ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN: 1584 - 2665

POWER FACTOR DETERMINATION OF INDUCTION MOTOR FREQUENCY CONTROLLED DRIVES

Ivan KOSTOV, Vania RANGELOVA

Technical University Sofia – Branch Plovdiv, BULGARIA

ABSTRACT
Some methods for determining the power factor in frequency controlled induction motor drives are analyzed. A novel approach is proposed for power factor determination only by measuring the stator currents and by using support frequency, equal to the frequency of the stator voltage without measuring this voltage. The approach is simple and can be described in an elegant mathematical way. The effectiveness of the approach is confirmed by software simulation experiments.
KEY WORDS
power factor measurement, induction motor, vector control, scalar control, IR-compensation.

1. INTRODUCTION

In frequency controlled drives very often is necessary to be known the magnitude of the power factor (PF) of the induction motors. It is important when are designing optimal on PF frequency controlled drives and for building of stabilization systems of magnetic flux in the air gap of the motor with the help of the vector IR - compensation [1,2,3]

Power factor is defined by IEEE and IEC as the ratio of true power to apparent power: PF = W/VA. In that way it is possible to read simultaneously phase difference between loading voltage and current as well as their shape. Cos(φ) is determined like phase difference between primary harmonics of the loading voltage and current. Power factor is more common parameter. In circuits where voltages and currents are not sinusoidal, power factor is not equal to cos(φ) determined like phase difference between primary harmonics of the voltage and current. In those case it is very important to determine corectlly PF. Non sinusoidal signals have in the following cases:

- non linear loads
- high – power equipment with three phase rectifiers
- single - phase equipment with rectifiers
- sources with non sinusoidal waveform

It is important to measure and control the power factor on two basic reasons. The first one, bad PF demand more power of the loading source. The second, distortion of the current shape not only decreasing PF but cooperate for increasing of the heater losses in the loading line [4].

In the case of controlled drives with sinewave loading the PF and cos(φ) quantitative coincide, in the frequency controlled drives but between them have difference. Typical feature of those frequency controlled drives is that phase, magnitude and angular frequency of the stator voltage are known in advance. The stator current is measured continuously [5].

All that gives opportunity to precise the power factor of induction motors which are supplied with frequency converters with only measuring the phase stator currents. In the paper is given one method of its determining.

2. METHODS FOR POWER FACTOR DETERMINATION

First method. In those case is used the principle for measurement of the time difference between zero values of the stator voltage and current. For these method are typically the difficulties of determining of zero values of the stator current, especially for the low modulating frequencies.

At fig.1 is shown the form of the stator current at low modulating frequence with the parameters of the induction motor model acording to Appendix 1. Despite the regime is not typical it shows the special fault of those method of determining the power factor. Measurement of the PF with its help is not proper for the systems with high dynamic qualitative indices.

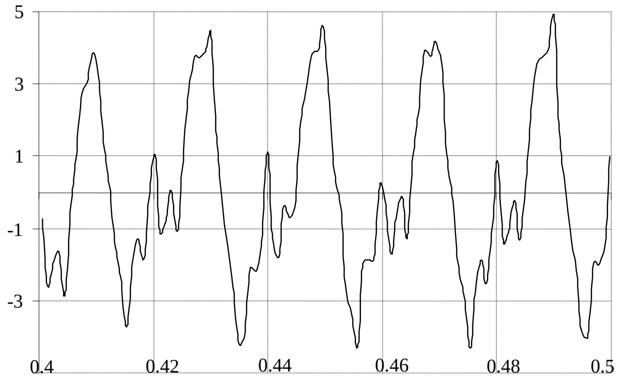


Figure.1. Stator current change of the induction motor at step changing of the load until nominal. *f_{sn}=50Hz; modulating frequency f_m=200Hz; t, s; i_a, A* .

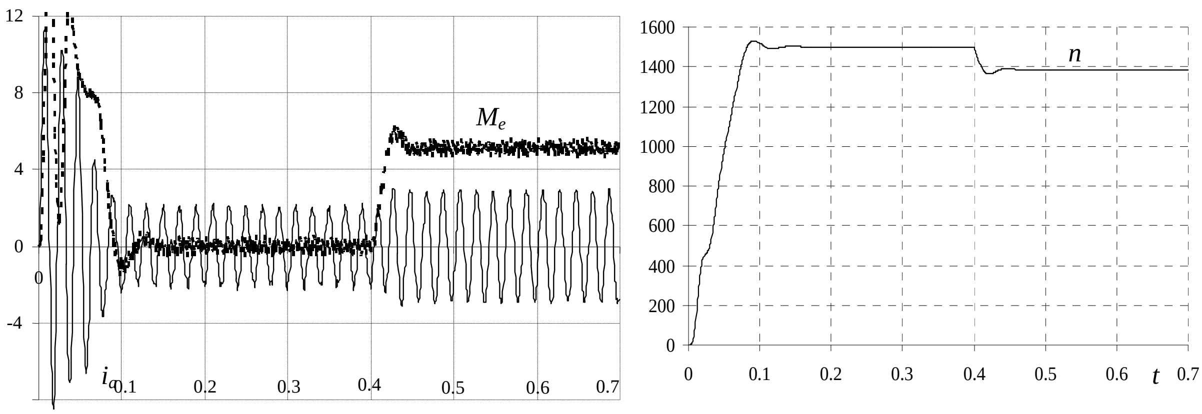
Second method. It is used the formulae for the determining of the angle between two vectors **a** and **b** in plane [5]

$$\cos(a,b)=\frac{a_x b_x + a_y b_y}{\sqrt{a_x^2+a_y^2}\sqrt{b_x^2+b_y^2}}. \tag{1}$$

For the space vectors of the stator current and voltage (1) will be transform in the following way

$$\cos(u,i)=\cos(\varphi)=\frac{u_x i_x + u_y i_y}{\sqrt{u_x^2+u_y^2}\sqrt{i_x^2+i_y^2}}=\frac{P}{S}=\mathrm{PF}. \tag{2}$$

That expression give the connection between the projection of the space vectors of the stator voltage and current, true and apparent power and power factor. Its value doesn't depend of the kind of the space frame of reference - unmovable, synchronous moving with the stator or synchronous moving with the rotor.



i ii

Figure.2a. Transient processes of the electromagnetic moment, stator current (i) and velocity (ii) of the induction motor at starting, at no load and load regimes. *f_{sn}=50Hz; modulating frequency f_m=2kHz; t,s; M_e, Nm; i_a, A; n, r/min.*

When the frame of reference is orientated on module of the supply voltage, the expression (2) is transforming in

$$\cos(u,i)=\cos(\varphi)=\frac{i_x}{\sqrt{i_x^2+i_y^2}}=\frac{P}{S}=\mathrm{PF}. \tag{2a}$$

At fig.2a are shown the transient processes of the electromagnetic moment M_e and stator current i_a at starting of the induction motor with squirrel-cage rotor with parameters according to Appendix 1. Processes are simulated in Simulink medium for motor without saturation and without losses in the steel, with sinusoidal pulse width modulation (PWM)

At fig.2b are shown the transient processes for the velocity at the same conditions. At fig.2b is shown changing of the PF at the same conditions with using of (2). In that case it is observed some noise in the last results, which is restricted from first order low-pass filter with timeconstante T_F. Presence of noise in the measured value is connected with non-sinusoidal character of the load voltage and the quantization step of smiling program. Smaller step gives better results.

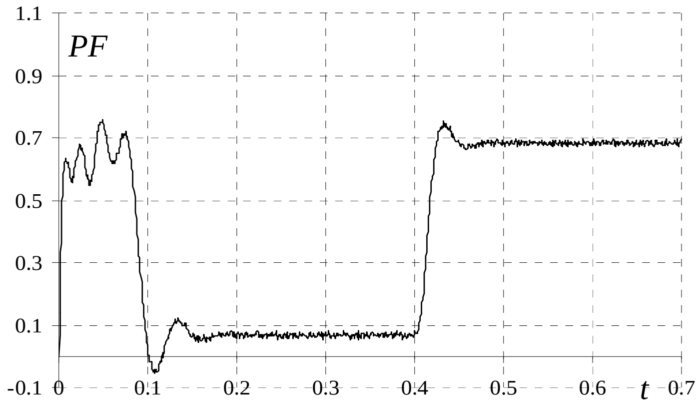


Figure.2b. Power factor change of the induction motor at starting of no load and at load. *f_{sn}=50Hz; modulating frequency f_m=2kHz; T_F=5ms; t, s.*

That way of measurement of the PF has advantage that there is no need to measure the voltage and its angle frequency and phase. It is assumed that they are known in advance from the control of frequency transducer. Disadvantage of the method is the necessity that measuring part must be available with two-phase model of the electric machine. Those model often is find in the controlling part.

3. APPROACH FOR POWER FACTOR DETERMINING

It is interesting to find possibilities for determining the PF only with measuring the stator currents and with using the base frequency and phase, which are equal to frequency and phase of the loading voltage, but without measuring it. The base for that approach is consist in usage of expression (2a) for determining the PF.

It is consider T-replacing scheme of the asynchronous motor. Taking in mind that loading voltage is symmetrical, balanced 3 phase circuits, we look at the following time function (of two variables) of the stator current.

$$i_{ac}(t) = \sqrt{i_a(i_a + i_c) + i_c^2} \,. \tag{3}$$

Knowing the relation in the 3 phase symmetrical loading circuits [3,4]

$$i_a(t) = I_m \sin\omega t\,,\ i_b(t) = I_m \sin\left(\omega t + \frac{2\pi}{3}\right), i_c(t) = I_m \sin\left(\omega t + \frac{4\pi}{3}\right) \text{ и } i_a(t) + i_c(t) = -i_b$$

We can replace in (3)

$$i_{ac}(t) = \sqrt{i_a^2 + 2i_a i_c + i_c^2 - i_a i_c} = \sqrt{(i_a + i_c)^2 - i_a i_c} = \sqrt{(-i_b)^2 - i_a i_c} = \sqrt{i_b{}^2 - i_a i_c} \,. \tag{4}$$

$$i_{ac}(t) = I_m \sqrt{\left[\sin\left(\omega t + \frac{2\pi}{3}\right)\right]^2 - \sin(\omega t)\sin\left(\omega t + \frac{4\pi}{3}\right)} = I_m \sqrt{\sin^2\left(\omega t + \frac{2\pi}{3}\right) - \sin(\omega t)\sin\left(\omega t + \frac{4\pi}{3}\right)} \,. \tag{5}$$

We reduce the power of the sine and cosine [5], then (5) will be in the form

$$i_{ac}(t) = I_m \sqrt{\frac{1 - \cos\left(2\omega t + \frac{4\pi}{3}\right)}{2} - \frac{1}{2}\left[\cos\left(-\frac{4\pi}{3}\right) - \cos\left(2\omega t + \frac{4\pi}{3}\right)\right]} \,. \tag{6}$$

After some simple reforms it is received

$$i_{ac}(t) = I_m \sqrt{\frac{1}{2} + \frac{1}{2}\frac{1}{2}} = I_m \sqrt{\frac{3}{4}} = I_m \frac{\sqrt{3}}{2} = \sqrt{2} I_s \frac{\sqrt{3}}{2} = I_s \frac{\sqrt{3}}{\sqrt{2}} = I_s \sqrt{\frac{3}{2}} = i_{ac}(t) \,. \tag{7}$$

With equalizing (7) and (3) the last results is

$$I_s = \sqrt{\frac{2}{3}}\,\sqrt{i_a(i_a + i_c) + i_c^2}\,. \qquad (8)$$

That expression shows that root mean square value of the stator current can be measured continuously with continuously measuring of two from three phase sinusoidal currents. The value of PF can be find with the help of transformation, known like complex vector of the real variable. The complex vector is defined

$$\underline{i}_s = i_a + e^{j\frac{2\pi}{3}} i_b + e^{j\frac{4\pi}{3}} i_c\,. \qquad (9)$$

With using of synchronous frame of reference and transformation

$$\underline{i}_s^{xy} = I_m e^{j\varphi} = \frac{3}{\sqrt{2}} I_s\left(\cos(\varphi) + j\sin(\varphi)\right) = I_{s(Re)} + jI_{s(Im)}\,. \qquad (10)$$

From (10) it is follows that $I_{s(Re)} = \frac{3}{\sqrt{2}} I_s \cos(\varphi)$ and therefore

$$\cos(\varphi) = \frac{\sqrt{2}}{3}\frac{I_{s(Re)}}{I_s} = PF \qquad (11)$$

The last expression is development of (2a) with the help of space vector of stator current, but expressed with its root mean square value

The next step is to be transformed the variables in (11) like continuously functions of the time. For the numerator in (11) it happens with the help of transformation

$$I_{s(Re)} = \sqrt{3}\left[i_a \sin\left(\omega t - \frac{\pi}{6}\right) - i_c \cos(\omega t)\right] \text{ (Appendix 2).} \qquad (12)$$

For the denominator the (11) is used (8). From all it is, follows

$$\cos(\varphi) = \frac{\sqrt{2}}{3}\,\frac{\sqrt{3}\left[i_a \sin\left(\omega t - \frac{\pi}{6}\right) - i_c \cos(\omega t)\right]}{\sqrt{2/3}\sqrt{i_a(i_a + i_c) + i_c^2}} = \frac{i_a \sin\left(\omega t - \frac{\pi}{6}\right) - i_c \cos(\omega t)}{\sqrt{i_a(i_a + i_c) + i_c^2}} = PF \qquad (13)$$

The last expression proved principle opportunities for determining the PF with continuously measuring and functional treatment in the time of two from three stator currents. Advantage of the proposed method is the opportunity for measuring with usage of the information for values of two form three stator currents and frequency of the output voltage of the frequency transducer. In that way overcome the problems connected with the measuring of the first harmonic of the output voltage of the frequency transducer, which are typical for previous variants.

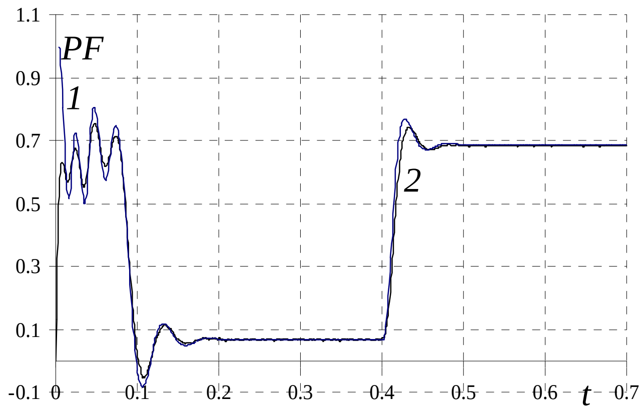


Figure.3. Power factor change from time at starting of the motor in no load and load regimes. *f_{sn}=50Hz; 1- sine wave load, no filter; 2-sine PWM, T_F=5ms.t, s.*

At fig.3 is shown changing of PF , defined with the help of (13) with models of electric drives in the Simulink area.

It is seen that shown at the figure results are almost the same like those from modeling in idealizing variant at the same figure with sinusoidal supply voltage.

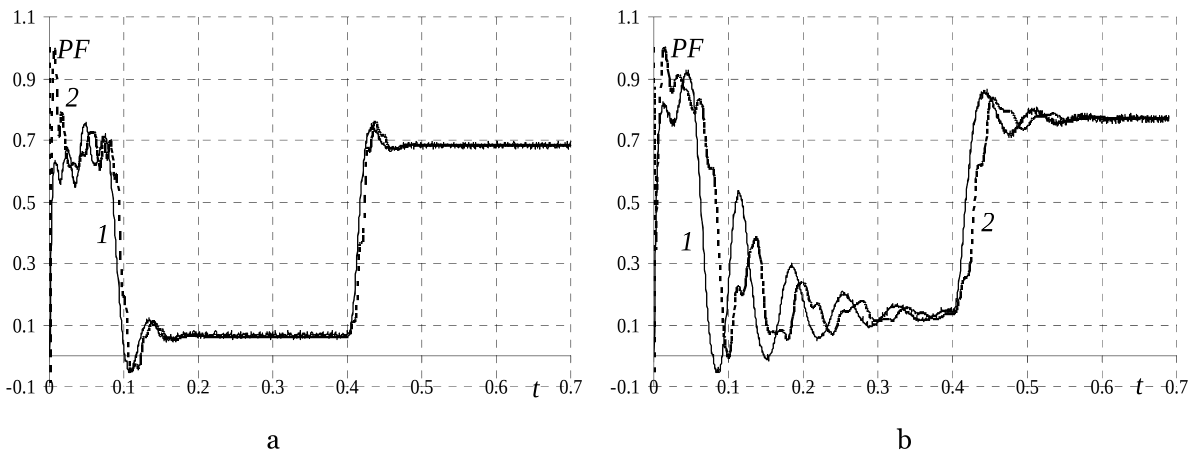


Figure.4. Power factor change from time at starting of the motor in no load and load regimes. *f_{sn}=50Hz (a) and for f_s =25Hz (b). 1- on (2) and on (13), 2- standard block for measuring of phase angle f_m=2kHz; T_F=5ms; t,s*

At fig.4 for the comparison are shown analogous characteristics, received on (2) and (13) for the different output frequencies f_s and f_{sn} of the transducer, compared with the proposed in the library of Simulnk proposals for measurement of phase angle. It is seen that with decreasing of the stator frequency is increasing the delay of measurement of library block, while the first two methods are give almost equal results, but determining of PF on (2) is more noisy with the comparison of that determining with (13).

4. CONCLUSION

In the paper is proved the opportunity of the power factor measurement of the power of asynchronous motors in frequency controlled drives with the help of space vector of stator current and is proposed approach for its determining with continuously measuring of two form three stator currents.

The approach is characterizing with very good noisy – resisting and better dynamic indexes from used. The quality are confirmed by means of modeling and simulating experiments. The propose approach can be use for the purpose of measuring, control, modeling and for training of specialists.

Appendix 1. Nominal data for the study motor

Type: T80B4AB3, P_N = 0.75 kW, U_N = 220 V, f_{sn} = 50 Hz, n_N = 1395min^{-1}, I_{sN} = 2.3 A; Z_p = 2, M_N = 5.13Nm, L_s = 0.026H, R_s = 10.2Ω, L_r = 0.061H, R_r = 10.52Ω, L_m = 0.457H, J_d = 0.0014×3 kgm^2.

Appendix 2. Determining the real space vector component of the stator current

$$\sqrt{3}\left[i_{as}\sin\left(\omega t-\frac{\pi}{6}\right)-i_{cs}\cos(\omega t)\right]=\sqrt{3}\left[I_m\sin(\omega t-\varphi)\sin(\omega t-\frac{\pi}{6})-I_m\sin(\frac{3\pi}{2}+\omega t-\frac{\pi}{6}-\varphi)\cos(\omega t)\right]=$$

$$=\sqrt{3}\left\{I_m\frac{1}{2}\left[\cos(\omega t-\varphi-\omega t+\frac{\pi}{6})-\cos(\omega t-\varphi+\omega t-\frac{\pi}{6})\right]+I_m\left[\cos(\omega t-\frac{\pi}{6}-\varphi)\cos(\omega t)\right]\right\}=$$

$$=\sqrt{3}\left\{I_m\frac{1}{2}\left[\cos(\frac{\pi}{6}-\varphi)-\cos(2\omega t-\varphi-\frac{\pi}{6})\right]+I_m\frac{1}{2}\left[\cos\left(\frac{\pi}{6}+\varphi\right)+\cos\left(2\omega t-\frac{\pi}{6}-\varphi\right)\right]\right\}=$$

$$=\frac{\sqrt{3}}{2}I_m\left[\cos(\frac{\pi}{6}-\varphi)+\cos(\frac{\pi}{6}+\varphi)\right]\frac{\sqrt{3}}{2}I_m\,2\cos\left(\frac{\pi}{6}\right)\cos(\varphi)=$$

$$=\frac{\sqrt{3}}{2}I_m\,2\frac{\sqrt{3}}{2}\cos(\varphi)=\frac{3}{2}I_m\cos(\varphi)=\frac{3}{\sqrt{2}}I_s\cos(\varphi)=I_{s(Re)}.$$

$$\Rightarrow I_{s(Re)}=\sqrt{3}\left[i_{as}\sin\left(\omega t-\frac{\pi}{6}\right)-i_{cs}\cos(\omega t)\right].$$

REFERENCES

[1.] *Munoz-Garcıa A., T.A.Lipo, and D. W. Novotny, A New Induction Motor V/f Control Method Capable of High-Performance Regulation at Low Speeds, IEEE Transactions On Industry Applications, Vol. 34, No. 4, 1998, 813-821.*

[2.] *Lin Feng-Chieh and S. Yang, On-line Tuning of an Efficiency-Optimized Vector Controlled Induction Motor Drive, Tamkang Journal of Science and Engineering, Vol. 6, No. 2, pp. 103-110 (2003).*

[3] *Yang Sheng-Ming and F. Lin, Loss-Minimization Control Of Vector-Controlled Induction Motor Drives, Journal of the Chinese Institute of Engineers, Vol. 26, No. 1, pp. 37-45 (2003).*

[4] *Krishnan R., Electric Motor Drives. Modelling, Analysis, and Control, Singapore, 2003, ISBN 81-297-0319-1.*

[5.] *Shreiner T. et all, Optimal frequency control of asynchronous electrical drives, Kishinev, 1982 (in russian).*

ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING