Low Cost Speed Sensor less PWM Inverter Fed Induction Motor Drive

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Abstract —An analysis of the PWM inverter induction motor drive with speed sensor less control is controlled by DC link current is presented in the paper. The first part of the paper is devoted to the verification of dynamic possibilities of the proposed concept of the control by means of simulation. The second part of the paper is devoted to the optimization of steady state performance. At the end the result achieved on the prototype model for 1.5Kw were presented.

INTRODUCTION

The application of microprocessors is easy to control in induction motor drives. However, in practice simple, cheap and reliable drives are often needed, where it is possible to control the speed, with more modest requests regarding dynamic features. A significant step in the direction of realization of such a drive is the acceptance of the control concept with as small number of sensors, as possible, and primarily without speed sensor.

The main goal of this paper is to describe the implementation of low cost speed-sensor less induction motor drive, based on the simple idea, the speed drop compensation in function of load, i.e. the dq axis dc link motor current. In order to increase speed of calculation of speed corrections, the lookup table stored in EPROM was used. This drive was made and tested in Tagore Engineering College, Department of Electrical and Electronics Engineering, Chennai.

DESCRIPTION OF THE DRIVE

Figure.11 presents the block diagram of the drive, where from we can see the basic idea of the applied manner of speed regulation. The system displayed consists of two basic parts, power part - frequency converter and control circuit system. Frequency converter consists of diode rectifier, DC link with LC filter, and three phase bridge connected IGBT inverter. The over current protection of transistors in the inverter requires fast and precise measurement of DC current. In the DC circuit there is a block for dynamic brake, consisting of the resistor and the braking transistor. The algorithm applied in the control circuit system is based on the simple idea that in the function of motor load the increase of stator frequency for slip frequencies is made.

As shown in Figure 1, the supply frequency (We) is calculated as a sum of the reference speed frequency

(Wref'=Wr) and the slip frequency (Wsl). The necessary slip frequency value is obtained from the slip frequency table, according to the reference speed and motor current. The information on the motor current value is obtained by means of dc link current value. In this way only one (previously mentioned) current sensor was used in the presented drive. In deriving the necessary analytical relations we must start from the v/f characteristics which is defined in advance and built in the "table of voltage", and which is used in the calculation procedure of the transistor leading time in the inverter. Such an approach enables a simple adjustment of mechanical motor characteristics to the needs of loading, for example, the increase of the initial moment in the traction application. There from it follows:

$$u_s\left(\omega_r,\omega_{sl}\right) = f\left(\omega_e\right) = f\left(\omega_r + \omega_{sl}\right) \qquad (1)$$

where us is the effective value of the stator voltage. In our case relation (1) is:

$$u_s = \begin{pmatrix} 0.2 + 0.8\omega_e & \omega_e \le 1 \\ 1 & \omega_e \le 1 \end{pmatrix} \qquad (2)$$

On the basis of known relations [6] in per unit, it can be written

$$\frac{2}{3}u_{dc}.i_{dc} = \eta_c\left(u_{qs}.i_{qs} + u_{ds}.i_{ds}\right) \qquad (3)$$

Where i_{qs}, i_{ds} and u_{qs} u_{ds} are the current and the voltage of the motor in q and d-axes, of synchronous reference frame, and h_c is inverter efficiency. From (3) we get

$$i_{dc} = \frac{3}{2}\frac{\eta_c}{u_{dc}}\left(u_{qs}.i_{qs} + u_{ds}.i_{ds}\right) \qquad (4)$$

If at time t=0 q axis and phase A aligned, the

$$u_{qs} = \frac{u_{dc}}{2} K_m(\omega_e)(1 + Bf_q) \qquad (5)$$

$$u_{ds} = \frac{u_{dc}}{2} K_m(\omega_e).Bf_d \qquad (6)$$

Where $K_m(\omega_e)$ is the modulation index of PWM inverter which is the function of basic frequency, i.e. ω_e in our case defined on the basis of (2), Bf_q and Bf_q corresponding to qd transformation of the harmonic terms. Upon the substitution of *(5)* and (6) into (4) it becomes

$$i_{dc} = \frac{3}{4} \eta_c K_m(\omega_e)(i_{qs}(1 + Bf_q) + i_{ds}.Bf_d) \qquad (7)$$

Expression (7) shows that the mean value of dc link current function is the q component of the machine current, i.e. the active Components of this current. From the machine theory it is known that

$$\omega_{sl} = \omega_{sl}(\omega_r, i_{qs}) \qquad (8)$$

Supposing the successfully realized speed regulation we have $\omega_{ref} = \omega_r$ that substituting (7) into (8) we get

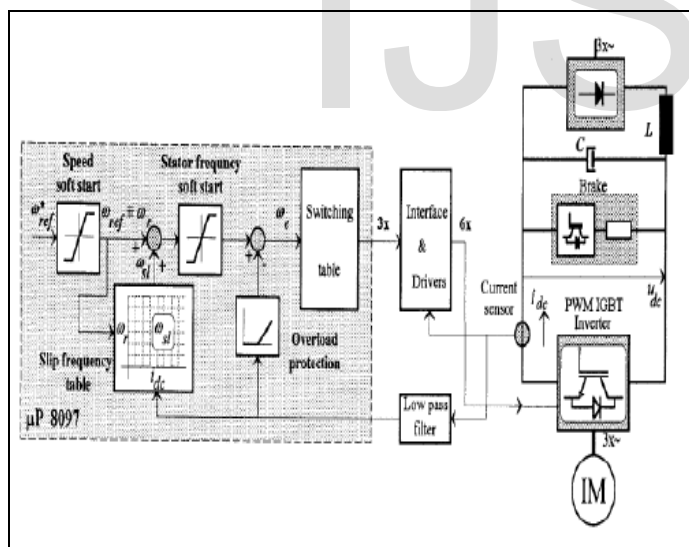$$\omega_{sl} = \omega_{sl}(\omega_{ref}, i_{dc}) \qquad (9)$$

Figure 1 Block diagram of whole system

On the basis of function (9) it is clear that depending on the mean value of dc link current, for a desired speed, we can determine the needed slip frequency, i.e. the basic frequency of the inverter. Relations derived (7, 8, 9) are very complex and depend on various magnitudes and parameters, losses in inverter, carrier-frequency, dead time, motor losses and saturation, change of motor parameters with frequency [7].Therefore, dependence (9) cannot be directly implemented into the control algorithm, but on the basis of it the table can be formed which would be written in into the EPROM, and Where from the processor would read out the Necessary values the control subsystem, presented in Figure 1, is realized by means of ATMAL'S 16-th bit processor 89C52. Apart from slip frequency table, there are two soft starts, limiting the dynamics of the change of the desired speed, i.e. frequency, by their adjustment dynamical processes can be optimized.

The overload protection block has higher priority and in the case when the current exceeds the permitted value it decreases the frequency, and thereby the speed until the load is reduced. This is particularly suitable for drive with the load torque directly depending on of the speed with inverters, in order to get the corresponding voltage and the frequency at the output, a sinusoidal PWM method is applied with the impressed third harmonic into the phase voltage. Since the inverter works at high frequencies of Commutation, for faster calculation three more lookup tables, voltage table, sin table and phase table are used: all of them are calculated and introduced into EPROM

The remaining indispensable hardware consists of the interface ensuring the division of the signal for positive and negative bridge branch and the auto protective drivers realizing a regular and reliable switching in and switching out of transistors. This part of the system unites the protection from excessive instant over current value. Also, the dead time is generated on drivers, which considerably simplified the control algorithm. Low pass filter in the dc. Current feedback has two significant functions. Primarily, it eliminates higher harmonics - the consequence of the inverter operation, thereby enabling the measurement of the mean value only of this current. Second, it enables stable operation of the drive even at higher resolution of current values for slip frequency table, which will be dealt with later The presented algorithm in this paper has some shortcomings. The static control speed error is depending on three factors, the numbers of rows and columns in the slip frequency table, and the based inverter frequency resolution. Those parameters are of great significance for the drive dynamic behavior, too. In this case the number of rows in the slip frequency table is depending on the desired reference speed resolution. In practice this number of rows is final. But the number of columns in the slip frequency table, and the based inverter frequency resolution is a very important parameter of the drive. These two resolutions affect the dynamical properties of

the drive. In order to research this question the mathematical model of the system was made, where the respective tests were made, which will be the topic of the next part of the paper. Also, the issue of the filling in of slip frequency table is to be stressed, because for obtaining these data with indispensable accuracy, it is necessary to know the values of all parameters of the motor, including their change in the regimes under consideration. This issue will be dealt with in detail.

MATHEMATICAL MODEL

The analysis of the system behavior during dynamic regimes was made by means of computer simulation. The synchronously rotating frame motor model with constant parameters was used. The inverter model was a simplified unit power factor (q_c=l) and only the based harmonics of the voltage were taken into consideration. Upon these simplifications from equations (5, 6 and 7) it follows

$$u_{qs} = \frac{u_{dc}}{2} K_m(\omega_e) \qquad u_{ds} = 0 \qquad (10)$$

$$i_{dc} = \frac{3}{4} \eta_c K_m(\omega_e) i_{qs} \qquad (11)$$

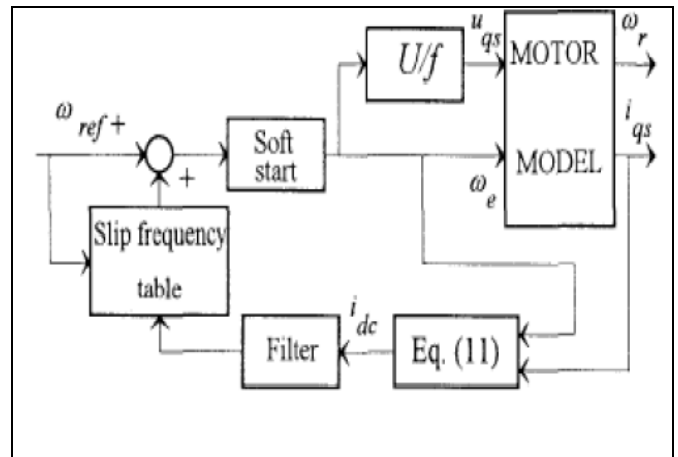The block diagram of mathematical model is shown in figure 2

Figure 2 Mathematical model of drive

The values for slip frequency table are calculated for the range of the desired speed and current i_{dc} from 0.1 to 2 p.u. with the increment of 0.1 p.u. The values for slip frequencies are calculated by using the system of equations, obtained when (10 and 11) are substituted in the model of induction motor. Then, in accordance with (9), independent variables were Wref and idc. dc link current has the minimal value during d e no load operation. The maximal dc link current values under which the stable operations are possible are the values in the regime when the desired speed is equal to the breakdown speed. In the table for the given values of the current smaller than the mentioned minimal values, the zeros were written, while for the values greater than the maximal, the value of the breakdown slip frequency is written. The basic frequency of the inverter in the model is changed in the range from 0.1 to 2 p.u. with the increase of 0.1 p.u. which is corresponds to the readjustment of the laboratory model.

The simulation results obtained show that the drive has satisfactory dynamic possibilities with a modest resolution in the slip frequency table, and based inverter frequency, when the low pass filter (LPF) in current feed-back is used. To come to this conclusion it is possible by compare Figures 3 and 4.
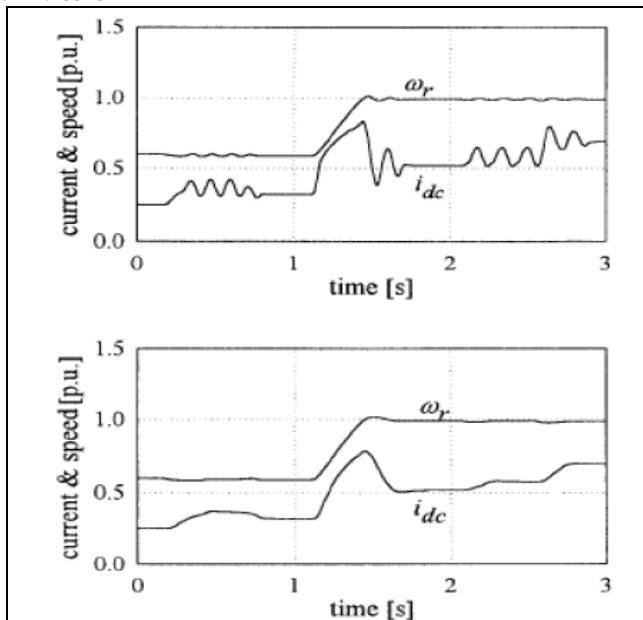
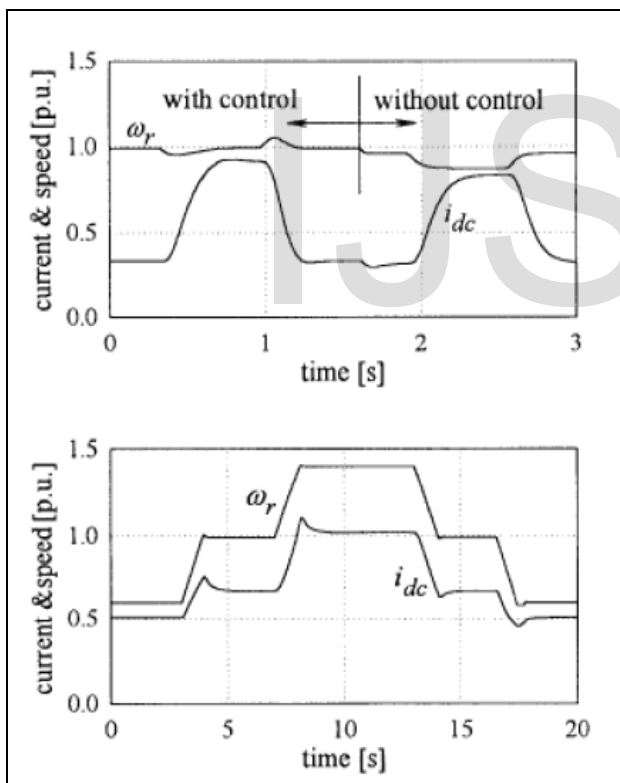Figure 3 Dynamic responses without LPF

Figure 4 Dynamic response of LPF

In Figure 6 the influence of speed control during load change is shown. Figure 7 represents the motor speed change when the reference speed is changed.

SLIP FREQUENCY TABLE

As mentioned, the slip frequency table must be formed with great attention, the quality of system operation is depending on these values, and therefore a special procedure for it was developed. The table can be filled in by simple measuring but though we have shown that the number of necessary data can be partially reduced, the number of measurements is high. In practice the carrying of these measurements is often impossible. In the previous part of the paper, the manner of calculating the data for the table was explained, for the case of constant parameters, however, if we wish to take into account the variation of some important parameters the definite additional dependences must be known. The paper analyses and applies the method of calculation based on the minimal number of measurements namely, it is necessary to carry out two measurements each in characteristic frequencies, at the drive in the steady state operation, with as big as possible difference in loading. This difference affects essentially the accuracy of the results obtained. In the mentioned measurements the speed, frequency, phase and dc current should be measured, and the ratio of the voltage and the frequency must be according to the adopted relation (1). On the basis of these measurements the parameters of equivalent circuit could be determined, where the stator resistance (it must be separately measured) and the leakage inductances were constant, and the resistance (R'r), mutual inductance (M) and core-loss resistance (Rp),are functions of the stator frequency. These functions are interpolated between the values obtained by measurements.

The data obtained are authentic because they are measured in the drive, but they are valid for v/f dependence where the measurements are made. On the basis of the data obtained, and mentioned parameter functions vs frequency, the arbitrary number of the values necessary for filling in slip frequency table could be calculated.

EXPERIMENTAL RESULTS

The experimental results of the proposed speed controller are shown in following figures. The tested drive model has the supply frequency range between 10% and 200%, with 1% resolution, there are 11 columns, i.e. 11 dc current values in range between no load and limited current (125% rated current) in the slip frequency table. The overload protection is activated on 125% rated load. The dynamic performance of the drive after reference speed change is illustrated by the waveforms

shown in Figures 5 and 6. In Figures 7 and 8 the influence of speed control during load change is shown. In figure 9 the hardware photo shown.
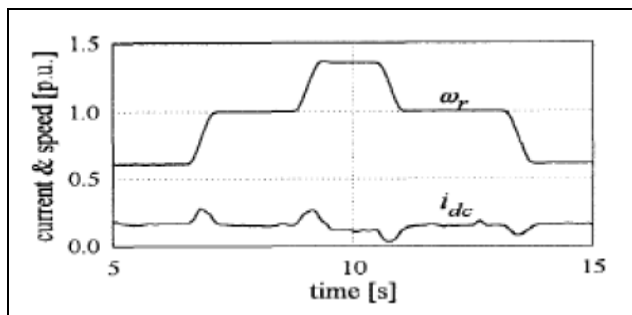

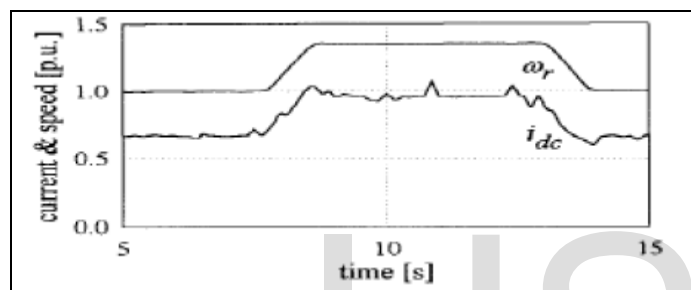Figure 5 Dynamic Performance of drive with speed reference
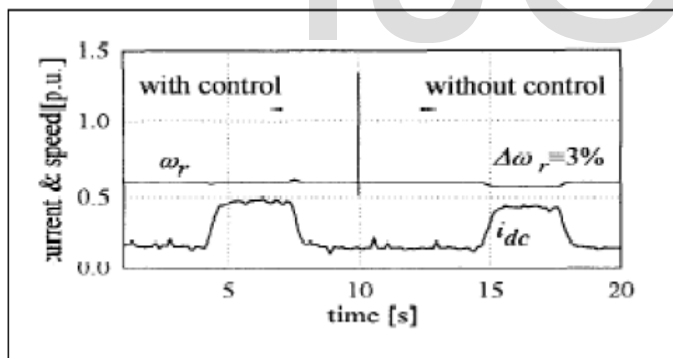

Figure 6 Speed change at No Load
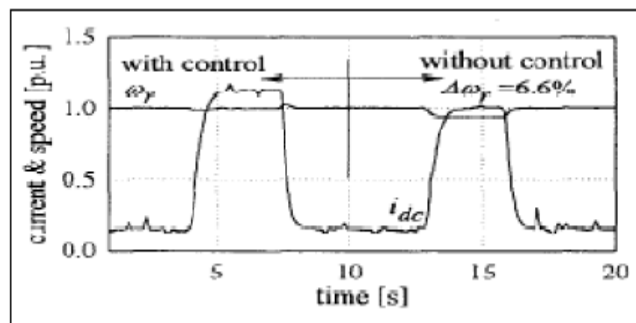

Figure 7 Speed Change under Load

Figure 8 Load Changes with w_{ref} = 0.6pu

CONCLUSION

A low cost speed sensor less drive is easily controlled general purpose induction motor drive with PWM inverter is developed. The results of the performed theoretical and the experimental investigations have confirmed the expected effectiveness of the proposed algorithm for speed control, based on a single measurement of dq axis dc link current. The Presented control concept is convenient for complicated drives, but with modest dynamic performances. In further work we will verify the control algorithm on drives of different powers with forward and reverse operation. We will Endeavour to extend the range of regulation to the braking systems, in the case under consideration the brakes were of short duration, only at the reduction of speed, during the speed which was not under a direct control, but only upon the end of this systems.

DRIVE DATA

Motor: 1.5 kW;
Speed : 1440RPM;
Load Current: 3.2 A.
Inverter: V_{dc}=510 V;
Input/output: 3phase 400V; 50 Hz

Figure 9 Hardware Photo

REFERENCES

[1]   W.Leonhard, "Adjustable-Speed AC Drives", Proc. Of the IEEE, Vo1.76,no.4, pp 455-471, April 1988.

[2]   Electric motor drives modeling, analysis and control by R.Krishnan

[3]   U.Baader,M.Depenbrock,G.Gierse "Direct Self Control of Inverter-Fed Induction Machine, a Basis for Speed Control without Speed-Measurement", IEEE IA Annual meeting, Annual Meeting, S.Diego, pp 486-492, October 1989

[4]   M.A.Choudhury, M.A.Rahman, "Determination of Operating Conditions of Submersible Induction Motors"' IEEE Trans. on IA, Vo1.28, No.3, pp 680-684, May/June 1992.

[5]   B.K.Bose, *"Power Electronics and AC Drives"* Prentice-Hall, New Jersey1986, pp. 140-160.

[6]   D.S. Coming and O.G. Staadt, "Velocity-Aligned Discrete Oriented Polytopes for Dynamic Collision Detection," *IEEE Trans. Visualization and Computer Graphics*, vol. 14, no. 1, pp. 1-12, Jan/Feb 2008, doi:10.1109/TVCG.2007.70405. (IEEE Transactions)

[7]   D. W.Novotny,S. A.Nasar, B.I. JefieniC, D.Maly, "Frequency Dependence of Time Harmonic Losses in Induction Machines", Proc. ICEM 90, Boston, July 1990.