Advance in Electronic and Electric Engineering.
ISSN 2231-1297, Volume 3, Number 9 (2013), pp. 1177-1196

http://www.ripublication.com/aeee.htm

Sensorless Speed Control of an Induction Motor Drive using Predictive Current and Torque Controllers

Srujana Dabbeti[1] and K. Vara Lakshmi[2]

[1]*PG Scholar, Department of EEE, Teegala Krishna Reddy Engineering College, JNTU- Hyd, AP, INDIA*
[2]*Assistant Professor, Department of EEE, Teegala Krishna Reddy Engineering College, JNTU-Hyd, AP, INDIA.*

Abstract

This paper presents sensor less speed control of an induction motor drive with predictive current controller and predictive torque control. Both the controllers do not require measurements of the motor speed and motor flux. A closed loop observer system with robustness against parameters variation is used for the control approach. The proposed observer computes the required state variables correctly in wide frequency range. In the system predictive current controller based on the computation of back electromagnetic force by the observer is implemented. In case of motor choke use, the choke parameters are added to predictive current controller algorithm. It is shown that the choke inductance has to be taken into account in predictive controller. The predictive method is based on examining feasible voltage vectors (VVs) in a prescribed cost function. The VV that minimizes the cost function is selected. A novel robust prediction model is presented. The whole proposed control idea makes the system practically insensitive to the changes of motor parameters, even at very low frequency. It is proved that the drive system is applicable to the high dynamic performance and wide range of rotor speed. By using predictive torque control we can control the ripple torque and also speed. The obtained simulation and experimental results confirm the good properties of the proposed speed sensor less induction motor drive.

Nomenclature

In the system description and results presentations the per unit system is used as shown in [3],[4].where the referenced-based values were listed.

IM – induction motor,
FOC – field oriented control,
PWM – pulse width modulation,
PCC – predictive current controller,
EMF – electromagnetic force (back EMF)
$\infty\beta$– stationary frame of references,
dq – rotating frame of references,
p.u. – per unit system
com – superscript denotes commanded value,
pred – superscript denotes predicted value,
^ - denotes value calculated in the observer,
bold style font denotes vector
CEMF, **C**2EMF – EMF transformation matrices,
e – motor EMF,
$\mathbf{i}_s$, $\mathbf{i}_r$ – stator and rotor current vector,
J - inertia,
k, k-1 – instants of calculation: actual, previous, etc.,
k_{ab} - observer gain,
L_r, L_s, L_m – motor inductances,
R_r, R_s – motor resistances,
T_{imp} - inverter switching period,
T_L - load torque,
$\mathbf{u}_s$ – stator voltage vector,
φ_e – angle position of the motor EMF vector,
$\rho_{\psi s}$ – angle position of the rotor flux vector
ω_r - rotor mechanical speed,
ω_2 – motor slip,
$\omega_{\psi r}$ – rotor flux vector speed
$\Psi r_,\ \psi_s$- rotor and stator flux vectors.

Keywords: Induction motor, observer, predictive current control, predictive torque control, sensorless drive.

1. Introduction

The induction motor is the most widely used electrical motor in industrial applications. The majority of induction machines are used in constant speed drives, but during the last decades the introduction of new semiconductor devices has made variable speed drives with induction machines available.

The work presented in this thesis is a continuation of a work that started with studies of the oscillatory behaviour of inverter fed induction machines (Peterson, 1991).However, there is more to improve in open loop drives; fast acceleration, fast braking, fast reversal and constant speed independent of load changes are all desirable properties of a drive system. This requires a fast-acting and accurate torque control in the low speed region [1].

All those properties are obtained with vector controlled induction machines (Leonhard, 1985). The drawback of this method is that the rotor speed of the induction machine must be measured, which requires a speed sensor of some kind, for example a resolver or an incremental encoder. The cost of the speed sensor, at least for machines with ratings less than 10 kW, is in the same range as the cost of the motor itself. The mounting of the sensor to the motor is also an obstacle in many applications. A sensor less system where the speed is estimated instead of measured would essentially reduce the cost and complexity of the drive system. One of the main reasons that inverter fed induction motor drives have become popular is that any standard induction motor can be used without modifications. Note that the term sensor less refers to the absence of a speed sensor on the motor shaft, and that motor currents and voltages must still be measured. The vector control method requires also estimation of the flux linkage of the machine, whether the speed is estimated or not.

Research on sensor less control has been ongoing for more than 10 years (Haemmerli, 1986 and Tamai et al, 1987), and it is remarkable that reliable sensor less induction motor drive systems are not readily available. The aim of the work presented here is to derive an applicable method for sensor less control of induction machines. The system must work with standard induction machines and the inverter hardware should not be considerably more complex than present-day open loop frequency inverters. Problems associated with sensor less control systems have mainly included parameter sensitivity, integrator drift, and problems at low frequencies. Some have tried to solve these problems by redesigning the induction machine (Jansen et al, 1994a).As it is most unfavourable using anything but standard machines, redesigned motors are not considered the best solution [2].

One of the mature control systems of induction motor is the field oriented control method. The FOC method is widely used and presents some high standards in modern industrial drives. A continuous trend in IM drives is to increase the reliability of the drive system. One solution is to decrease the amount of normally used sensors. Because of noises and other disadvantages the troublesome device in some of industrial drive system is the speed sensor. Therefore, in most modern IM drives speed sensor elimination is required. Instead of a speed sensor, different methods for speed calculation are proposed in the literature. Comprehensive reviews of the IM sensor less drives indicating that some problems with the sensor less control are persistent, so new solutions are still needed. Current work efforts are dedicated particularly to zero or very low speed range or to very high performance drives. Another problem in electrical drives is system sensitivity to inaccuracy and changes of motor equivalent circuit parameters.

Most of the FOC systems are very sensitive to that inaccuracy so some parameters should be estimated on-line. Also, robust structures of the control and estimation schemes are generally researched. The integral part of numerous FOC systems is the stator current controller. Good results of current control are reported for predictive current based controllers. In this paper PCC is implemented in the IM speed sensor less system with field oriented control method. In the FOC system instead of linear PI current controllers, predictive current controllers may be used. The current control algorithm previously presented was modified by using the observer system instead of simple load model. With such approach, better results were recorded. To avoid the system complication for the PCC, the back EMF calculation was integrated to flux and speed observer for FOC IM drive.

In this paper, new results as well as the new solution for integration of a motor choke in the current controller are presented. The proposed drive is speed sensor less and robust on motor parameters changes. The obtained results confirm that the system works properly without parameters estimation, even in very low speed ranges. Simulation results are presented [3].

The predictive torque control (PTC) method is of interest as an alternative to the direct torque control (DTC) method in applications where torque control is more important than speed control, such as the traction, paper, and steel industries. The PTC method shows faster dynamic response and causes less torque ripple compared to the DTC method because of its characteristic, i.e., predictive control

Different kinds of PTC methods have been investigated to date. The direct mean torque control method was introduced to control the mean value of the torque at a reference value .The deadbeat control method calculates the voltage reference to achieve a zero torque error in the next control step [4]. The model predictive control (MPC) method determines the optimum voltage by using the explicit model of the motor and inverter by minimizing a cost function [4].

In the MPC method, the criteria for voltage selection are more flexible. If cost function minimization is performed by the transfer function-based controlled auto regressive integrated moving average (CARIMA) model, the method is called generalized predictive control. The mathematical process is time consuming in this method. The finite control set model predictive control (FCS-MPC) method uses another approach to minimizing the cost function. In this method, the discrete nature of the power converters is contemplated. In this approach, the feasible voltage vectors (VVs) are examined in terms of cost and the one that minimizes the cost function is selected.

2. Proposed System

The stator field oriented control method is used in the drive [11]. The superior PI controllers regulate the motor speed and rotor flux. The commanded motor current $\mathbf{i}_s^{com}$ is transformed from dq to ∞β coordinates. The PCC controls the motor stator current in ∞β coordinates.

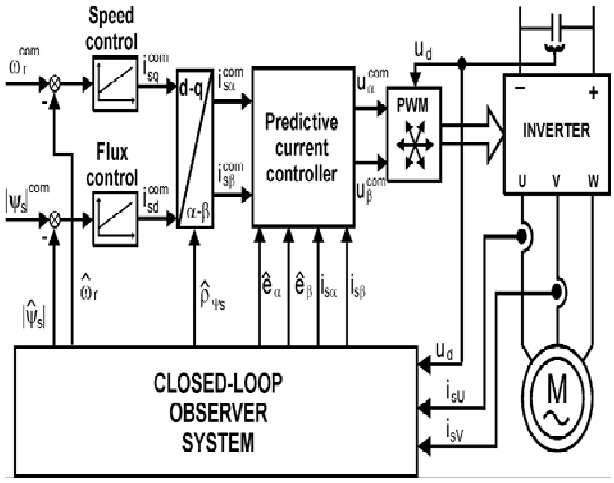

Fig. 1: Proposed closed loop observer system.

Calculations of the PCC are synchronized with PWM algorithm used for the inverter output voltage generation. The inverter with PWM and PCC works as controlled current source. The system works without speed sensor, while only the inverter input voltage and output currents are measured by hall-effect sensors. Other variables required by control system are calculated in closed-loop observer system.

2.1 Observer System

We can estimate the flux and speed by using closed loop observer system [5].Simultaneously, the motor EMF is calculated. The observer structure is presented in Fig. 2.

The observer is based on the known voltage model of the induction motor with the combination of the rotor and stator fluxes. The stator current relationships are presented in e.g[13]. To improve the estimation properties, a feedback part was added. The rotor and stator fluxes are computed as follows:

$$d\hat{\psi}_s/dt = \left(-\hat{\psi}_s + k_r\hat{\psi}_r\right)/\tau_s' + \hat{\mathbf{u}}_s - k_{ab}\left(\mathbf{i}_s - \hat{\mathbf{i}}_s\right) \qquad (1)$$

$$\hat{\psi}_r = \left(\hat{\psi}_s - \sigma L_s \hat{\mathbf{i}}_s\right)/k_r \qquad (2)$$

where: $k_r = L_m/L_r \quad \sigma = 1 - L_m^2/(L_s L_r) \quad \tau_s' = \sigma L_s/R_s$

and $\hat{\boldsymbol{\psi}}_s$, $\hat{\boldsymbol{\psi}}_r$, $\hat{\mathbf{i}}_s$, $\mathbf{i}_s$, $\mathbf{u}_s$ are vector in αβ coordinates,

The values in (1)-(2) and consequent relations are normalized – Appendix. The stator magnitude, stator and rotor angle position of the flux vectors are:

$$\left|\hat{\psi}_s\right| = \sqrt{\hat{\psi}_{s\alpha}^2 + \hat{\psi}_{s\beta}^2} \tag{3}$$

$$\hat{\rho}_{\psi s} = \operatorname{arc\,tg}\left(\hat{\psi}_{s\beta} / \hat{\psi}_{s\alpha}\right) \tag{4}$$

$$\hat{\rho}_{\psi r} = \operatorname{arc\,tg}\left(\hat{\psi}_{r\beta} / \hat{\psi}_{r\alpha}\right) \tag{5}$$

The estimated stator current vector for feedback correction is:

$$\hat{\mathbf{i}}_s = \left(\hat{\psi}_s - k_r \hat{\psi}_r\right) / \left(\sigma L_s\right) \tag{6}$$

Rotor mechanical speed:

$$\hat{\omega}_r = \hat{\omega}_{\psi r} - \hat{\omega}_2 \tag{7}$$

Is obtained from the difference between the motor flux synchronous speed and slip speed:

$$\hat{\omega}_{\psi r} - d\hat{\rho}_{\psi r} / d\tau \tag{8}$$

$$\hat{\omega}_2 = \hat{\psi}_{r\alpha} i_{s\beta} - \hat{\psi}_{r\beta} i_{s\alpha} / \left|\hat{\psi}_r\right|^2 \tag{9}$$

In (6) the current $i_s^{\wedge}$ is determined on base of transformed (2) equations. It can lead to obtain an algebraic loop – if an actual and estimated currents are determined from (2) and (6)and used in (1) the observer correction part disappear and (1) is well know stator voltage equation. But in real digital control system the difference between is and $i_s^{\wedge}$ continuously exists because is i_s last measured sample and $i_s^{\wedge}$ is estimated value for the next step of operation. Because of that one step delay between is and $i_s^{\wedge}$ does exist. The calculation step and sequence of (1)-(9) are significant for the observer operation.

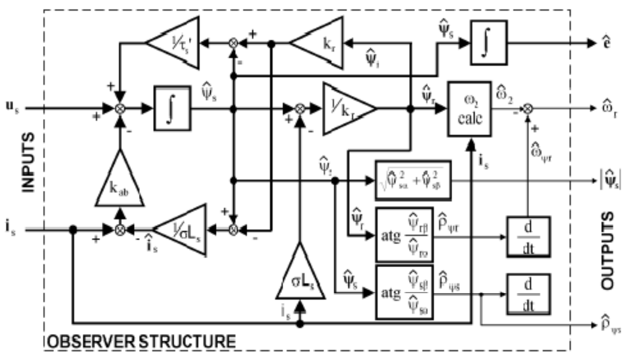

Fig. 2: Structure of the closed-loop observer.

The advantages of the stator equation (1) are that motor speed information is not required for flux computation. This eliminates any additional error associated with computing or even measuring such signals, especially at lower frequencies.

Such characteristic provides an additional advantage of the observer and helps to extend the stable operating point of and induction motor. It is particularly important for extreme low frequencies, even without additional techniques for parameters tuning or dc drift elimination [5].

In the observer EMF is calculated as well according to relation:

$$\hat{\mathbf{e}} = d\hat{\psi}_s / d\tau \tag{10}$$

Although a constant gain is used, it is possible to run the controller around zero frequency with parameter variations and without tuning techniques. If the controllers receive commanded torque, the drive system does not require a rotor speed signal. Speed is only to do closed loop control. The motor parameters appearing in the observer are the motor inductances and the stator resistance. The inductances have little effect on the performance, while the stator resistance has a small effect at frequencies close to zero.

The presented flux and speed observer has proved to be highly insensitive against stator resistance mismatch. This significantly extends the stable operating region even without parameter tuning. Rotor resistance is not included in the observer system, so it has no noticeable effect on it; however it is included in slip calculation.

2.2 Predictive Current Controller

The EMF was calculated using the simple equation of the IM model. In this paper, the accuracy of EMF calculation is improved. Better accuracy of EMF calculation is obtained using flux and speed closed-loop observer presented in the previous section. The observer structure is extended in order to calculate the EMF simultaneously with flux and speed computation. So in PCC the EMF calculation part is removed and substituted by the signals obtained directly from the observer system.

The relations of the PCC are based on the equations of the ∞β model of the IM .For PCC derivation purposes the IM was modelled as an inductance and EMF connected in series, while the small motor resistance was neglected.

Stator current dynamic system is described by:

$$d\mathbf{i}_s / dt = \left(\mathbf{u}_s^{com} - \check{\mathbf{e}}\right) / \left(\sigma L_s\right) \quad \hat{\mathbf{e}} = d\hat{\psi}_r / d\tau \tag{11}$$

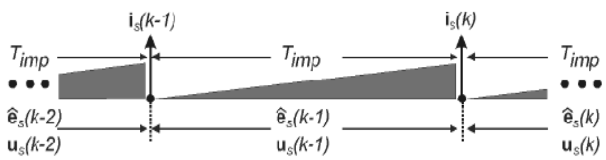

Fig. 3: Used notation in PCC for switching periods.

Assuming the notation presented in Fig. 3 and for small T_{imp} it is possible to convert (12) to the next discrete form:

$$[\mathbf{i}_s(k) - \mathbf{i}_s(k-1)]/T_{imp} = [\mathbf{u}_s^{com}(k-1) - \mathbf{e}(k-1)]/(\sigma L_s) \qquad (12)$$

Considering (11) for period (k-1)…(k) the known values are: commanded voltage $\mathbf{u}_s^{com}$ (k-1) and measured current $\mathbf{i}_s$ (k-1)

Other variables as $i_s(k)$ and e(k-1) are unknown and should be predicted.

In [8] the EMF value e(k-1) was simply predicted based on known samples of e(k-2) and e(k-3) as follows:

$$\hat{\mathbf{e}}(k-2) = \sigma L_s(\mathbf{i}_s(k-2) - \mathbf{i}_s(k-1))/T_{imp} + \mathbf{u}_s^{com}(k-2) \qquad (13)$$

$$\hat{\mathbf{e}}(k-3) = \sigma L_s(\mathbf{i}_s(k-3) - \mathbf{i}_s(k-2))/T_{imp} + \mathbf{u}_s^{com}(k-3) \qquad (14)$$

In this paper instead of (14)-(15) the EMF is calculated in the flux and speed observer according to (12) [5]. The samples of $\mathbf{e}^{\wedge}$*(k- 2)* and $\mathbf{e}^{\wedge}$*(k- 3)* calculated by the observer are memorized and used in the successive calculations.

The change of position of the EMF vector is:

$$\Delta\varphi_e[(k-2),(k-3)] = \Delta\varphi_e = \varphi_e(k-2) - \varphi_e(k-3) \qquad (15)$$

The calculations of (15) require two arc tangent calculations for obtaining φ_e (k-2) and φ_e (k-2). To simplify (15) calculation of trigonometric relation with only one arc tangent function is used:

$$\Delta\varphi_e = a\tan\frac{\hat{e}_\alpha(k-2)\hat{e}_\beta(k-3) - \hat{e}_\alpha(k-3)\hat{e}_\beta(k-3)}{\hat{e}_\alpha(k-2)\hat{e}_\alpha(k-3) + \hat{e}_\beta(k-2)\hat{e}_\beta(k-3)} \qquad (16)$$

In the IM the EMF speed changes slowly so for small T_{imp} it is possible to predict $\mathbf{e}^{\wedge}$(k-1) by rotating EMF vector with small $\Delta\varphi_e$ angle calculated by (16).

The predicted value of $\mathbf{e}^{\wedge}$(k-1) is:

$$\mathbf{e}^{pred}(k-1) = \mathbf{C}_{EMF}\hat{\mathbf{e}}(k-2) \qquad (17)$$

$$\mathbf{C}_{EMF} = \begin{bmatrix} \cos(\Delta\varphi_e) & \sin(\Delta\varphi_e) \\ -\sin(\Delta\varphi_e) & \cos(\Delta\varphi_e) \end{bmatrix} \qquad (18)$$

The IM stator current sample at instant (k) is predicted:

$$\mathbf{i}_s^{pred}(k) = \mathbf{i}_s(k-1) + [\mathbf{u}_s^{com}(k-1) - \mathbf{e}^{pred}(k-1)]T_{imp}/(\sigma L_s) \quad (19)$$

To optimize PCC action the minimization of current regulation error was chosen as cost function. The current regulation error at instant (k-1) and (k) is as follows:

$$\Delta\mathbf{i}_s(k-1) = \mathbf{i}_s^{com}(k-1) - \mathbf{i}_s(k-1) \tag{20}$$

$$\Delta\mathbf{i}_s(k) = \mathbf{i}_s^{com}(k) - \mathbf{i}_s^{pred}(k) \tag{21}$$

In [6] the next controller function was used:

$$\mathbf{u}_s^{com}(k) = \sigma L_s\left[\mathbf{i}_s^{com}(k+1) - \mathbf{i}_s^{pred}(k) + \mathbf{D}_{Is}\right]/T_{imp} + \hat{\mathbf{e}}^{pred}(k) \tag{22}$$

The voltage vector $\mathbf{u}_s^{com}$ (k) calculated with (22) is applied to the minimize stator current regulation error at (k+1).Equation (23) is based on (11) with addition of correction part $\mathbf{D}_{Is}$:

$$\mathbf{D}_{Is} = W_1\mathbf{C}_{EMF}\Delta\mathbf{i}_s(k) + W_2\mathbf{C}_{2EMF}\Delta\mathbf{i}_s(k-1) \tag{23}$$

$$\mathbf{e}^{pred}(k) = \mathbf{C}_{2EMF}\hat{\mathbf{e}}(k-2) \tag{24}$$

$$\mathbf{C}_{2EMF} = \begin{bmatrix} \cos(2\Delta\varphi_e) & \sin(2\Delta\varphi_e) \\ -\sin(2\Delta\varphi_e) & \cos(2\Delta\varphi_e) \end{bmatrix} \tag{25}$$

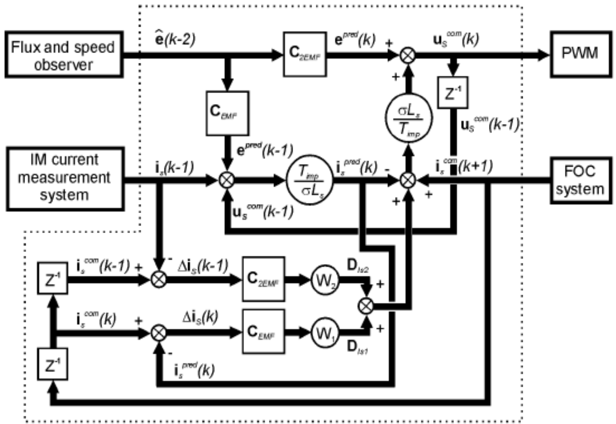

Fig. 4: Predictive current controller structure.

2.3 Predictive Torque Controller

For application of the sensorless observer in predictive torque control, both observer and prediction models have to be applied without using measured speed. When the prediction model is applied without using measured speed, the accuracy of the prediction can be affected by the error of estimated speed. In order to compensate this effect, a closed-loop prediction model is proposed [4].

Thus far, the PTC method has not been adopted in many industrial applications because it is implemented by means of speed sensor in most cases. Thus, one of the main advantages of the DTC method is not included in the PTC method. There have been few investigations into implementing PTC without using a speed sensor. In [4], a predictive method is used in a neural network observer in order to estimate the speed.

Some investigations have proposed sensor less methods for predictive current control in the FOC method.

The main goal of PTC is direct control of the stator flux and torque by means of a predictive method. Predicting the stator flux and torque is based on the induction motor and the inverter nonlinear models that are called prediction models.

The stator flux and current prediction are based on full order discrete model of IM in stationary reference frame. If feedback loop is added to IM model, uncertainties (estimated speed error, unbalance current measurement, and parameter variation) can be compensated. In this way, prediction will be performed more accurately. By using current prediction error for feedback loop, the closed-loop prediction model will be achieved as follows:

$$\hat{\bar{\psi}}_s(k+1) = \hat{\bar{\psi}}_s(k) + t_s\left(\bar{V}_s - R_s\bar{I}_s\right) + K_{p1}\, t_s \operatorname{sgn}\left(\bar{I}_s - \hat{\bar{I}}_{sp}\right) \tag{26a}$$

$$\begin{aligned}\hat{\bar{I}}_s(k+1) = {} & \frac{1}{\sigma L_s}\left\{\hat{\bar{\psi}}_s(k+1) - \left(1 - \frac{t_s}{\tau_r}\right)\hat{\bar{\psi}}_s(k)\right\} \\ & + \left(1 - \frac{t_s}{\sigma\tau_r}\right)\bar{I}_s + j\hat{\omega}_r\, t_s\left(\bar{I}_s - \frac{\hat{\bar{\psi}}_s(k)}{\sigma L_s}\right) \\ & + K_{p2}\, t_s \operatorname{sgn}\left(\bar{I}_s - \hat{\bar{I}}_{sp}\right)\end{aligned} \tag{26b}$$

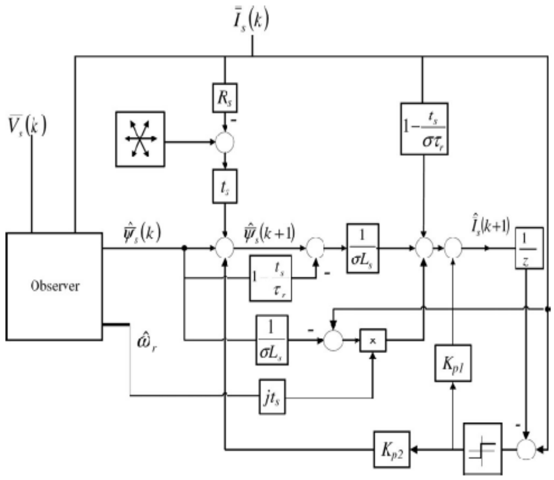

Fig. 5: Sensorless prediction model block diagram.

where $\hat{\bar{\psi}}_s$ is the stator flux that will be attained from observer, $\bar{V}_s$ and $\bar{I}_s$ are the stator voltage and current, respectively, and R_s is the stator resistance. τ_r is the rotor time constant, L_s, L_r , and L_m are the stator, rotor, and mutual inductances, respectively, t_s is the sampling interval, and $\sigma = 1 - L_m^2/L_sL_r$.. $\hat{w}_r$ is estimated rotor speed that will be gotten from observer and $I_{sp}\hat{}\bar{}$ is the last predicted stator current. Superscript " ^ " indicates variables that are calculated from IM model. Variables without this superscript are measured variables. K_{p1} and K_{p2} are coefficients of the sliding mode feedback for the prediction model.

$$K_{p1} = K_{p11} + jK_{p12} \tag{27a}$$

$$K_{p2} = K_{p21} + jK_{p22}. \tag{27b}$$

Assigning feedback gains will be elaborated on later in the paper. By applying the predicted stator flux and stator current, the next step torque can be calculated as follows:

$$\hat{T}(k+1) = \frac{3p}{4}\hat{\bar{\psi}}_s(k+1) \times \hat{\bar{I}}_s(k+1) \tag{28}$$

where $T\hat{}$ is the torque and p is the number of poles. Fig. 5 shows the sensorless prediction model block diagram.

2.4 Predictive Control Method.

Cost function is a criterion for predicting the best voltage to apply. It shows how close torque and flux are to their set points. In this paper, FCS-MPC is utilized in order to minimize the cost function. This method is based on examining feasible VVs in cost function. The VV that minimizes the cost function is selected. Therefore, the following cost function is calculated for each feasible VV[5]:

$$J_j = \frac{1}{2}\left(\left|\hat{T}_j(k+1) - T^*\right|^2 + Q\left|\left|\hat{\bar{\psi}}_{sj}(k+1)\right|^2 - |\bar{\psi}_s^*|^2\right|\right) \tag{29}$$
$$j = 1, 2, ..., 7$$

where $T_j\hat{}$ $(k + 1)$ and $\psi_{sj}{}^{-\,\hat{}}(k + 1)$ are the predicted torque and stator flux, which are calculated by means of (26) and (28) considering application of jth VV. T^* and / $\bar{\psi}$*/ are the torque and the flux references. Q is a weighting factor that determines the importance of flux control compared to torque control. The VV which minimizes the cost function will be chosen as the best apply. This VV has to be exerted to the induction motor through the inverter. If the proposed prediction model is used beside two different kinds of observers, two sensorless predictive control methods will be achieved.

2.5 System with Motor Choke

In some IM drives the choke is installed between the inverter and motor terminals. The main role of the motor choke is to limit the rate of rise of the motor supply voltage (dv/dt). It prevents the reflections of voltage wave which if not solved cause over voltages.

The motor choke with series inductance has an influence on the drive operation [6]-[7]. In some cases the filter parameters have to be taken into account in the control and estimation process. The same is for motor choke.

The closed-loop observer used in the proposed system has high robustness on system parameters changes, but the PCC is sensitive to motor inductance variations.

For the system with motor choke and PCC algorithm, the motor choke inductance L_1 has to be added into all components containing σL_s. So in the PCC calculations, instead of σL_s component the substitute inductance L_{s1} is used:

$$L_{s1} = \sigma L_s + L_1 \tag{30}$$

The simulation results shown in Fig. 6 present the PCC open loop results in case when L_1 is used and when the L_1were omitted.

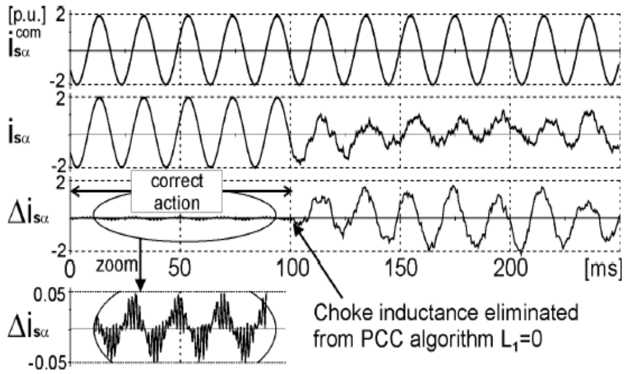

Fig. 6: PCC action in the drive with motor choke at 100ms instant the choke inductance L1 was set to 0.

In Fig. 6, up until the100ms instant the PCC is working correctly because L_1 is taken into account in the PCC dependencies. At 100ms instant inductance L_1 is set to 0 only in PCC equations – without elimination of the choke in the drive. After that the abnormal work of the system is observed. This confirms that choke inductance has to be known for PCC.

3. Simulation Investigations

In the first step the PCC working without FOC was investigated. The system was working with motor choke. The response is shown in Fig. 7.

In Fig. 7 IM motor current magnitude was changed from 0.5p.u. to 1p.u. The current commanded value was obtained in 7 steps. Stator frequency was kept constant during this test.

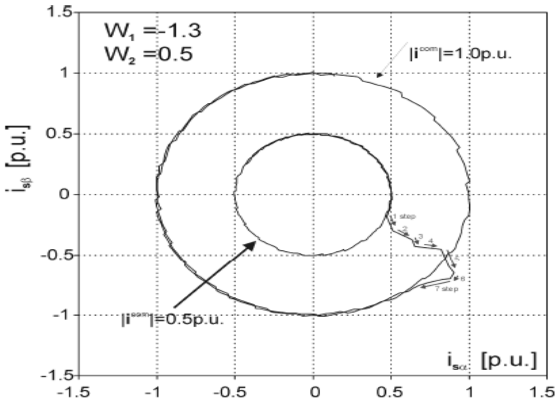

Fig. 7: PCC operation for the IM drive with motor choke commanded step change of stator current magnitude.

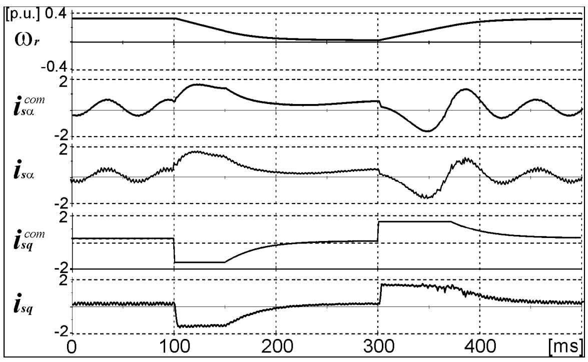

Fig. 8: Sensorless operation motor current control in αβ and DQ references during commanded speed changes.

In Fig. 8 motor speed changes are commanded – decreasing and increasing. The waveforms of the current present consistency between commanded and actual currents components. Proper work of the whole system is noticeable.

4. Simulation Results

Simulation of sensor less speed control of induction motor is done using Predictive current control and torque control are presented [3],[4].dynamic modelling of induction motor is taken from [10].

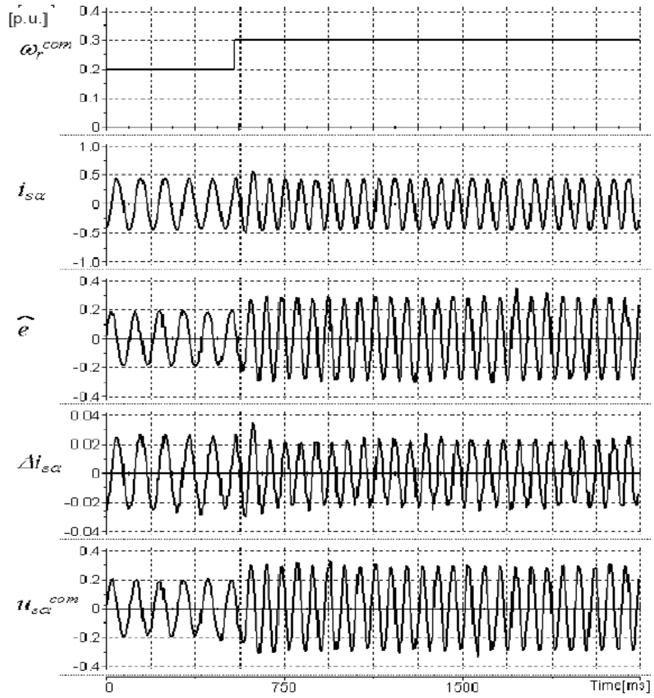

Fig.9. Step change of motor frequency related to wr 20% to 30% of the motor rated mechanical speed.

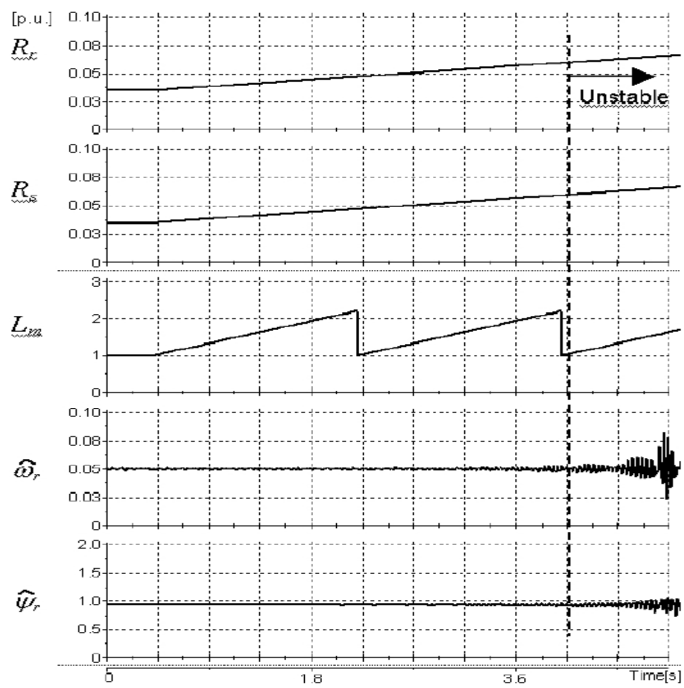

Fig.10. Response of the system for the simultaneously changes of motor parameters (runs at 5% of rated speed) – for t> 4s system is unstable (the result of high simultaneous parameters changes). Nominal par. are in Tab. I.

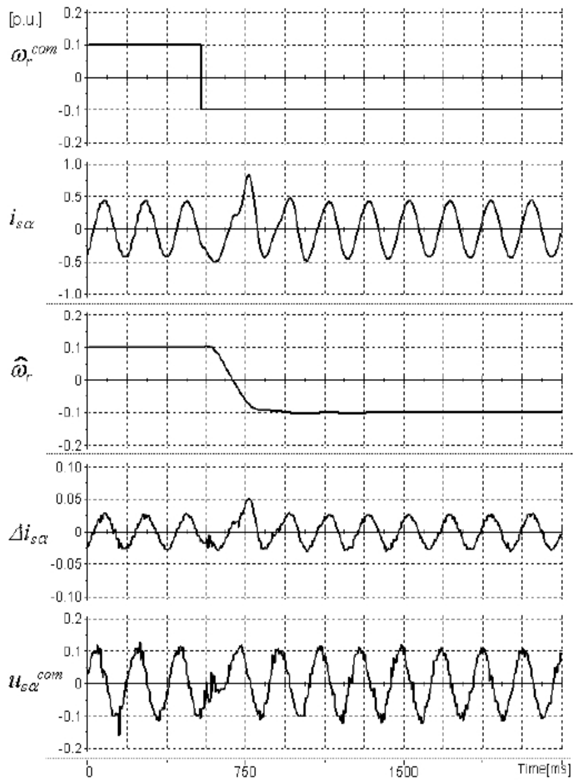

Fig. 11: Motor reversing from -10% to 10% of rated speed under load.

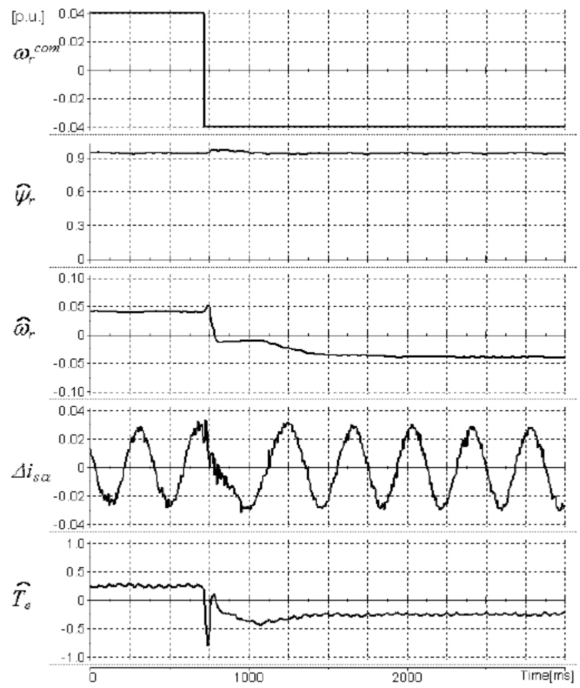

Fig. 12: Motor reversing from- 4% to 4% of rated speed under load.

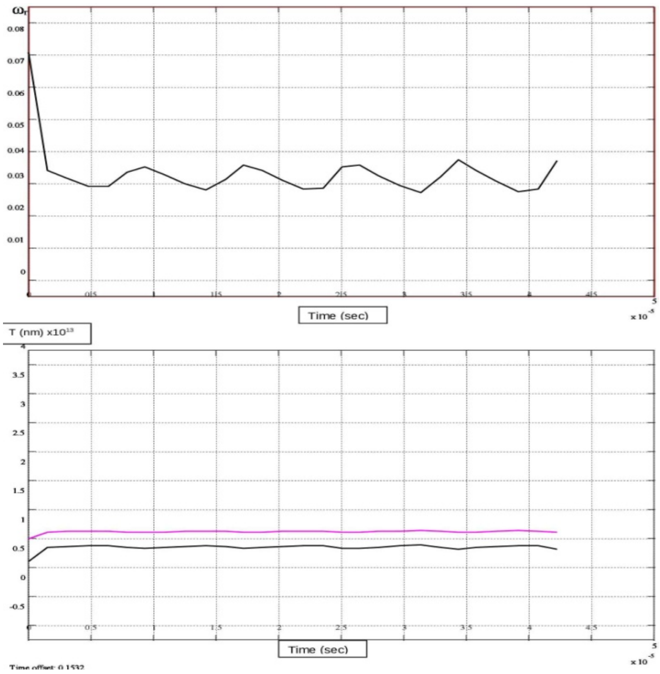

Fig. 13: Speed & Torque wave forms of Predictive Torque Control

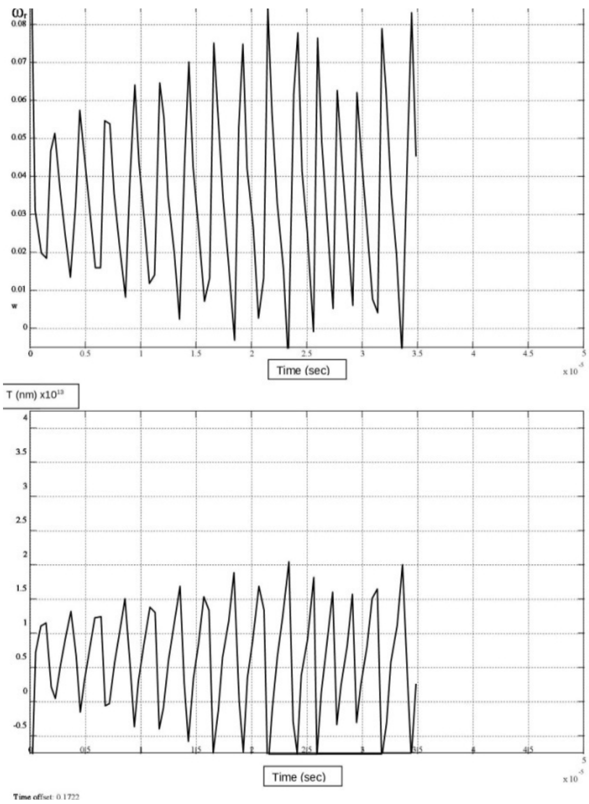

Fig. 14: Speed & Torque wave forms of Predictive Torque Control with different feedback gains.

5. Conclusions

The predictive current controller and torque control are based on the computation of back EMF by the observer. The whole control does not require measurements of the motor speed and flux. The state variables are calculated by the observer system using only the command value of stator voltage and the measured stator current and dc link voltage. The whole system is practically insensitive to inaccuracy of calculations and the deviation of motor parameters. In case of motor choke use, the choke parameters are added to PCC algorithm. It was shown that the choke inductance has to be taken into account in PCC calculations.

A novel robust sensor less prediction model for FCS-MPC method is also proposed in this paper. This will advance the PTC method resulting in it becoming a superior alternative for the DTC method in industrial applications. The obtained simulation and experimental results confirm the good properties of the proposed speed sensor less IM drive. The proposed IM drive works correctly without speed measurements even at very low speed.

In this predictive torque control method, speed and flux is directly controlled. The speed will be in the form of sine wave, so that higher order harmonics can be easily eliminated.

Table 1: Induction motor data.

Parameters	Value	Description
PN	5.5Kw	Nominal power
UN	3x400V 50Hz	Nominal voltage
IN	11 A	Nominal current
nN	1450 rpm	Nominal speed
J	0.029 kgm2	Inertia
Rs	1Ω (0.48pu)	Stator resistance
Rr	1.07Ω (0.48pu)	Rotor resistance
Lm	215mH(1.606pu)	Mutual inductance
Ls	220mH(1.651pu)	Stator inductance
Lr	215mH(1.651pu)	Rotor inductance

References

[1] A. Abbou, T. Nasser, H. Mahmoudi, M. Akherraz, A. Essadki, “Induction Motor controls and Implementation using dSPACE,” *Wseas Transactions On Systems And Control*, Issue 1, Volume 7, January 2012

[2] J. Holtz, "Sensorless Control of Induction Machines—With or Without Signal Injection?," *Trans. on Industrial Electronics*, v. 53, No. 1, 2006

[3] Jaroslaw Guzinski, Haitham Abu-Rub, “Predictive Current Control Implementation in the Sensorless Induction Motor Drive,” *IEEE*, 2011.

[4] Fengxiang Wang, S. Alireza Davari, Davood A. Khaburi, Ralph Kennel, "Sensorless Model Predictive Torque Control for Induction Machine by using the Sliding Mode Full-Order Observer," *IEEE*, 2011.

[5] Haitham Abu-Rub, Nikolaos Oikonomou, "Sensorless Observer System for Induction Motor Control," *IEEE*, 2008.

[6] Jaroslaw Guzinski, "Sensorless AC Drive Control with LC Filter"

[7] Tomasz Laczynski, Axel Mertens, "Predictive Stator Current Control for Medium Voltage Drives With *LC* Filters," *IEEE Transactions On Power Electronics*, Vol.24, No.11, November 2009.

[8] S.J. Henriksen, R.E. Betz, B.J. Cook, "Practical Issues with Predictive Current Controllers,"

[9] Haitham Abu-Rub, Jarosław Guziński, Jose Rodriguez, Ralph Kennel, Patricio Cortés, "Predictive Current Controller for Sensorless Induction Motor Drive,"*IEEE*,2010.

[10] Burak Ozpineci, Leon M. Tolbert, "Simulink Implementation of Induction Machine Model — A Modular approach,"

[11] B. K. Bose, *Modern Power Electronics and AC Control,* PTR, 2002.

[12] Karel Jezernik, Miran Rodi, Karel Jezernik, Miran Rodi, "Torque Sensorless Control of Induction Motor," *IEEE*, 2008.

[13] Simi P.B, C.Harini, Dr. Hari Krishna Prasad. P, "Sensorless Motor Drives with Predictive Current Control," *IOSR Journal Of Environmental Science, Toxicology And Food Technology*, Issue 2, Volume 3, Jan. - Feb. 2013.

[14] Jaroslaw Guzinski, "Closed Loop Control of AC Drive with LC Filter,"*IEEE*, 2008.

[15] Jaroslaw Guzinski, "Sensorless AC Drive Control with LC Filter," *EPE,* 2009.

[16] T. Raghu, J. Srinivas Rao, and S. Chandra Sekhar, "Simulation of Sensorless Speed Control of Induction Motor Using APFO Technique," *International Journal of Computer and Electrical Engineering,* Vol. 4, No. 4, August 2012.

[17] Francisco A. S. Neves, Thomas G. Habetler, Gustavo G. Parma, Benjamim R. Menezes, Selênio R. Silva, "An Evaluation of Sensorless Induction Motor Drives for Low Speed Operation"

[18] Marian P. Kazmierkowski, Luigi Malesani, "Current Control Techniques for Three-Phase Voltage-Source PWM Converters: A Survey" *IEEE Transactions on Industrial Electronics*, Vol.45, No.5, October 1998.

[19] Saeid Kohan Sal Lotf Abad, "Simulation of Indirect Field Oriented Control of Induction Machine in Hybrid Electrical Vehicle with MATLAB Simulink," *5thSASTech 2011*, Khavaran Higher-education Institute, Mashhad, Iran. May 12-14.

[20] Dal Y. Ohm, "Dynamic Model Of Induction Motors For Vector Control,"

[21] Shahab Kaynama, Osman Kukrer, "A Suboptimal Discrete-Time Predictive Current Controller for a Voltage-Source Inverter," *IEEE International Conference on Control Applications*, *Japan,* September 8-10, 2010.

[22] Ralph Kennel, Arne Linder, "Predictive Control of Inverter Supplied Electrical Drives,"
[23] Juan C. Ramirez Martinez, Ralph M. Kennel, Tobias Geyer, "Model Predictive Direct Current Control,"
[24] Joachim Holtz, "Sensorless control of Induction Motor Drives," Proceedings of the IEEE, Vol.90, No.8, August, 2002.