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SPEED SENSORLESS VECTOR CONTROL OF INDUCTION MACHINE BASED ON THE MRAS THEORY

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Abstract— This work describes a model-reference adaptive system (MRAS) for the speed estimation of induction motor from terminal voltages and currents. The estimated speed is used as feedback in a vector control system, thus achieving good bandwidth for speed control without the use of shaft-mounted sensors. This technique uses for controlling induction Motor using Vector control. Simulation has been done in Matlab software. In MATLAB, Due to Embedded Legacy C source code can be verified through simulation with this legacy code as controller and plant model in simulink block diagram. In vector control, accuracy of internal parameter such as resister of motor armature and inductance affects control performance. Internal parameters are used, for example, feed-forward compensator of current controller and parameters of observer model in position Sensorless. Production-quality code suitable for implementation with good readability, customization and performance, can be generated by combining add-on tool of RTW, RTW Embedded Coder.

Key words: MRAS, Embedded Legacy C source code, feed-forward compensator, RTW, RTW Embedded Coder.

Introduction

In recent years, the control of high-performance induction motor drives for general industry applications and production automation has received widespread research interests. Many schemes have been proposed for the control of induction motor drives, among which the field oriented control [1, 2], or vector control, has been accepted as one of the most effective methods. In following table1 summarizes the control technique advantages and disadvantages [3].

CONTROLLER DEVELOPMENT RELATED OPTIONAL TOOLS

Some of the solutions provided for different development phases are listed in figure 1. In vector control, accuracy of internal parameter such as resistance of motor armature and inductance affects control performance. Internal parameters are used, for example, feed-forward compensator of current controller and parameters of observer model in position sensorless.

DYNAMIC MODEL IN SPACE VECTOR FORM

The dynamic equivalent circuits in literature [1] are shown.

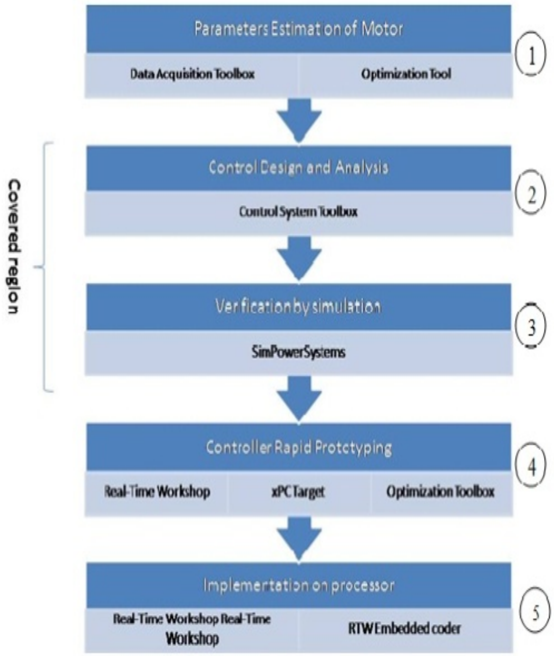

Fig. 1-Controller development process and related optional tools

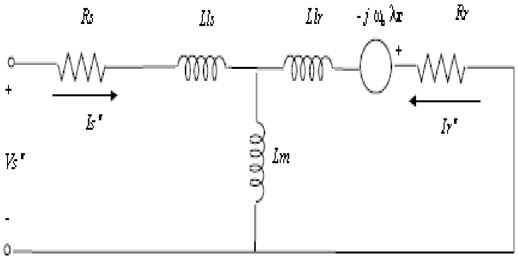

Fig. 2-Dynamic Equivalent Circuit on a Stationary Reference Frame [1]

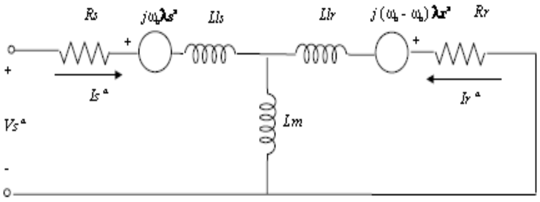

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Fig. 3-Dynamic Equivalent Circuit on an Arbitrary Reference Frame Rotating at ωa [1]

MODEL REFERENCE ADAPTIVE SYSTEM (M.R.A.S) TECHNIQUE

A model-reference adaptive system (MRAS) for the estimation of induction motor speed from measured terminal voltages and currents [3]. The estimated speed is used as feedback in a vector control system, thus achieving moderate bandwidth speed control without the use of shaft-mounted transducers [4]. This technique is less complex and more stable than previous MRAS tacholess drives. Different speed sensorless estimation is shown in Figure 4

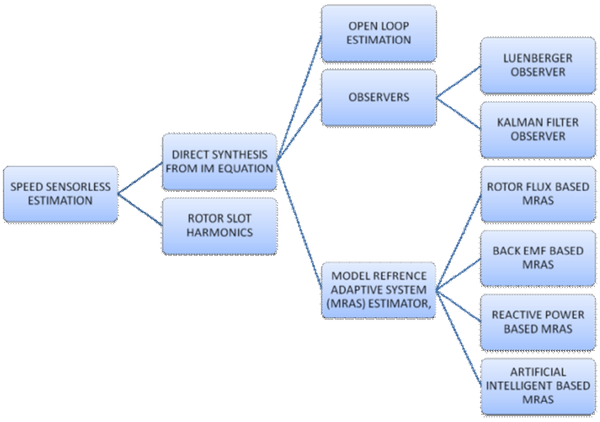


Fig. 4-speed sensorless estimation Techniques

SYSTEM MODELLING

It is important to determine accurate flux vector in induction motor. Some of the methods to detect flux vector include direct detection, where magnetic sensor by hall element is used, and indirect detection, where slip angular frequency is added to the detected rotating angular velocity. In figure 5 and figure 6, model that estimates flux vector and rotating angle using flux observer.

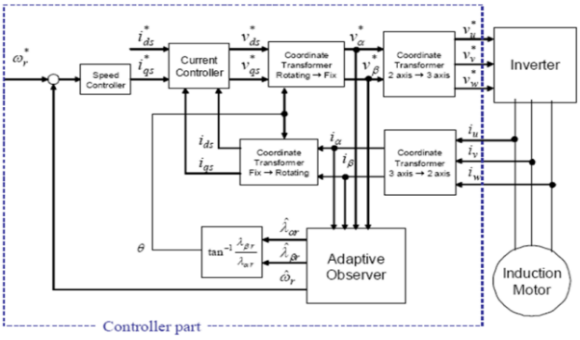


Fig. 5-Position sensorless vector control configuration.

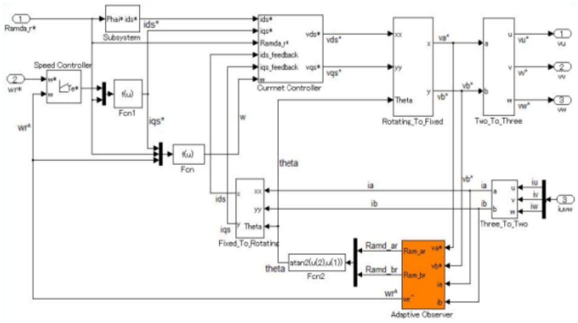


Fig. 6-Modelling of controller part

Internal model of coordinate transformer subsystem

Internal model of coordinate transform is shown in figure 7.In figure 8 Current controller is PI control loop with feed forward compensator considered in synchronously Rotating co-ordinate system. This model compensates, by feed forward, no stationary term of power Supply frequency ω obtained from electric formula of motor's analogous circuit in orthogonal two axis rotating coordinate system.

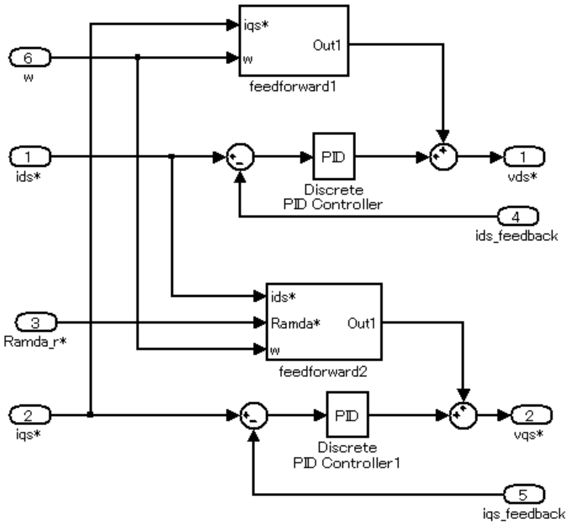


Fig. 7-Internal model of current controller subsystem

Adaptive observer is constructed by two-phase fixed coordinate system. Modeling of adaptive Observer is described in the next Topic.

VELOCITY SENSORLESS BY ADAPTIVE SECONDARY FLUX OBSERVER

Modeling of Adaptive Flux Observe State-space expression of induction motor in orthogonal two axes fixed coordinate system can be expressed in the equation below [4]:

$$dx/dt = Ax + B\nu_s\ ,\quad i_s = Cx \qquad (1)$$

Where $x = [i_{\alpha s}\ i_{\beta s}\ \lambda_{\alpha r}\ \lambda_{\beta r}]$

$\nu_s = [\nu_{\alpha s}\ \ \nu_{\beta s}]$ $\quad i_s = [i_{\alpha s}\ \ i_{\beta s}]$

$$A = \begin{pmatrix} -(R_s+M^2R_r/L_r)/(\sigma L_s)I & (Rr/\varepsilon Lr)I-(\omega_r/\varepsilon)J \\ (MR_r/L_r)I & -(R_r/L_r)I+\omega_r J \end{pmatrix}$$

$B = [\ (1/\sigma Ls)I\ \ \ 02x2\ ]T\ , C = [I\ \ 02x2]$

$\sigma = 1 - M2/(LsLr)\ ,\ \varepsilon = \sigma\ LsLr/M$

$$I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \qquad J = \begin{pmatrix} 1 & -1 \\ 1 & 0 \end{pmatrix}$$

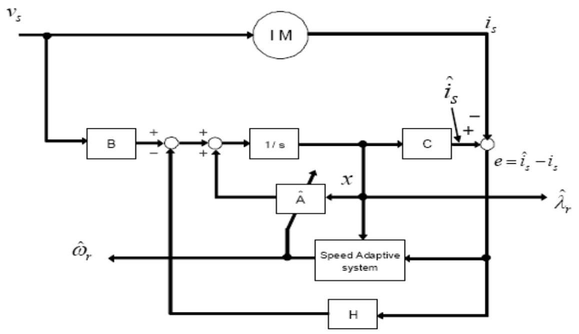


Fig. 8-State-space expression of observer in Figure 9 can be expressed in the equation below [4]:

$$d\hat{x}/dt = \hat{A}\hat{x} + Bv_s - He \qquad ,\hat{i}_s = C\hat{x} \qquad (2)$$

Where, H is observer gain, ^ is estimation value, e is current error e=$\hat{i}_s$-i_s[4,5]

$$\hat{A} = \begin{pmatrix} -(R_s+M^2R_r/L_r)/(\sigma L_s)I & (Rr/\varepsilon Lr)I-(\ \hat{\omega}_r\ /\varepsilon)J \\ (MR_r/L_r)I & -(R_r/L_r)I+\ \hat{\omega}_r\ {}_r J \end{pmatrix}$$

Then, parameter adjusting law of estimation electric angular velocity ωr are provided by the following equation using size of outer product of current error vector, e, and estimation flux [5]:

$$\hat{\omega}_r = K_p\left(J\hat{\lambda}_r\right)e + K_i\int\left(J\hat{\lambda}_r\right)^T edt \qquad (3)$$

Observer gain H is designed in a way to ensure adaptability of control system consisting of adaptive observer and induction motor, i.e. limt->∞ e=0 Assuming that terms other than velocity estimation value is true value, equation concerning current error, e, can be expressed as below from formulas (1) and (2). It can be obtained by subtracting (1) from (2) and define matrix Bω by separating term of ω from system matrix. Its complete derivation is omitted here [5, 6]

$$e = C(sI_4 - A + HC)^{-1}B_\omega(-\ \Delta\omega_r J\ \hat{\lambda}_r)$$

$$= G(s)\ (-\ \Delta\omega_r J\ \hat{\lambda}_r) \qquad (4)$$

Where

$\Delta\omega = \hat{\omega}_r - \omega_r$

I4: 4x4-unit matrix, $\qquad B\omega = [I/\varepsilon\ \ -1]^T$

Then, consider feedback system comprising linear time-invariant block G(s) and nonlinear time Variation block similar to the Fig. below. Applying Popov's hyper stability [5,6], the following needs to be satisfied to ensure stability, limt->∞ e=0

Linear time-invariant block G(s) is SPR (Strictly Positive Real).

Input, v1, and output, w1, of nonlinear time variation block satisfy Popov's equation [5, 6, 7] for all time t1>t0.

$$\int_{t0}^{t1} v^T\omega_1 dt \geq -\gamma_0^2 \qquad (5)$$

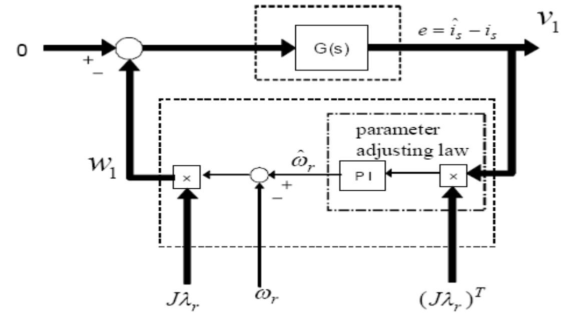


Fig. 9-Current error block feedback system [7]

It is possible to prove that (2) is satisfied by using (5). Optimal feedback gain H obtained from the only solution of Riccati equation is applied to make G(s) SPR as a condition of (1).

$H = PCTR^{-1}$ (6)

Riccati equation:

$PAT + AP - PCTR^{-1}CP + BWQBWT = 0$ (7)

Where, P: Solution of Riccati equation, Q, R: Weight matrix.

The weight matrices are Q=1, R=y I, respectively (however, y is a small positive number) (8)

MODELLING OF OBSERVER

Parameters of motor and each matrix of state-space expression are defined in program (M-file) of MATLAB language, (7) is solved using the Control System Toolbox, and optimal feedback is obtained.

[H, P, E] = lqe(A, Bw, C, Q, R)

COMPLETE SIMULINK MODEL

Figure.11 on the next page indicates model of the overall system .Reference voltage from CPU subsystem is compared with carrier wave with PWM Generator block provided in SimPowerSystems and generates six PWM pulses. The mechanism switches each gate of IGBT of three arm bridge circuit block (Block name: Universal Bridge), and drive connected induction motor block

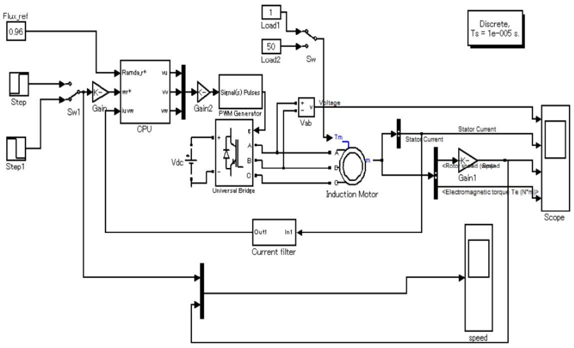
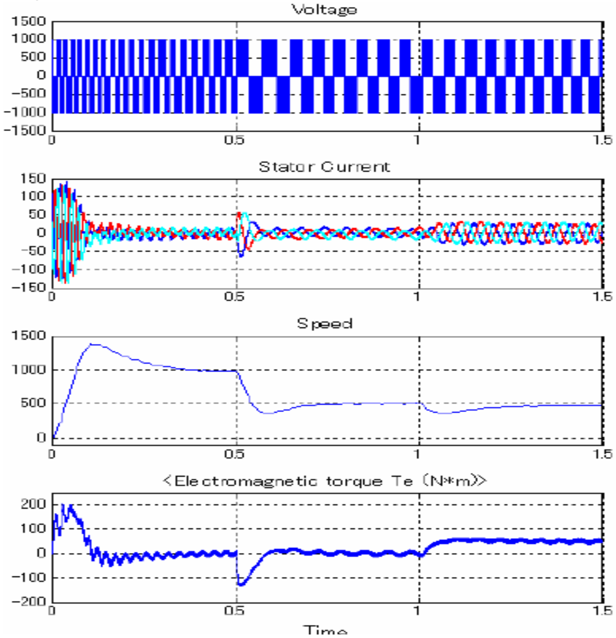


Fig. 10-Complete simulink model for MRAS based vector control of Induction Motor

SIMULATION RESULTS

Reference speed 1000 rpm to 500 and torque change 1N-m to 50 N-m

Figure 12 shows simulation results from 0 to 1.5 seconds. 0 to 0.5 seconds show velocity step response when velocity reference value is changed from 0[rpm] to 1000[rpm], 0.5 to 1.0 show velocity step response of 1000[rpm] to 500[rpm], and 1.0 to 1.5 show torque step response when external load torque is changed from 1[N] to 50[N]. Voltage between inverter UVs, armature current, rotating velocity, and transient response of torque are simulated



From the top,
Voltage between inverter UVs [V],
Three-phase stator current of motor [A],
Fig. 11-Motor rotating velocity [rpm], and torque [Nm]

When reference speed signal 1000rpm and load torque 1N-m

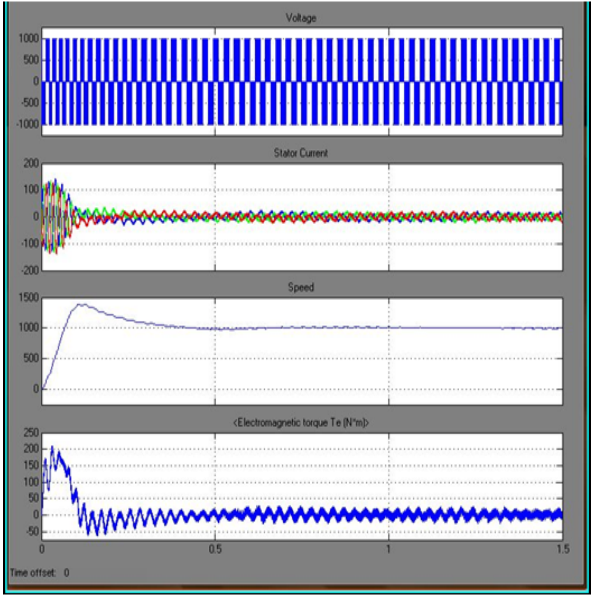


Fig. 12-Stator voltage, stator current, speed, torque vs. time

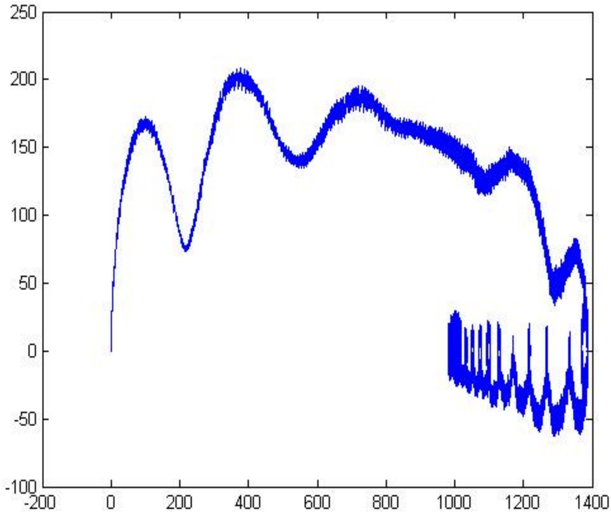


Fig. 13-Torque-Speed curve up to t=1.5sec

In figure 13, speed peak shoot is 1425 rpm and steady state speed 1050 rpm get in .3 sec. Stator transient current overshoot up to 100A and study state current 34.21A. We can see that reference speed tracking very fast for low load condition. In Figure 14 torque speed curve is shown speed transient is less as compare to old references.

When reference speed signal 1000rpm and load torque 50N

In figure 15 speed peak shoot is 1400 rpm and steady state speed 1010 rpm get in .3 sec. Stator transient current overshoot up to 150A and study state current 43.233A. We can also see that reference speed tracking very fast for high load condition. In Figure 16 torque speed curve is shown speed transient is less as compare to old references.

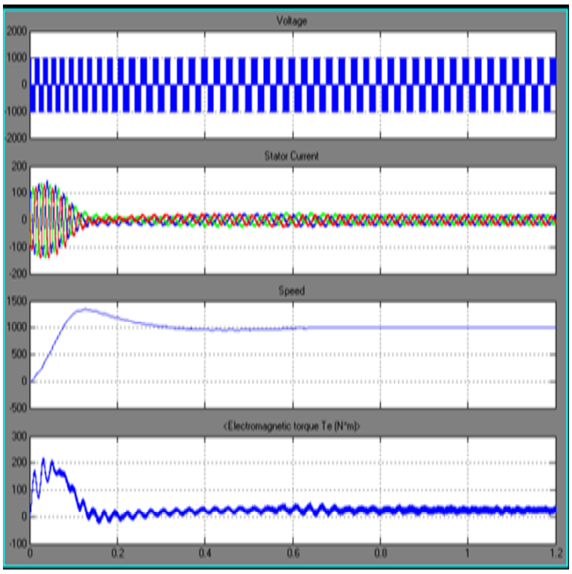


Fig. 14-Stator voltage, stator current, speed, torque vs. time

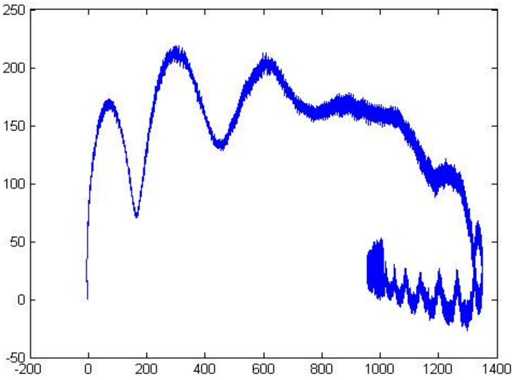


Fig. 15-Torque-Speed curve for t=1.5sec

Soft starting and take in reverse direction 1000to-1000rpm reference signal & load 1N

In figure17 machine start with start .speed changes from 1000 rpm to -1000 rpm .we can seen in soft start machine speed transient is low it acquired simultaneous -1000 rpm with linearly decrease speed .speed peak shoot is 1090.2 rpm and -1092.4 rpm.

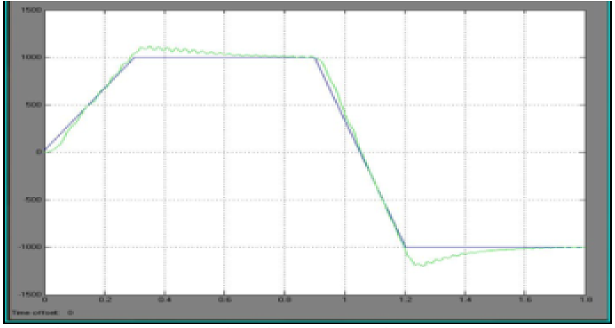


Fig. 16-Rotor speed and reference signal 1000 to -1000

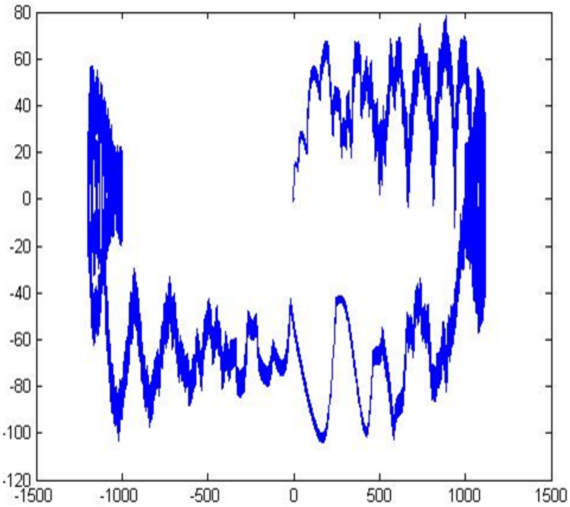


Fig. 17-*Torque and speed upto t=1.8*

Steady state speed 1010-rpm get in .31 sec. Stator transient current overshoot up to 35A and study state current 25.233A in positive direction. We can see that reference speed is varied linearly than dynamic response of machine very good .In Figure 18 torque speed curve shown how speed is move 1000rpm to -1000rpm.

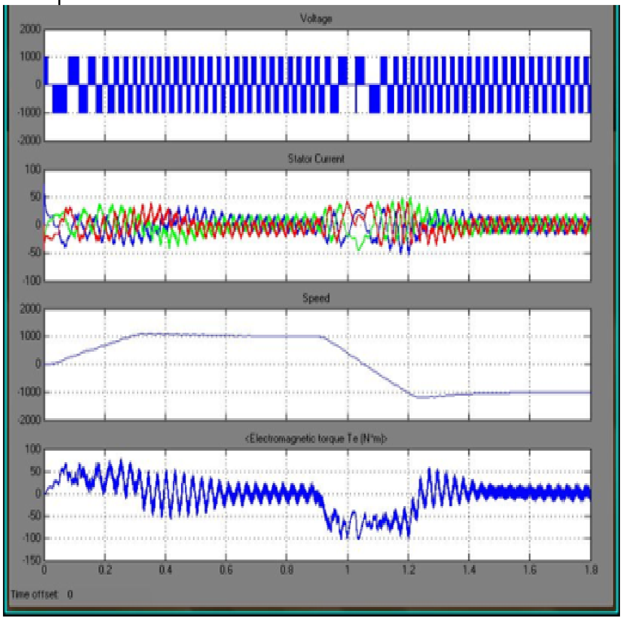


Fig. 18- Stator voltage, stator current, speed, torque vs. time

Stability of design control system G(s) adaptive observe model

Figure 20 I_a and I_b is shown, circle represent that i_a and i_b are 90^{o}.Figure 21 is a bode diagram of linear time-invariant block G(s) drawn with the LTI Viewer of the Control System Toolbox. From the phase diagram, it can see that weight factor of (8) y=1, y=0.006, are within ±90° across the whole frequency range, and they are stable.

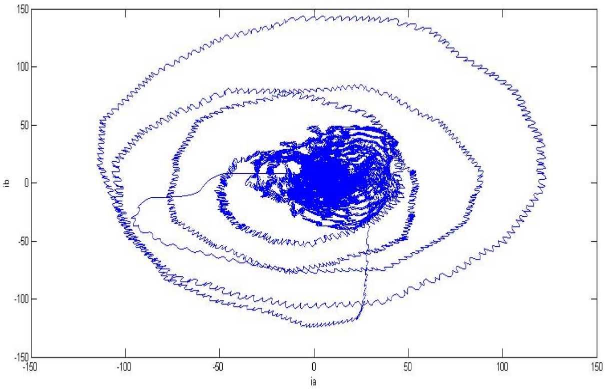


Fig. 19-Plot of I_a and I_b

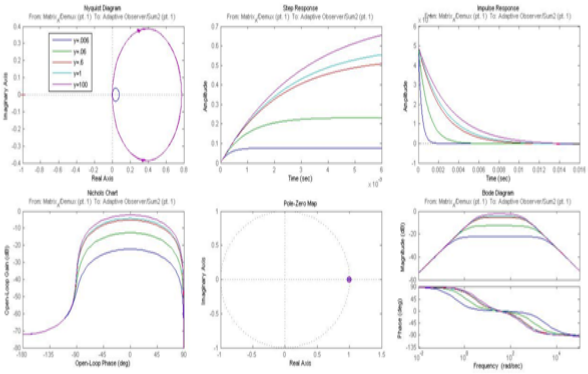


FIG. 20-G(s) responses of different value of y

CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

It presents position-Sensorless vector control simulation by observer using optimal feedback gain as an example of process from algorithm design to logic verification, by using MATLAB/Simulink. Result in simulation verifies that MRAS technique with vector control give good dynamic responses with change of reference speed. This work can extend by following way:

Generation of vector control PWM signal using PC/laptop installed with D-SPACE and MATLAB simulation environment. Make virtual instrument kit for controlling machine using DSPACE controller Desk. Use above simulation for controlling induction machine in real time system. Verify result with Real time Workshop (Figure 22).

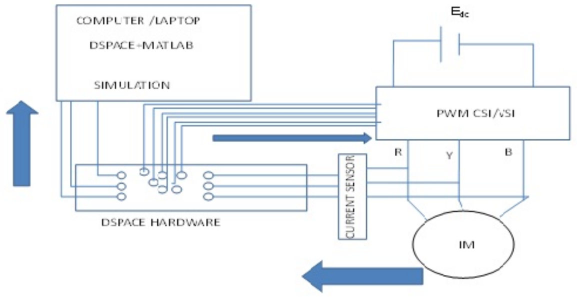


Fig. 21-hardware implimentation of vector control using mras of induction machine

References

[1] Vas P (1998) *Sensorless Vector and Direct Torque Control. Oxford, U.K.:Oxford Science*.

[2] Shauder C. (1992) *IEEE Trans. Ind. Appl*., 28, 5, 1054–1061.

[3] Maurizio Cirrincione, Marcello Pucci (2005) *IEEE trans. Industrial electronics*, 52, 2.

[4] Colin Schauder (1992) *IEEE transactions on industry applications*, 28, 5.

[5] Masaru Hasegawa, Keiju Matsui (2002) *IEEE-IECON*, PE-03, 83-88.

[6] Holtz J. (2002) *Proc. IEEE*, 90, 8, 1359–1394.

[7] Yoshihiko (2003) *Institute of Electrical Engineers Journal D (Industrial Application Journal)*, 123-D, 5, 600.

Symbol description

R	Resistor [Ω]	
L	Self-inductance [H]	
M	mutual inductance [H]	
θ	Rotor flux rotation angle[rad]	
ω	Rotor flux angle velocity [rad/sec]	
ωr	Electric angular velocity [rad/sec]	
Te	Electric torque	[N]
i	current value	[A]
v	voltage value	[V]
λ	Flux linkage	
Pm	number of pole pairs	
s	Laplace operator	
s	Variable in the stator	
r	Variable in the rotor	
U, V, W	Variables in three-phase fixed coordinate system	
α, β	Variables in orthogonal two-axis fixed coordinate system	
d, q	Variables in orthogonal two-axis rotating coordinate system	
*	Target value	
^	Estimation value	
vds, vqs		Voltage target value on d and q axes
va, vb		Voltage target values on α, β axes
vu, vv, vw		Voltage target values on UVW axis
ids, iqs		Current target values on d and q axes
iu, iv, iw		Current value on UVW axis
ia, ib		Current values on α and β axes
theta		Rotor flux rotation angle (power supply angle)
γ 0		constant independent of time
Ramd_ar, Ramd_br Rotor flux of α and β axes		

Table 1- Comparison of different methods for speed control of induction machine

Type of control	Advantage	Disadvantage
Stator voltage control	used for Low-power application Where low starting torque required	Speed range narrow, not suitable for constant-torque load
Rotor voltage control	Increase low starting torque, efficiency can be increase by slip power recovery	Imbalance voltage, poor dynamic performance
Frequency control	Constant torque and constant power drive mode	Air gap flux saturation ,at low frequency high stator current
Stator Voltage & frequency control	Constant torque and constant power drive mode, PWM can be used	Input power factor of converter low, poor dynamic performance
Current control	Fault current control	Harmonics, torque pulsation, pf very low
Voltage ,current and frequency control	Operate in field weakening mode	Poor dynamic performance, low power factor
Scalar close loop control	Control transient and steady state response	The parameter of IM are coupled to each other and stator control lacks in producing fast dynamic response