Scalar Control of Induction Motor Drives Using dSPACE DS1104

H. Akroum, M. Kidouche, and A. Aibeche
Laboratory of Applied Automation (LAA), FHC
University M'Hamed Bougara of Boumerdes (UMBB)
Boumerdès, ALGERIA
akroum@yahoo.fr, kidouche_m@hotmail.com, nababd2001@yahoo.fr

Abstract—**This paper deals with design and implementation of Voltage/Frequency (V/f) control of induction motor (IM) drives. Sinusoidal PWM (SPWM) and non sinusoidal PWM, using an injected Zero-Sequence Signal (ZSS), are used for controlling the motor. An analytical approach is used to design the Proportional Integral Controller with antiwindup. The design procedure uses only the name plate data. A 3Kw, 3-phase, 50Hz, 1420rpm, induction motor and a dSPACE DS1104 hardware/software are used to carry out the control application. The experimental results show the effectiveness of the control method.**

Keywords- induction motor; V/f control; PI controller; dSPACE

I. INTRODUCTION

The V/F controlled drives are parameter independent, easy to implement and low cost but they are classified as low performance drives [1]-[7]. Therefore, the V/f control algorithm is widely adopted in general purpose inverters, such as adjustable-speed pumps, fans, or blowers where high control quality would be superfluous. In high performance systems vector control methods are necessary [1]-[5]. In V/F control methods, the stator voltage is adjusted in proportion to the supply frequency, except for low and above base speeds. At low frequency operation the voltage drop across stator resistance must be taken into account. The simplest stator resistance compensation method consists of boosting the stator voltage to compensate the voltage drop across the stator resistance [5, 6]. However, it is not easy to determine the boost voltage as it is easy to get flux saturated [2, 3, 5, 6]. Alternatives to the simple boost voltage are described in [4]-[6]. However these methods need machine parameters and are complicated [1, 3]. The open Loop V/F method always suffers from oscillations especially under light load conditions [1, 2, 9-12]. Many studies in relation to this instability problem have been carried out [8]-[12].

This paper deals with design and implementation of Voltage/Frequency (V/f) control of induction motor drives. For our knowledge, in text-books and literature, the unique description of designing slip-regulator using analytical approach was described in [13]. Another contribution is done in this paper.

Sinusoidal PWM (SPWM) and non sinusoidal PWM, using an injected Zero-Sequence Signal (ZSS), are used for controlling the motor. An analytical approach is used to design the Proportional Integral controller with antiwindup. The design procedure uses only the name plate data. A 3Kw, 3-phase, 50Hz, 1420rpm, induction motor and a dSPACE DS1104 hardware/software are used to carry out the control application. The experimental results show the effectiveness of the control method.

II. PWM GENERATION

In power electronics, pulse width modulation (PWM) has been subject of intensive research and a large variety of PWM methods has been described in the literature [14]-[23]. The most widely used methods are the sinusoidal PWM (SPWM) and the space vector PWM (SVPWM) [15]. The use of an injected Zero-Sequence Signal (ZSS) initiated the research on non sinusoidal PWM [15, 18, 22-23].

Figure 1. gives the block diagram of the hybrid modulator for generating the different ZSS.

There is a large number of ZSS [15, 20, 23]. For example the use of μ=0.5 results in the SVPWM which is, in term of harmonic distortion factor, superior to all other methods [15]. The use of μ= and μ=0 results in DPWMMAX (Discontinus PWMMAX) and DPWMMIN respectively.

Fig. 2 gives the Simulink model implementation of PWM with an injected ZSS. In our implemented application sinusoidal and non sinusoidal (SVPWM, DPWMMIN ..etc) duty cycles can be generated.

III. OPEN LOOP V/F CONTROL

Assuming that the voltage drop across the stator resistance is small in comparison with the stator voltage, the stator flux Ψ_s can be expressed as [1, 2]:

$$\psi_s \approx \frac{V_s}{\omega_s}. \tag{1}$$

where V_s is the per phase stator voltage, $\omega_s = 2\pi f_s$ (rad/sec), f_s is the supply frequency (Hz).

The torque developed in an induction motor can be expressed as [1, 2]:

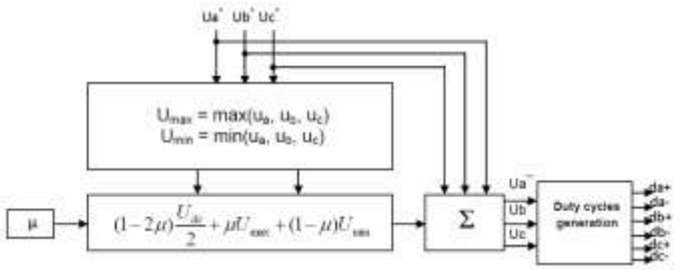

Figure 1. Block diagram of the hybrid modulator generating PWM signals with injected Zero-Sequence Signal (ZSS)

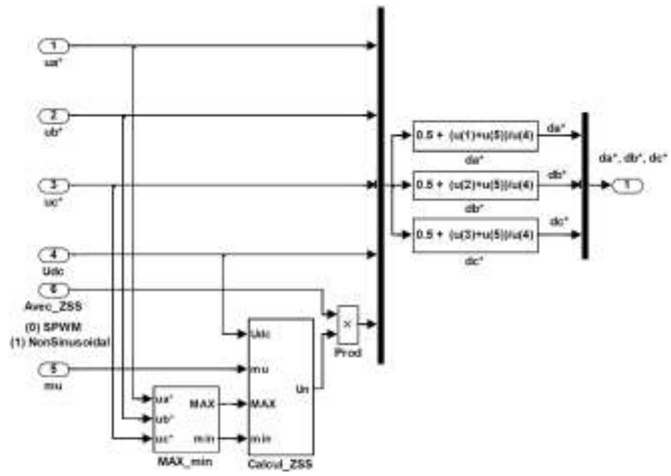

Figure 2. Simulik model of the hybrid modulator generating PWM signals with injected Zero-Sequence Signal (ZSS)

$$T = P_p \frac{R_r}{g\omega_s} \frac{V_s^2}{(R_s + \frac{R_r}{s})^2 + (X_S + X_r)^2} . \quad (2)$$

where P_p = pole pairs, R_s and R_r = stator and rotor resistance, X_s and X_r = stator and rotor reactance, s =slip. For small slip (normal operating conditions) the torque can be approximated as:

$$T \approx \frac{P_p}{R_r} \left(\frac{V_s}{\omega_s} \right)^2 s\omega_s . \quad (3)$$

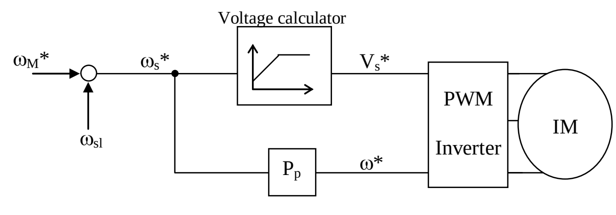

Figure 3. Basic Open Loop V/F Speed Control Pp is the number of pole pairs

If the ratio V_s/ω_s is kept constant (i.e. flux constant), the torque could be controlled by controlling the slip speed $s.\omega_s$ [1, 2]. Figure 3 shows the basic concept of the open loop V/F control approach. A fixed value of slip velocity, ω_{sl}, (corresponding to 50% of rated torque), is added to the reference velocity, ω_M^*, of the motor to result in the reference synchronous frequency, ω_S^*. This frequency is next multiplied by the number of pole pairs, P_p, to obtain the reference output frequency, ω^*, of the inverter, and it is also used as the input to the voltage calculator.

At low speed, the voltage drop across the stator resistance must be taken into account in maintaining constant flux. Conversely, at speeds exceeding that corresponding to the rated frequency, ω_{rat}, the constant V/F condition cannot be satisfied. Therefore the stator voltage is calculated in accordance to the following equation [2]:

$$V_s = \begin{cases} (V_{srat} - V_{s0}) \dfrac{\omega}{\omega_{rat}} + V_{s0} & for \ \ \omega \le \omega_{rat} \\ V_{srat} & for \ \ \omega \ge \omega_{rat} \end{cases} . \quad (4)$$

where V_{srat} is the stator rated voltage, ω_{rat} is the rated frequency and V_{s0} denotes the rms value at zero frequency as illustrated in Fig 4.

The real time Simulink model for open loop V/F speed control of three phase induction motor is shown in Fig. 5.

V. CLOSED LOOP V/F CONTROL

A. *Base Conception of Closed Loop V/f Control*

Figure 6. shows the base conception of closed loop V/f control. The speed ω_M* (measured or estimated) is compared with the reference speed ω_M*. The speed error signal is applied to a *PI* controller which generates the reference sleep speed ω_{sl}*. The slip speed must be limited for stability and over current prevention [1]. The reference synchronous speed, ω_{syn}, is obtained by addition of ω_{sl}* and ω_M.

The real time Simulink model for closed loop V/F control of three phase induction motor is shown in Fig 7.

B. *Slip Regulation Design*

The V/f induction motor drive system using a PI-Controller can be modeled as shown in Fig. 8. [13]. (J and B are the machine's mechanical parameters inertia and frictional damping coefficient).

From (3) the torque developed can be considered proportional to slip speed $s.\omega_M$:

$$T \approx K_f s\omega_M . \quad (5)$$

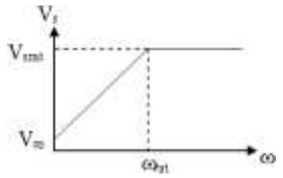

Figure 4. Voltage versus frequency relation

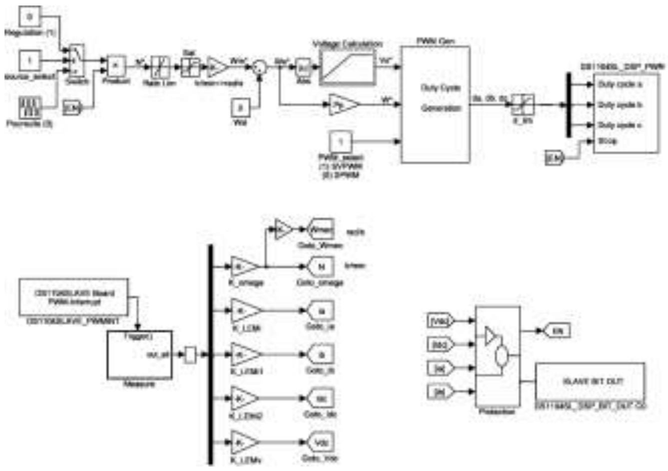

Figure 5. Real time Simulink model for V/F speed control.

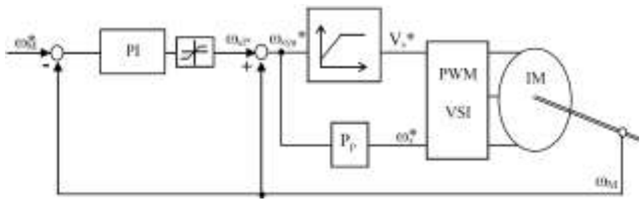

Figure 6. Closed loop V/f control.

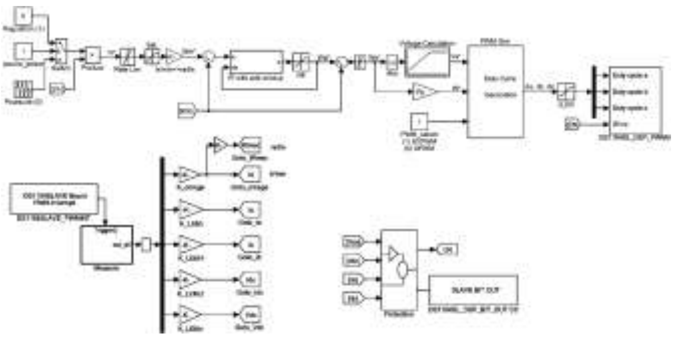

Figure 7. Real-time Simulink model for closed loop V/f control.

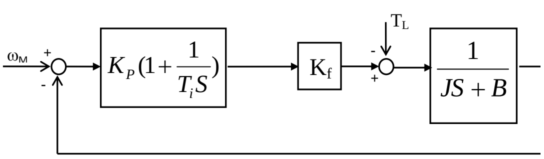

Figure 8. Linearised model of IM constant V/f drive using PI regulator.

where $K_f = \left(\frac{T}{s\omega_M}\right)_{at\,rated\,condition}$

Assuming the load torque T_L=0, the open loop transfer function H(S) can be expressed as:

$$H(S) = \frac{K_P K_f}{B}\frac{T_i S+1}{T_i S}\frac{1}{T_m S+1}. \tag{6}$$

where $T_m = \frac{J}{B}$.

In this paper coefficient B was not neglected but if the frictional damping coefficient B can be neglected, the open loop transfer function H(S) can be expressed as:

$$H(S) = \frac{K_P K_f}{JT_i}\frac{T_i S+1}{S^2}. \tag{7}$$

Coefficients of the PI regulator can be determined as follows:

The parameter T_i can be determined by neutralizing the effect of the slowest pole which improves the dynamic response of the system. The pole that will be canceled in (6) is T_m^{-1}. The parameter T_i is done by:

$$T_i = T_m. \tag{8}$$

H(S) in (6) can be rewritten as:

$$H(S) = \frac{K_P K_f}{BT_m}\frac{1}{S}. \tag{9}$$

Therefore the closed loop system $H_C(S)$ has an equivalent first order system expressed by:

$$H_C(S) = \frac{1}{\tau_m S+1}. \tag{10}$$

where $\tau_m = \frac{BT_m}{K_P K_f}$

If we choose a value for τ_m (for example 0.5 s) the parameter K_p can be determined by:

$$K_P = \frac{BT_m}{\tau_m K_f}. \tag{11}$$

To prevent the hardware from damaging by overcurrent or overvoltage appearance, the designed controller output has to be limited. That limitation causes nonlinearities in the system. The saturation situation leads to keeping the integral part integrating the supplied error. It results in rising (winding up) the output. It lasts until plant feedback exceeds reference value, and negative error appears in the input of PI. That change effects in high output of the integral part compensating previously grown error. It causes overshoots in the responses, and if the signal was saturated for significant amount of time, it would even deteriorate the control, and system would become unstable.

Therefore to overcome that situation, antiwindup part is added to the controller [24]. Its basic structure is presented in Fig. 9.

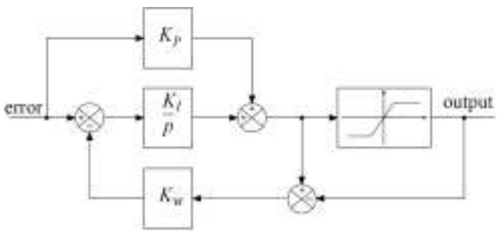

Figure 9. Linearised model of IM constant V/f drive using PI regulator.

The gain K_I is expressed by :

$$K_I = \frac{K_P}{T_i}. \quad (12)$$

The anti windup gain K_w can be expressed by:

$$K_w = \frac{1}{T_i}. \quad (13)$$

V. EXPERIMENTAL RESULT

The experimental testing ground (see Fig. 9.) contains:

- An experimental platform using a 3 kW three phase squirrel cage induction motor (T_{rated}=20Nm, $(s.\omega_M)_{rated}$=8.4 rad/s, J=0.046 kgm^2, B=0.001 Nms/rad) fed by a SEMIKRON IGBT PWM VSI. The load torque is controlled by a magnetic powder breaker (FP3),
- A personal computer with MATLAB/Sirnulink software to design a simulate induction machine control,
- A dSPACE DS1104 DSP-board and ControlDesk software used for real time control of the induction motor drive,
- An interface board for signal conditioning for current and voltage LEM transducers as well as a speed and torque sensors,
- An interface board to adapt control signals to the IGBT drivers and to protect power modules using drivers' error signal.

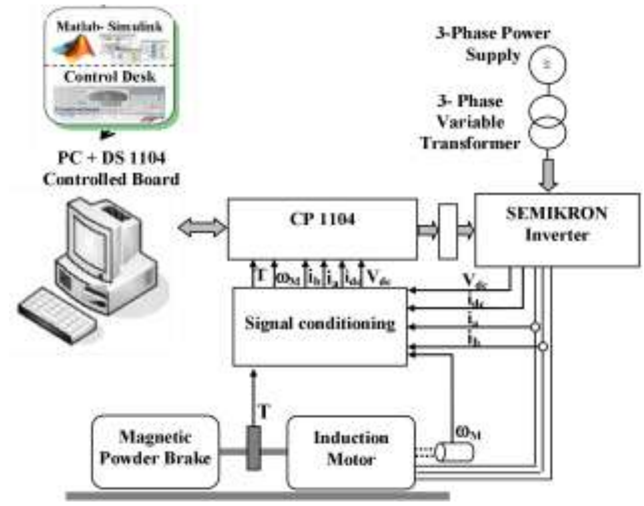

Figure 10. Block diagram of the laboratory hardware apparatus..

In present case: $T_i = T_m = 4.6\,s$

For τm=0.2s the gain K_p can be determined by:

$$K_P = \frac{BT_m}{\tau_m K_f} = 0.191$$

In Fig. 11, screen dump of open loop constant V/F controlled IM drive is presented.

In Fig. 12 and Fig. 13, screen dumps of closed loop constant V/F controlled IM drive are presented.

VI. CONCLUSION

In this paper a design and implementation of Voltage/Frequency (V/f) control of induction motor (IM) drives are described. Sinusoidal PWM (SPWM) an non sinusoidal PWM, using an injected Zero-Sequence Signal (ZSS), are used for controlling the motor. For the closed loop V/f An analytical approach was used to design the Proportional Integral controller. In the design procedure only the name plate data was used. A 3Kw, 3-phase, 50Hz, 1420rpm, induction motor and a dSPACE DS1104 hardware/software was used to carry out the control application. The experiments illustrate the succefull the effectiveness of the control method.

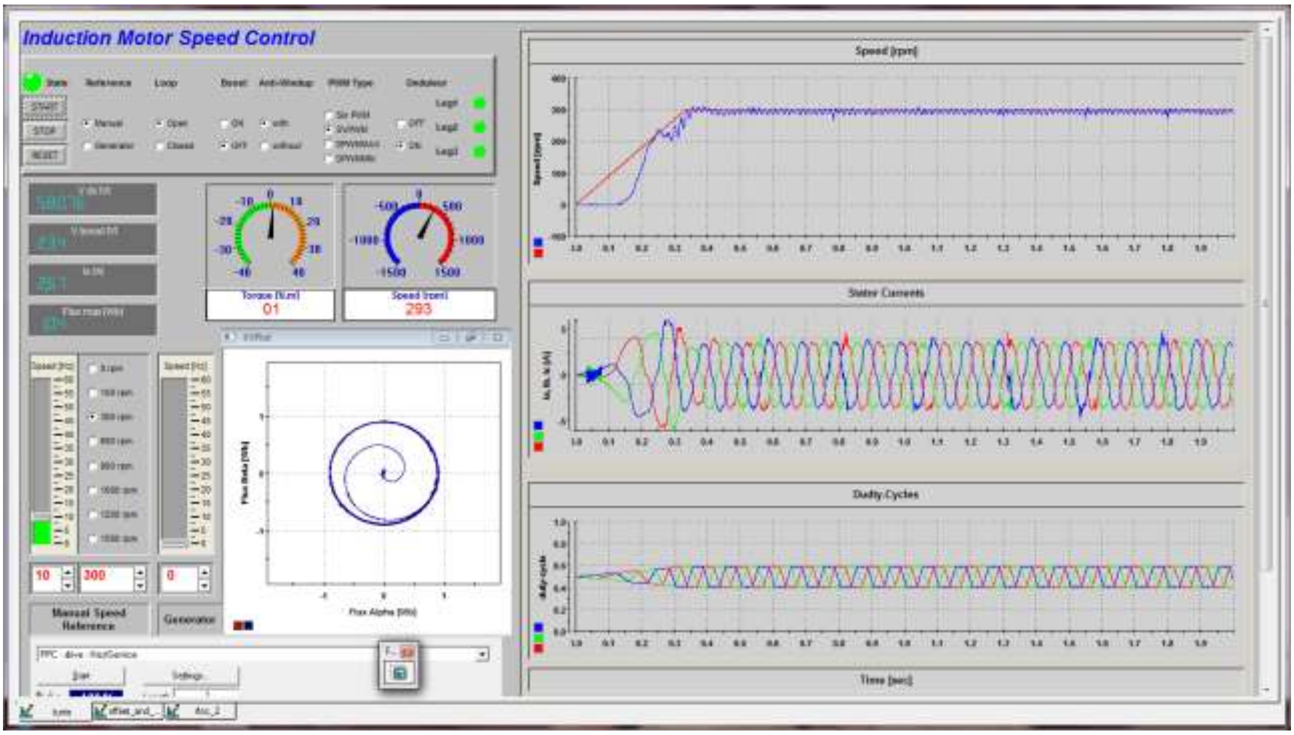

Figure 11. The ControlDesk panel for open loop V/fcontrolled IM drive: step repense for ω_M*=300rpm (T_L=0Nm).

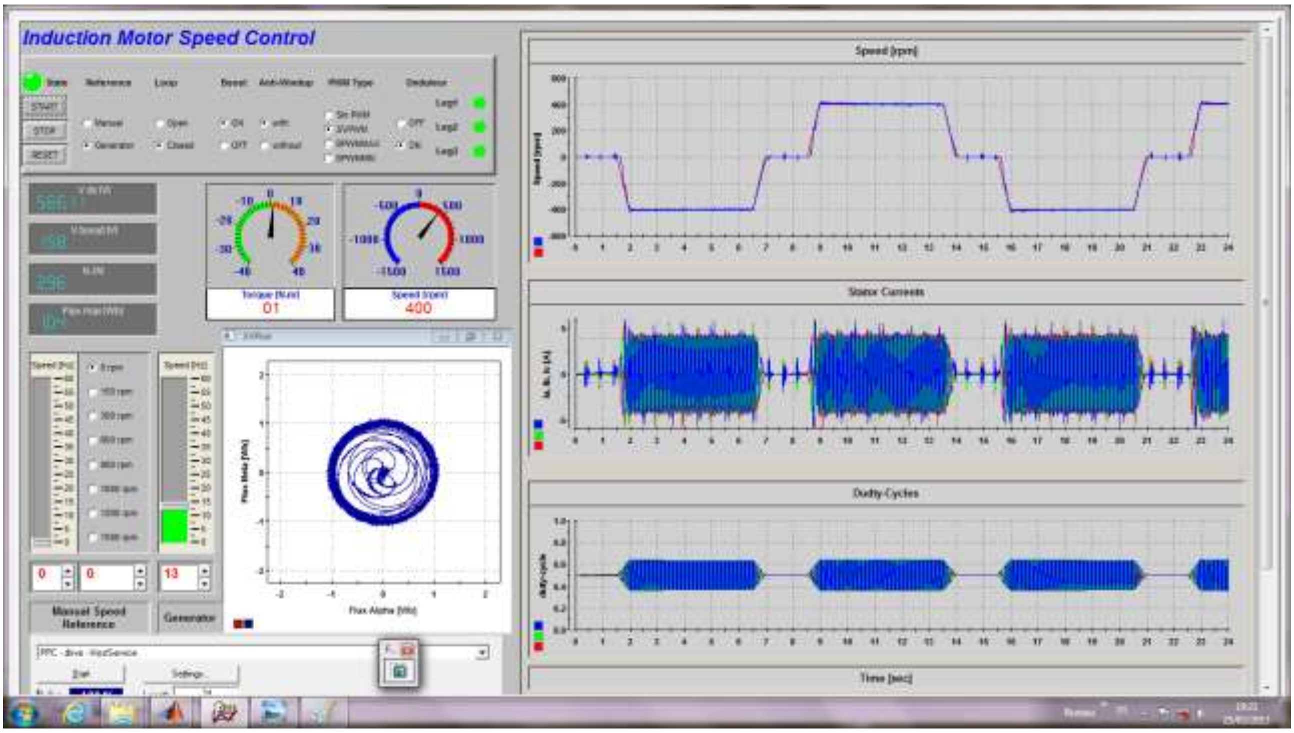

Figure 12. The ControlDesk panel for closed loop V/fcontrolled IM drive: tracking repense (ω_M*∈[-400rpm 400rpm], T_L=0 Nm).

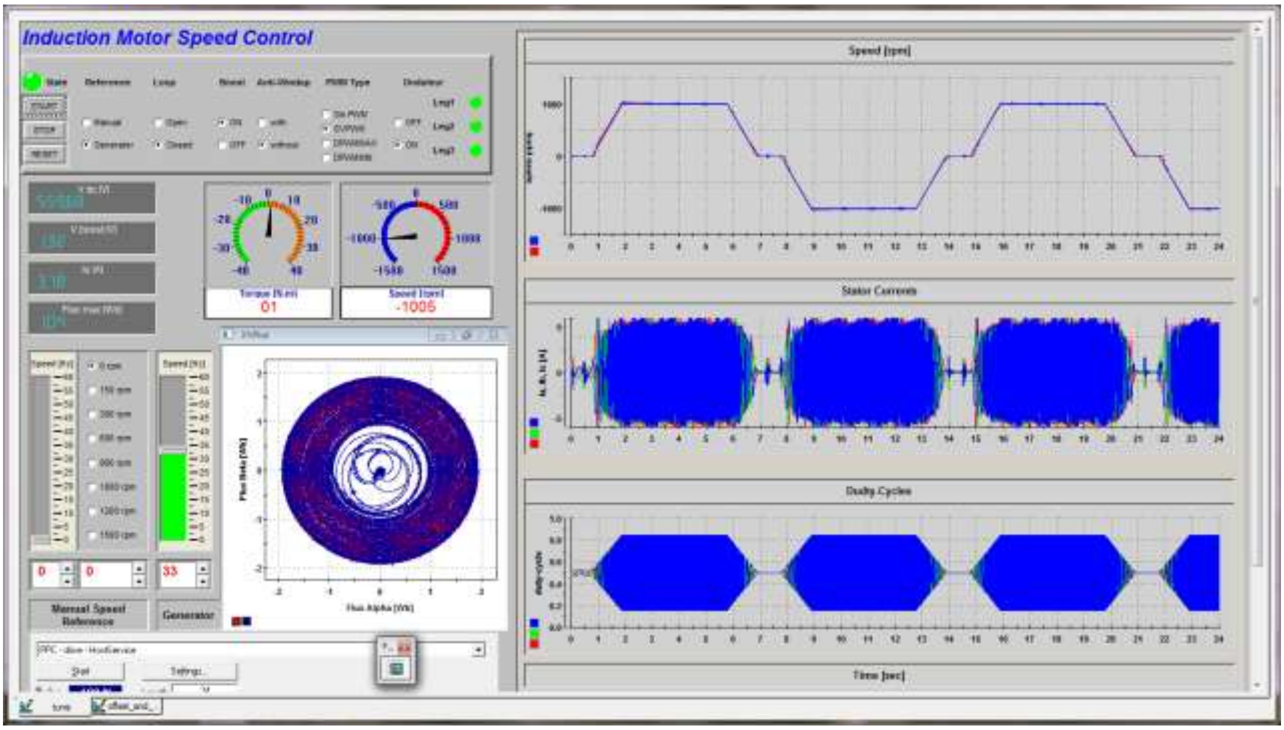

Figure 13. The ControlDesk panel for closed loop V/fcontrolled IM drive: tracking repense (ω_M*∈[-1000rpm 1000rpm], T_L=0 Nm).

REFERENCES

[1] B.K. Bose, Power Electronics and AC Drives, Prentice-Hall,'' NJ, USA, 2002.

[2] A. M. Trzynadlowski, Control of Induction Motors. Academic Press, CA, USA, 2001.

[3] Holtz, J., ''Sensorless control of induction motor drives, '' Proceedings of the IEEE, Vol. 90, No. 8, August 2002, pp. 1359 - 1394.

[4] Wei Chen ; Dianguo Xu ; Rongfeng Yang ; Yong Yu ; Zhuang Xu ''A novel stator voltage oriented V/F control method capable of high output torque at low speed,'' International Conference on Power Electronics and Drive Systems, PEDS2009, 2-5 Nov. 2009, pp 228 - 233.

[5] I. Boldea, ''Control issues in adjustable speed drives, '' IEEE Industrial Electronics Magazine, Vol. 2, No. 3, Sept. 2008, pp. 32 - 50.

[6] A. Munoz-Garcia, T.A. Lipo, D.W. Novotny, ''A new induction motor V/f control method capable of high-performance regulation at low speeds, '' Vol. 34, No. 4, July/August 1998, pp. 813 - 821.

[7] H. Akroum, M. Kidouche, A. Aibeche, ''A dSPACE DSP Control Platform for V/F Controlled Induction Motor Drive and Parameters Identification,'' Lecture Notes in Electrical Engineering (LNEE), vol. 121, pp. 305-312, 2011.

[8] C.J. Francis, H. Zelaya De La Parra, ''Stator resistance voltage-drop compensation for open-loop AC drives,'' Electric Power Applications, IEE Proceedings, Vol. 144 , No. 1, January 1997, pp.21 - 26.

[9] A. Oteafy, J. Chiasson, ''A Study of the Lyapunov Stability of an Open-Loop Induction Machine IEEE Transactions on Control Systems Technology,'' Vol. 18 , No. 6, Nov. 2010, pp. 1469 - 1476.

[10] K. Suzuki, S. Saito, T. Kudor, A. Tanaka, Y. Andoh, ''Stability Improvement of V/F Controlled Large Capacity Voltage-Source Inverter Fed Induction Motor,'' in 41st IAS Annual Meeting. Conference, Record of the 2006 IEEE Vol. 1, Oct. 2006, pp. 90-95.

[11] M. Zhiwen, L. Fei, T.Q. Zheng, "A New Stabilizing Control Method for suppressing Oscillations of V/Hz Controlled PWM Inverter-fed Induction Motors Drives," in 37th IEEE Power Electronics Specialists Conference, 2006, pp. 1-4.

[12] Y. Q. Xiang, ''Instability compensation of V/Hz PWM inverter-fed induction motor drives,'' in Conf. Rec. IEEE IAS Annu. Meeting, vol. 1, Oct. 1997, pp. 613-620.

[13] J. Holtz, ''Pulsewidth modulation—A survey,'' IEEE Trans. Ind. Electron, VOL. 39, NO. 5, pp. 410-420, December 1992.

[14] E.R.C. da Silva, E.C.dos Santos, C.B. Jacobina, "Pulsewidth Modulation Strategies," IEEE Industrial Electronics Magazine, Vol. 5 (2), 2011, pp. 37-45.

[15] J. Holtz, ''Pulsewidth modulation for electronic power conversion,'' in Proc. IEEE, vol. 82, pp. 1194–1214, Aug. 1994.

[16] M. Depenbrock, ''Pulse width control of a 3-phase inverter with non-sinusoidal phase voltages,'' in Proc. IEEE Int. Semiconductor Power Converter Conf. (ISPCC'77), 1977, pp. 399–403.

[17] M. A. Boost and P. D. Ziogas, ''State-of-theart carrier PWM techniques: A critical evaluation,'' IEEE Trans. Ind. Applicat, vol. 24, pp. 271–280, Mar./Apr 1988.

[18] G. V. Stanke, ''Analysis and realization of a pulsewidth modulator based on voltage space vector,'' IEEE Trans. Ind. Applicat, vol. 24, pp. 142–150, Jan./Feb 1988.

[19] A. Trzynadlowski and S. Legowski, ''Minimum-loss vector PWM strategy for three phase inverter,'' IEEE Trans. Power Electron, vol. 9, pp. 26–34, Jan. 1994.

[20] H. W. van der Broeck, H. C. Skudelny, and G. V. Stanke, ''Analysis and realization of a pulsewidth modulator based on voltage space vector,'' IEEE Trans. Ind. Applicat, vol. 24, pp. 142–150, Jan./Feb 1988.

[21] V. Blasko, ''A hybrid PWM strategy combining modified space vector and triangle comparison methods,'' in Proc. Power Electronics Specialists Conf. (PESC) Rec. 1996, pp. 1872–1878.

[22] A. M. Hava, R. Kerkman, and T. A. Lipo, ''A high-performance generalized discontinuous PWM algorithm,'' IEEE Trans. Ind. Applicat. vol. 34, pp. 1059–1071, Sept./Oct. 1998.

[23] D.Shah, S. Nandi, "Analytical Approach to Design of Slip-Controller for Constant Volts/Hz Scheme Induction Motor Drive Using Motor Name-plate Details," in Canadian Conference on Electrical and Computer Engineering, 2007. CCECE 2007, pp. 393 - 396.

[24] G. F. Franklin, J. D. Powell, A. Emami-Naeini, Feedback Control of Dynamic Systems, 5-th edition, Pearson Prentice Hall, 2006.