ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2009. No. 6(94)
ELEKTRONIKA IR ELEKTROTECHNIKA

ELECTRICAL ENGINEERING
T190
ELEKTROS INŽINERIJA

Modelling of Frequency Controlled Induction Drive with Ventilator Type Load

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Introduction

The greatest part of produced electrical energy is consumed by motors of industrial and commercial enterprises. Despite of great variety of motor types (direct current, electronic commutator motors, synchronous, permanent magnetic field synchronous motors, hysteresis and stepper motors) used, the induction motors are horse of the industry. They overcame direct current motors due to low price and reliability. New power electronic equipment and control strategies reduced the price and complexity of power converters. Frequency converter provides the motor with three phase voltage, whose amplitude and frequency can vary from zero to rated values and even greater. These parameters can be changed in accordance with features of driven equipment. Frequency converter compensates shortcomings of induction motors and variable speed drive with induction motor obtains new features resulting in expansion area of their application and economy of electric power. Variable speed drives improve process control and increase efficiency of manufacturing [1]. They are distinguished for smooth starting and breaking as well as good dynamic properties.

Three phase inverter switches are switched in proper order seeking to obtain desired amplitude and frequency of output voltage. Switching is concurrent of inverter operation, therefore motor, supplied by frequency converter operates in dynamic mode. Modelling of variable speed drive is complex problem, requiring solving a set of nonlinear equations of motor together with nonlinear equations, describing frequency inverter.

The great number of induction motors, controlled by frequency converters, is employed in pumps, fans and blowers. They operate at ventilator load. Matching of motor, load and converter characteristics is important problem and can be solved by elaborating computer models and analyzing simulation results.
Computer model of the starting processes of the induction motor, under basis of differential equations in the stationary reference frame is examined in article [2]. The model of the induction motor and frequency converter developed for electronic circuit simulation program *PSpice* is considered in the work [2]. The implementation of the developed model of the motor allows presenting the mechatronic system frequency converter – AC induction motor, which includes the electrical and mechanical parts as a unified model. A step function in the input of system was assumed in papers [2, 3, 4]. Model of the drive with inverter and ramp input, operating at no load is presented in [5].

The purpose of this work is to develop a computer model for investigation of the starting transients of frequency controlled induction motor at smooth starting and ventilator load.

Mathematical model of induction motor

Computer model of the starting processes of the induction motor, under basis of differential equations in the stationary reference frame, fixed to a stator is presented in [2]. This model is used as the base of frequency controlled electric drive and looks like this:

$$\begin{cases} u_{1\alpha} = \left[\left(\frac{1}{L_1} + \frac{L_m k_1}{L_1 L_2''}\right)\Psi_{1\alpha} - \frac{L_m}{L_1 L_2''}\Psi_{2\alpha}\right] R_1 + \frac{d\Psi_{1\alpha}}{dt}; \\ u_{1\beta} = \left[\left(\frac{1}{L_1} + \frac{L_m k_1}{L_1 L_2''}\right)\Psi_{1\beta} - \frac{L_m}{L_1 L_2''}\Psi_{2\beta}\right] R_1 + \frac{d\Psi_{1\beta}}{dt}; \\ u'_{2\alpha} = \left[\frac{1}{L_2''}(\Psi_{2\alpha} - k_1\Psi_{1\alpha})\right] R'_2 + \frac{d\Psi_{2\alpha}}{dt} + \omega\cdot\Psi_{2\beta}; \\ u'_{2\beta} = \left[\frac{1}{L_2''}(\Psi_{2\beta} - k_1\Psi_{1\beta})\right] R'_2 + \frac{d\Psi_{2\beta}}{dt} - \omega\cdot\Psi_{2\beta}, \end{cases} \quad (1)$$

where $\Psi_{1\alpha}$, $\Psi_{1\beta}$, $\Psi_{2\alpha}$, $\Psi_{2\beta}$, $i_{1\alpha}$, $i_{1\beta}$, $i_{2\alpha}$, $i_{2\beta}$ are stator and rotor flux linkage and stator and rotor current components aligned with orthogonal α, β axis; R_1 is stator resistance and R'_2 is rotor resistance, referred to stator; ω is speed of rotor; $u_{1\alpha}$, $u_{1\beta}$, $u'_{2\alpha}$, $u'_{2\beta}$ are components of stator and rotor voltages along direct and quadrature axis. Parameters of modelled motor are presented in Table 1.

Table 1. Parameters of induction motor

Parameter	U	P	n	f	Rated current	cosφ	Rated torque	Locked rotor torque	Locked rotor current	Breakdown torque	Breakdown current
Units	[V]	[kW]	[rpm]	[Hz]	[A]		[N·m]	[N·m]	[A]	[N·m]	[A]
Value	400	4	2890	50	13,22	0,88	13,22	30,9	50,26	40,6	34,04

Dynamic models of frequency controlled drive

Many of low power equipment, such as fans, blowers, pumps do not need great speed accuracy at operation. These drives usually do not contain sensors for feedback and their cabling systems. Frequency converter delivers three phase voltages U_A, U_B, U_C, whose amplitude and frequency are changed by scalar law relating them by ratio $U/f = const$. At smooth starting these both two variables are changed from zero to rated values, therefore ramp of voltage and ramp of frequency should be included into model. Computer model of open-loop frequency controlled drive is elaborated using Matlab Simulink SimPowerSystem toolbox.

Model of induction drive with ventilator load

If the motor drives pump or ventilator, it operates with ventilator load. Then load torque is proportional to speed square

$$T_L = k \cdot \omega^2 . \tag{3}$$

Rated torque of motor is calculated as

$$T_r = \frac{P}{\omega_0} , \tag{4}$$

where P is motor power in watts, ω_0 is synchronous speed in rad/s. Rated parameters are given in Table 1.

Constant k is calculated from Eq. (3) in this way

$$k = \frac{T_r}{\omega_0} = 1,29 \cdot 10^{-4} .$$

Model of frequency controlled drive with ventilator load is given in Fig. 1. Model inputs are "Speed reference" and "Torque reference".

Model comprises converter and its control circuits, included into Simulink block "Space vector control" subsystem. Outputs of subsystem are phase currents, speed and torque delivered by motor as well as inverter output voltage.

Control block inside subsystem is responsible for smooth starting of the motor. Blocks in the upper side of the subsystem form ventilator load of motor, which is proportional to speed square. It is set as reference torque.

For constructing of frequency and voltage ramps, typical Simulink blocks were applied. Ratio U/f is kept constant and steady - state speed is equal to reference speed 1800 rpm.

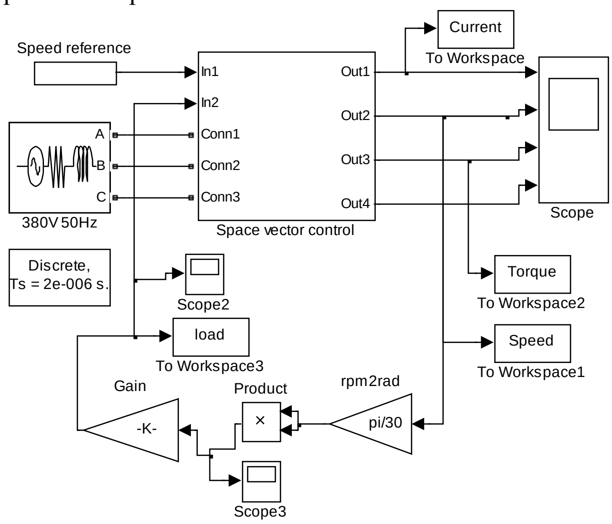

Fig. 1. Model of frequency controlled induction drive with ventilator load

Motor accelerates with 600 rpm per second and reaches steady state value in 3 s (Fig. 2).

Torque response at assumed acceleration 600 rpm/s and no load is shown in Fig. 3. Average torque value during starting approximately is constant. The maximum value at beginning of starting does not exceed rated torque.

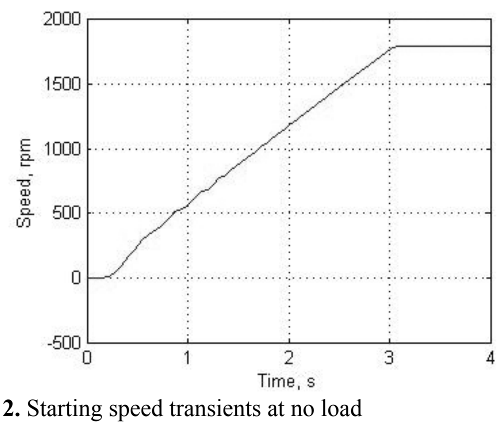

Fig. 2. Starting speed transients at no load

Obviously, the motor can deliver higher acceleration and shorter settling time if the voltage and frequency inputs should be provided by ramps with greater slope.

When the rotor speed reaches steady-state value, the motor torque approaches to zero at no load.

Experimentally measured torque transients are given in Fig. 4. Experiments were made with experimental equipment of Semiconductor Physics Institute.

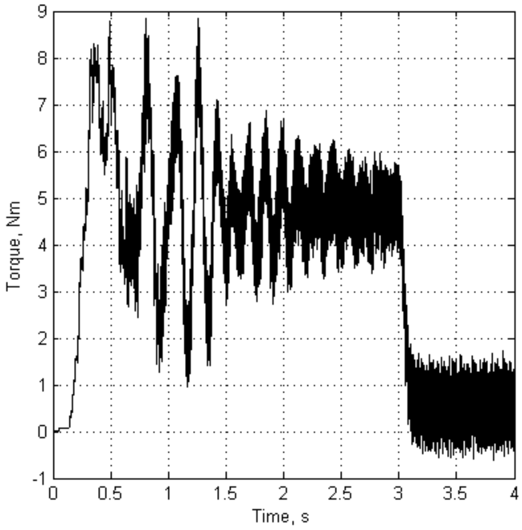

Fig. 3. Starting torque transients at no load

Current response at no-load is shown in Fig. 5. Starting with assumed ramp input limits starting current, which does not reach rated value.

Speed response of the system with ventilator load is presented in Fig. 6. Reference speed is chosen 3000 rpm. Acceleration of the motor is approximately the same as that at no load.

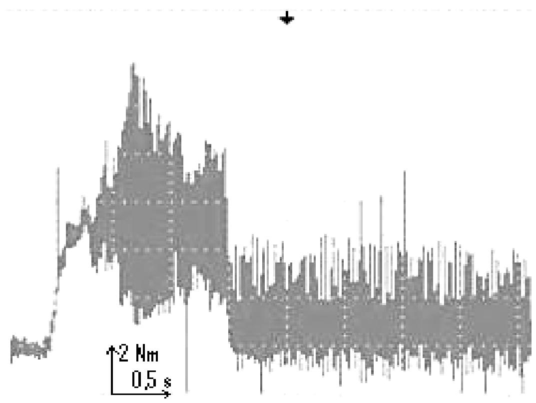

Fig. 4. Experimental results of torque transients at no load

Steady-state value of speed reaches 2700 rpm and corresponds to 10% speed error in the open loop system. For greater accuracy closed loop control system with speed feedback or vector control modes should be used.

Torque response at ventilator load is shown in Fig.7. At smooth starting and chosen ramp the maximum torque value does not exceed rated that at the beginning of the starting transients.

Afterwards the torque rises as the load increases with speed square. The steady state value of delivered torque is less than rated because speed does not reach its reference value and load torque, depending on speed square also does not reach the value of rated torque.

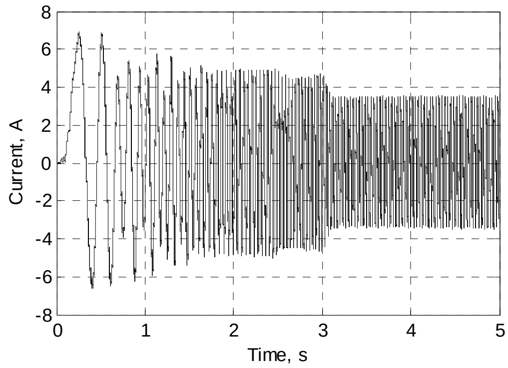

Fig. 5. Starting current transients at no load

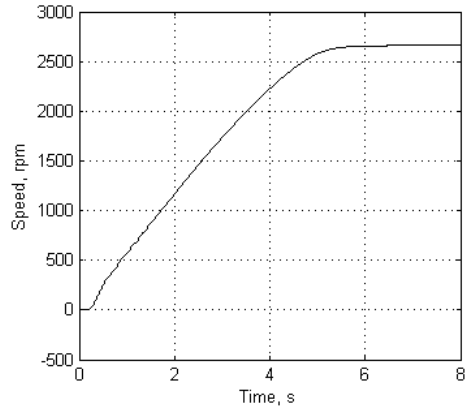

Fig. 6. Speed response of the system with ventilator load at smooth starting

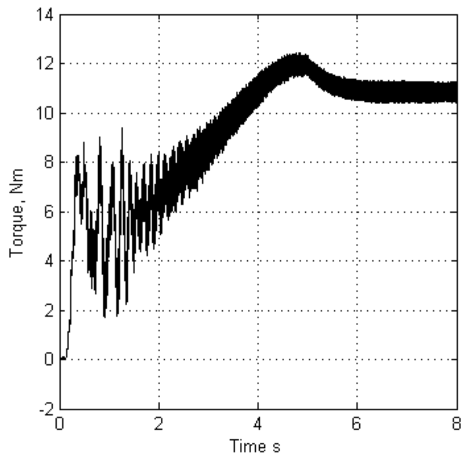

Fig. 7. Starting torque transients at ventilator load

The beginning of the torque transients passes with approximately constant mean value of torque while speed is small, but increasing speed develops load torque, proportional to speed square and finally, when they become equal, the speed of motor reaches the steady state value.

Conclusions

1. The Simulink model of the variable speed drive with ventilator load was developed. Simulation results are compared with experimental ones.

2. Smooth starting with chosen reference speed ramp 600 rpm/s at no load gives both the maximum torque and the current less than rated those.
3. Speed steady- state error of the drive with ventilator load is equal approximately to 10%.
4. Shorter starting time can be achieved with greater speed reference ramp slope.
5. Speed error can be reduced by using closed loop system speed feedback or field control systems.

Acknowledgement

This work was supported by the Lithuanian State Science and Studies Foundation under High-tech development program project B – 13/2008.

References

1. **Bose B. K**. Modern Power Electronics and AC Drives. Prentice Hall PTR, 2001.
2. **Petrovas A., Lisauskas S., Batkauskas V., Baškys A.**Variable Speed Drive Controlled by Special Algorithm // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 4(68). – P 59–61.
3. **Rinkevičienė R., Baškys A., Petrovas A.** Model of Simulation of Dynamic characteristics of the System Frequency Converter –AC Induction motor // Electronics and Electrical Engineering, 2008. – No. 2(82). – P. 65–68.
4. **Rinkevičienė R., Batkauskas V.** Modelling and Investigation of Vector Controlled Induction Drive // Electronics and Electrical Engineering, 2008. – No. 1(81). – P. 53–56.
5. **Rinkevičienė R., Petrovas A., Batkauskas V., Baškys A.** Dynamics of variable speed drive. The 18th International Conference „Electromagnetic disturbances EMD‘2008“ Proceedings. – P. 229–232.

Received 2009 03 27

R. Rinkevičienė, A. Petrovas. Modelling of Frequency Controlled Induction Drive with Ventilator Type Load // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 69–72.

The great number of induction motors, controlled by frequency converters, is employed in pumps, fans and blowers. Their operation develops ventilator load of the motor. For matching dynamic characteristics of motor, load and converter, Simulink model of frequency controlled drive with smooth starting was developed and simulation results were analyzed .Simulation results were compared with experimental ones. Investigation of transients in the system with scalar control indicates good matching experimental and simulation results. Average torque value during starting at no load approximately is constant at assumed acceleration 600 rpm/s The maximum torque and current values at beginning of starting do not exceed rated those. Simulation of the drive with ventilator load at smooth starting and chosen ramp indicates the maximum torque value not exceeding rated that at the beginning of the starting transients. Afterwards the torque rises as the load increases with speed square. Steady-state speed error corresponds to 10% in the open loop system. For greater accuracy closed loop control system with speed feedback or vector control systems should be used. Ill. 7, bibl. 5 (in English; abstracts in English, Russian and Lithuanian).

Р. Ринкявичене, А. Петровас. Моделирование частотного привода при вентиляторной нагрузке // Электроника и электротехника. – Каунас: Технология, 2009. – № 6(94). – С. 69–72.

Большое количество асинхронных двигателей используется в приводах насосов, вентиляторов, дымоотводов. Все они создают нагрузку вентиляторного типа для двигателя. Для исследования динамических характеристик двигателя, инвертора и нагрузки была разработана Simulink модель с плавным пуском. Результаты симуляции были сравнены с достаточно хорошо совпадающими экспериментальными результатами. Среднее значение пускового момента и тока, при заданном ускорении 600 об/мин/с, не превышает номинальных значений. Дальше, с увеличением нагрузки, момент увеличивается до установившегося значения. Отклонение скорости от заданного значения составляет 10 %. Для большей точности желательно использовать системы с обратной связью, или системы векторного управления. Ил. 7, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Rinkevičienė, A. Petrovas. Dažninės pavaros su ventiliatorine apkrova modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 6(94). – P. 69–72.

Siurblių, ventiliatorių, pūtimo įrenginių elektros pavarose naudojama daug asinchroninių elektros variklių. Šie įrenginiai sukuria ventiliatorinę apkrovą. Variklio, dažnio keitiklio ir apkrovos dinaminėms charakteristikoms tirti buvo sudarytas dažninės pavaros sklandaus paleidimo *Simulink* modelis. Imitacijos rezultatai buvo palyginti su gana gerai sutampančiais eksperimentiniais rezultatais. Vidutinė neapkrauto variklio sukuriamo momento vertė sklandaus paleidimo metu, esant nustatytam pagreičiui 600 aps/min/s, neviršija nominaliosios vertės. Pavaros su ventiliatorine apkrova momentas, esant nustatytam pagreičiui 600 aps/min/s , paleidimo metu neviršija nominaliosios momento ir srovės verčių. Didėjant apkrovai, momentas didėja ir įgauna nusistovėjusią vertę. Statinė greičio paklaida siekia 10 %. Greičiui tiksliau nustatyti reikia naudoti uždarąją greičio reguliavimo sistemą arba vektorinio valdymo būdus. Il. 7, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).