RESEARCH OF THE INDUCTION MOTOR'S SELF-STARTING MODE

ASINHRONĀ DZINĒJA PAŠPALAIDES REŽĪMA IZPĒTE

K.Ketners, E.Ketnere, S.Kļujevska, M.Koņuhova

Keywords: the induction motor, mathematical model, self-start

The asynchronous electric drive is the most widespread kind of a drive of units and mechanisms. This type of drive is applied in the most various industries in developed countries. The electromechanical systems created on the basis of three-phase induction motors are the most widespread both in the industry and in municipal and agriculture. Now the given systems actively take root in transport, in machine-tool construction and robotics. These systems make the basic share power consumption, about 50 % of all electric power produced in the world. At studying the processes occurring in complex electromechanical systems, there is a necessity for development of dynamic models of these systems adequately displaying a real condition [1-3].

The most difficult object from the point of view of mathematical descriptions is the induction motor (IM) [4]. The IM is essentially nonlinear part and represents itself as an object of regulation and management at automation of manufacturing processes. Therefore definition of static and dynamic parameters of a mode is required. In this connection there is a necessity for accessible programs development means which would not demand special preparation in the field of programming and, simultaneously, would enable to carry out researches of work the IM in transitive modes.

Research of dynamic operating modes the IM in view of the electromagnetic transitive phenomena caused by sharp change of a condition of the motor is pressing question of modern practice of use of quick-response asynchronous drives. Necessity of the account of interference of mechanical and electromagnetic processes is obvious. The statements on insignificant influence on the IM behavior from electromagnetic transients and their insignificant duration in comparison with course of mechanical transitive modes met in the literature are incorrect and can lead to undesirable consequences.

In the given article results of calculation of IM starting-up processes or faults (step down a voltage) and self-start after fault are resulted, repeated inclusion for various power electric motors, thus the mechanical time constant and a kind of fault are varied.

For the decision of the specified problems the program has been developed on the basis of computer language FORTRAN in which basis the biphase mathematical model of the electric machine in coordinate axes *d, q*, *0* has been put. The great value for modeling has a choice of system of coordinate axes and forms of record of the equations as accuracy and stability of the decision depends on it.

At research of dynamic operating modes the IM when a feed is carried out from the infinite power network, the Park – Gorev's equations, which have been written down in coordinate axes, rotating synchronously with a stator field are rather convenient. Then stator voltage U_d and U_q are set at the decision as constants. The fifth order of the equations and nonlinearity of this system results in the fact that the analytical decision is practically impossible.

For the basic operating mode the impellent mode [4] is accepted. After transformations the system of the differential equations for the induction motor becomes:

$$\left.\begin{aligned} U_{1d} &= R_1 i_{1d} - \omega_{0el}\Psi_{1q} + \frac{d\Psi_{1d}}{d\tau} \\ U_{1q} &= R_1 i_{1q} + \omega_{0el}\Psi_{1d} + \frac{d\Psi_{1q}}{d\tau} \\ U_{2d} &= R_2 i_{2d} - (\omega_{0el} - \omega)\Psi_{2q} + \frac{d\Psi_{2d}}{d\tau} \\ U_{2q} &= R_2 i_{2q} + (\omega_{0el} - \omega)\Psi_{2d} + \frac{d\Psi_{2q}}{d\tau} \end{aligned}\right\}. \quad (1)$$

The equation of rotor's movement:

$$T_M \frac{d\omega}{d\tau} = [M_{em} - M_{StL}], \quad (2)$$

Where T_M - a time constant of the machine in electric radians;

$M_{em} = X_{ad}(i_{2d} i_{1q} - i_{2q} i_{1d})$ - the electromagnetic torque.

Expressions for flux linkages, included in (1), we shall write down in the way where flux linkage for all machines' contours in axes *d, q*, *0* contain only the constants independent in time inductances:

$$\left.\begin{aligned} \Psi_{1d} &= X_1 i_{1d} + X_{ad} i_{2d}; \\ \Psi_{1q} &= X_1 i_{1q} + X_{ad} i_{2q}; \\ \Psi_{2d} &= X_2 i_{2d} + X_{ad} i_{1d}; \\ \Psi_{2q} &= X_2 i_{2q} + X_{ad} i_{1q}; \end{aligned}\right\}. \quad (3)$$

The system of the equations (1) is necessary to resolve in the equation concerning derivatives

$\frac{d}{d\tau}\Psi_i$:

$$\left.\begin{aligned} \frac{d\Psi_{1d}}{d\tau} &= U_{1d} - R_1 i_{1d} + \omega_{0el}\Psi_{1q} \\ \frac{d\Psi_{1q}}{d\tau} &= U_{1q} - R_1 i_{1q} - \omega_{0el}\Psi_{1d} \\ \frac{d\Psi_{2d}}{d\tau} &= U_{2d} - R_2 i_{2d} + (\omega_{0el} - \omega)\Psi_{2q} \\ \frac{d\Psi_{2q}}{d\tau} &= U_{2q} - R_2 i_{2q} - (\omega_{0el} - \omega)\Psi_{2d} \end{aligned}\right\}; \quad (4)$$

$$\frac{d\omega}{d\tau} = [M_{em} - M_{StL}]/T_M. \quad (5)$$

Let's transform (4) to a matrix type:

$$\frac{d}{d\tau}\begin{bmatrix}\Psi_{1d}\\ \Psi_{1q}\\ \Psi_{2d}\\ \Psi_{2q}\end{bmatrix}=\begin{bmatrix}U_{1d}-R_1 i_{1d}+\omega_{0el}\Psi_{1q}\\ U_{1q}-R_1 i_{1q}-\omega_{0el}\Psi_{1d}\\ U_{2d}-R_2 i_{2d}+(\omega_{0el}-\omega)\Psi_{2q}\\ U_{2q}-R_2 i_{2q}-(\omega_{0el}-\omega)\Psi_{2d}\end{bmatrix}. \tag{6}$$

The algebraic equations (3) connecting flux linkage with currents we shall present as:

$$\begin{bmatrix}\Psi_{1d}\\ \Psi_{1q}\\ \Psi_{2d}\\ \Psi_{2q}\end{bmatrix}=\begin{bmatrix}X_1 & 0 & X_{ad} & 0\\ 0 & X_1 & 0 & X_{ad}\\ X_{ad} & 0 & X_2 & 0\\ 0 & X_{ad} & 0 & X_2\end{bmatrix}*\begin{bmatrix}i_{1d}\\ i_{1q}\\ i_{2d}\\ i_{2q}\end{bmatrix}. \tag{7}$$

The algebraic equations (3) connecting flux linkage with currents we shall present as:

$$[\Psi]=\begin{bmatrix}\Psi_{1d}\\ \Psi_{1q}\\ \Psi_{2d}\\ \Psi_{2q}\end{bmatrix}; \quad [X]=\begin{bmatrix}X_1 & 0 & X_{ad} & 0\\ 0 & X_1 & 0 & X_{ad}\\ X_{ad} & 0 & X_2 & 0\\ 0 & X_{ad} & 0 & X_2\end{bmatrix}; \quad [I]=\begin{bmatrix}i_{1d}\\ i_{1q}\\ i_{2d}\\ i_{2q}\end{bmatrix};$$

$$[UE]=\begin{bmatrix}U_{1d}-R_1 i_{1d}+\omega_{0el}\Psi_{1q}\\ U_{1q}-R_1 i_{1q}-\omega_{0el}\Psi_{1d}\\ U_{2d}-R_2 i_{2d}+(\omega_{0el}-\omega)\Psi_{2q}\\ U_{2q}-R_2 i_{2q}-(\omega_{0el}-\omega)\Psi_{2d}\end{bmatrix}.$$

The algebraic equations (3) connecting flux linkage with currents we shall present as:

$$\frac{d}{d\tau}[\Psi]=[UE], \tag{8}$$

where $$[\Psi]=[X]*[I]. \tag{9}$$

Having substituted the equation (9) in (8), we shall receive:

$$\frac{d}{d\tau}[X]*[I]=[UE], \tag{10}$$

As $[X]=const$, we shall transform (10) to a kind:

$$[X]*\frac{d}{d\tau}[I]=[UE]. \quad (11)$$

Having resolved system (11) concerning derivative currents, we shall receive:

$$\frac{d}{d\tau}[I]=[X]^{-1}*[UE], \quad (12)$$

where $[X]^{-1}$ - a inverse matrix $[X]$.

Thus the received mathematical model of the induction motor represents the matrix equation (12), described transitive electromagnetic processes in the IM and the equation of movement of the rotor (5), reflecting mechanical transients. For model of the induction motor with a squirrel-cage rotor it is accepted U_{2d} also U_{2q} equal to zero. The major operational transitive mode providing a continuity of technological process, self-start of the induction motor [5,6] - a mode at which the electric motors which were not stopped at a significant voltage reduction, are not disconnected from a network is, and at restoration of a feed are capable to move at a speed up to nominal rotation frequency. For the analysis of such mode the program is developed, allowing modeling a starting-up mode of the IM, voltage reductions and the subsequent restoration of a voltage, that as a matter of fact and reflects process of self-starting. Using the above mentioned equations, modeling a mode of starting-up of the induction motor with fan load *Ms=0.8*n2* has been carried out. For research of an operating mode of the induction motor at step down a voltage as a result of fault in a network, the data of the induction motor with the following parameters have been used:

P_{2nom} =30kW; n_N=3000min^{-1}; X_μ=3,8; $R_1^{'}=0{,}030$; $X_1^{'}=0{,}073$; X_s=3,873; $R_2^{''}=0{,}018$; $X_2^{''}=0{,}11$; $X_{k.p}=0{,}13$; $R_{2p}=0{,}024$; $R_{k.p}=0{,}054$.

In fig. 1-3 characteristics of change of the current, electromagnetic torque and rotation frequency of the induction motor are submitted depending on time at step down the voltage up to 0,9; 0,8; 0,7; 0,6 from rating value as a result of fault. The analysis of modeling results has shown that at step down a voltage up to 0,6 from U_{nom} the induction motor passes in a generating mode (at the moment of time *t=0,6s.*) then there is a self-starting process of the induction motor after voltage restoration.

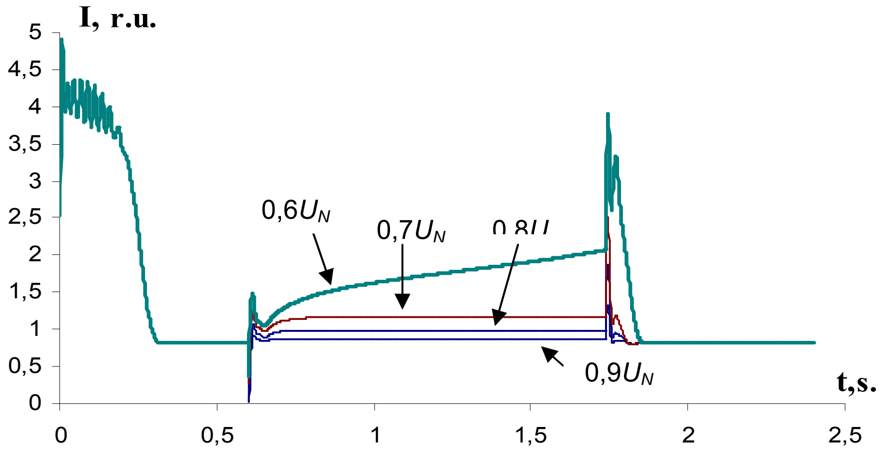

Fig. 1. The characteristic of change of a current of the induction motor from time at step down of the voltage up to 0,9; 0,8; 0,7; 0,6 from rating value as a result of fault and after a feed restoration.

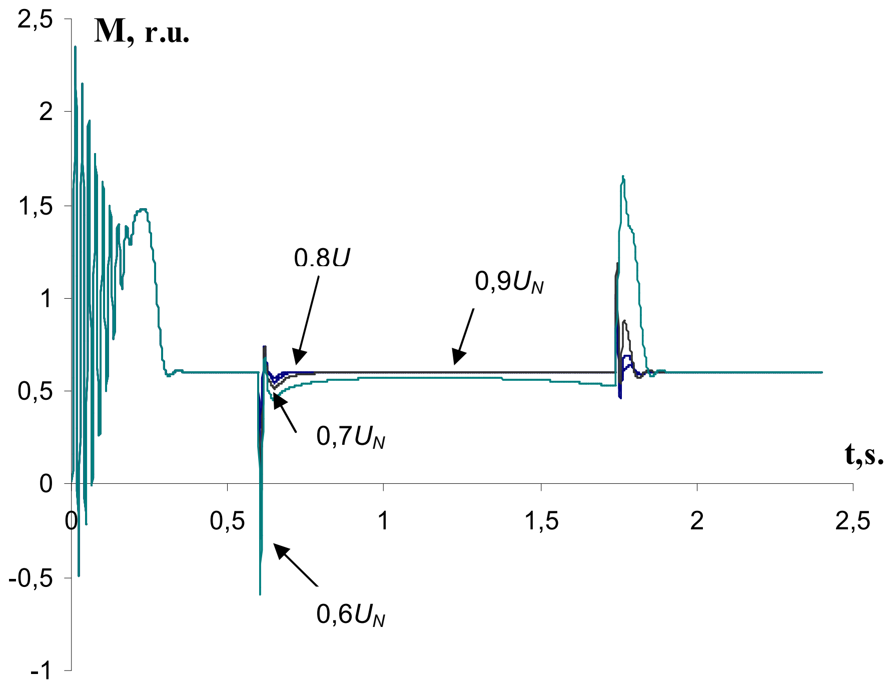

Fig. 2. The characteristic of change of the electromagnetic torque of the induction motor from time at step down of the voltage up to 0,9; 0,8; 0,7; 0,6 from rating value as a result of fault and after feed restoration.

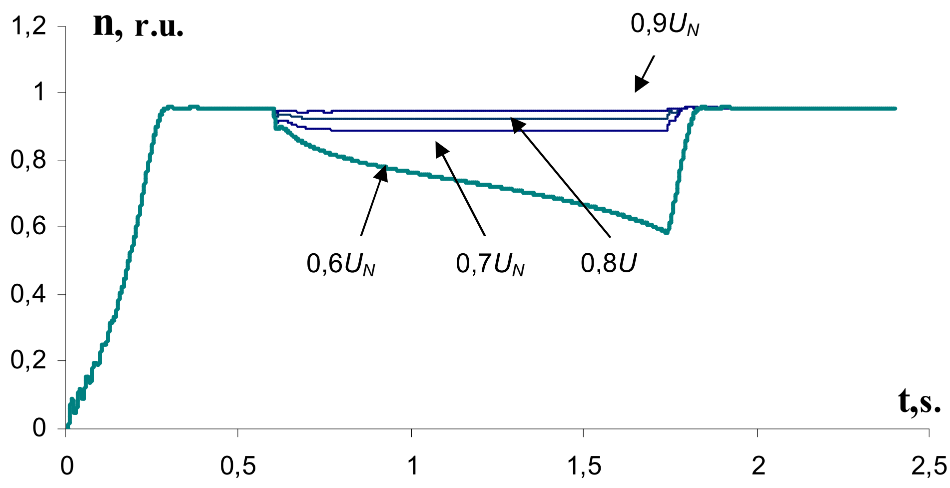

Fig. 3. The characteristic of change of rotation frequency of the induction motor from time at step down of the voltage up to 0,9; 0,8; 0,7; 0,6 from rating value as a result of fault and after a feed restoration.

CONCLUSIONS

The offered simulation program for transient processes in the IM allows investigating the dynamic modes essentially distinguished from a nominal mode. The analysis of the lead calculations allows to allocate mode's characteristic parameters and to determine a range of their change. In particular for a mode resulted on fig. 1-3 at step down of the voltage up to $0{,}6U_N$ transition of the motor in a generating mode and additional charging of a fault point takes place. It is essential for maintenance of reliable selective work of protection devices of the researched electromechanical system.

REFERENCES

1. Копылов И.П. Математическое моделирование электрических машин. Учебник для вузов. – 3-е изд. – М.: Высш.шк., 2001.

2. Копылов И.П. Электрические машины. – М.: Высшая школа, 2006. – 607 с.

3. Dirba J., Ketners K., Levins N ., Pugačevs V. Transporta elektriskās mašīnas. – Rīga, RTU, 2001. –327 lpp.

4. Dirba J., Ketnere E., Ketners K. Asinhronās slodzes matemātiskais modelis // Rīgas Tehniska universitātes zinātniskie raksti / Enerģētika un elektrotehnika / Rīga, 1997, 54-57 lpp.

5. Башарин А.В., Постников Ю.В. Примеры расчета автоматизированного электропривода на ЭВМ. Учебное пособие для вузов. – Л.: Энергоатомиздат, 1990. – 512.с.

6. Сыромятников И.А. Режимы работы асинхронных и синхронных двигателей. // М.. Энергоатомиздат, 1984.

Karlis Ketners, Prof., Dr. sc. ing.
Riga Technical University, Faculty of Power and Electrical Engineering
Address: Kronvalda boulevard 1, LV 1010, Riga, Latvia
Phone: +371 7089926, Fax: 7089418
e-mail: ketners@eef.rtu.lv

Elena Ketnere, Asoc. Prof., Dr. sc. ing.
Riga Technical University, Faculty of Power and Electrical Engineering
Address: Kronvalda boulevard 1, LV 1010, Riga, Latvia
Phone: +371 7089929
e-mail: ketnere@eef.rtu.lv

Svetlana Kļujevska, Doc., Dr.sc.ing.
Riga Technical University, Faculty of Power and Electrical Engineering
Address: Kronvalda boulevard 1, LV 1010, Riga, Latvia
Phone: +371 7089929
e-mail: svzimina@eef.rtu.lv

Marina Koņuhova, Bak.Sc.Ing., Masters student
Riga Technical University, Faculty of Power and Electrical Engineering
Address: Kronvalda boulevard 1, LV 1010, Riga, Latvia
Phone: +371 7089926
e-mail: miska-marmiska@one.lv

Ketners K., Ketnere E., Kļujevska S., Koņuhova M. Asinhronā dzinēja pašpalaides režīma izpēte.
Darbā tiek aplūkoti asinhronā dzinēja pārejas procesu matemātiskās modelēšanas jautājumi, kurus apraksta diferenciālvienādojumi d,q,0 koordinātu sistēmā. Asinhronā dzinēja (AD) dināmisko darba režīmu izpēte ar elektromagnētisko pārejas procesu ievērošanu, ko izraisa dzinēja darba režīma izmaiņa, ir aktuāls jautājums mazinerces asinhronās piedziņas izmantošanā. Tāpēc ir nepieciešami noteikt statiskos un dinamiskos režīma

parametrus. Asinhronā dzinēja matemātiskais modelis ir dots matricu formā, kas lielā mērā atvieglo tas diferenciālvienādojumu sistēmu pārveidojumu Koši formā risināšanai ar skaitliskajām metodēm. Izstrādāta modeļa pamatā veikta asinhronā dzinēja palaides procesa, īsslēguma (sprieguma pazemināšanas), pašpalaides un atkārtotas pieslēgšanas procesa analīzi pēc sprieguma atjaunošanos dažādas jaudas dzinējiem, turklāt mainījas laika mehāniskā konstante un īsslēguma veids. Veikto aprēķinu analīze ļauj noteikt raksturīgākus režīma parametrus un to izmaiņas diapazonu, kas ir svarīgi pētāmas elektromehāniskās sistēmas aizsardzības aparatūras selektīva droša darba nodrošināšanai.

Ketners K., Ketnere E., Klujevska S., Konuhova M.. The research of the induction motor's self-starting modes.

In the present work the questions of mathematical simulation of transients of the induction motor, described by the differential equations in system of coordinates d, q, 0 are considered. Research of dynamic operating modes the IM in view of the electromagnetic transitive phenomena caused by sharp change of a condition of the motor is pressing question of modern practice of use of quick-response asynchronous drives. Therefore definition of static and dynamic parameters of a mode is required. The induction motor's model is submitted in the matrix form, which substantially facilitates reduction of its system of the differential equations form Coshie for the decision numerical methods. On the basis of the developed model the analysis results of calculation of IM starting-up processes or faults (step down a voltage) and self-start after fault are resulted, repeated inclusion for various power electric motors, thus the mechanical time constant and a kind of fault are varied. The analysis of the lead calculations allows to allocate mode's characteristic parameters and to determine a range of their change. It is essential for maintenance of reliable selective work of protection devices of the researched electromechanical system.

Кетнер К., Кетнере Э., Клюевская С., Конюхова М. Исследование режима самозапуска асинхронного двигателя.

В настоящей работе рассмотриваются вопросы математического моделирования переходных процессов асинхронного двигателя (АД), описываемые дифференциальными уравнениями в системе координат d,q,0. Исследование динамических режимов работы АД с учетом электромагнитных переходных явлений, вызванных резким изменением состояния двигателя, является актуальным вопросом современной практики использования малоинерционных асинхронных приводов. Поэтому требуется определение статических и динамических параметров режима. Модель асинхронного двигателя представлена в матричной форме, что в значительной степени облегчает приведение его системы дифференциальных уравнений к форме Коши для решения численными методами. На основании разработанной модели проведен анализ процесса пуска АД, короткого замыкания (к.з.) (понижения напряжения) и самозапуска после к.з., повторного включения для электродвигателей различной мощности, при этом варьировалась механическая постоянная времени и вид к.з. Анализ проведенных расчетов позволяет выделить характерные параметры режима и определить диапазон их изменения, что существенно для обеспечения надежной селективной работы устройств защиты исследуемой электромеханической системы.