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The Frequency Converter Output Voltage Control with Motor Current Minimum Tracing

The new method of frequency converter output voltage amplitude control based on the tracing of minimum value of AC induction motor phase current amplitude has been proposed. The voltage amplitude is controlled in real time in such a way that for a 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 the developed method is less complicated comparing to vector control. It can be applied in the situations when motor load changes randomly and the fast response of the motor supply voltage amplitude is not needed.

Keywords: *AC induction motor, motor current, supply voltage amplitude, real time control, frequency converter, observation of current amplitude.*

Introduction

The main problem in control of AC induction motor speed using frequency converter is control of amplitude of AC voltage provided by the converter. There are two widely used amplitude control methods: scalar and vector control [1–5].

The scalar control is based on the steady–state model of motor. The linear law of 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 of motor is used. The vector control 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 [6]. 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 [1]. Because of this, complex algorithms must be applied and, as consequence, ex-

pensive high performance DSP should be employed for vector control realization [5].

In this work we would like to present some alternative for vector control. The proposed method is based on the tracing 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 [7, 8].

1. Investigation of the inverter and motor phase current

The experimental investigation of the inverter DC current (IDC) and motor phase current amplitude (IP) on amplitude of voltage supplied by the frequency converter (UA) was provided to obtain the initial data for development of UA control method. 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 control unit controls the operating of the frequency converter and implements the Space Vector Pulse Width Modulation (SVPWM) method 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 IDC, which is taken from the DC bus by inverter (Fig. 1). The experimental dependences of IDC and IP on the UA 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 2900 rpm at $f_p = 50 Hz$) 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 IDC and IP become minimal practically at the same U_A value. Therefore, the minimal value of IP corresponds to maximal efficiency of motor. The measurement of IP is convenient for U_A control realization because the IP dependence minimum is expressed stronger as compared to IDC minimum (Fig. 2).
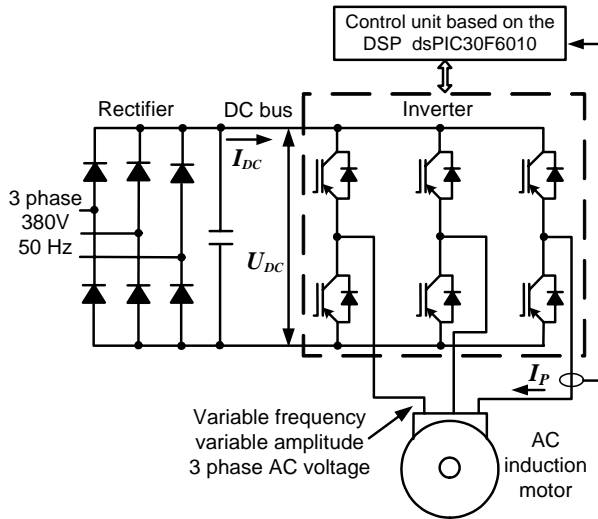

Fig. 1. The block diagram of frequency converter

The experimental dependences of IP 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 IP minimum and, consequently, motor efficiency maximum depend strongly on U_A.

The dependences of the relative value of U_A on the motor load torque, which correspond to minimal IP, for various fp (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.

2. Frequency converter output voltage amplitude control algorithm

The purpose of the U_A control is to keep the U_A value, 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 this optimization is to select the value of $U_A=U_{Aopt}$ from the Q region of possible values, at which

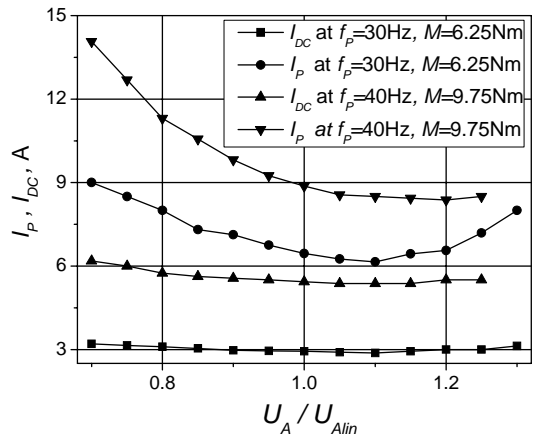$$I_P(U_{Aopt}) = \min_{U_A \in Q} I_P(U_A) \qquad (1)$$

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
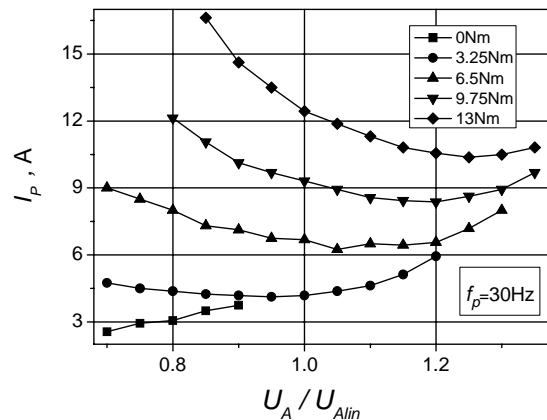

Fig. 3. The dependences of the motor supply phase current amplitude on the relative voltage amplitude at $f_p = 30Hz$ 0and various motor load torque values
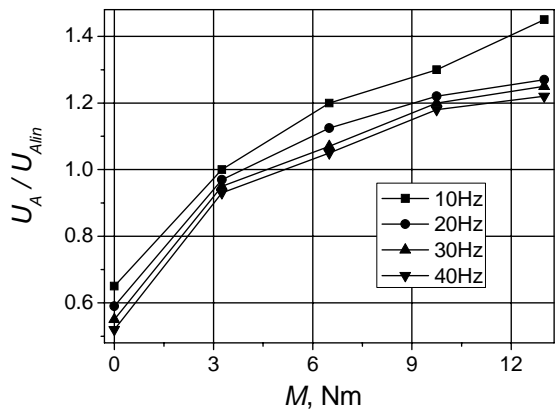

Fig. 4. The dependences of the relative motor supply voltage amplitude, which correspond to minimal motor phase current amplitude, at various phase frequencies

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 $U_A \geq U_{A0}$.
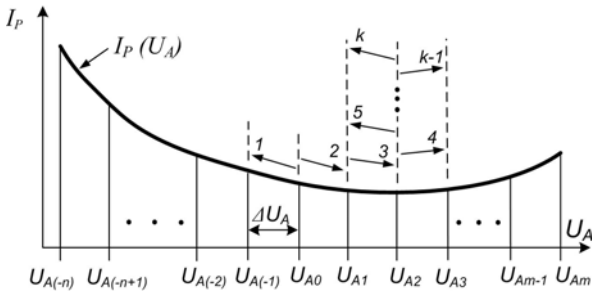

Fig. 5. The algorithm of phase current amplitude minimum search

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

Step 1 set $j = 0$,

Step 2 if $I_P(U_{Aj-1}) \geq I_P(U_{Aj})$ and $j < m$,

Step 3 increment j by 1 and goto *Step* 2,

Step 4 else decrement j by 1,   (2)

Step 5 if $I_P(U_{Aj}) \leq I_P(U_{Aj+1})$ and $j > -n$,

Step 6 decrement j by 1 and goto *Step* 5,

Step 7 else goto *Step* 3,

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

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 $U_A = U_{A1}$ (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.

## 3. Implementation and investigation of the frequency converter output voltage amplitude control algorithm

The proposed frequency converter output voltage amplitude control algorithm (2) was employed in the experimental example of the frequency con-verter, which implements the SVPWM method for the three phase variable frequency and variable 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 $\Delta U_A = 0.03U_{A0}$ 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 discreteness in time $\Delta t = 0.5$s. The measurement of I_P was not reliable if $\Delta t < 0.5$s. 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.
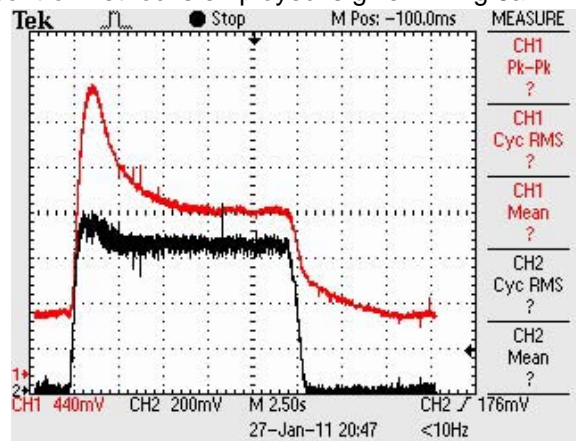
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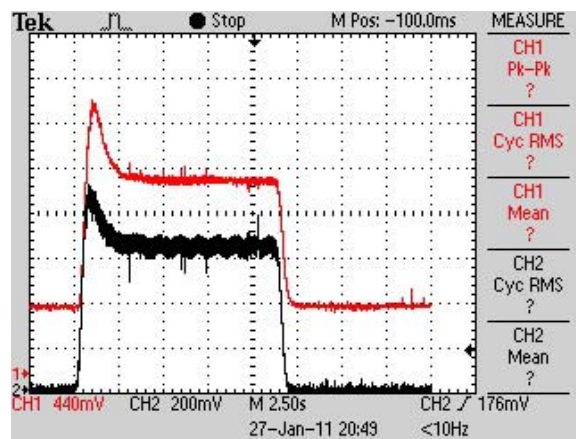
b

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 minimum tracing (a) and linear amplitude control (b) are applied. The transients are obtained at 30 Hz phase frequency

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 minimum observation can be used effectively in the situations when the fast response of the motor supply voltage is not needed.

Conclusion

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

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