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Program to Determine Optimum Operating Parameters to Control the Induction Machine Used in Some Electrical Drives

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Abstract

There are practical situations, as is the case of electrical drive systems of oil field pumping units, in which the induction machine has a relatively low loading. In this situation the optimization is done by changing the voltage supply. This paper presents a program for determining the voltage supply whose energetic parameters are optimal.

Key words: *simulation, induction machine, electric drives.*

Introduction

The electrical drive systems of oil field pumping units are produced in most cases by induction machines with high bars. Specificity of this type of action is that it requires a high starting torque and the choice of driving motors is realized, firstly, to achieve this goal. In steady state operation, however, the driving motor remains at a relatively low load, the percentage of loading being influenced by a possible failure of motor choice. In paper [1] states that in a study of a group of wells were found driving motors with a load factor very small (17 ,..., 25%) and in paper [2] states that most wells were investigated have motors with a load factor of 25 ,..., 45%. It is obvious that in such an operating regime, the energetic parameters of the pumping unit motor are relatively low. This is why the importance of this topic.

In order to optimize energetic parameters of the induction machine is given the idea of using a voltage regulator with thyristors disposed between the supply and motor drive, allowing the "adjustment" of alternative voltage on a large range, so that, for a given load factor (sub-unitary), to undertake a proper adjustment of voltage supply, respectively to obtain a maximization / minimization of certain energetic parameters of motor, which mainly include: efficiency, power factor, total loss of motor and power absorbed.

Formal mathematical model of the induction machine

Mathematical model of asynchronous motor, in the phasor-compact variant, is the classical one, which is presented in the coordinates system (d, q):

$$\underline{U_1} = R_1 \underline{I_1} + \frac{d\underline{\Psi_1}}{dt} + j\omega\underline{\Psi_1};$$

$$0 = R_2 \underline{I_2} + \frac{d\underline{\Psi_2}}{dt} + js\omega\underline{\Psi_2}. \tag{1}$$

The symbols are the usual: indexes 1 and 2 are referring to the stator/rotor of the motor. It was taken into consideration the fact that at the generalized electrical machine (having number of pairs of poles, p=1) we have:

$$\Omega_k - \Omega_2 = s\Omega_1 = s\omega. \tag{2}$$

Relations between magnetic fluxes and currents, in phasor-compact form, will be the following:

$$\underline{\Psi_1} = L_1 \underline{I_1} + L_m \underline{I_2} \quad ; \quad \underline{\Psi_2} = L_2 \underline{I_2} + L_m \underline{I_1} \ . \tag{3}$$

In these relations the notation of inductivities is the usual one.

The equations system (1) must be detailed in the form of Cauchy equations. Having in view relations (3), this detailing can be realized in form of equations "in currents" or "in fluxes". The choice of the variant depends, in generally, by preference of the user but it can depend by some further developing of the equations, which can become convenient in a specific variant. For example, the Cauchy equations system for asynchronous motor, in terms of "currents" can be written in the following form:

$$\begin{aligned}
\frac{di_{1d}}{dt} &= a1*U_d - b1*i_{1d} + (c1 - d1*s)*i_{1q} + e1*i_{2d} + (1-s)*f1*i_{2q};\\
\frac{di_{1q}}{dt} &= a1*U_q + (d1*s - c1)*i_{1d} - b1*i_{1q} - (1-s)*f1*i_{2d} + e1*i_{2q};\\
\frac{di_{2d}}{dt} &= -a2*U_d + b2*i_{1d} - (1-s)*c2*i_{1q} - d2*i_{2d} + (e2*s - f2)*i_{2q};\\
\frac{di_{2q}}{dt} &= -a2*U_q + (1-s)*c2*i_{1d} + b2*i_{1q} + (f2 - e2*s)*i_{2d} - d2*i_{2q}.
\end{aligned} \tag{4}$$

The components of statorical/rotorical currents and the tension U are given by axis (d, q); the coefficients a1,...,f2 are functions by motor parameters, having the expressions:

$$\begin{aligned}
&a1 = ax*X_2 \ ; \ a2 = ax*X_m \ ; \ b1 = a1*R_1 \ ; \ b2 = a2*R_1 \ ; \ c1 = a1*X_1 \ ; \ c2 = a2*X_1 \ ;\\
&d1 = a2*X_m \ ; \ d2 = e1*X_1/X_m \ ; \ e1 = a2*R_2 \ ; \ e2 = a1*X_1 \ ; \ f1 = a1*X_m \ ;\\
&f2 = a2*X_m, \text{ respectively } ax = 2\pi f_1/(X_1*X_2 - X_m^2).
\end{aligned} \tag{5}$$

The equations system (4) has 5 unknowns: $i_{1d}, i_{1q}, i_{2d}, i_{2q}, s$. The fifth unknown, who is referring to the motor slip (s), assumes establishing of the fifth equation usually based on torques equation from driving system. In principal, detailing of Cauchy equations can refer to the following aspects:

- Current repression, especially since it is asynchronous motors with high bars;
- Effect of longitudinal magnetic saturation, which is important in case of drives in that rotation is modified cyclically in large limits;

- Effect of transversal saturation, which is important when the load is modified cyclically in large limits.

Program Presentation

Taking into account, first, mathematical model presented above, for the calculus of some energetic parameters of driving motor, in such cases has been designed a program using the MATLAB® programming environment. This program takes into account a set of asynchronous motors by ASI type, used in electric drives of oil field pumping units.

For these motors, which can have of synchronism rotation by 1500, 1000 and 750 rot/min, are known data catalogue. The program allows simulation of operation for other motors, which are different by those existing in program database. In these cases, the catalogue data will be required during the program running. In the initializing section of simulation program there are foreseen many GUI interfaces to communicate with the user. By these interfaces, the user can choose synchronism rotation and power of electrical driving motor. An example of this kind of interface, which allows selection of motor power, is presented in figure 1 and figure 2.

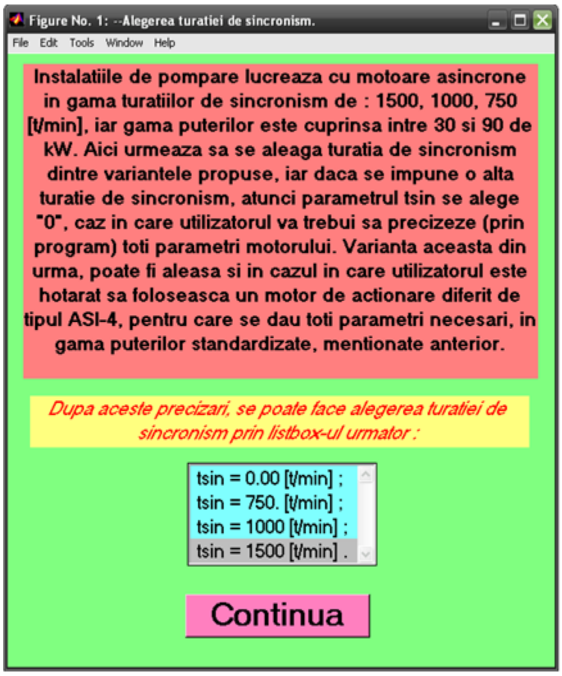

Fig. 1. Interface for choosing of engine speed of rotation.

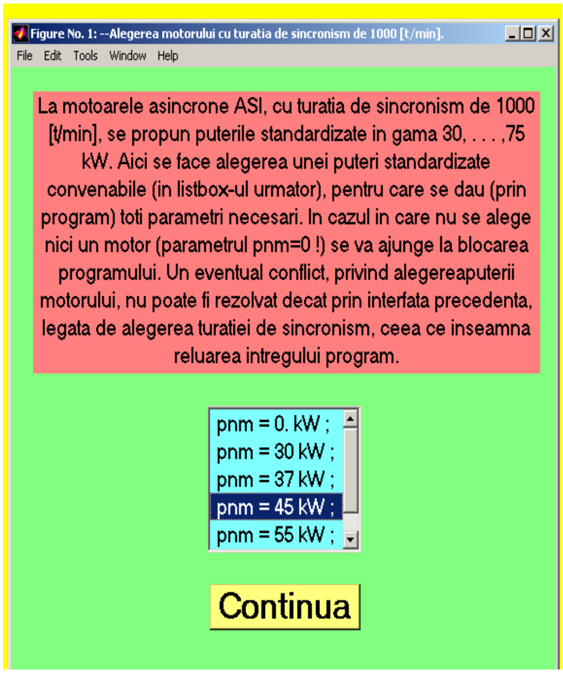

Fig. 2. Interface for choosing of engine power.

Having in view that in stabilized operation regime the motor driving load remains relatively low, for simulating, using the „input" function of MATLAB®, it determines the load regime of the motor according with its nominal electromagnetic torque.

For different values of supply voltage, the program can determine the following data:

- sliding;
- loss in stator, [kW];
- loss in rotor, [kW];

- electromagnetic power,[kW];
- loss in iron, [kW];
- mechanical and in ventilation loss, [kW];
- useful power at the shaft, [kW];
- absorbed power by motor, [kW];
- total loss in motor, [kW];
- efficiency, at a given supply voltage;
- total reactive power, [kvar];
- apparent power, [kVA];
- power factor, [cosφ].

After processing of these parameters, the program will determine:

- minimal value of loss and the value of supply voltage which allows obtaining of this minimal value;
- minimal value of absorbed power and the value of supply voltage which allows obtaining of this minimal value;
- maximal value of power factor and the value of supply voltage which allows obtaining of this maximal value.

It will be made a graphical representation in function of the following parameters: power factor, efficiency, loss in motor power and absorbed power from supply or combined variants.

Simulation Results

For simulation it was choosen a motor having nominal power by 45 kW and a synchronism turation by 1500 rot/min. The load factor was established at 43.7%. It were obtained the following results:

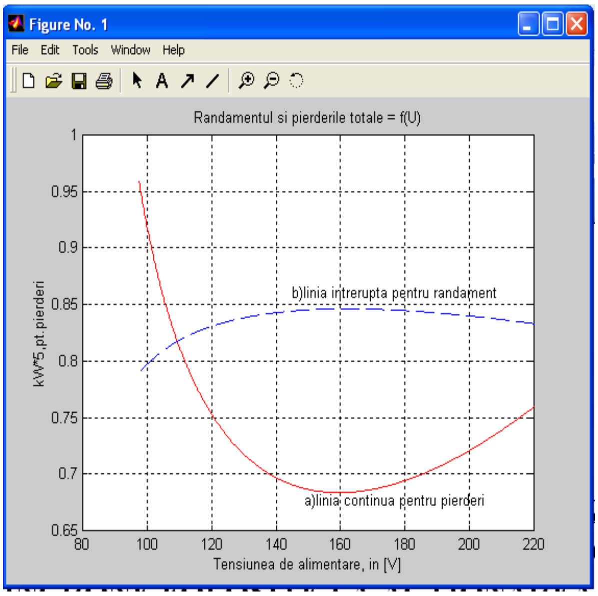

Fig.3. Efficiency variation curve and loss curve depending on voltage.

- maximal value of efficiency is 0.8461 for a value of voltage by 161.92 V;
- minimal loss are 3.4178 kW for a value of voltage by 159.28 V;
- minimal value of absorbed power is 22.1601 kW for a value of voltage by 141.0200 V;
- maximal value of power factor is 0.9271 for a value of voltage by 98.34 V.

In figure 3 on the same chart, depending on supply voltage is presented the variation curve of loss in motor and efficiency variation curve. The curve of loss was divided by 5, so that it can be „compatible" with the representation scale of the efficiency; this can be observed in specifications that are made in ordinate axis.

The two parameters – efficiency, respectively total loss, were chosen especially to be represented in the same figure because they are in some way „connected" (with exception of representation scale) by comparison with the other two parameters, power factor and absorbed power, which have more differences and they can be represented in separate figures.

What is essential, and this can be tested for any other load of a given motor, is the fact that the voltage values for which it can be obtained the maximization/minimization of the two initial parameters are closed values (the differences are quite insignificant). In case of a system automatization for voltage regulation, taken into account as an automatization base the two parameters, it can consider the semisum of values of two voltages as a common voltage value.

In this idea, in figure 4 is presented the voltage curve depending on load, in order to obtain maximizing of the efficiency, respectively minimizing total loss for the motor having 45 kW and 1500 rot/min.

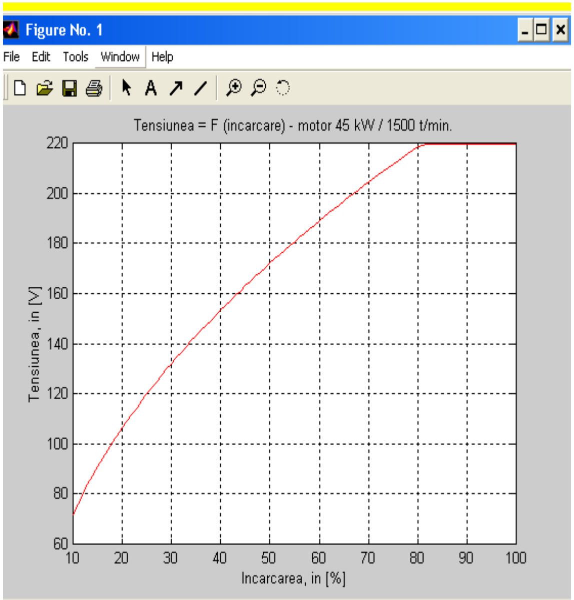

Fig. 4. Voltage curve depending on load for maximizing of efficiency, respectively minimizing of total loss in motor.

Obviously, similar curves can be obtained for other parameters of the same motor or for different variants of motors. They are obtained so that they can be reused by a spline function, for any load of driving motor (in the given case, for the motor having 45kW/1500 rot/min) establishing the necessary voltage for optimizing operation regime of driving motor according with the considered parameters.

In representing of these curves, in any case, it was taken in consideration the stability in operation of asynchronous motor (having in view the method of reducing of supply voltage) at its given load coefficient with a safety coefficient by 10%.

Voltage curve in function of motor load for a given optimum operation regime can be used for prescription of thyristors firing angle in the idea of using a voltage regulator with thyristors for motor supply. The entire process can be properly automatized. It can be important the comparison of total motor loss in operation at optimum voltage regime with reference to nominal voltage supply. So, for the motor with 45 kW and 1500 rot/min, if it would operate at optimum regime at a load coefficient by 30%, the total loss will be 2.8863 kW. In regime of nominal voltage, having same load coefficient, the total loss is growing at 3.825 kW (figure 3).

The energy saving is by 0.9387 kW, and for a month, the energetic consume is reduced with 675 kWh approximately. It is not a very important energy saving but in time and taken in consideration thousands of motors this can represent very much.

Of course, at the basis of a right evaluation of this kind of elements has to be a detailed technico-economic calculus, which considers all aspects, not only a more suitable parameters „mate" (we can discuss about absorbed power, power factor, the load of line systems and transformators, the cost of modifying of installation, etc.). It is possible to take in consideration at a given load an optimal voltage, more global for more energetic parameters of the motor. In any of cases, this kind of programs can represent a starting base

The problem of optimizing of this kind of process, which is driven electrically, is in principle, a very complex one and, in generally, it can be analyzed only from an electrical point of view, but in this case, the results will be only partial. The priorities by „technological”, „mechanical” or „electrical” type, which are imposed at a moment, must be taken in consideration too. Otherwise, a study by this type can be seen only like an element in a complex assembly.

Conclusions

Pumping installation with rocker for oil extraction is usually driven by asynchronous motors with tall bars. Their choosing is made depending on starting torque, which is necessary to the installation.

In this manner, the majority of motors appear in stabilized operation regime having a low level of load. This means that they operate at very low energetic parameters.

Using a supply voltage, which is reduced properly using a regulator with thyristors, it can be attend to an optimum operation regime of motor in comparison with some parameters of its (or some pairs parameters). In this situations it can be realized an automatizing of the driving system. Some of the curves, which are designed in certain conditions for a given motor having a given load, demonstrate these possibilities.

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Program pentru determinarea parametrilor de funcționare optimi pentru controlul maşinii de inducție utilizată în unele acţionări electrice

Rezumat

Sunt situații practice, aşa cum este cazul sistemelor de acţionare electrică a unităților de pompare din exploatările petroliere, în care maşina de inducţie are o încărcare relativ scăzută. În această situaţie optimizarea se face prin modificarea tensiunii de alimentare. Lucrarea prezintă un program pentru determinarea tensiunii de alimentare pentru care parametrii energetici sunt optimi.