



Evaluation of Various Types of Indirect vector Control of Induction Motor Drives

Pradeep B Jyoti[†], J.Amarnath^{††}, and D.Subbarayudu^{†††}

[†]Head of The Electrical Engineering Department, Shirdi Sai Engineering College, Bangalore, India

^{††}Professor in Electrical Engineering Department, JNTU, Hyderabad, India

^{†††}Professor in Electrical Engineering Department, G. Pulla Reddy Engineering, Kurnool, India

ABSTRACT:- This paper confers the efficacy and effectiveness of the vector controlled induction motor drive computed by the stability of performance in terms of the settling time (time taken to attain the required rpm and torque), peak overshoot and the steady state error. A series of inputs, of rpm and torque load, have been scrutinized to deduce the most appropriate vector control technique for the induction motor drive. The work provides a contrast between the effectiveness of the techniques. Stator flux oriented vector control technique perform marginally superior than the other two techniques when the peak overshoot is taken into consideration. All the three vector control techniques perform in a identical fashion, when the settling time is considered. Indirect Vector control technique performs marginally better than the other two techniques when the steady state error is considered. The projected work concludes that, based on the overall performance evaluation, the three vector control techniques demonstrate identical control performance.

Key words: Vector control, Induction motor drives, peak overshoot.

I. INTRODUCTION

Electrical drives have gone through countless transformations over the years, and consequently so have the techniques to manipulate their speed and torque. Numerous studies are being carried out in order to realize efficient and stable control systems and techniques. With our knowledge in associated subjects on the rise, the control techniques are also advancing with time.

Induction motors find wide scale application in industries because they are rugged, reliable, economical and unsusceptible to massive overloads. According to available statistics, in industrialized countries, about two third of the generated electrical energy is consumed by electrical motors. However, its speed control is quite complicated due to its complex mathematical model and nonlinearity because of coupling and core saturation, making its use in high performance applications a daunting task. So additional weight is being given to come up with new methodologies for achieving precise speed and torque control of induction motors [17].

For electrical drives good dynamic performance is mandatory so as to respond to the changes in command speed and torques. Creation of vector control, revolutionized high performance control of ac drives. With this theory induction motor can be controlled like a separately excited dc motor. The field-oriented control (FOC) in particular, has become very popular since it delivers superior dynamic and static performance. Field oriented control (FOC) draws support from the initiative of decoupling torque and flux by means of nonlinear coordinate transformation and manipulating these variables by exploiting the direct and quadrature current vector components by means of unit vector ($\sin\theta_e$ and $\cos\theta_e$). Ultimately, the reference stator voltage vector is provided by current regulators. FOC consists of two techniques: (1) direct or feedback vector control and (2) indirect or feed-forward vector control. In direct FOC, unit vectors are generated by stator voltages and currents (Voltage model estimator) or by stator currents and rotor speed (Current model estimator). The short comings of this technique are: (1) reliance on the rotor resistance value and (2) computation constrains and time delay due to the application of current control loops and axes transformation [1, 2,10].

A substitute to the FOC of the PWM inverter fed induction motor is the stator flux vector control (SVFC). Using this control technique, the reference stator voltage vector is calculated from torque and rotor flux references and is employed to control the stator flux. Stator flux vector control technique doesn't possess current loop regulation, consequently amplifying the torque dynamics. Stator flux vector control employs stator flux so there is a coupling effect. To surmount this coupling effect a decoupling component of current is included into the flux control loop. As a result, superior dynamic performances compared to FOC may be attained [5].

Vector control method involves a speed feedback signal produced by a speed encoder. Sometimes speed encoder is not needed. Using flux estimator we can compute the synchronous speed and rotor speed as a result eliminating use of speed encoder in drives.

The field of power electronics came into existence quite early in the twentieth century. After few decades of painstaking labor, power converters such as the mercury valve rectifiers, thyratrons, cycloconverters, load commutated inverters, current source and voltage source inverters, etc. were created. Given their ability to control the flow rate and the form of electric energy, these power converters could control the motion of electric machines as well as the processes which call for electric power in AC or DC form. The creation of the three phase VSI in particular was noteworthy as it proved to be a improved performance and economical device. History recognizes and credits D. Prince for the invention of the earliest and most basic inverter device in 1925. He proposed the name "inverter" for his creation since its working characteristics are on the contrary compared rectifiers; instead of AC to DC voltage transformation, DC to AC. Still inverters did not find popularity until the advent of the modern power electronic switches.

The invention of thyristor in 1957 pioneered the age of modern power electronics. After addressing the size, cost, efficiency, consistency, and performance deficits of the earlier power converter switching devices, the solid state semiconductor thyristor reaped quick recognition. Its application in power converter circuits with inherent natural commutation characteristics such as cycloconverters, phase controlled rectifiers, and reactive power compensators, etc. in particular has been the most realistic method till date. Nonetheless, the thyristor would have a need of integrated commutation circuits in forced commutation applications, due to absence self commutation, making the drive bulky, costly, and complicated. As a result, its application in forced commutation power electronic converters, in the VSI applications in particular, was restricted and was rendered obsolete with the development of gate-turn-off solid state semiconductor devices such as the Bipolar Junction Transistor (BJT), Metal Oxide Silicon Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor (IGBT), and Gate Turn Off (GTO) thyristor. IGBT switches in particular have turned out to be the most widely utilized devices and have transformed the PWM-VSI drives.

Recently, a lot of work has been done in the field of power electronics. Devices with high power ratings and high switching frequencies are promptly accessible. There are superior pulse width modulation (PWM) methods such as space vector PWM and hysteresis band PWM using which improved waveforms can be realized. These methods can be effortlessly executed by employing microcontrollers and DSP [3, 6, 8, and 11].

For induction motors vector control of the rotor flux has been achieved indirectly. In this method, the space vector of the stator current consists of two components: magnetizing current and torque- producing current. By employing the uniform pulse width modulated inverter, torque pulsation is trimmed down and a strong control with speedy dynamic response for induction motor is realized. The computer simulations demonstrate that the performance of the vector control of the induction motor is the same as the performance of the separately excited DC motor [26].

To simplify arithmetic operators and elude complex calculating iron loss, vector control for induction motor overlooks iron loss in engineering. Nonetheless, disregarding iron loss, decoupling control of vector control is not obtained precisely, which diminishes the efficiency of the control system. Development of parameter identification has enabled us to identify the parameter of iron loss with real-time precision. A new technique which takes into account the iron loss, achieves decoupling control of torque and flux by manipulating components of gap current, which ultimately command stator currents to realize vector control. Simulations indicates enhancement of the proposed control in dynamic performance. [22]

Using Luenberger and Kalman estimators, speed vector-controlled induction motor drive systems, in which rotor flux estimation is executed have been evaluated by researchers. A relative study of the stability of the estimators and of the control systems which are included in the control loop is achieved using both simplified and full digital method and modifying the sampling time used for each of the methods. The studies are predominantly focused on the low and high speed regions. The evaluations are made by the means of Eigen values of the estimators in each study. [21]

For induction motors based on the stator flux vector control, torque control algorithms have been developed. For each sampling period, the magnitude of the stator voltage is computed to keep the stator flux the same as the reference vector, while the stator flux reference vector is computed to keep the rotor flux amplitude unvarying under all operating circumstances. The enhanced stator and rotor flux estimation algorithm facilitates robust and stable working of the drive, even at low speeds. The induction motor torque is controlled by changing the flux angular velocity, facilitating drive operation with ripple-free torque and fixed switching frequency in the steady state. The algorithm generates good behavior of the drive in both transient and steady-state operating conditions. [20].

Comparing all the control methods for induction motor drives, Direct Torque Control (DTC) is free of machine rotor constraints and doesn't call for speed or position sensors. The DTC scheme is distinguished by the absence of PI regulators, coordinate transformations, current regulators and PWM signals generators. DTC permits a better torque control in steady state and transient operating conditions. In Space Vector Pulse Width Modulation (SVPWM), the switching instants of different space vectors are determined in each sampling period to reduce torque ripple. The time durations of two adjacent voltage space vectors and the equivalent zero-voltage space vectors are computed in this method based on maximum and average switching frequency, permitted for the switching devices in the three phase inverter. [23]

Variable voltage and frequency supply to a.c. drives is invariably realized using a three-phase voltage source inverter. Numerous pulse width modulation (PWM) techniques are employed to produce variable voltage and frequency supply. The most popular PWM technique for three-phase voltage source inverters is space vector PWM (SVPWM) and carrier-based sinusoidal PWM. There is a rising trend of employing space vector PWM (SVPWM) due to their simpler digital realization and superior dc bus exploitation. [24]

The performance of the vector control depends on accurate measurements of constraints in the motor. One of the most important parameters is rotor resistance. An adjusting technique for on-line identification of the rotor resistance can be based on the artificial neural networks. By employing the BP algorithm theory, the rotor flux error between the neural network model and voltage model is back propagated to accommodate the weights of the neural network model which can be employed to compute the rotor resistance. The neural network observer can make out the rotor resistance precisely and swiftly. Meanwhile it has a good robust performance also. [25]

This paper strives for obtaining high precision, swift reaction and evenness of speed and torque control of three phase induction motor drive by means of its simulation by Direct vector control, Indirect vector control and Stator flux vector control methods. To manipulate current within the voltage fed inverter, hysteresis band PWM has been employed.

II. MODEL OF INDUCTION MOTOR DRIVE

A. Simulation Model of Direct/Indirect Vector Control

The representation for direct vector control induction motor drive is illustrated in the Figure 1 below. For feedback assessment voltage model is utilized. In this simulation we have taken dc voltage of 780V for the inverter. The hysteresis band is taken of 1Amp.

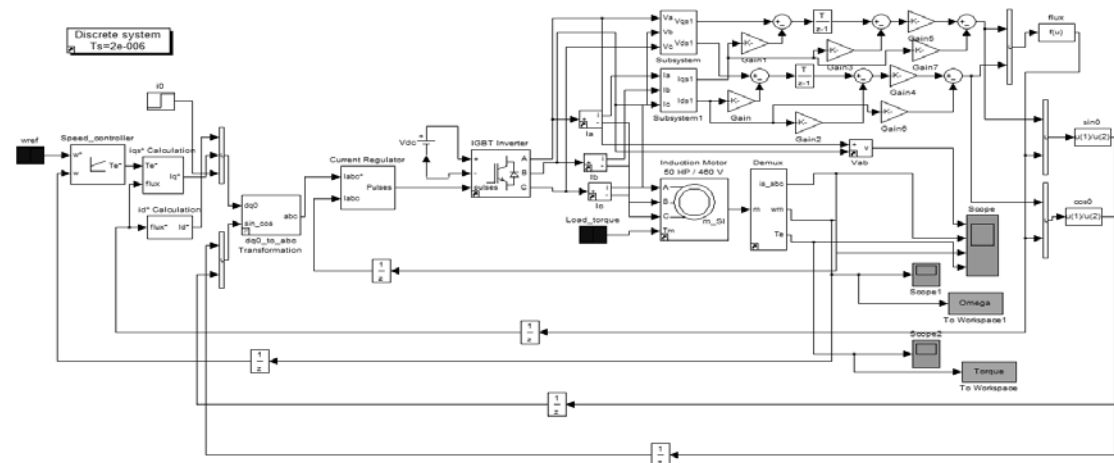


Figure 1 Simulation Model for Direct Vector Control

Likewise, the simulation mock up for indirect vector control induction motor drive is illustrated in the Figure 2 below

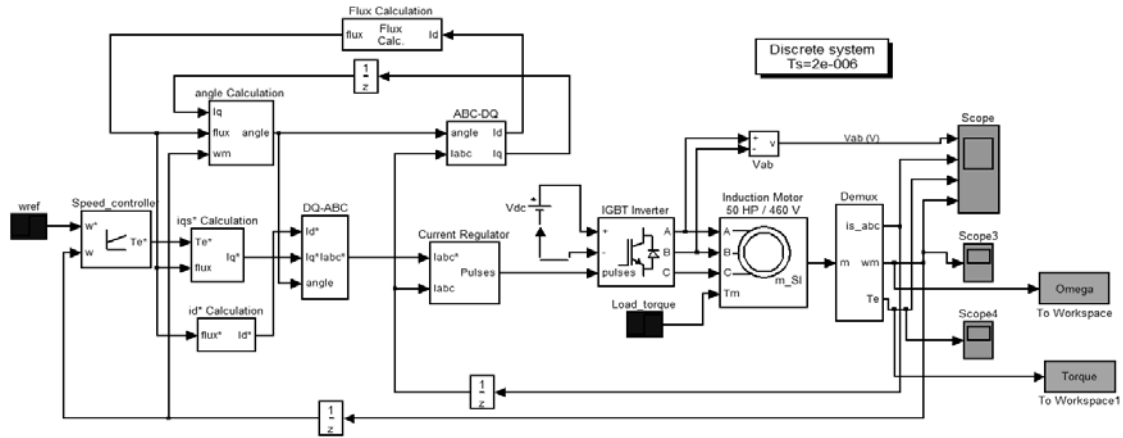


Figure 2. Simulation Model for Indirect Vector Control

The simulation representation for stator flux oriented vector control induction motor drive is shown in the Figure 3 below

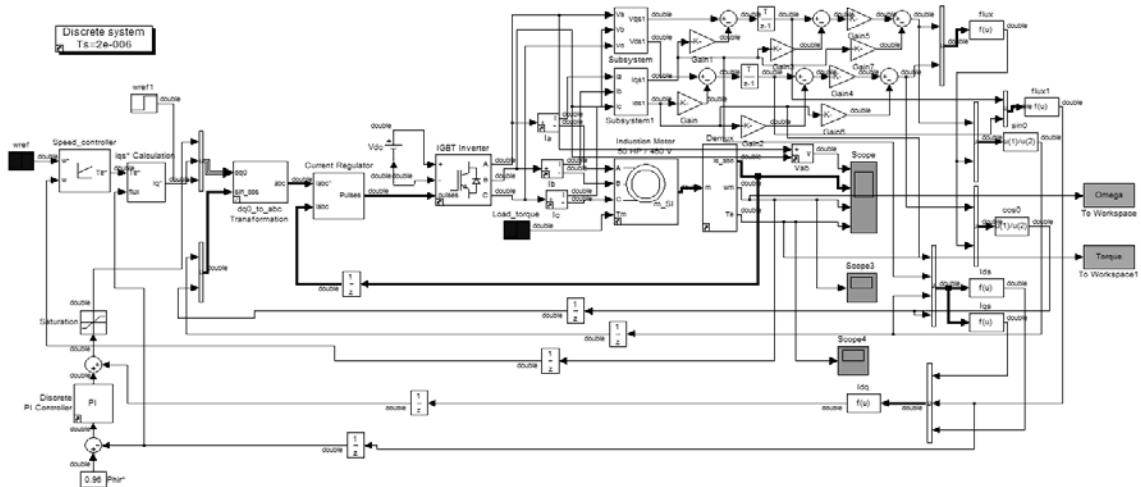


Figure 3 Simulation Model for Stator Flux Oriented Vector Control

III. SIMULATION RESULTS

The simulation has been prepared using MATLAB. Important constraints and parameters for this design have been discussed in this section below.

A. Gain of the PI Controller

The gain of PI controller is set 13 and 45 correspondingly. To decide the values to be used for the gains, an test simulation has been carried out with the Direct Vector Control model (discussed later in depth). A full factorial DOE has been executed with the corresponding gain changing with values of (12, 13, 14) and the integral gain changing with values of (40, 45, 50). The test runs are performed to compare the gains in order to deliver the most stable performance for the vector control of the induction motor drive. The results have been illustrates in Table 1 below:

Table 1: Experiment results for Performance with varied Kp and Ki

Performance with Different Kp and Ki					
Run #	Kp	Ki	Overshoot %	Settling time	SSE
1	12	40	35.62	3.7942	0
2	12	45	34.75	3.7296	0
3	12	50	33.94	3.6737	0
4	13	40	33.99	3.8382	0
5	13	45	33.18	3.7471	0
6	13	50	32.43	3.6875	0
7	14	40	32.48	3.8643	0
8	14	45	31.73	3.7917	0
9	14	50	31.05	3.7238	0

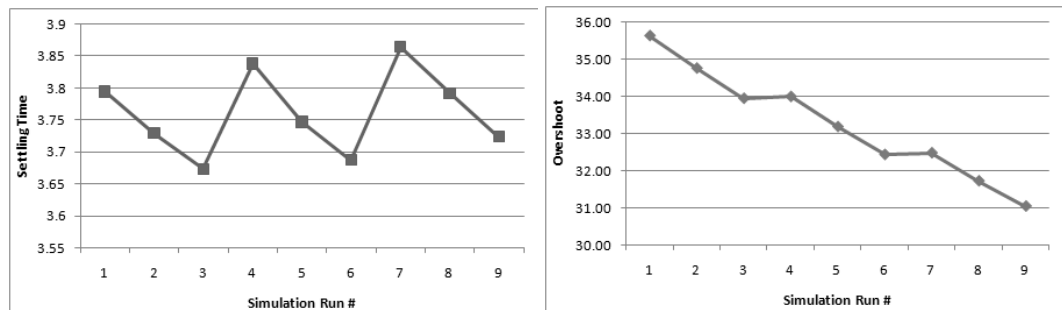


Figure 4. Experiment results for Performance with varied Kp and Ki

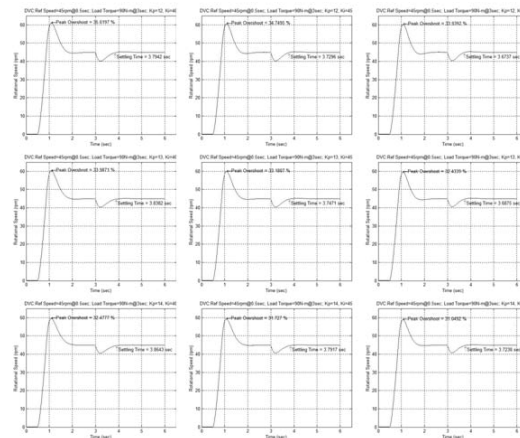


Figure 5. Experiment results for Performance with varied Kp and Ki .

Fig 4 and 5 and the table 1 illustrate that the performance with changed Kp and Ki. We can discern that the settling time is rising with an increasing Kp and decreasing with an increasing Ki. Also, we can notice from the graph that the peak overshoot is reducing with increasing Kp and Ki.

The aforementioned evaluation demonstrates that the PI gains of 13 and 45 deliver the most stable performance for the vector control.

B. Different Loading Conditions

There are two significant parameters in the Induction motor circuit, motor speed (reference) and the load torque. The simulations to compare the performance of different vector control techniques have to be executed under different load circumstances, i.e. different reference speed and the load torque.

Based on the induction motor constraints and parameters, it has been resolved that the reference speed can change anywhere between 0 and 150 (approx) and the load can be as high as 200 (approx). As a result, a suitable permutation of load cases has been established as below as seen in table 2..

Table 2: Load Case table for Simulation runs

Run #	Reference Speed	Load Torque
	rad/sec	N-m
1	45	90
2	45	180
3	145	90
4	145	180

Also, reference speed has been employed as a step load with the step at 0.5 seconds. The load torque has been employed as a step load with the step at 3 seconds.

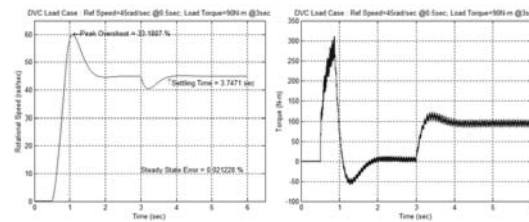


Figure 6. DVC: Rotor Speed & Motor Torque for Ref Speed=45rad/sec@0.5sec; Load Torque=90N-m@3sec

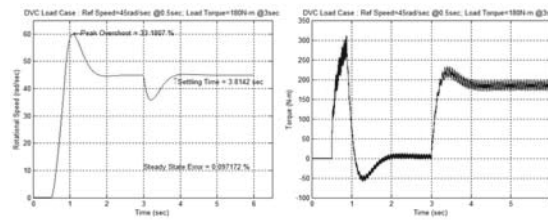


Figure 7. DVC: Rotor Speed & Motor Torque for Ref Speed=45rad/sec@0.5sec; Load Torque=180N-m@3sec

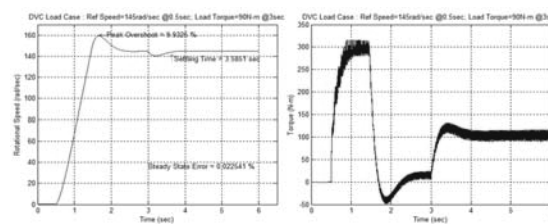


Figure 8. DVC: Rotor Speed & Motor Torque for Ref Speed=145rad/sec@0.5sec; Load Torque=90N-m@3sec

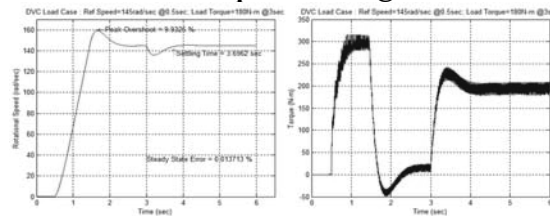


Figure 9 DVC: Rotor Speed & Motor Torque for Ref Speed=145rad/sec@0.5sec; Load Torque=180N-m@3sec

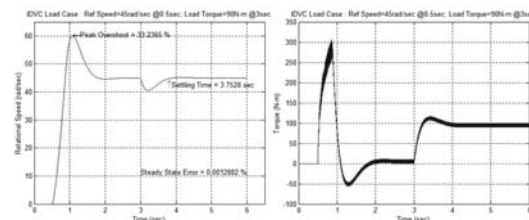


Figure 10. IDVC: Rotor Speed & Motor Torque for Ref Speed=45rad/sec@0.5sec; Load Torque=90N-m@3sec

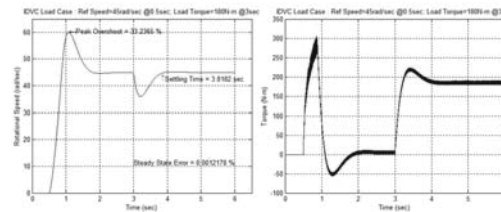


Figure 11. IDVC: Rotor Speed & Motor Torque for Ref Speed=45rad/sec@0.5sec; Load Torque=180N-m@3sec

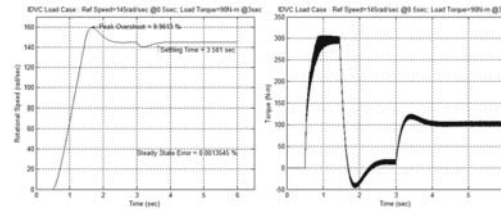


Figure 12. IDVC: Rotor Speed & Motor Torque for Ref Speed=145rad/sec@0.5sec; Load Torque=90N-m@3sec

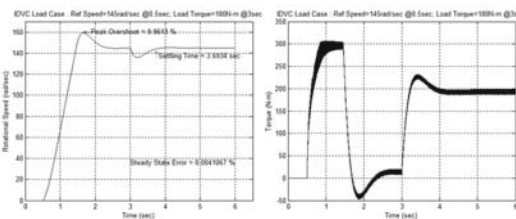


Figure 13 IDVC: Rotor Speed & Motor Torque for Ref Speed=145rad/sec@0.5sec; Load Torque=180N-m@3sec

Fig 10 to 13 shows the various possible loading cases for indirect vector control

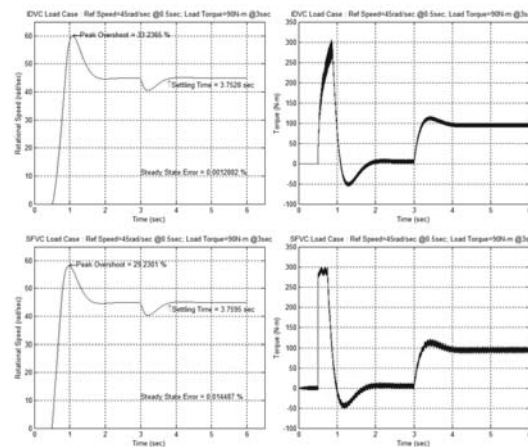


Figure 2 SFVC: Rotor Speed & Motor Torque for Ref Speed=45rad/sec@0.5sec; Load Torque=90N-m@3sec

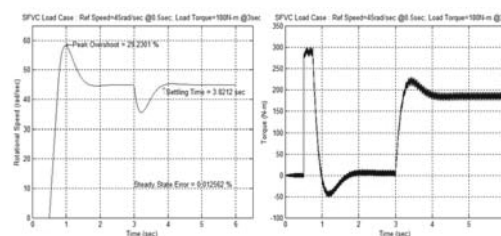


Figure 15 SFVC: Rotor Speed & Motor Torque for Ref Speed=45rad/sec@0.5sec; Load Torque=180N-m@3sec

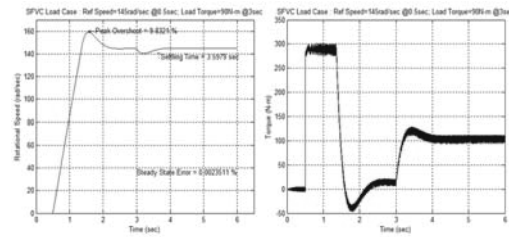


Figure 16 SFVC: Rotor Speed & Motor Torque for Ref Speed=145rad/sec@0.5sec; Load Torque=90N-m@3sec

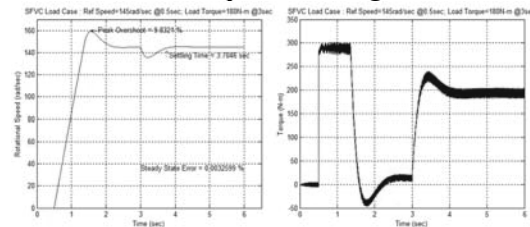


Figure 17 SFVC: Rotor Speed & Motor Torque for Ref Speed=145rad/sec@0.5sec; Load Torque=180N-m@3sec

Fig 14 to 17 shows the various possible loading cases for stator flux vector control.

IV. COMPARISON OF VECTOR CONTROL METHODS

It is imperative that we scrutinize the performance of the different vector control techniques simulated in the previous section. The working of the vector control of the induction motor can be judged comprehensively by investigating the settling time (time taken to attain the target level of rotational speed), peak overshoot (the overshoot above the target rotational speed) and the Steady State Error. Below is the comparison of the methods based on the above two constraints.

Table 3 Peak overshoot and settling time for different vector control techniques

COMPARING PERFORMANCE OF VECTOR CONTROL TECHNIQUES				
		Peak Overshoot (%)	Settling Time (sec)	Steady State Error (%)
Direct Vector Control	Run #1	33.18	3.75	0.0212
	Run #2	33.18	3.81	0.0972
	Run #3	9.93	3.59	0.0225
	Run #4	9.93	3.70	0.0137
Indirect Vector Control	Run #1	33.24	3.75	0.0013
	Run #2	33.24	3.82	0.0012
	Run #3	9.96	3.58	0.0014
	Run #4	9.96	3.69	0.0041
Stator Flux Oriented Vector Control	Run #1	29.23	3.76	0.0145
	Run #2	29.23	3.82	0.0126
	Run #3	9.83	3.60	0.0024
	Run #4	9.83	3.70	0.0033

Note: The Peak Overshoot and Settling Time are observed from the rotor speed in the runs.

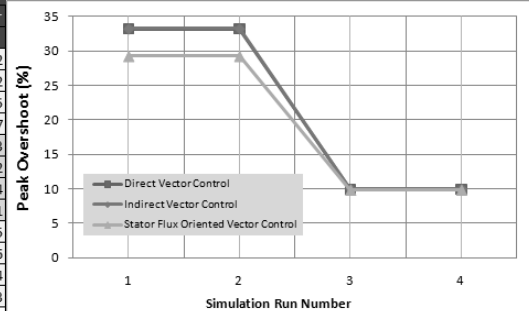


Figure 18 Comparison of different vector control techniques for Peak overshoot (%)

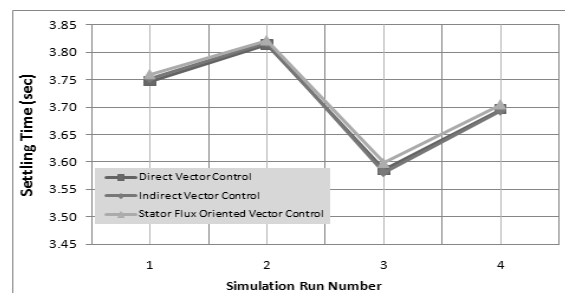


Figure 19 Comparison of different vector control techniques for Settling time (sec)

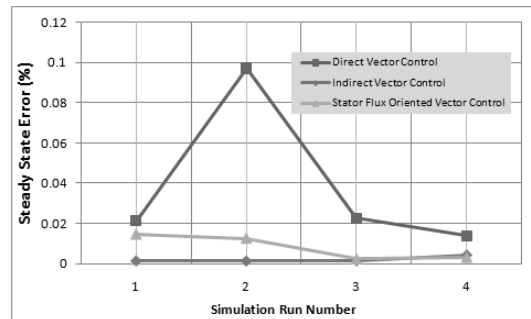


Figure 20 Comparison of different vector control techniques for Steady State Error (%)

V. CONCLUSIONS

Using this paper, simulation of direct vector control, indirect vector control, and stator flux oriented vector control techniques has been scrutinized. Voltage model flux estimator has been employed for estimate or compute flux. Nonetheless, a current model has also been demonstrated that can be employed for flux estimation. Using these voltage and current model estimators, speed of the induction motor can also be computed. In direct vector control, rotor flux is employed for production of unit vector signals that are necessary to convert variables from stationary frame to synchronously rotating reference frame or vice versa.

In stator flux oriented vector control, there is a coupling effect. For this we have added a decoupling component of current in the flux component of current loop. The unit vectors are produced by the feedback estimation methods.

In indirect vector control a speed encoder is obligatory. The unit vector signal is realized with rotor speed and slip speed. The slip speed can be computed with torque component of current and rotor flux.

The outcome of the simulation demonstrates that transient response is very swift for vector controlled drive. All the three techniques display approximately the identical performance as depicted by simulation results. Stator flux oriented vector control takes somewhat less computational time in contrast to direct and indirect vector control techniques [16]. So, it can be concluded that vector controlled induction motor drives have very prompt transient response and very few static error (approximately 0.02%) and these drives are very appropriate for precise speed control over an extensive scope.

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APPENDIX

Parameters of Induction Motor

The parameters of the induction motor used in simulation are given below: Power = 50 HP = 37.3 KW

Voltage (L-L) = 460 V Power factor = 0.8

Line current = 58.52 A $L_m = 34.7$ mH

$R_s = 0.087 \Omega$

$L_s = 35.5$ mH $R_r' = 0.228 \Omega$ $L_r' = 35.5$ mH $P = 4$

Inertia (J) = 1.662 Kg-m²

Friction factor

= 0.1

$T_r = 0.1557$ sec.