ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2011. No. 3(109)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 125 AUTOMATION, ROBOTICS
AUTOMATIZAVIMAS, ROBOTECHNIKA

Induction Motor Voltage Amplitude Control Technique based on the Motor Efficiency Observation

V. Bleizgys, A. Baskys, T. Lipinskis
Center for Physical Sciences and Technology,
A. Gostauto 11, LT- 01108 Vilnius, Lithuania, phone +370 5 2613989, e-mail: mel@pfi.lt
Faculty of Electronics, Vilnius Gediminas Technical University,
Naugarduko str. 41, LT-03227, Vilnius, Lithuania; phone: +370 5 2744767, e-mail: algirdas.baskys@vgtu.lt

Introduction

The main problem in control of AC induction motor speed is control of amplitude of AC voltage provided by the frequency converter. There are two widely used amplitude control methods: scalar and vector control [1–7].

The scalar control is based on the steady–state model of motor. The linear law of voltage amplitude control (ratio amplitude to phase frequency U_A / f_p = const) should be applied to keep the magnetizing flux of the motor practically unchanged according this model. This allows us to keep the torque of the motor nearly independent on the motor velocity. The scalar control is used when the motor load is approximately independent on motor speed or if load dependence on speed is known in advance.

If the motor load changes randomly and the fast response is needed the vector control is used. It is based on the dynamic model of the motor. The instant values of speed and flux of motor should be measured for full realization of vector control. However, it is complicated to provide these measurements [8]. Therefore, if the control of motor is not relevant at very low speed, the sensorless method of vector control can be used [1, 3].

The equations of motor dynamic model must be solved and the data for calculations should be extracted from the motor phases current transients in real time for realization of sensorless vector control. Because of this, complex algorithms must be applied and, as consequence, expensive high performance DSP should be employed for vector control realization [6].

In this work we would like to present some alternative for vector control. The proposed method is based on the observation of motor phase current amplitude instant value. The amplitude of voltage is controlled in real time in such a way that for the given instant motor load and speed the instant phase current amplitude would be minimal (the efficiency of the motor would be maximal). The realization of this method of voltage amplitude control is less complicated as compared to vector control. It is enough to measure the motor phase current amplitude and to find in the real time the amplitude of voltage, at which phase current at given instant motor load and speed is minimal. The proposed motor supply voltage amplitude control method is relevant because the efficiency of motor is one of the main characteristics of electric motor drives [9–11].

Investigation of the inverter and motor phase current

The experimental investigation of the inverter DC current (I_{DC}) and motor phase current amplitude (I_P) on amplitude of voltage supplied by the frequency converter (U_A) was provided to obtain the initial data for development of U_A control technique. The experimental example of the frequency converter developed in Center for Physical Sciences and Technology was used for this purpose. The block diagram of the frequency converter is given in Fig.1. It contains rectifier, which converts standard 3 phase AC voltage to DC voltage, and inverter that converts DC voltage to variable frequency variable amplitude 3 phase AC voltage for motor supply. The

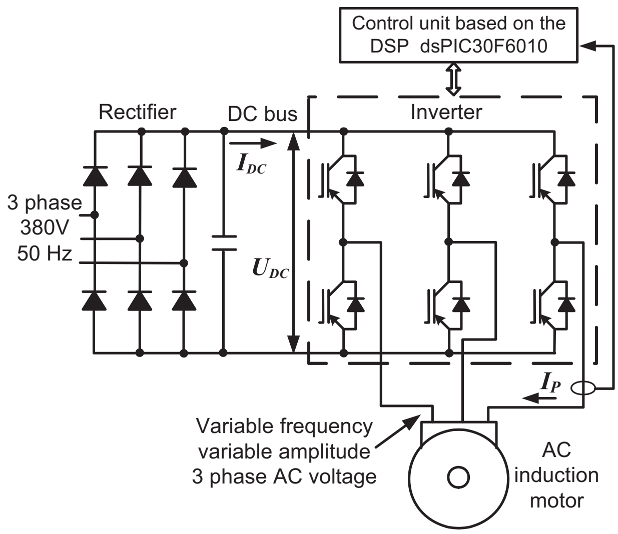

Fig. 1. The block diagram of frequency converter

control unit controls the operating of the frequency converter and implements the Space Vector Pulse Width Modulation (SVPWM) method [2, 3] for switching of inverter transistors.

The maximal efficiency of the motor supplied by the frequency converter at given motor load and speed corresponds to minimal I_{DC}, which is taken from the DC bus by inverter (Fig.1). The experimental dependences of I_{DC} and I_P on the U_A for various phase frequency (f_p) (for various speed of motor) and motor load torque values are presented in Fig. 2. The results are obtained for 4 kW (speed 2900rpm at f_p =50Hz) AC induction motor. A special test bench was used for this purpose. It includes the AC induction motor fed from the frequency converter. The motor drives the 5.5 kW DC generator, which acts as the motor load. The test bench includes the motor load torque and rotation velocity sensors. The investigation results show that the I_{DC} and I_P become minimal practically at the same U_A value. Therefore, the minimal value of I_P can be used as criterion for the estimation of U_A, at which the motor efficiency is maximal. This is more convenient for U_A control realization because the I_P dependence minimum is expressed stronger as compared to I_{DC} minimum (Fig. 2).

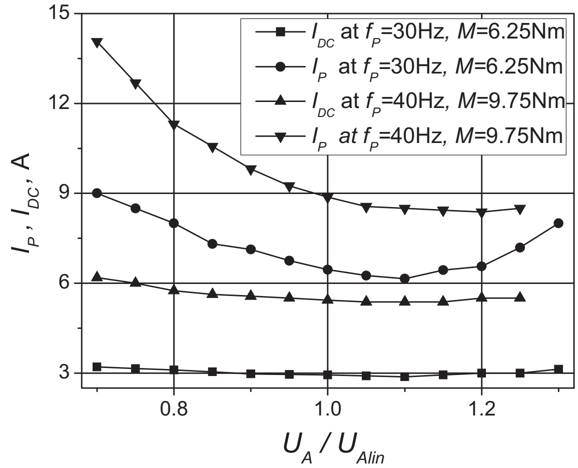

Fig. 2. The dependences of the inverter DC bus current and motor supply phase current amplitude on the relative voltage amplitude at various phase frequency (at various motor speed) and motor load torque. The $U_{A\ lin}$ is the amplitude of voltage required by the linear voltage amplitude control law

The experimental dependences of I_P on the relative value of U_A for various motor load torque values at f_p=30Hz (at 1700 rpm motor speed) are presented in Fig. 3. It is seen that the U_A value, at which I_P is minimal and, consequently, motor efficiency is maximal, depends strongly on motor load torque.

The dependences of the relative value of U_A on the motor load torque, which correspond to minimal I_P (maximal motor efficiency), for various f_p (various motor speed) are given in Fig.4. The control algorithm employed in the frequency converter should guarantee the variation of U_A in accordance with these dependences.

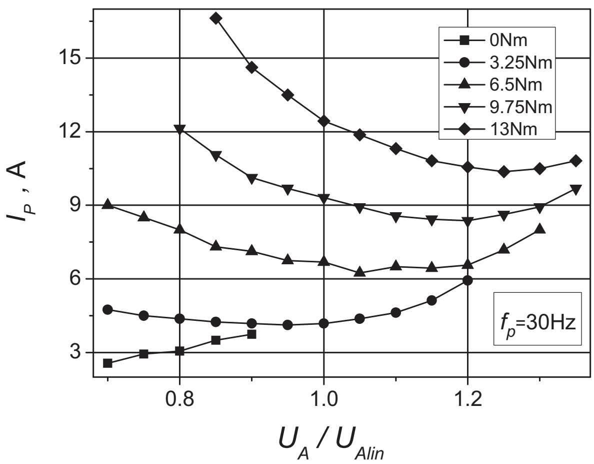

Fig. 3. The dependences of the motor supply phase current amplitude on the relative voltage amplitude at f_p=30Hz and various motor load torque values

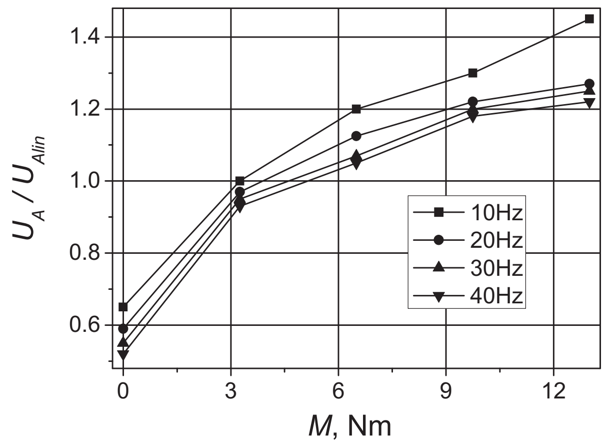

Fig. 4. The dependences of the relative motor supply voltage amplitude, which correspond to minimal motor phase current amplitude, on motor load torque at various phase frequencies

Motor supply voltage amplitude control algorithm

The purpose of the U_A control is to keep the U_A value, at which the efficiency of the motor is close to maximal, i.e., at which the I_P would be close to minimal. The results obtained during the experimental investigation show that I_P depends strongly on motor load and speed and has the only minimum (Figs. 2 and 3). The single variable optimization problem should be solved continuously in the real time. The aim of the optimization is to select the value of U_A=U_{Aopt} from the Q region of possible values, at which

$$I_p\left(U_{\mathrm{Aopt}}\right) = \min_{U_{\mathrm{A}} \in Q} I_p\left(U_{\mathrm{A}}\right). \quad (1)$$

The range of possible values of U_A is split up in to the zones with the even width ΔU_A (Fig. 5). There are n zones where $U_A < U_{A0}$ and m zones where $U_A \geq U_{A0}$.

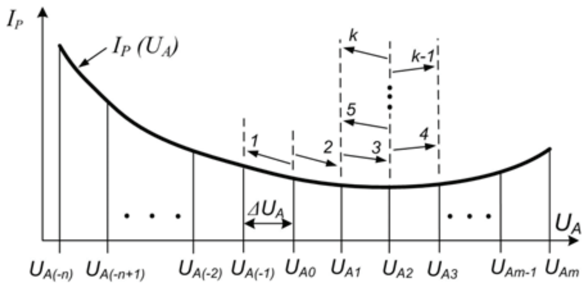

Fig. 5. The algorithm of phase current amplitude minimum search

The developed algorithm of function $I_P\ (U_A)$ minimum search is as follows:

$$\begin{cases} Step\ 1 \quad set\ \ j=0, \\ Step\ 2 \quad if\ \ I_P(U_{A\,j-1}) \geq I_P(U_{A\,j})\ \ and\ \ j<m, \\ Step\ 3 \quad increment\ \ j\ \ by\ \ 1\ \ and\ \ goto\ \ Step\ 2, \\ Step\ 4 \quad else\ \ decrement\ \ j\ \ by\ \ 1, \\ Step\ 5 \quad if\ \ I_P(U_{A\,j}) \leq I_P(U_{A\,j+1})\ \ and\ \ j>-n, \\ Step\ 6 \quad decrement\ \ j\ \ by\ \ 1\ \ and\ \ goto\ \ Step\ 5, \\ Step\ 7 \quad else\ \ goto\ \ Step\ 3, \end{cases} \tag{2}$$

where $j = -n, -n+1, \dots, -2, -1, 0, 1, 2, \dots, m-1, m$.

The initial value $U_A = U_{A0}$ for function $I_P(U_A)$ minimum search using algorithm (2) corresponds to the value of U_A obtained at given f_p for linear control law (for law U_A/f_p=const). The U_A in the proposed algorithm has only discrete values with ΔU_A discreteness (Fig 5). First of all, the values of I_P at $U_A = U_{A0}$ and $U_A = U_{A(-1)}$ are measured and compared according the algorithm (2) (move 1 in Fig. 5), i.e. the gradient of function is tested moving to the left. Since the function increases, the movement direction is changed and values of I_P at $U_A = U_{A1}$ (move 2 in Fig. 5), $U_A = U_{A2}$ (move 3) and $U_A = U_{A3}$ (move 4) are measured. The increment of function during the 4th move is registered, therefore, the minimum of function is in range $U_{A1} < U_A < U_{A3}$. The algorithm changes the movement direction (makes move 5) and after that cyclically repeats moves 4 and 5. If the motor operating conditions (load torque, speed) changes and function minimum moves out of range $U_{A1} < U_A < U_{A3}$, the algorithm (2) seeks again the function minimum in the same way.

Implementation and investigation of the motor supply voltage amplitude control algorithm

The proposed motor supply voltage amplitude control algorithm (2) was employed in the experimental example of the frequency converter, which implements the SVPWM method for the three phase variable frequency and amplitude voltage forming. It was realized using DSP dsPIC30F6010. The isolation amplifier with short circuit and overload detection HCPL788J was employed for measurement of the phase current. The investigation of the developed algorithm was performed using the test bench and AC induction motor mentioned in this paper previously. The width of zone ΔU_A =0.03U_{A0} was chosen for the realization of the algorithm. The discrete change of U_A values and measurement of I_P was provided every 0.5s during the function $I_P\ (U_A)$ minimum search, i.e. the U_A change discreetness in time Δt=0.5s. The measurement of I_P was not reliable if Δt<0.5s. The reason is that the response of the I_P measurement circuit output to I_P change is slow due to the low-pass filter, which is essential because of the high EMD produced by the inverter.

The response of the I_P to motor load torque pulse change for the case when the proposed U_A control method is employed is given in Fig.6a. The obtained transients are compared to the transients gained using linear control of U_A (Fig.6b). They show that the developed U_A control method guarantees lower steady state value of I_P, i.e. higher motor efficiency as compared to the case when linear control of U_A is used. Additionally, it provides lower load torque overshoot and, as a consequence, lower AC induction motor drive overload during the instant load torque increment. On the other hand, it is seen that the I_P overshoot is higher and has longer duration in the case when proposed control method is employed (compare transients given in Figs.6a and 6b). Consequently, the proposed U_A control method based on the I_P observation can be used effectively in the situations when the fast response of the motor supply voltage is not needed.

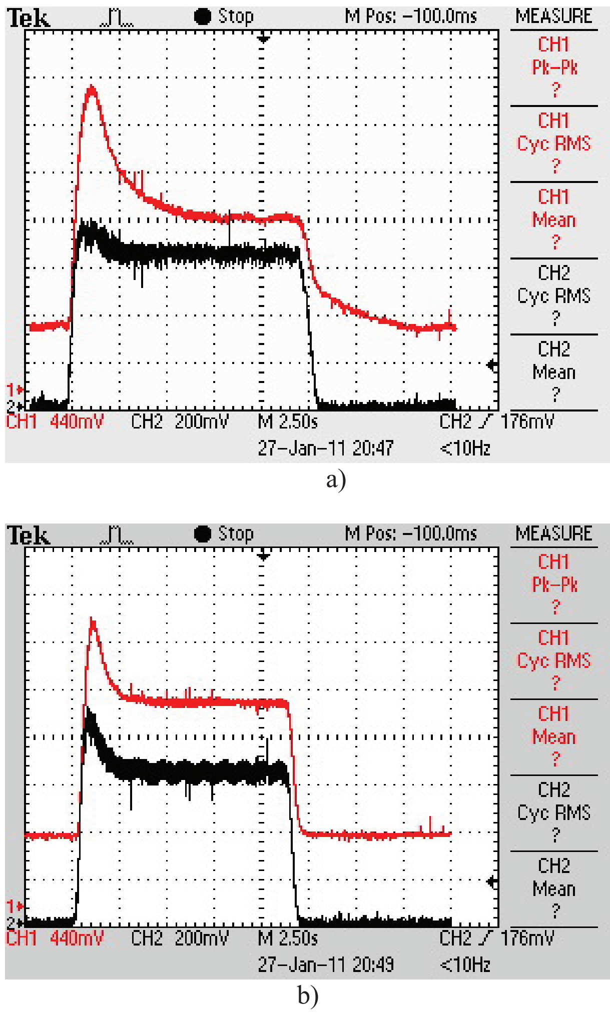

Fig. 6. The response oh the motor phase current amplitude (upper curves, 1div =2.5A) to pulse change of motor load torque (bottom curves, 1div = 4Nm) when motor supply voltage amplitude control based on the motor phase current amplitude observation (a) and linear amplitude control (b) are applied. The transients are obtained at 30 Hz phase frequency

Conclusions

The proposed AC induction motor supply voltage amplitude control algorithm, which is some alternative for the vector control, allows us to vary the amplitude automatically in such a way that the efficiency of the motor at given motor load torque and rotation speed would be maximal. The realization of the algorithm is more simple and cheap as compared to the vector control algorithms. However, the developed algorithm can be applied if the fast response of the motor supply voltage amplitude is not needed.

Acknowledgement

The authors would like to thank Ph.D. student of Vilnius University Mr. Andrius Bleizgys for help in creating of program for data processing.

References

1. **Kazmierkowski M. P., Krishnan P., Blaabjerg F.** Control in Power Electronics. Selected Problems. – Elsevier Science, 2002. – 627p.
2. **Baskys A., Bleizgys V., Gobis V.** The impact of output voltage modulation strategies on power losses in inverter. //Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 47–50.
3. **Neacsu D.** Space Vector Modulation // Proceedings of the 27th Annual IEEE Industrial Electronics Society Conference. – Denver, 2001. – P. 1583–1592.
4. **Rinkevičienė R., Batkauskas V.** Influence of the Inverter Boost Voltage on the Transients of Variable Speed Drives //Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 4(92). – P. 75–78.
5. **Valentine R.** Motor Control Electronics Handbook. – McGraw–Hill, 1998. – 754 p.
6. **Mehrizi–Sani A., Filizadeh S., Wilson P. L.** Harmonic and Loss Analysis of Space–Vector Modulated Converters // Proceedings of the Int. Conference on Power Systems Transients IPST'07. – Lyon, 2007. – P. 1–6.
7. **Petrovas A., Lisauskas S., Batkauskas V., Baskys A.** Variable Speed Drive Supplied by the Voltage Formed using Special–purpose Algorithm // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 7(87). – P. 53–56.
8. **Grouni S., Ibtiouen R., Kidouche M., Touhami O.** Real Time Rotor Flux Estimation for Induction Machine Drives: an Experimental Approach // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 8(104). – P. 69–72.
9. **Jankūnas V., Eidukas D., Guseinovienė E., Cirtautas V.** Investigation of Supply Posibilities of Mechatronic Actuator // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 5(93). – P. 25–28.
10. **Bleizgys V., Baskys A.** The Influence of Supply Voltage Amplitude Variation Law on AC Induction Motor Efficiency in Variable–Speed Drive // Solid state phenomena, 2010. – Vol.164. –P. 1–4.
11. **Aghion C., Ursaru O., Lucanu M.** Three–Phase Motor Control using Modified Reference Wave // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 3(99). – P. 35–38.

Received 2011 02 08

V. Bleizgys, A. Baskys, T. Lipinskis. Induction Motor Voltage Amplitude Control Technique based on the Motor Efficiency Observation // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 3(109). – P. 89–92.

The technique of voltage amplitude control of AC induction motor supplied by the frequency converter has been proposed. It is based on the observation of motor phase current amplitude value. The amplitude of motor supply voltage is controlled in real time in such a way that for given instant motor load and speed the phase current amplitude would be minimal, i.e. the efficiency of the motor would be maximal. The realization of this method of voltage amplitude control is less complicated as compared to vector control. It is enough to provide the continuous measurement of motor phase current amplitude and to find in the real time the amplitude of voltage, at which phase current amplitude is minimal. The proposed technique can be applied in the situations when the fast response of the motor supply voltage amplitude is not needed. The developed technique has been investigated experimentally using special test bench. Ill. 6, bibl. 11 (in English; abstracts in English and Lithuanian).

V. Bleizgys, A. Baškys, T. Lipinskis. Asinchroninio elektros variklio įtampos amplitudės valdymo metodas, pagrįstas variklio naudingumo veiksnio stebėjimu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 3(109). – P. 89–92.

Pateikiamas asinchroninio elektros variklio, maitinamo dažnio keitiklio, įtampos amplitudės valdymo metodas. Jis remiasi variklio srovės amplitudės stebėjimu. Variklio maitinimo įtampos amplidudė valdoma realiu laiku, taip, kad, esant tam tikrai variklio apkrovai ir greičiui, srovės amplitudė būtų minimali, t. y. variklio naudingumo veiksnys būtų maksimalus. Toks variklio įtampos amplitudės valdymas yra paprastesnis nei vektorinis valdymas. Tam pakanka nepertraukiamai matuoti variklio srovės amplitudę ir realiu laiku nustatyti, kokia turėtų būti įtampos amplitudė, kad, esant tam tikriems variklio apkrovai ir greičiui, srovės amplitudė būtų minimali. Metodas taikytinas, kai nebūtina, kad variklio maitinimo įtampos amplitudė sparčiai keistųsi. Sukurtas metodas ištirtas eksperimentiškai, naudojant specialų tyrimo stendą. Il. 6, bibl. 11 (anglų kalba; santraukos anglų ir lietuvių k.).