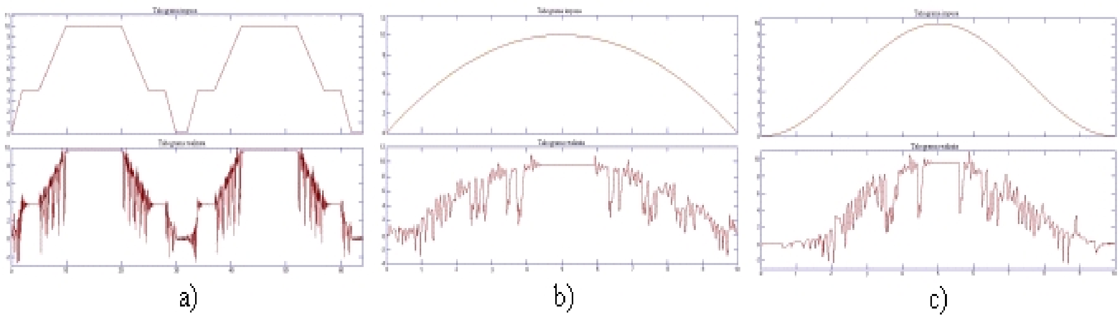


Fig.4. Simulation results for scalar control: a) linear trajectory; b) parabolic trajectory; c) sinusoidal trajectory

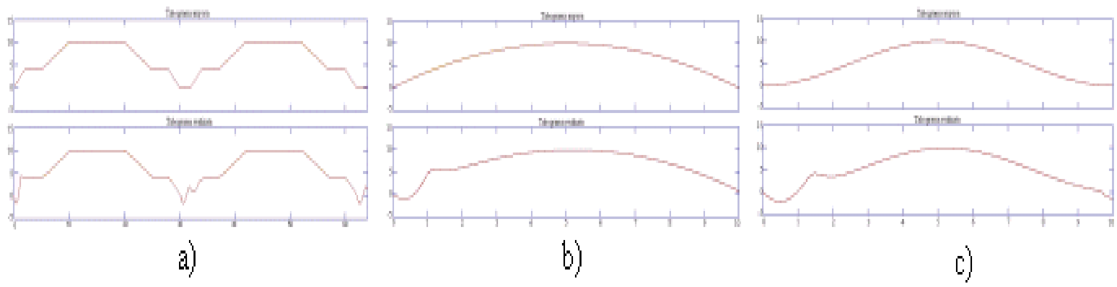


Fig.5. Simulation results for field-oriented control: a) linear trajectory; b) parabolic trajectory; c) sinusoidal trajectory

## 4. ANALYSIS OF EXTRACTION MACHINE FOR AUTOMATION

In order to do the analysis of the extraction machine for automation, it must be considered this machine as the central part of a complex system. For this reason its parameters are influenced by the other equipments functioning, like, for example, the load and unload processes in the surface and underground ramps.

The importance of this system automation results from the analysis of the total pause time and the percentages of this due to the various causes. Thus, (30...50)% of the total pause time is due to the surface load/unload processes, (20...40)% is due to the underground load/unload processes and (20...40)% is for the extraction machine, from which (10...16)% is for the electrical part.

In order to automate the extraction-mining machine there must be satisfied several conditions. The most important are the followings:

- choose the movement direction on load or unload ramp signal;
- two different ways to stop the machine;
- allow manual control in maintenance period and unpredicted emergency cases;
- achieve the speed tahogram with a maximum 10% error;
- control the brake action at start moment;
- stop the machine at the end of the cycle and ensure the precision for load and unload;
- ensure low speed for the start period time;
- limit the acceleration at maximum 1m/s$^2$;
- control the position in the shaft.

In fig.6 is presented the block diagram for extraction mining machine with squirrel cage induction motor drive and power electronics.

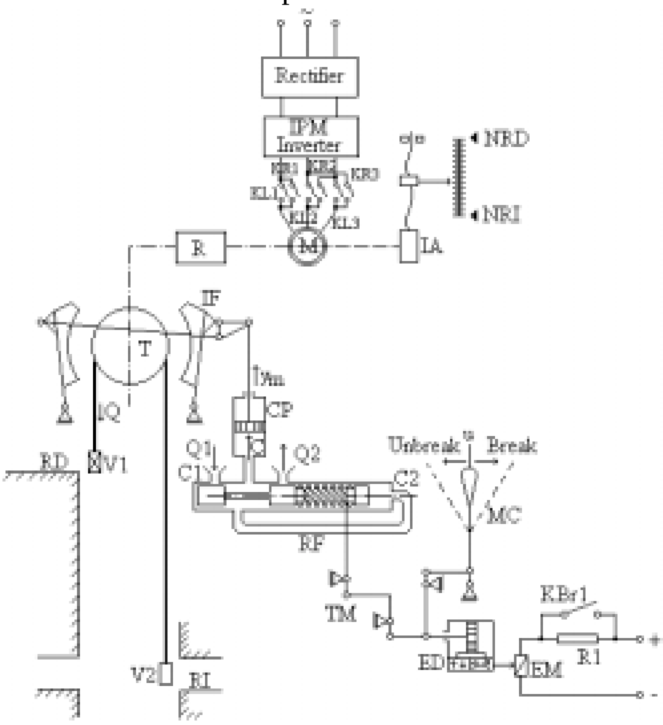


Fig.6. Extraction mining machine block diagram

## 5. CONTROL SOFTWARE

Based on the theoretical considerations presented above it was designed a software, implemented in assembly language, to control the extraction-mining machine. This software can be a way to modernize the mining industry.

In fig.7 are shown the control screens of the software. In fig.7.a, b and c there are the cases of automatic control by the linear, parabolic and sinusoidal trajectories and in fig.7.d the manual control for emergency case.

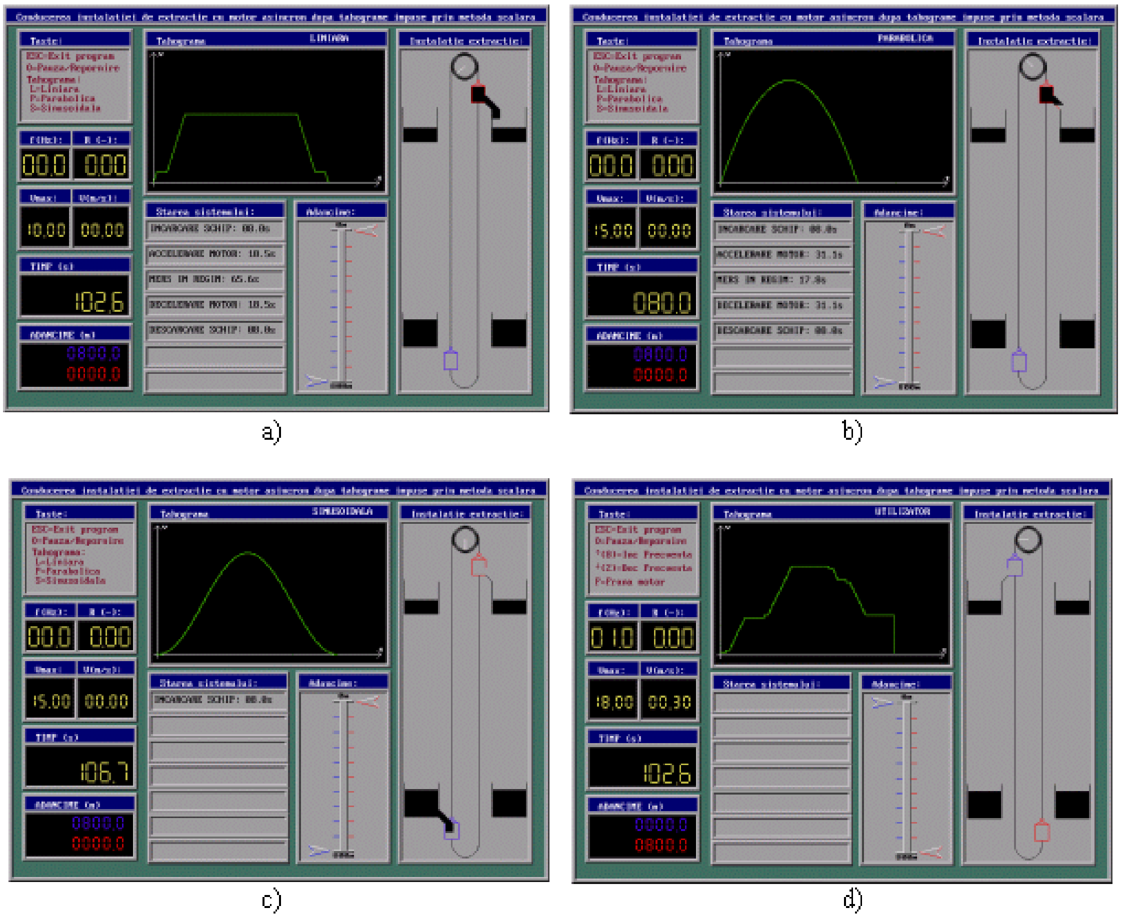


Fig.7. Software screens for: automatic control: a) linear trajectory; b) parabolic trajectory; c) sinusoidal trajectory; d) manual control

## 6. CONCLUSIONS

1. There are considered three speed control diagrams in order to optimize the induction motor movement.
2. The V/Hz and FOC algorithms are simulated in MatLab-Simulink.
3. Software-oriented real-time controller written in assembly language is applied to mining extraction machine.

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