SENSOR-LESS VECTOR CONTROL USING ADAPTIVE OBSERVER SCHEME FOR CONTROLLING THE PERFORMANCE OF THE INDUCTION MOTOR

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ABSTRACT

Sensorless vector control technique using adaptive observer scheme is being used to control the performance of induction motor which is demonstrated by the help of matlab/simulink software; a suitable tool for vector control of AC motor. Simulation is done by using the observer which uses optimal feedback gain as an example of process from algorithm design to verification of logic. Control design scheme 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 sensor less position.

The same technique also can be applied to other types of motor like PMSM. This adaptive observer is used with the field oriented control of the induction motor. It is based on using induction motor model with the estimation of the load torque besides the estimation of the stator resistance and the robustness of this adaptive observer is with respect to the variation in the resistance of stator. The performance of the suggested adaptive observer scheme is present on via numerical simulation and the obtained results from that adaptive observer show the effectiveness of suggested scheme.

ABSTRAK

Teknik kawalan vektor tanpa sensor menggunakan skim pemerhati penyesuaian yang digunakan untuk mengawal prestasi motor aruhan yang ditunjukkan oleh bantuan perisian MATLAB / SIMULINK; alat yang sesuai untuk kawalan vektor AC motor. Simulasi dilakukan dengan menggunakan pemerhati yang menggunakan perolehan maklum balas yang optimum sebagai contoh proses daripada reka bentuk algoritma untuk pengesahan logik. Skim reka bentuk kawalan dalam kawalan vektor, ketepatan parameter dalaman seperti rintangan daripada angker motor dan kearuhan mempengaruhi prestasi kawalan. Parameter dalaman digunakan, sebagai contoh, pengawal arus pengimbang pemacu-hadapan dan parameter model pemerhati dalam kedudukan tanpa sensor.

Teknik yang sama juga boleh digunakan untuk lain-lain jenis motor seperti PMSM. Pemerhati penyesuaian ini digunakan dengan kawalan berorientasikan medan motor aruhan tersebut. Ini berdasarkan menggunakan model motor aruhan dengan anggaran tork beban selain anggaran rintangan pemegun dan kekukuhan pemerhati penyesuaian ini adalah berkenaan dengan perubahan dalam rintangan pemegun. Prestasi cadangan skim pemerhati penyesuaian ini dibentangkan melalui simulasi berangka dan keputusan yang diperolehi daripada pemerhati penyesuaian itu menunjukkan keberkesanan skim yang disyorkan.

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LIST OF SYMBOLS

Resistor	R
Self-inductance [H]	L
Mutual inductance [H]	M
Rotor flux rotation angle [rad]	θ
Rotor flux angle velocity [rad/sec]	ω
Electric angular velocity [rad/sec]	ω_r
Current value [A]	i
Voltage value [V]	v
Electric torque [N]	T
Flux linkage	λ
Number of pole pairs	P
Laplace operator	s
Variable in the stator	s
Variable in the rotor	r
Variables in three-phase fixed coordinate system	U, V, W
Variables in orthogonal two-axis fixed coordinate system	α,ß
Variables in orthogonal two-axis rotating coordinate system	d, q
Target value	*
Estimation value	^
Voltage target value on d and q axes	vds, vqs
Voltage target values ona,ßaxes	va, vb
Voltage target values on UVW axis	vu, vv, vw
Current target values on d and q axes	ids, iqs
Current value on UVW axis	iu, iv, iw

Current values on a and ß-axes	ia, ib
Subscript indicating target value	*
Rotor flux rotation angle (power supply angle)	theta (ϴ)
Rotor flux rotating angler velocity (power supply angler velocity)	w
Electric angler velocity estimation value	wr
Rotor flux of α and ß-axes	Ramd_ar, Ramd_br
Flux linkage	λ
Number of pole pairs	P
Laplace operator	s

CHAPTER ONE: INTRODUCTION

The sensorless vector control using feedback gain as an instance of process from the algorithm design to logic verification using adaptive observer scheme for controlling the performance of induction motor (Dr.JBV Subrahmanyam 2011, Tarek BENMILOUD 2011) by using MATLAB/Simulink is presented in the thesis. Nowadays, the direct field oriented control (FOC) technique is outspread used in high performance induction motor (IM) drives (J.P. Caron 1995),(Volat 2000). It permits the electromagnetic torque control to be separated from the rotor flux one by the aid of coordinate transmission, and thus to handle induction motor (IM) as dc motor. Such control method needs the knowledge of the rotor flux, which is indirectly measurable. Rotor flux observers' are commonly used in order to avoid expensive sensors (Alamir 2002).

Knowing that the efficiency of the control strategy is established on right rotor flux detection, the drive functioning is strictly connected to these of the rotor flux observer(M. Alexandru 2002). Accordingly, the performances of the observer, in terms of accuracy, stability and robustness censoriously influence those of the drive. In this work, proposal for improving the performances and robustness of the adaptive flux observer of induction motor, using the estimation of the load torque as an added input for the adaptive observer is going to be considered. The estimation of the load torque will provide profound estimation of the rotor flux, because the adaptive observer will have more similarity to the real model of the induction motor. With the help of simulation results, the effectiveness of the proposed scheme is being discussed. The reasons depicted as below demonstrate that MATLAB/Simulink is a tool suitable for vector control of Induction Motor in this thesis.

- Configuration of the vector control diagram can be expressed by Simulink block diagram clarifying the signal stream through grouping and organizing function unit as subsystem.
- Easy to express matrix formula often used in system expression of motor.
- Able to model and simulate multi domain systems such as mechanical and electrical as like a simulator for mathematical expression model.
- The embedded legacy of C code as controller and plant model can be verified through the simulation in simulink block diagram.
- Able to co-simulate with magnetic field analysis software, mechanical analysis software and electric circuit simulator.
- Optional toolboxes and extended block sets provide solutions for a wide variety of development phases from algorithm design, verification, and prototype testing to implementation.

Some of the "solutions provided for development phase" are listed below and what is covered in this thesis is clarified as well.

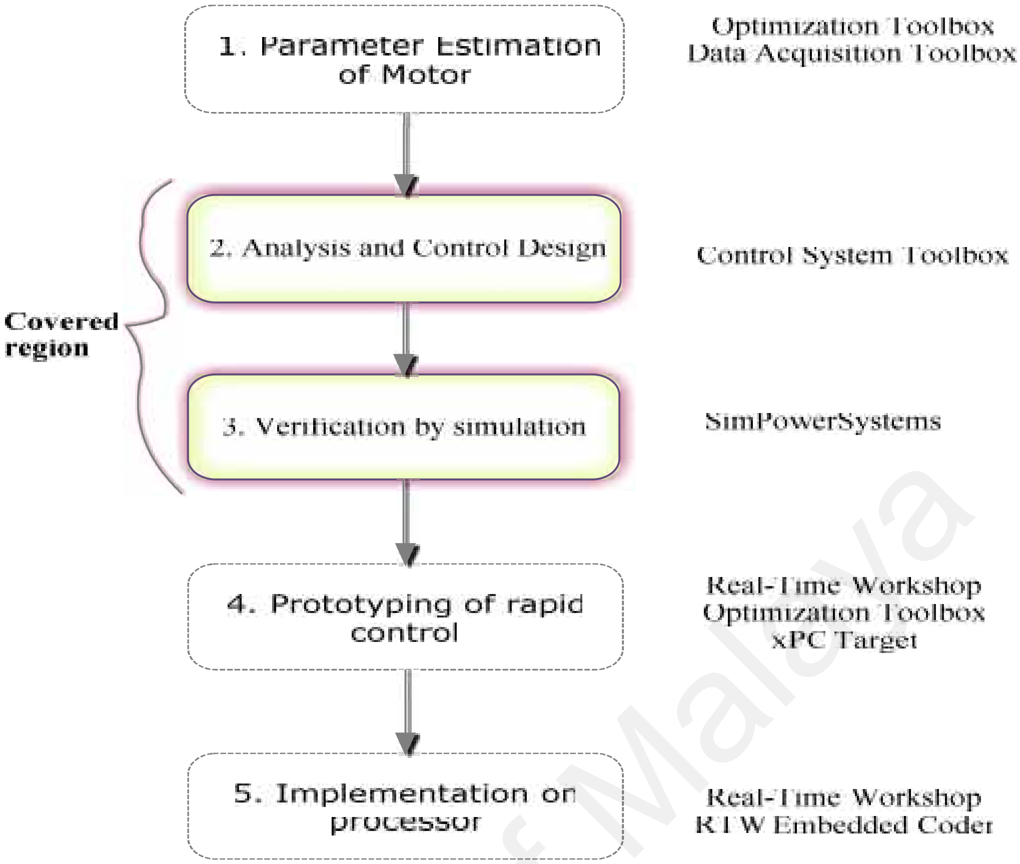

Figure1. 1 Related optional tool together with controller development process

Accuracy of internal parameter in vector control such as inductance and the resister of motor armature affect control performance. Internal parameters are used, for instance, parameters of observer model in position sensor less and feed-forward compensator of current controller. In the process of 1 of figure 1.1, some methods are possible such as; the same input voltage is applied to actual motor and motor modelled in Simulink, and from the cost function that minimizes output current deviation, each parameter is estimated in least square method. Data Acquisition Toolbox provides interface with A/D, D/A boards, and allows acquisition of real signal by MATLAB program execution. The Optimization Toolbox, function library providing various optimization methods, is available for optimization calculation for parameter estimation(Ugale, Dond et al. 2012).

In the process of 2, Control System Toolbox is available for designing observer based on modern control theory, and verifying its characteristic features(Korlinchak and Comanescu 2012).

In the process of 3, simulation of the whole system is executed based on the parameters and observers obtained from the processes 1 and 2.

The SimPowerSystems, electric systems library, provides inverter and motor blocks. Because the prepared Motor block is an ideal model not including non-linearity such as magnetic saturation, a method such as co-simulating with magnetic analysis tool is considered in a more realistic simulation.

In the process of 4, xPC can be used for real-time simulation of actual motor, and tune Simulink model while monitoring in signal time. The real time work shop ("RTW") can generate c-code from controller modelled by Simulink and implement on MPU or DSP. On the other hand, as plant of simulation is ideal model, control parameter tuning might be required for actual machine.

In the process of 5, with the good readability for production-quality code suitable for implementation, performance and customization can be generated by combining add-on tool of RTW, RTW Embedded Coder.

1.1 Objectives:

The Objectives of this work are as follows:

- Design and analysis of adaptive observer for controlling the performance of induction motor.
- Get the controllable results of different parameters of induction motor by the adaptive observer and recommendation for more reliable system.

1.2 Outline of the project report:

The remainder of this report is organised in the following manner:

Chapter 2 provides the literature review of the different techniques of sensorless control of induction motor. A detail study of all sensorless methods with their advantages, disadvantages has been discussed along with the controlling schemes and according to that review based comparison also discussed.

Chapter 3 deals with the methodology that has been implemented to control the performance of induction motor by adaptive observer scheme. This chapter includes comprehensive analysis on the different sections of the simulation that what controlling technique is used in each of the section with mathematical operation.

Chapter 4 presents the results performed by simulation software-matlab at different values in terms of changing the parameters of induction motor, on external load and at different speeds for achieving the object of the project.

Chapter 5 summarizes all the study and analysis performed for the project and enhances the future work with recommendation which can be done to get the more accurate and reliable system.

CHAPTER TWO-LITERATURE REVIEW

2.1 Introduction

For modern industrial applications the high performance based electric motor drives are believed a crucial demand. Previously, the dc motors have been universally used for this purpose. However, frequent maintenance, heavy weight and large size requirements make the dc motors a highly expensive solution. Furthermore, mechanical assembly of commutator-brush cause unwanted sparking, which is really not allowed in certain practical applications. Such fundamental defect of dc motors motivated the researchers for persistent efforts to find out the more beneficial solution to the problems, and many successful efforts have been made to adopt induction motor instead of dc ones. Induction motor has huge advantages like reliability, simplicity, virtually maintenance free, and less expensive. Nevertheless, the time varying nature and nonlinearity of induction motor drive requires a large amount of real-time computation and fast switching power devices (M.S. ZAKY 2008).

Due to the recent developments in the field of power electronics using field oriented control (FOC) technique, the accurate speed and torque control of induction motor is now possible. FOC has two integral types of method known as Direct and Indirect methods. The direct FOC method rely on generating unit vector signals, which are required for flux orientation, and it comes from the fluxes measured by using the hall effect flux sensor or also search the coils, or estimated. On the other hand, indirect field oriented applies the speed of rotor and from the dynamic equation of the rotor usually drive the slip angular frequency to generate the signals to achieve the orientation flux. Despite the fact that the indirect motor is highly sensitive to the variations of motor parameters, such us rotor time constant, still it is practically preferred than the direct one. This is due to the direct method requires a modification or a particular design for the machine. Additionally, the breakability of the flux sensors frequently reduces the inherent robustness of induction motor drive (Consoli, Scarcella et al. 2004).

2.2 Speed-Sensorless control

Realization of the high precision speed control and high performance of IM drives information regarding accuracy of speed is always necessary. Traditionally, a direct kind of speed sensors such as an encoder was usually mounted to the motor shaft and the purpose was to measure the speed. Such methods uses the required additional electronics, extra space, extra wiring, careful mounting and frequent maintenance which takes away the reliability and inherent robustness of drives becomes expensive also due to addition of extra cost in it.

Due to these reasons, the advancement of alternative option in indirect methods turn to be an important research (Holtz 2002). Therefore, the research community have a great motivation and interest to develop a speed sensorless IM drive. A lot of advantages are expected from speed sensorless IM drives like reduced size, reduced hardware complexity, better noise immunity; elimination of direct type of sensor writing, less maintenance requirements and the most important one is the low cost, which is always a top priority of industrial reasearchers. They are also preferred not for high speed applications but also in hostile environments (Ilas, Bettini et al. 1994, Zaky 2012).

For the next generation of commercial motor drives, not only for induction machines, but also include other machines, say for instance; permanent magnet synchronise motors(PMSM) and switched reluctance motors(SRM), the positive features of sensorless speed systems will be preferable (Sheng-Ming and Shuenn-Jenn 2000, Rahman, Zhong et al. 2003).

2.3 Speed estimation schemes of sensorless induction motor drives

Elimination of direct speed sensors of IM drives are successfully reported recently. These attempts employ the parameters of IM and motor terminal variables in some way to estimate the motor speed. A common notion arises like; to which extent the method will succeed without deteriorating the dynamic performance of the drive. Recently, several methods have been proposed for the estimation of speed for the high performance of induction motor drives. Among those methods some are based on a phenomenon of non ideal type such as rotor-slot-harmonics (Holtz 2002, Staines, Caruana et al. 2006). Spectrum analysis is required for such methods, and that really is a time consuming type procedures. They permit a very compact narrow band of controlling the speed. An alternative class algorithm based on some type of probing signals injected into terminals of stator (current and / or voltage) just to detect the rotor flux and the speed of the motor accordingly (Hinkkanen, Leppanen et al. 2005, Holtz 2006). Such probing signals which introduce formerly a high frequency (Hz) torque pulses and therefore speed ripple is the result in return. That is also the reason of distortion of some useful data due to the interference with high Hz probing signals.

Despite of the reality regarding merit of such methods of estimation speed near zero they undergo from very large calculation time also called computation time, also limited bandwidth control and complexity. Alternatively, by using the terminal quantities like current and voltage the speed information can be obtained (Schauder 1992, Marwali and Keyhani 1997, Liu and Wang 2008). For this purpose it includes so many different methods such as; Extended Kalman Filters(Smidl and Peroutka 2012), Model Reference Adaptive Systems (MRAS)(Khan and Iqbal 2012), simple open loop speed calculators (Tajjudin, Rahiman et al. 2012), Artificial Intelligence Techniques (Siddique, Yadava et al. 2003) and adaptive flux observer (Lesan, Doumbia et al. 2012, Savoia, Verrelli et al. 2012). Methods based on model are characterised due to their good performance at high speed, also their simplicity. Nevertheless, they display the lower accuracy at low speed mostly and it has reason of due to parameters variation. Speed estimation schemes of speed-sensorless induction motor drives can be classified as follows:

2.3.1 Rotor Slot Harmonics (RSH) Method

The process of speed calculation is based on detecting the space harmonics which are induced by rotor slots (Holtz 2002, Staines, Caruana et al. 2006).Space harmonic components are generated by the rotor slots in the air gap magneto motive force (mmf), and that regulated the flux linkage of stator at a frequency which is proportional to the speed of rotor and also to the number of rotor slots (Nr). Since Nr is generally not a multiple of three, the rotor slots harmonics bring on voltage of harmonic in the phases of stator and that comes along as triple harmonics with respect to the fundamental stator voltage V_{s1}.

$$V_{s1} = \hat{V}_{s1} \sin(N_r w_r \pm w_s)\, \tau, \qquad (2.1)$$

Where $Nr = 3n \pm 1$,

n = 1, 2, 3…

As all triple harmonics from the larger fundamental voltage can be easily separated which are from sequence zero, and that sequence voltage denoted as vo is the sum of all the three phase voltages which is connected in a wye-connected winding of stator. Though adding the voltages of phase, all non-triple components also including the basics, become sett off while the triple harmonics add up in it.

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) \qquad (2.2)$$

In order to isolate the signal which represents the angular velocity of the rotor mechanical one, a band pass filter is employed which have adaptively tuned central frequency to the rotor slot harmonic frequency $N_r w_r + w_s = \frac{2\Pi}{\tau_{s1}}$ in equation (2.1). The block diagram of speed estimation based on rotor slot harmonics is shown in Figure 2.1. The harmonic rotor signal V_{s1} is extracted by the adaptive band pass filter, and that filtered signal is digitised by observing its zero crossing instants tz. On each zero crossing through one count for memorizing the digitised position of rotor angle theta ϑ, there is a software counter for increments and in the same way to that of encoder increments by digital differentiation a slot frequency signal is then obtained. With reference to Eqn. (2.1) the accurate speed of rotor is subsequently computed (Holtz 2002).

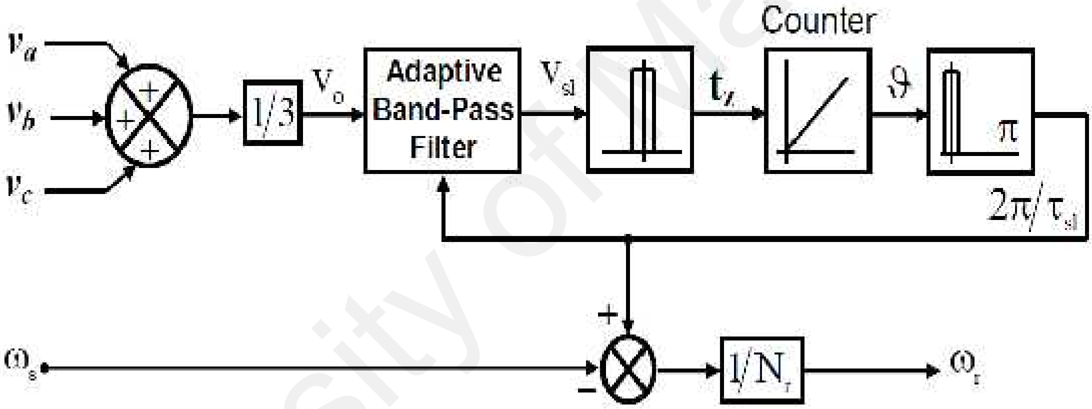

Figure 2. 1 Block diagram of speed estimation based on rotor slot harmonics(Holtz 2002)

Problem with this technique as mentioned earlier that this approach required very high precision measurements in which there is need to increase the hardware/software complexity, which is not acceptable to industrials. Also, they suffer from large computation time, complexity and limited bandwidth control.

2.3.2 Frequency Signal Injection (FSI) Method

This method scheme for speed estimation is based on signal injection. Superimposition of a high frequency voltage signal on the fundamental voltage is distinctively used to excite the anisotropic phenomena of the motor, and the position of the rotor or the direction of the flux is keyed out from the current response. This yielded for the comportment of the significant torque and therefore speed ripple. Also due to interference with other signals of the same kind which carry the useful information may be distorted. In addition, the common drawback of this method is that their dynamic response is normally simply moderate (Hinkkanen, Leppanen et al. 2005, Holtz 2006).

Basic structure of speed estimation using the FSI method is shown in the fig.2.2, for the performance of the current control in the field of coordinates an estimated filed angle $\hat{\delta}$ is used. Through the voltage signal $V_c = V_c e^{jw_c t}$ a revolving carrier frequency w_c is injected. The attenuation in the carrier frequency components in the measured machine currents are by the low pass filter (LPF) in the feedback path of the controller of current. Extraction of the carrier which generated current vector i_c is by the bass pass filter (BPF), and the speed of the rotor can be calculated by using the phase-locked loop (PLL)(Holtz 2002).

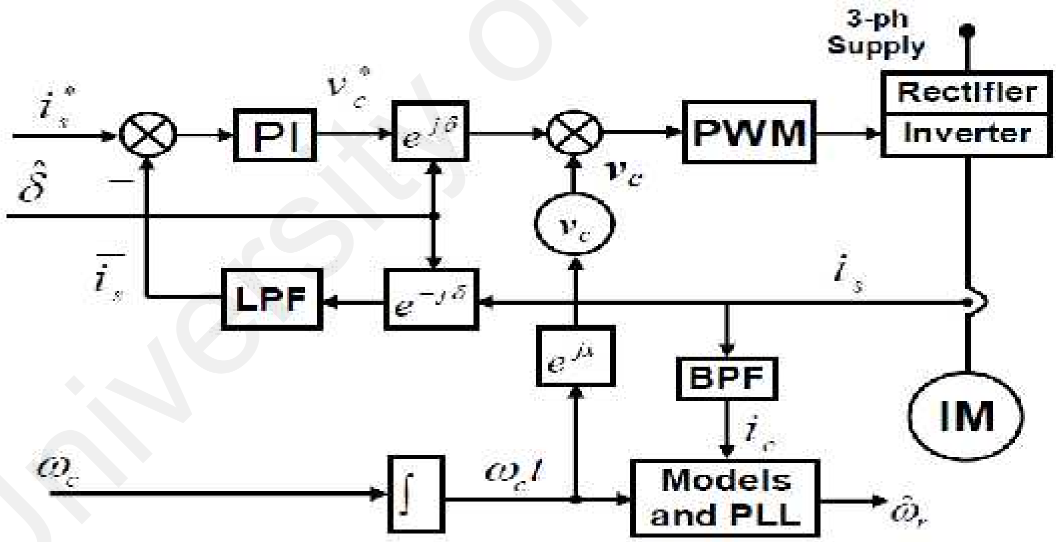

Figure 2. 2 Speed estimation method based on signal injection(Hinkkanen, Leppanen et al. 2005)

2.4 Machine Model (MM) Methods

The outstanding deal of research interest is given to this category method of speed estimation, which is based on machine model due to its simplicity. This section can be sorted according to the algorithm being used for the estimation of speed. Detail of this machine model type of estimating the speed of motor can be sum up by the following few methods.

2.4.1 Direct calculation method (DCM)

Due to small computational time and simplicity, the direct calculation method (DCM) is characterized for induction motor to estimate speed. The source of establishment of this speed estimation method is the rotor flux estimation process. Speed estimation can be summarized as follows (Ilas, Bettini et al. 1994, Elloumi, Ben-Brahim et al. 1998, Wolbank, Woehrnschimmel et al. 2000, Sangsefidi, Ziaeinejad et al. 2012).

Firstly, based on the measured currents and stator voltages by using equation number 2.3 and 2.4 below, the rotor flux is estimated in stationary reference frame.

$$\frac{\lambda^{s}{}_{qr}}{dt} = \frac{L_r}{L_n} v^{s}_{qs} - \frac{L_r}{L_n}\left(R_s i^{s}_{qs} + \sigma L_s \frac{di^{s}{}_{qs}}{dt}\right) \tag{2.3}$$

$$\frac{\lambda^{s}{}_{dr}}{dt} = \frac{L_r}{L_m} v^{s}_{ds} - \frac{L_r}{L}\left(R_s i^{s}_{ds} + \sigma L_s \frac{di^{s}{}_{ds}}{dt}\right) \tag{2.4}$$

$$p\lambda^{s}{}_{qr} = \frac{L_m}{T_r} i^{s}{}_{qs} + w_r \lambda^{s}{}_{dr} - \frac{1}{T_r}\lambda^{s}{}_{qr} \tag{2.5}$$

$$p\lambda^{s}{}_{dr} = \frac{L_m}{T_r} i^{s}{}_{ds} + w_r \lambda^{s}{}_{qr} - \frac{1}{T_r}\lambda^{s}{}_{dr} \tag{2.6}$$

Secondly, in the stationary frame of the d-axis the relation of the angle theta θ_e of vector rotor flux λ_r can be defined as below;

$$\theta_e = w_e t = \tan^{-1}\frac{\lambda^{s}{}_{qr}}{\lambda^{s}{}_{dr}} \tag{2.7}$$

Where,

$$\left.\begin{aligned} \lambda^{s}{}_{qr} &= \left|\hat{\lambda}_r\right| \sin w_e t \\ \lambda^{s}{}_{dr} &= \left|\hat{\lambda}_r\right| \cos w_e t \end{aligned}\right\} \tag{2.8}$$

$$\dot{\theta}_e = w_e = \frac{\lambda^{s}{}_{dr}\dot{\lambda}^{s}{}_{qr} - \lambda^{s}{}_{qr}\dot{\lambda}^{s}{}_{dr}}{\lambda^{s}{}_{dr}{}^{2} + \lambda^{s}{}_{qr}{}^{2}} \tag{2.9}$$

Equation number 2.5 and 2.6 substitute in eqn. 2.9, the estimated rotor speed become;

$$\widehat{w}_r = \left[\frac{1}{\hat{\lambda}_r^2}\left(\lambda^s{}_{dr}\dot{\lambda}^s{}_{qr} - \lambda^s{}_{qr}\dot{\lambda}^s{}_{dr}\right) - \frac{L_m}{T_r}\left(\lambda^s{}_{dr}i^s{}_{qs} - \lambda^s{}_{qr}i^s{}_{ds}\right)\right] \tag{2.10}$$

Where,

$$\hat{\lambda}_r^2 = \lambda^s{}_{dr}{}^2 + \lambda^s{}_{qr}{}^2$$

Hence, given an overall knowledge of motor parameters, the Speed ω_r instantaneous can be estimated from the equation 2.10. The process of all these is illustrated in the below figure, number 2.3, estimation of rotor flux is necessity for calculation of rotor speed as shown from the block diagram.

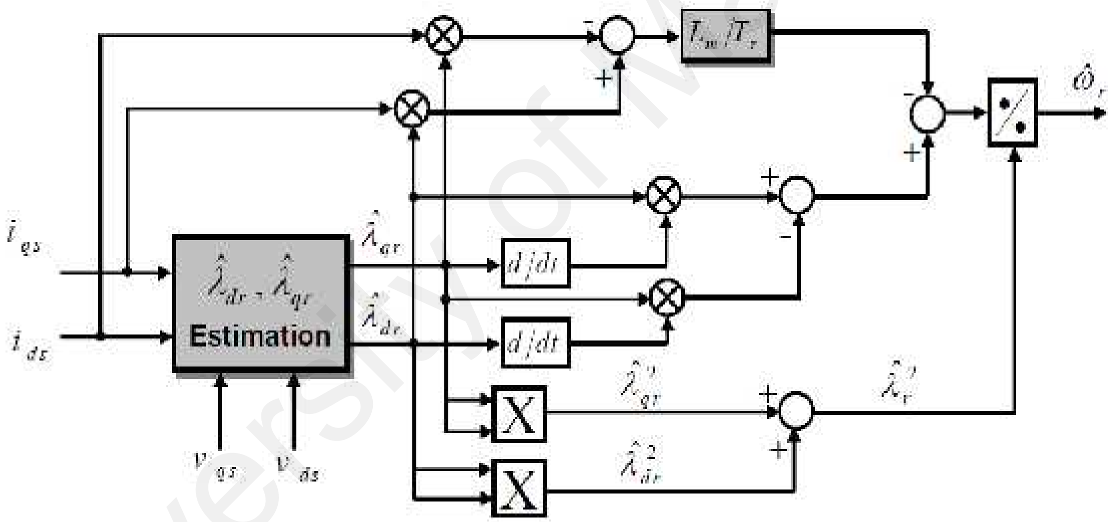

Figure 2. 3 Rotor speed estimation Block diagram structure based on direct calculation method (Wolbank, Woehrnschimmel et al. 2000)

When the frequency approaches to zero, there are three problems occurs related to the rotor flux estimation. First, is that there is need of ideal integral which is necessary to reach near to high result. Second, we need its sensitivity to variation of parameters specially the resistance R_s which has large influence at very low speed, and the 3rd one is the influence of the dead-time when has the use of the actual stator voltage to the pulse width modulation (PWM).

2.4.2 Model reference adaptive system

For sensorless induction motor drives, the model reference adaptive system (MRAS) method is the one of the famous speed observers. It is one of many promising methods technique employed in the adaptive control. Between various types of adaptive configuration system, the MRAS is vital for a wide range of application. Since, it contributes as to relatively easy in implementation of the systems with high speed of adaption; this is one of the most notable advantages of the adaptive system. Due to the fact, a measurement of the difference between the outputs of the reference model, and the adjustable model is found right away by the comparison of the outputs or states of the reference model along with those of the adjustable system. The demanded dynamics of actual control loop are represented by the block "reference model", and the block of adjustable model represents the same structure as the reference one merely with parameter of adjustable one. Instead of any unknown ones as shown in the figure number 3.4, the consistence of the MRAS model basically is one on the reference model, adjustable model and an adaptive mechanism.

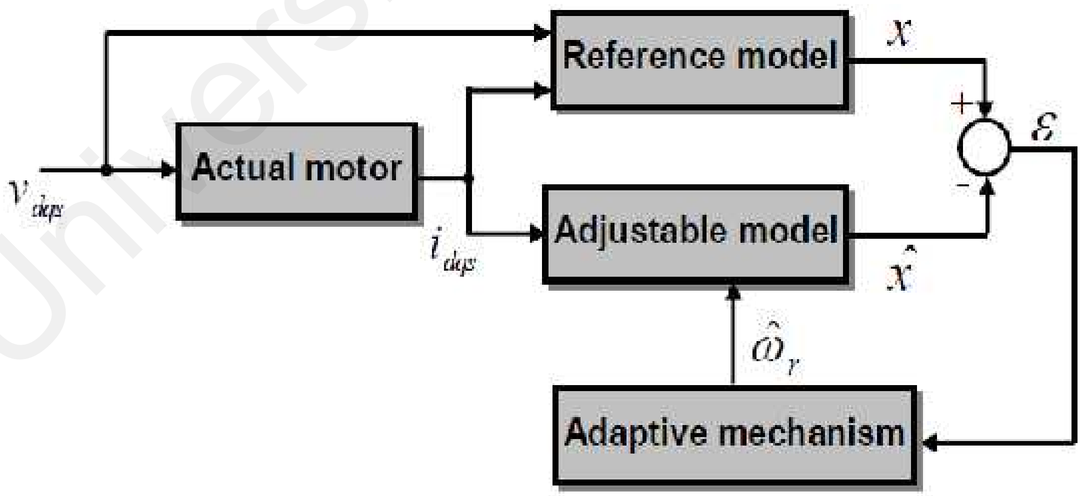

Figure 2. 4 Using the MRAS the block diagram of rotor speed estimation structure(Rashed and Stronach 2004)

The state variable x is calculated by the independent reference model of the rotor speed from the current and voltage terminal, and the dependent model on the rotor speed which is adjustable model estimate the state variable $\hat{x}$. For speed generation of the estimated speed $\hat{w}_r$, use the error which is shown in the diagram ε between calculated and estimated state variables.

From review of this technique, it is noted that the estimation of speed methods using MRAS can be assorted in to several types following to that state variable. Among them the most ordinarily used are the back emf-based MRAS, rotor flux-based MRAS, and the stator current-based MRAS.

2.4.2.1. Rotor Flux-Based MRAS

As an output value the rotor flux is used in rotor Flux-Based MRAS method for the model to estimate the speed of the rotor. Whilst the rotors flux of the method of adjustable in equation number 2.12 is in conformity with that of reference model equation number 2.11. The speed of the adjustable model represents as the real speed of the rotor (Schauder 1992, Marwali and Keyhani 1997, Liu and Wang 2008).

$$\frac{d\lambda_r^s}{dt} = \frac{L_r}{L_m} V_s^s - R_s i_s^s - \sigma L_s \frac{di_s^s}{dt} \qquad (2.11)$$

$$\frac{d\hat{\lambda}_r^s}{dt} = j\hat{w}_r \hat{\lambda}_r^s - \frac{1}{T_r}\hat{\lambda}_r^s + \frac{L_m}{T_r} i_s^s \qquad (2.12)$$

Using the rotor flux based MRAS, the speed estimation algorithm is shown in the figure 2.5, and estimated speed of the rotor is expressed as;

$$\hat{w}_r = K_p\left(\lambda^s{}_{qr}\hat{\lambda}^s{}_{dr} - \lambda^s{}_{dr}\hat{\lambda}^s{}_{qr}\right) + K_1 \int \left(\lambda^s{}_{qr}\hat{\lambda}^s{}_{dr} - \lambda^s{}_{dr}\hat{\lambda}^s{}_{qr}\right) dt \qquad (2.13)$$

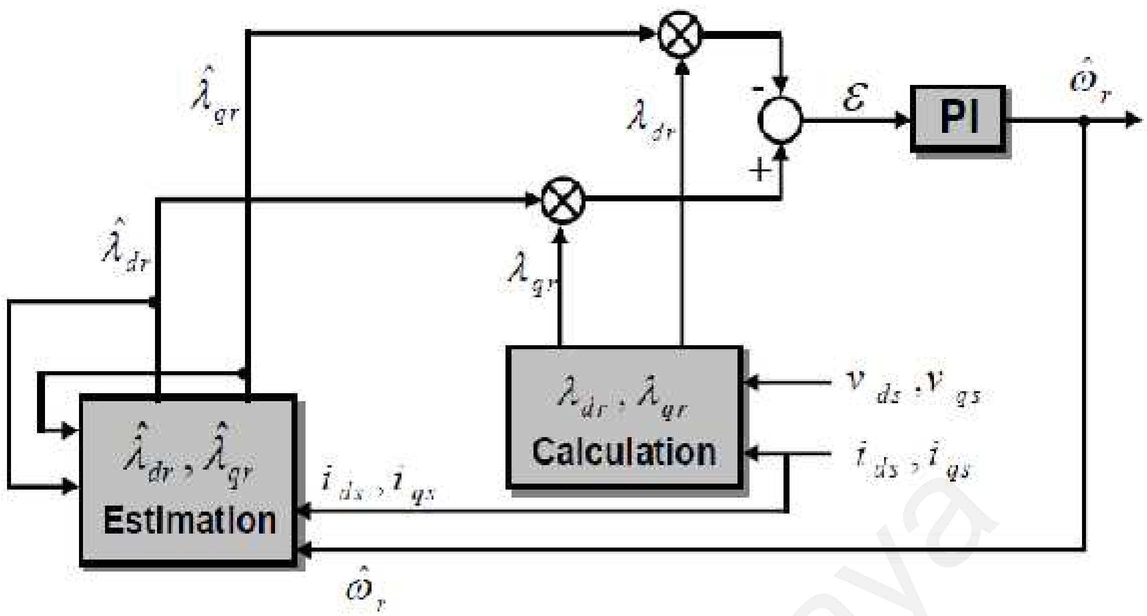

Figure 2. 5 using rotor flux MRAS based method the block structure of rotor speed estimation (Liu and Wang 2008)

In the MRAS based rotor flux method, problems with initial drift and conditions occurs due to presence of an open integration in the stator. Instead of pure integration there can be use a low pass filter. However, it has a capability of degrading the effect on estimation of speed at low speeds and also introduces a time delay.

2.4.2.2. Back emf-Based MRAS

If back emf based MRAS method is based on rather than rotor flux, the model of reference adaptive approaches to offers an alternative solution for avoiding the problems which are involved with the open integration. In this approach the open integration is circumvented as such and other than in the MRAS based on the rotor flux. There are none low pass filters that create a bandwidth limit. Particularly for the stator of resistance, a more extremely possible source of inaccuracy is a potential mismatch of the parameters of the reference model (Marwali and Keyhani 1997, Rashed and Stronach 2004).

$$e = V_s^s - R_s i_s^s - \sigma L_s \frac{di_s^s}{dt} \tag{2.14}$$

$$\hat{e} = \frac{L_m}{L_r}\left[j\hat{w}_r(L_m i_s^s + L_r i_r^s) - R_r i_r^s\right] \tag{2.15}$$

Firgure number 6 shows the block diagram of estimation of speed by using the back emf based MRAS model.

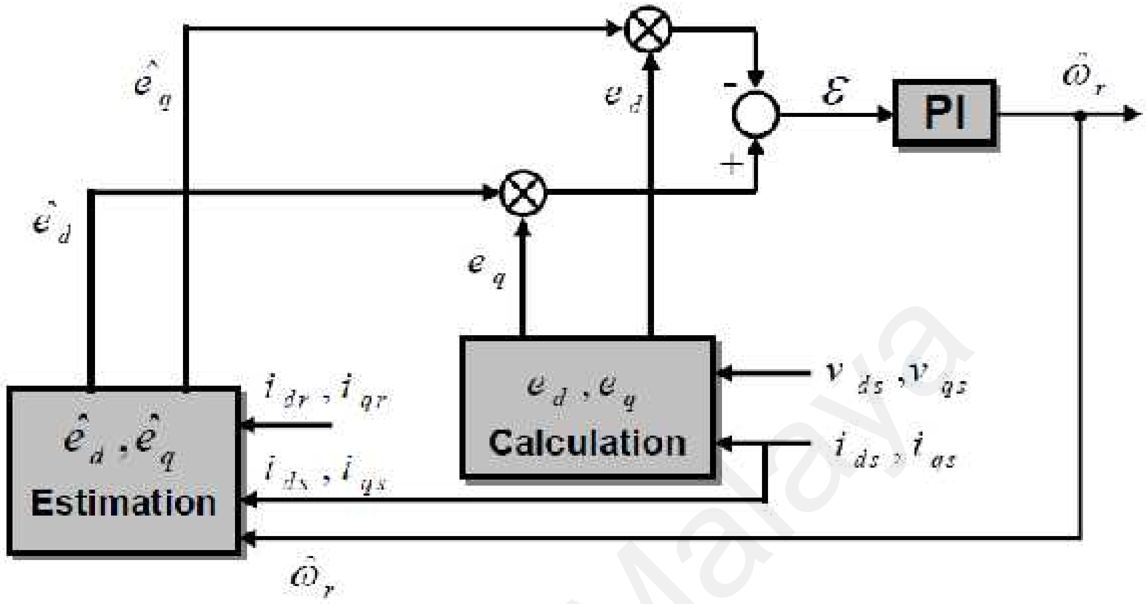

Figure 2. 6 Using back EMF based MRAS block diagram of rotor speed estimation(Rashed and Stronach 2004)

From reference model based on the current and voltage terminals the back emf e is calculated, and however $\hat{e}$ is the back emf calculated from the adjustable model.The estimated speed of rotor by this method is expressed as:

$$\hat{w}_r = K_p\left(e_q\hat{e}_d - e_d\hat{e}_q\right) + K_1\int\left(e_q\hat{e}_d - e_d\hat{e}_q\right)dt \tag{2.16}$$

2.4.2.3. Stator Current-Based MRAS

For the aforesaid reasons, the stator current might be used as an output value for estimation of the speed MRAS based model. According to this method, the estimation of the rotor speed is by using the rotor flux which is denotative in terms of the current of stator, voltage of the stator the parameters of the motor.

$$\lambda_{dr}^{s} = \frac{L_r}{L_m}\left[\int\left(V_{ds}^{s} - R_s i_{ds}^{s}\right)dt - \sigma L_s i_{ds}^{s}\right] \tag{2.17}$$

$$\lambda_{qr}^{s} = \frac{L_r}{L_m}\ \int\left(V_{qs}^{s} - R_s i_{qs}^{s}\right)dt - \sigma L_s i_{qs}^{s}] \tag{2.18}$$

Current of stator by using the motor speed and the rotor flux expressed as;

$$i_{ds}^{s} = \frac{1}{L_m}\left(\lambda_{dr}^{s} + w_r T_r \lambda_{qr}^{s} + T_r \frac{d\lambda_{dr}^{s}}{dt}\right) \tag{2.19}$$

$$i_{qs}^{s} = \frac{1}{L_n}\left(\lambda_{qr}^{s} + w_r T_r \lambda_{dr}^{s} + T_r \frac{d\lambda_{qr}^{s}}{dt}\right) \tag{2.20}$$

Stator current is estimated as below by using the eqauation number 2.19 and 2.20 and the estimated speed .

$$\hat{i}_{ds}^{s} = \frac{1}{L_m}\left(\lambda_{dr}^{s} + \hat{w}_r T_r \lambda_{qr}^{s} + T_r \frac{d\lambda_{dr}^{s}}{dt}\right) \tag{2.21}$$

$$\hat{i}_{qs}^{s} = \frac{1}{L_n}\left(\lambda_{qr}^{s} + \hat{w}_r T_r \lambda_{dr}^{s} + T_r \frac{d\lambda_{qr}^{s}}{dt}\right) \tag{2.22}$$

From the relationship of above calculated and estimated stator currents, the difference which is in the stator current is received as;

$$i_{ds}^{s} - \hat{i}_{ds}^{s} = \frac{T_r}{L_m}\lambda_{qr}^{s}(w_r - \hat{w}_r) \tag{2.23}$$

$$\hat{i}_{qs}^{s} - i_{qs}^{s} = \frac{T_r}{L_n}\lambda_{dr}^{s}(w_r - \hat{w}_r) \tag{2.24}$$

Multiply and add equation (2.23) and (2.24) together with the flux of the rotor , we have the following expression ;

$$(i_{ds}^{s} - \hat{i}_{ds}^{s})\lambda_{qr}^{s} + (\hat{i}_{qs}^{s} - i_{qs}^{s})\lambda_{dr}^{s} = \frac{T_r}{L}(w_r - \hat{w}_r)\left({\lambda_{dr}^{s}}^{2} + {\lambda_{qr}^{s}}^{2}\right) \tag{2.25}$$

The error of the rotor speed we can write from the above equation number (2.25) as;

$$w_r - \hat{w}_r = n\left[(i_{ds}^{s} - \hat{i}_{ds}^{s})\lambda_{qr}^{s} + (\hat{i}_{qs}^{s} - i_{qs}^{s})\lambda_{dr}^{s}\right] \tag{2.26}$$

Where as;

$$n = \frac{L_m}{T_r}\frac{1}{\left[(\lambda_{dr}^{s})^2 + (\lambda_{qr}^{s})^2\right]}$$

Block diagram of stator current based method of MRAS is shown in the figure number 2.7. Whereas from equation (2.26) ,we determined the speed estimation error from the rotor flux and the stator current. With appropriate integral gains and proportional using the PI controller,the error is continuously reduced to zero. The mangnitude of the rotor flux in equation number (2.26) is constantly maintained as like generally in vector control.

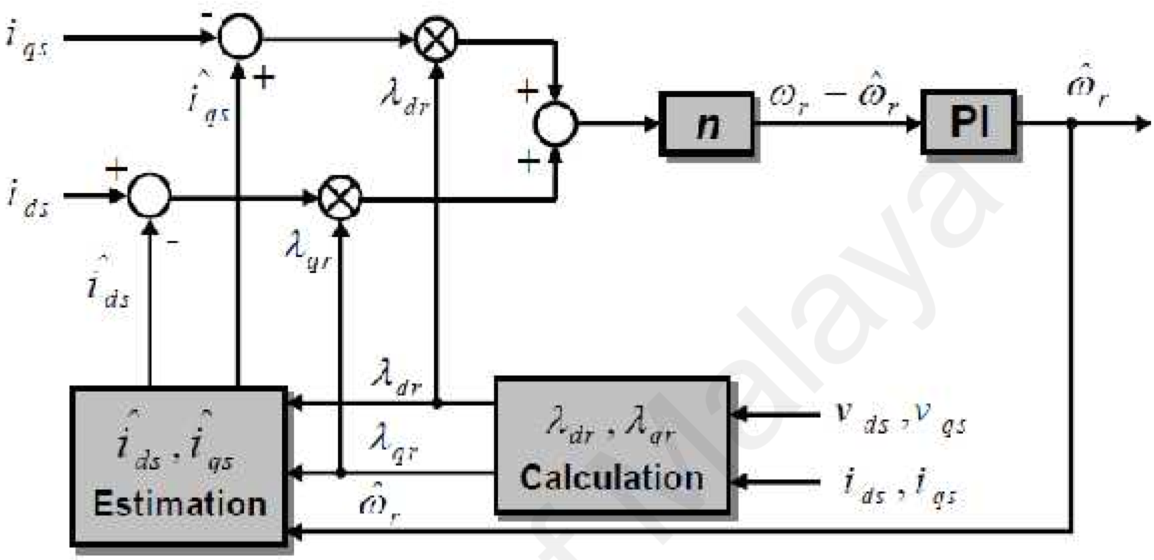

Figure 2. 7 Speed estimation configuration scheme by using the stator current based MRAS method(Schauder 1992)

This method on the other hand can develop accurate estimation of speed and the fast convergence. Afterward the error of the stator current is acted as a function of the first degree of the estimation speed error. In this method of MRAS using the back emf and rotor flux, the connection of relationship between the error of speed estimation and the model error is not clear and that is the reason controller gain of the MRAS has a nonlinear characteristic type. Therefore, as a result ,these types of methods are considered as difficult to estimate the speed at the zero speed and in a low region of speed owing to the increment of this nonlinear type characteristic(Schauder 1992, Rashed and Stronach 2004). On the other hand, based on MRAS the stator current is denoted as a function of the first degree for the value of error in the estimation of speed. Hence, this method also produce the fast estimation of speed and in the parameter error it has robust variations(Abu-Rub and Guzinski 2011, Ravi Teja, Chakraborty et al. 2012).Furthermore, for the betterness in the performance this method offers a considerable improvements of the sensorless vector controller at the low speed.Summary of MRAS method review is shown in the below table number 2.1.

Table 2. 1 Advantages and distadvantage of MRAS method

Advantages	**Drawbacks**
Algorithms of MRAS are robustness.	Main drawback of MRAS algorithm are their sensitivity to inaccuracies in reference model.
Fast convergence.	Designing of the adaption mechanism block have a lot difficulties.
Small computation time.	Selection of the adaptive gains mechanism is selection between achieving high robustness against noise and fast response and the disturbance effect the system in this case.

2.5 Kalman Filter approach

The system which has many unknown noises such as; ripple in the current by PWM, noise by the modelling error, error in measurement and so forth for that system the algorithm of Kalman Filter (KF) is suitable and all these errors are treated as disturbance in this algorithm method. In real type of system, some uncertainties in the environment and model as disturbances, as modelling inaccuracies and noises should be considered (Al-Tayie and Acarnley 1997, da Silva and Kankam 1997, Garcia Soto, Mendes et al. 1999, Khalil, Strangas et al. 2009). With random noises the state equations can be expressed as;

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t) + G(t) \qquad (2.27)$$

$$y(t) = Cx(t) + v(t) \qquad (2.28)$$

Where, $x(t)$ is the state variable, $u(t)$ is the commands variables, and $y(t)$is the output variables. However, $G(t)$ and $v(t)$ are the input and output noises respectively.

The KF method is not purely applicable for the nonliear problems,whereas the linearity plays a significant role in its performance as an optimal filter and in its derivation. Undertakes of the extended kalman filter (EKF) method by using the linearized approximation, the attempts to get over this kind of the difficulty where the linearization is performed for the current estimate state. Discretization of equation (2.27) and (2.28) is required for this process as;

$$x(k+1) = A(k)x(k) + B(k)u(k) + G(k) \tag{2.29}$$

$$y(k) = C(k)x(k) + v(k)$$

(2.30)

Algorithm of Kalman filter is expressed as;

$$P(0) = Var\{X(0)\} \tag{2.31}$$

$$\hat{X}(0) = E\{X(0)\} \tag{2.32}$$

$$P(K+1) = A(K)P(k)A^{T}(K) + Q \tag{2.33}$$

$$\hat{X}(K+1) = A(K)\hat{X}(K) + B(K)u(K) \tag{2.34}$$

$$K(K+1) = P(K+1)C^{T}(K)[C(K)P(K+1)C^{T}(K) + R]^{-1} \tag{2.35}$$

$$\hat{X}(K+1/K) = \hat{X}(K+1) + K(K+1)\ y(K) - C(K)\,\hat{X}(K+1)] \tag{2.36}$$

Where;

K(k+1) = the Kalman gain matrix.

Var(x) = the variance of x.

P(k) = error covariance matrix.

E(x) = the expectation of x.

y(k) = the estimated output.

The matrix R shows the noise developed by transforming the estimated output into sampled data model, and Q is the disturbances here such as the error which produced by transforming into the sampled one data of the system. Approach structure of the kalman filter is typically shown in figure number 2.8. Due to modelling error and imperfection of the current controller the error is produced.

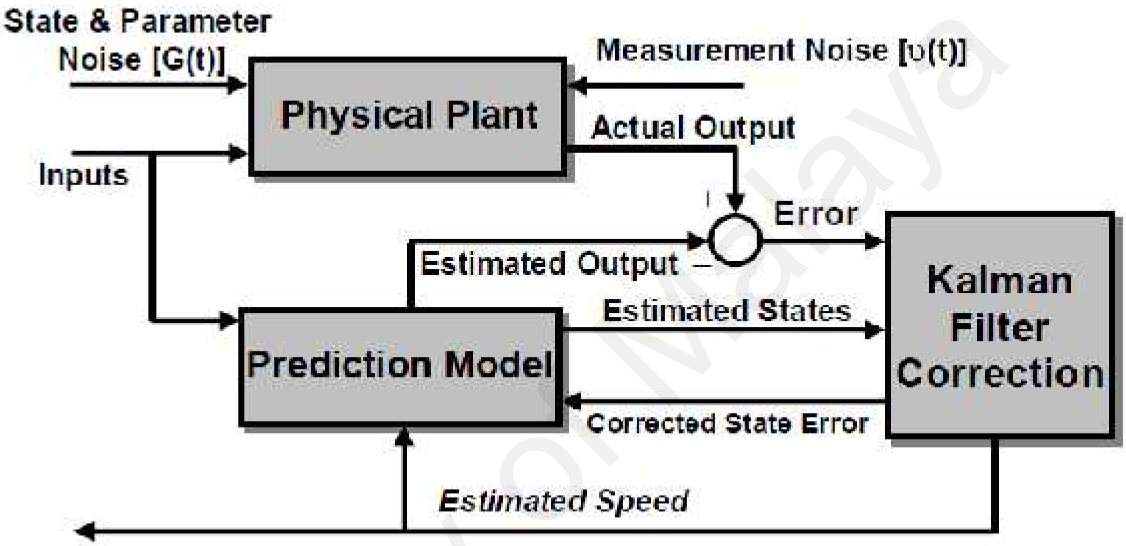

Figure 2. 8 Kalman filter structure for estimation of speed(Khalil, Strangas et al. 2009)

The inputs to the plant are fed into a prediction type model, and the output of that plant is equated with the output from the model. The resulting error which comes after being compared is fed into a kalman gain correction stage for the purpose of reducing the error in the estimated states from that prediction model. The approach of this method of kalman filter has some inherent type of disadvantages such like; the absence of the tuning criteria and design, and the influence of computation burden. As well, it is comparatively difficult to analyse and required much more powerful type microprocessors.

2.6. Artificial intelligence techniques

Control of the non linear dynamic systems and to identify the use of Artificial Intelligence (AI) has been suggested. Reason is that they can guess a wide range function of nonlinear to any wanted accuracy of degree. Furthermore, Artificial Intelligence (AI) has the advantages of the exemption from ripples of input harmonics and the robustness to the variations of parameters. Latterly, there have been many researches, investigations into the application of Artificial Intelligence to the IM drives, the power electronics, and also including the estimation of the speed(Campbell and Sumner 2002, Lopez, Romeral et al. 2006, Rafiq, Habibullah et al. 2012, Sedhuraman, Himavathi et al. 2012). AI’s two applications are used in research for induction motor in which neural network (ANNs) model and Fuzzy logic control (FLC) based model are in research area field.

2.6.1 Neural Network based model

Using NN model with the two well-known current and voltage model are necessary for estimating the speed of an induction motor, because the voltages and the currents of the induction motor are calculated in the stationary reference frame which is very much convenient to express the equation (2.41) and (2.42) in the stationary frame(Wang, Lin et al. 2010).

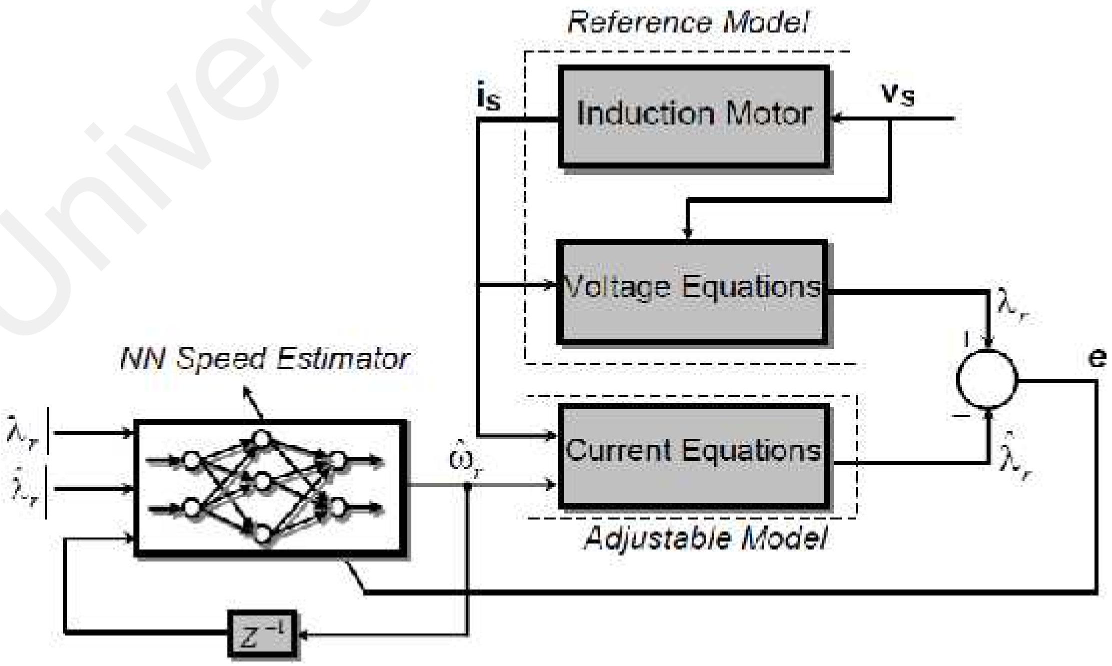

Figure 2. 9 Using Artificial NN model structure of the speed estimation(Wang, Lin et al. 2010)

Illustration of the method using NN model and also the equations (2.41) and (2.42) are defined in the figure number 2.9. Equations are expressed as follows (Seong-Hwan, Tae-Sik et al. 2001):

$$P\begin{bmatrix}\lambda_{dr}^{s}\\ \lambda_{qr}^{s}\end{bmatrix} = \frac{L_r}{L_m}\left[\begin{bmatrix}v_{ds}^{s}\\ v_{qs}^{s}\end{bmatrix} - \begin{bmatrix}R_s + \sigma L_s p & 0\\ 0 & R_s + \sigma L_s p\end{bmatrix}\begin{bmatrix}i_{ds}^{s}\\ i_{qs}^{s}\end{bmatrix}\right] \qquad (2.41)$$

$$P\begin{bmatrix}\lambda_{dr}^{s}\\ \lambda_{qr}^{s}\end{bmatrix} = \begin{bmatrix}\frac{-1}{T_r} & -w_r\\ w_r & \frac{-1}{T_r}\end{bmatrix}\begin{bmatrix}\lambda_{dr}^{s}\\ \lambda_{qr}^{s}\end{bmatrix} + \frac{L_m}{T_r}\begin{bmatrix}i_{ds}^{s}\\ i_{qs}^{s}\end{bmatrix} \qquad (2.42)$$

Reference model is defined by the voltage equations that don't involve w_r and defining the current equation with method of adjustable model by the involvement of w_r.The $\hat{w}_r$ estimated speed is defined as the output of the ANNs, which afterwards is used as the input of the adjustable model. The error occurs between the flux from the reference model λ_r and the flux from the adjustable model $\hat{\lambda}_r$ when the estimated speed deviates from the real speed. Subsequently that error is back-propagated to the model AAN and the weights of model NN are adjusted online to decrease the error. Eventually, the output of the model NN pursues the real speed. Though methods which are based on ANN also give the good speed estimation along with parameters mismatch, however they are in truth, they are comparatively very complicated and needs large time for computation.

2.6.2 Fuzzy logic based model

In the existing research area literature on fuzzy logic control there are two most popular methods reviewed, the Mamdani and Sugeno systems. Both of these methods are characterised by the logics rules "IF-THEN" and in nature have the same antecedent type structure. Nevertheless, there is difference between them in the structure of the consequent parts. The consequent of the method based on Sugeno rule is nonlinear or linear type function of the inputs variables, whereas comparatively with the consequent of a Mamdani based rule is a fuzzy type set(Venkataramana Naik and Singh 2012).The development of the structure is for both such as type-1 fuzzy logic control (TP1FLC) which reduced order and type-2 fuzzy logic control (TP2FLC) as shown in the figure number 2.10, as the fuzzification and de-fuzzification procedure is quite remain same as type-1 fuzzy logic control (TP1FLC)(Qilian and Mendel 2000).

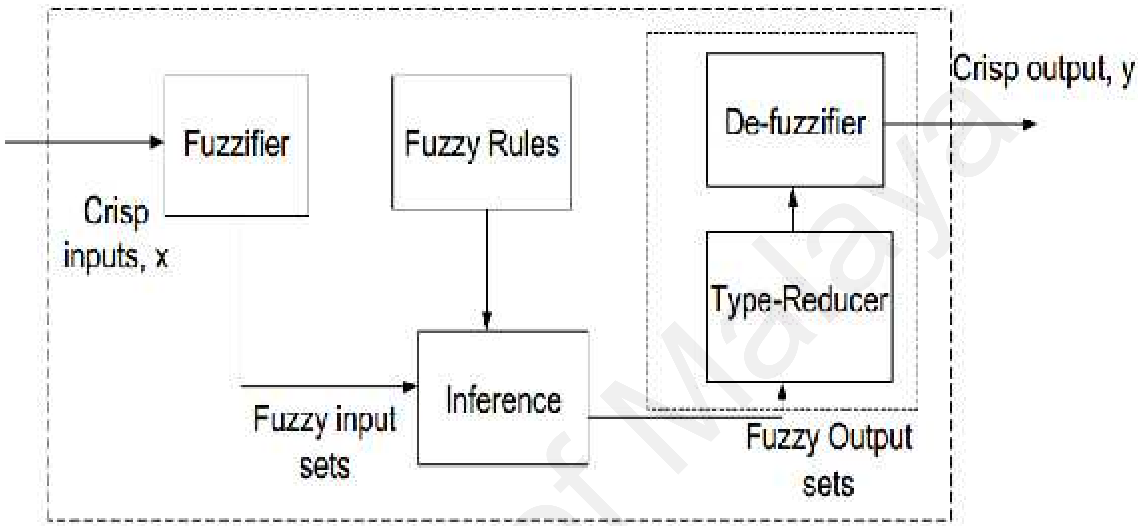

Figure 2. 10 type-2 Fuzzy logic Control(Venkataramana Naik and Singh 2012)

It has been observed also from research review papers by using the PI fuzzy controller that the oscillation has been not only cancelled but the speed profile became the smoother as well(Abdalla, Hairik et al. 2010). The PI controller with fuzzy logic scheme for the direct control of the torque is shown in the figure number (2.11); the main feature of this scheme is the fuzzy self adaptation PI control block.

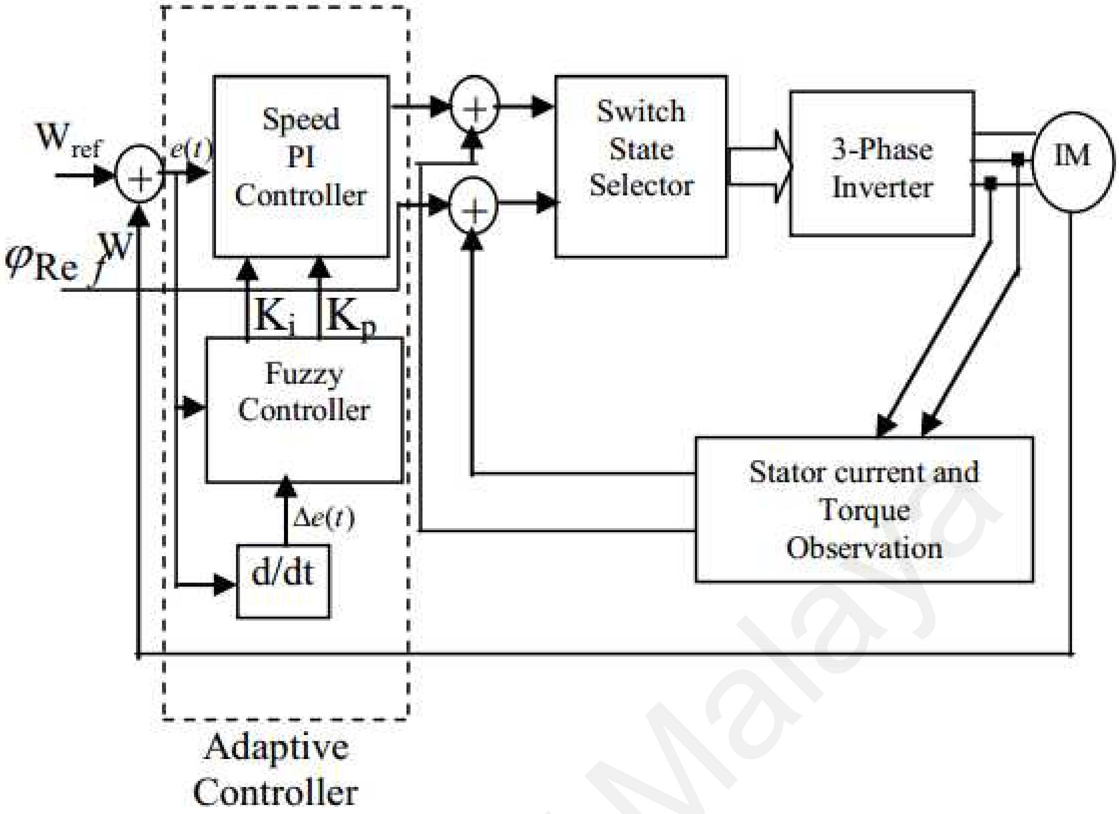

Figure 2. 11 PID controller with Fuzzy logic block diagram of induction motor(Lopez, Romeral et al. 2006)

Scaled value in this method regarding the error speed and the change of the speed error are used by the control of fuzzy for the updates of proportional gain values Kp and the integral ki gain. Using the set of fuzzy logic rules give the excellent control of performance even for the vibrations in parameter and the characteristic of nonlinearity based drive system.

2.7 Sliding mode observer (SMO):

For the speed estimation drives of the induction motor, currently there is a growing interest of using the sliding mode observer (SMO) which is based on the scheme of Variable Structure Control (VSC) theory. It also extends many good properties such as; better performance against the dynamics of un-modelled, insensitivity to the variations of parameter, disturbance from external rejection and dynamic response is fast. For speed estimation (state estimation of a nonlinear plant) of induction motor drives these properties are very much important. However, the positive application of SMO is its application for estimation of speed in induction motor drives which requires the elimination of chattering problem (Derdiyok 2005, Jingchuan, Longya et al. 2005, Edelbaher, Jezernik et al. 2006, Khater, Zaky et al. 2006, Lascu and Andreescu 2006).

Representation of induction motor is by its own dynamic model which is expressed in the reference stationary frame in terms of the rotor flux and stator current as by the following state equations.

$$\frac{d}{dt}\begin{bmatrix} i_s^s \\ \lambda_r^s \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}\begin{bmatrix} i_s^s \\ \lambda_r^s \end{bmatrix} + \begin{bmatrix} b_1 \\ 0 \end{bmatrix}[U_s^s] = AX + Bu_s$$

(2.43)

Whereas,

$a_{11} = aI$,

$a_{12} = cI + dJ$,

$a_{21} = eI$,

$a_{22} = -\varepsilon a_{12}$,

$b_1 = bI$,

Estimation of the rotor flux the SMO can be built as;

$$\frac{d\hat{X}}{dt} = \hat{A}\hat{X} + Bu_s + K_1 sgn(\hat{i}_s^s - i_s^s) \quad (2.44)$$

Where the K_1 is a matrix gain which is arranged as below, and the structure of the SMO regarding speed estimation algorithm is shown in Fig. 2.12.

$K = [K \quad -K]^T$,

$K = KI$,

K is switching gain.

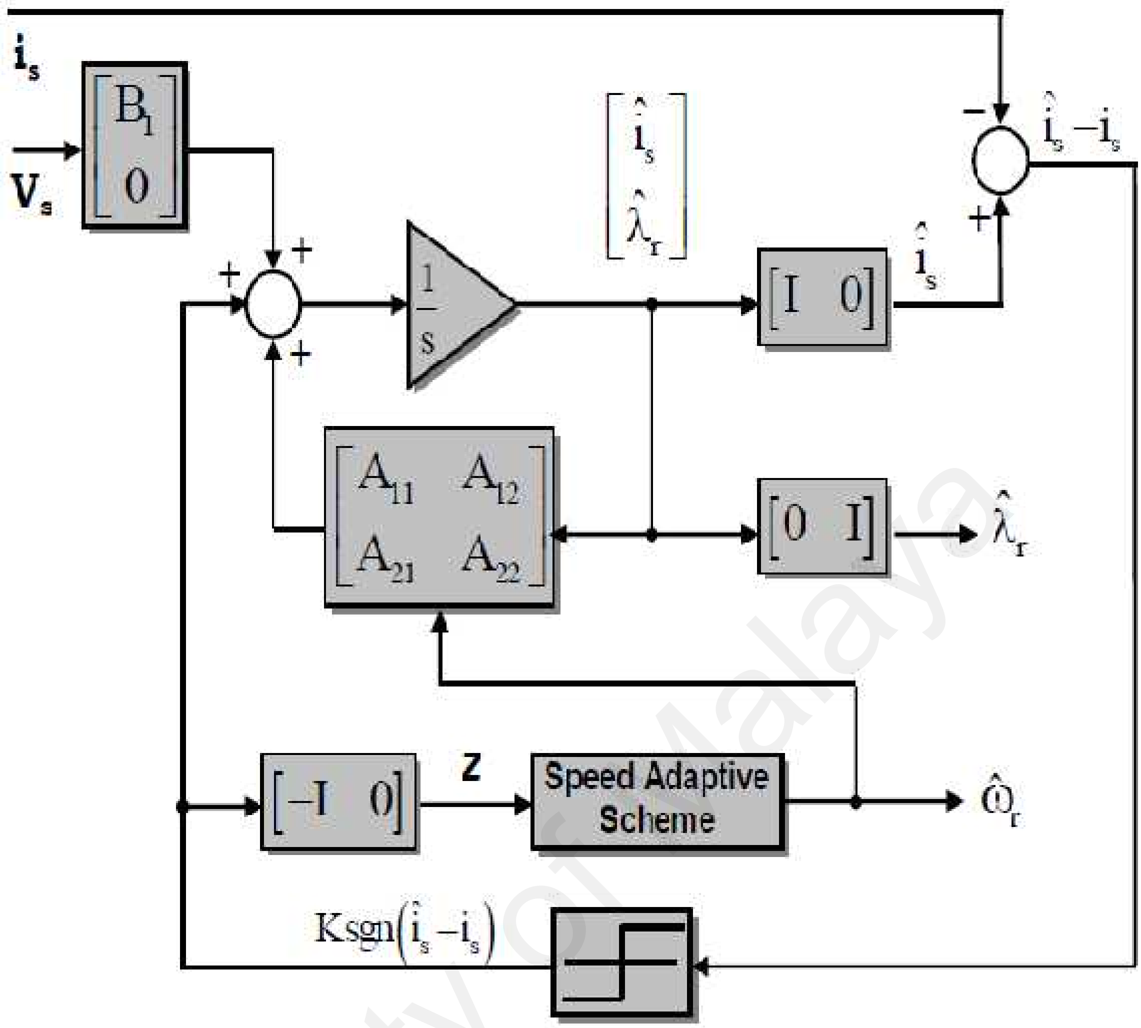

Figure 2. 12 Sliding Mode Observer (SMO) Block diagram (Lascu and Andreescu 2006)

Based on the Lyapunov theory the equation of the estimation speed rotor can be express as below,

$$\hat{w}_r = -K\left[\int sgn(\hat{i}_{ds}^{s} - i_{ds}^{s})\,.\,\hat{\lambda}_{qr}^{s} - sgn(\hat{i}_{ds}^{s} - i_{ds}^{s}).\,\hat{\lambda}_{dr}^{s}\right]dt \qquad (2.45)$$

2.8 Speed estimation at low speed

In the exact dynamic estimation of the vector, stator flux is the main problem in the sensorless vector control of ac drives throughout the wide range of speed operation and using only variables of terminal that are currents and voltages. The major difficulties originated on the state of estimation at very low speed are due to fundamental excitation is low and the performance of the observer tends to be very poor. The causes are the sensitivity to the variations of the parameter model, drifts, disturbances and un-modelled nonlinearities, limitation in accuracy of acquisition signals and dc offsets. The main three sources of the poor estimation of speed are as Data Acquisition Errors, Voltage Distortion due the PWM Inverter and Stator Resistance Drop(Tajima, Guidi et al. 2000, Holtz 2002, Holtz and Juntao 2003, Consoli, Scarcella et al. 2004).

2.8.1 Data Acquisition Errors

Data Acquisition Errors turns to substantial at low speeds. Reason for that are the current sensors converts the currents of the machine in to the voltage signals which are afterwards digitised through A/D converters. Dc offset component specially the parasitic are superimposed on top to the analogue signals and appear as ac components which belongs to fundamental frequency right after their transformation to the synchronous type coordinates. For the current controller they act as disturbances. That’s why torque ripple generates and there is also another problem in it which is the effect of unbalanced gains of the current acquisition channels(Holtz 2002).

2.8.2 Voltage Distortion due the Pulse Width Modulation (PWM) Inverter

Usage of Pulse Width Modulation (PWM) controlled switches is the task to produce the desired voltage on the stator winding by the power inverter. Afterwards the time of the switching of the existing transistor is not infinitely short. During the commutations, the knowledge about the necessary blanking time must brought which avoid short circuiting the dc link which is known as “dead time” also. The importance of small time is because of that inverter nonlinearity also introduces a phase error in the output-voltage vector and a magnitude.

In the addition of the dead time across the switch during the ON State there is voltage drop also at finite level which is the reason of introducing an extra, also called additional error in the magnitude of the voltage at output. Taking in consideration, regarding inverter model enables the more estimation of vector stator flux linkage speed accurate and accordingly, better speed estimated is achieved(Holtz 2002, Holtz and Juntao 2002).

2.8.3 Stator Resistance Drop

Compared with the stator voltage the resistive drop of voltage is small in the upper speed range. That's the reason the speed estimation and the stator flux vector can be made with better accuracy, frequency of stator is also low at the low speeds. Voltage of the stator reduces in direct proportion almost, while at low speed it becomes significant and the resistive drop voltage maintains its magnitude order. Speed estimation is because of the great influence on the estimation accuracy of the flux stator vector due to the resistive voltage drop. On other way, the vibrations of the resistance of the stator which takes in considerable variations are found when the temperature of machine changes at the varying load. These variations are supposed to be tracked which are necessary to maintain the stability of the flux estimation at the low speed (Holtz 2002, Holtz and Juntao 2003). Several methods for improving the performance of the voltage model at low frequency have been proposed. For instance, accurate measurements for the stator current and voltage, compensation of the voltage drop due to inverter, and the resistance of the stator also can be identified with an adaptive scheme(Holtz and Juntao 2002, Holtz and Juntao 2003).

2.9 Parameter Adaption

In spite of the facts referred from reviewed research, the method based on machine model for the estimation of the speed are characterised due to their simplicity. Sensitivity due to variations in parameter is one of the problems associated also with them. Resistance region in the low speed of the stator plays an important role, and value of resistance should be known with the good precision in order to achieve the accurate estimation of the rotor speed(Zamora and Garcia-Cerrada 2000, Vasic, Vukosavic et al.

2003). Heating of the motor usually is the reason of vibration in the winding resistance which is considerable. Afterwards it becomes the causes of the mismatch between the actual resistance of the winding and its corresponding value in the model system which is used for the estimation of the speed. This might lead not only to a large error estimation of speed but also the instability occur as well, and recently the consequence for that the numerous online schemes for the resistance of stator recognition have been proposed (Zamora and Garcia-Cerrada 2000, Vasic, Vukosavic et al. 2003).

Identification availability of online resistance of stator schemes can be sorted into a couple of clear cut categories. Reliability of all these methods is on the measurements of the stator current and primarily there is requirement of the information regarding voltage of the stator as well (Vasic, Vukosavic et al. 2003, Edelbaher, Jezernik et al. 2006). To update the value of stator resistance, the most famous method includes the different kinds of estimators which frequently use an adaptive mechanism (Vasic, Vukosavic et al. 2003, Edelbaher, Jezernik et al. 2006). Stator resistance is supposed to be determined through reactive power which is based on model reference adaptive system (MRAS) (Edelbaher, Jezernik et al. 2006). The reliability of the reactive power is on the accuracy of other parameters such as rotor resistance which are not necessarily constant and reason as results is prone to error. Another reliability of reactive power is on leakage inductance. For the estimation of the speed and the resistance of the stator, there is method of Adaptive full order flux observers (AFFO) which are developed with the help of using Popov’s and Lyapunov stability criteria(Hossein Madadi Kojabadia 2005, Wang, Lin et al. 2010). With regard to computation while these types of schemes are not intensive and might AFFO with matrix non zero gain become unstable. For speed estimation and the resistance of the stator with the help of using the model reference adaptive system which is developed with the help of using stability criterion of Popov’s (Vasic, Vukosavic et al. 2003, kojabadi 2005). With the difference between two types of stator currents which is measured and the observed stator current, in this method mechanism of stator resistance adaption can be determined.

Need of the wide speed range which could have maximum required speed, which means considerably exceeds the speed of the motor's rated speed are required for the application such as gearless traction drives and spindle. Redoubtable difficulties occur during speed estimation in the field weakening region regardless of the method used for the estimation of speed. In the region of field weakening the model which have approaches on AC machines, considered as the main problem which have roots from the fairly large variation of magnetizing inductance as the main saturation of flux which is neglected in estimation of speed based model. Hence, the exact estimation of speed is possible in the weakening field region using the approach of model based. If and only modifying the algorithm of the speed estimation in such way in which the variation of the main flux saturation is made out within the estimator (Myoung-Ho and Dong-Seok 2003, Tae-Sung, Myoung-Ho et al. 2005). In the speed base region, the induction motor of a field oriented operates with reference of rated rotor flux which is constant. Hence, as result the magnetizing inductance can be considered as equal to its value of rated and as constant also. At higher speeds the operation in the weakening field region compare to rated speeds causes that the flux of the rotor reference has to be diluted below the value of rated speeds. The variation of the flux of rotor reference in the machine implies the variable level of the main flux saturation and accordingly the variable parameter of the machine is the magnetizing inductance (Levi and Mingyu 2002, Levi and Mingyu 2003).Value of magnetizing inductance especially the accurate one is extremely important for many reasons. First one, the correct setting of the d-axis reference current of stator in a drive of vector controlled which needs the precise value magnetizing inductance to be known. Second one, the accurate estimation of the speed using the model based machine's approaches for the procedure in the field region weakening.

Third reason, is the dependency of constant time of rotor which is identification schemes on magnetizing of inductance such as the process in which utilize the method of reactive power(Levi and Mingyu 2002). Correct value of the magnetizing inductance is required to be known for the estimation of accurate constant time of rotor in the field of weakening region.

In the area of research, many are committed on this and giving the way to better speed estimation in the weakening field oriented type control of induction motor which is in constant flux region operation. Nevertheless, the analyses on the inductance of magnetising identification regarding the improvement of the speed estimation in the field of weakening region are still seldom made (Huang and Liaw 2003). In the state of transient and steady state the better dynamic response can get by the representation of the fitted quadratic polynomial of the current field for the nonlinear magnetizing inductance. Magnetizing inductance identification method is employed on which measured voltage of stator and currents depends and also the magnetizing curve of the machine(Levi and Mingyu 2003).

2.10 Adaptive flux observer (AFO)

For the purpose of speed estimation of induction motor drives the Adaptive Flux observers are also used. The construction of the adaptive observer is essentially framed in three types of main parts: Model of the induction motor, feedback gains of the observer, and mechanism of adaption regarding rotor speed as shown in the figure 2.13.

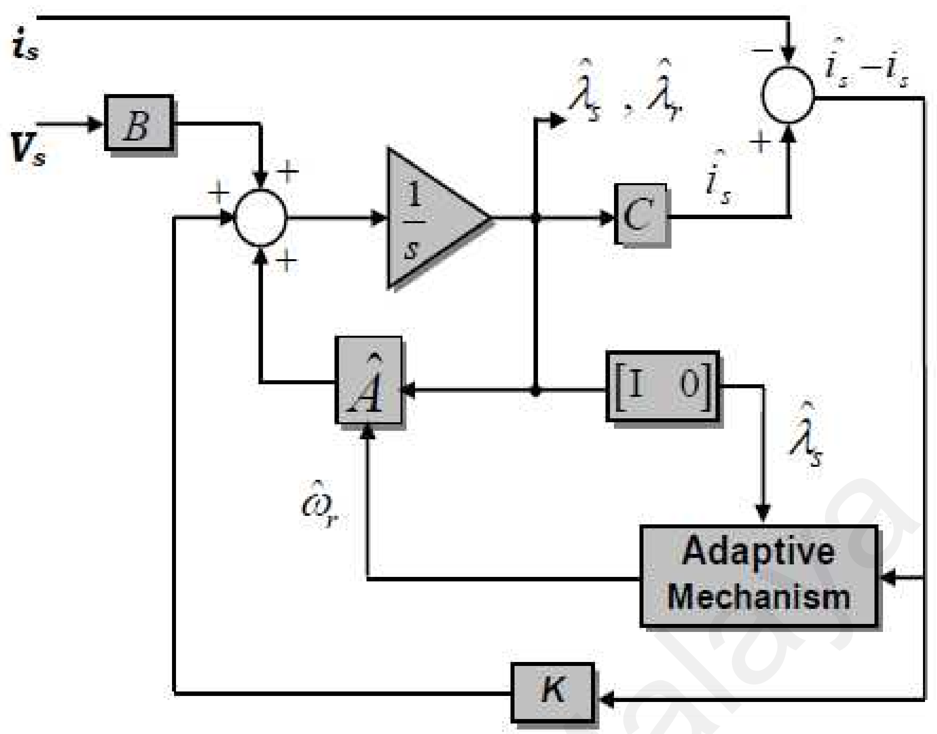

Figure 2. 13 speed estimation block diagram of Adaptive Observer(Tarek BENMILOUD 2011)

The characteristic of estimation speed is ruled by the task of the observer's which is the PI gains and feedback gains of the mechanism of adaption. Below are the equations of induction motor which described in a reference rotating frame with the angular velocity;

$$\frac{d}{dt}\begin{bmatrix}\hat{\lambda}_s \\ \hat{\lambda}_r\end{bmatrix} = \begin{bmatrix}A_{11} & A_{12} \\ A_{21} & A_{22}\end{bmatrix}\begin{bmatrix}\lambda_s \\ \lambda_r\end{bmatrix} + \begin{bmatrix}B_1 \\ 0\end{bmatrix}[V_s^s] = AX + Bv_s \quad (2.46)$$

$$i_s = C_X \quad (2.47)$$

Whereas,

$a_{11} = aI,$

$a_{12} = cI + dJ,$

$a_{21} = eI,$

$a_{22} = -\varepsilon a_{12},$

$b_1 = bI,$

Equations of the stator and rotor flux are expressed below estimated through the adaptive flux observer;

$$\frac{d\hat{X}}{dt} = \hat{A}\hat{X} + Bv_s + K(\acute{i}_s - i_s) \quad (2.48)$$

$$\acute{i}_s = C\hat{X}$$

Adaptive observer based on the theory of Lyapunov the estimated rotor speed is obtained as follows:

$$\hat{w}_r = K_p[\hat{\lambda}_{qs}.(\hat{i}_{ds} - i_{ds}) - \hat{\lambda}_{ds}(\hat{i}_{qs} - i_{qs})] + K_1 \int \hat{\lambda}_{qs}.(\hat{i}_{ds} - i_{ds}) - \hat{\lambda}_{ds}(\hat{i}_{qs} - i_{qs})]dt$$

(2.49)

Detailed use of method is described in chapter three with full adaptive scheme observer, and combination of other adaptive schemes for developing improved adaptive observer for controlling the performance of induction motor.

2.11 Final summarise comments

Merits of each methods are presented regarding the estimation of the speed in the form of comparison are shown in below table number 2.2. The criteria for comparison purpose of speed estimation method includes Low speed operation (LSO), Steady State Error (SSE), Parameter Sensitivity (PS), Complexity (C), Dynamic Behaviour (DB), Noise Sensitivity (NS) , and Computation Time (CT).

Table 2. 2 Comparison of different methods regarding estimation speed

Method/Criteria		CT	C	NS	PS	LSO	DB	SSE
FSI		3	5	4	1	1	2	2
RST		3	5	4	1	1	2	2
MMM	SM	2	2	2	1	2	1	1
	AI	4	3	2	1	2	1	1
	AFO	2	2	2	3	3	1	2
	KF	5	5	1	2	2	2	2
	MRAS	3	2	4	3	4	3	2
	DCM	2	2	4	4	4	3	2

Grading of merit based ranges is from 1 to 5 in the table 2.2, where (1) indicates “the best behaviour” whereas (5) indicates “the weakest one” as shown in the table number 2.3.

Note all the comparison is based on the comprehensive study and the investigation of the literature review.

Table 2. 3 Grading on merit based of speed estimation

Best	Very Good	Good	Satisfactory	Weak
1	2	3	4	5

According to the adopted set of criteria comparison of different speed estimation is shown in the form of chart based on above table of grading in figure number 2.14.

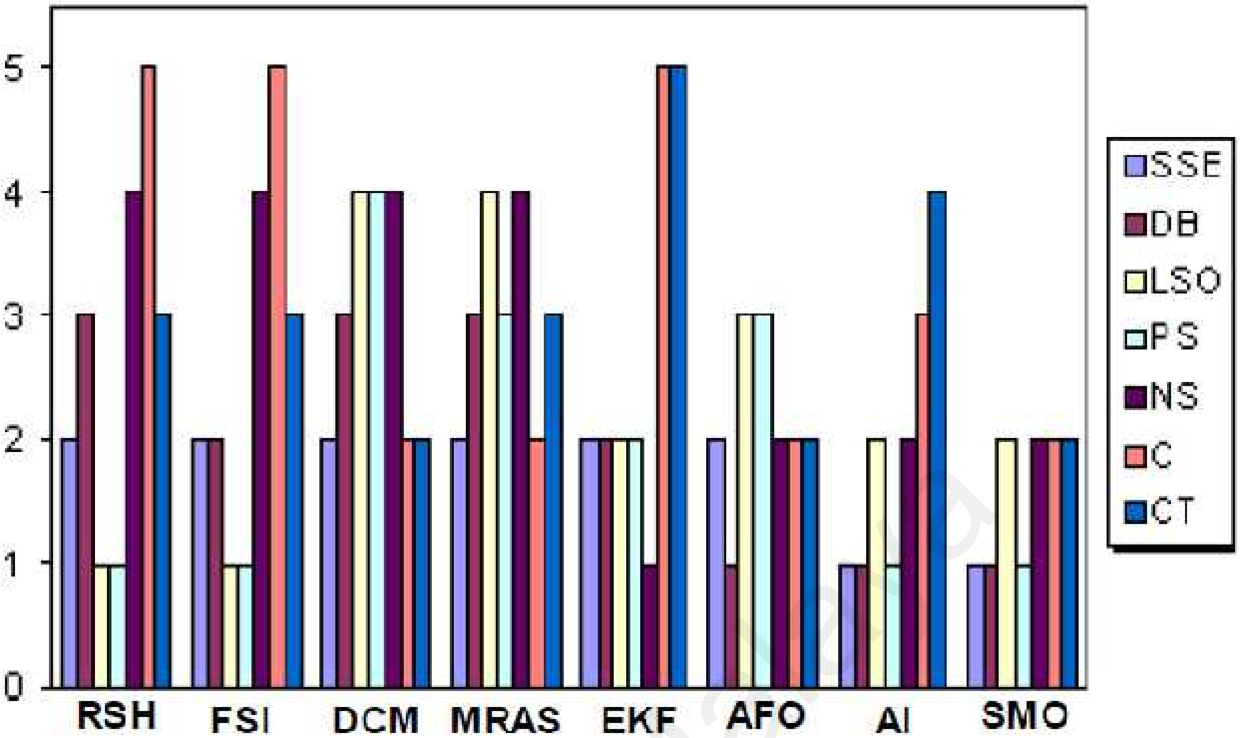

Figure 2. 14 Different methods of speed estimation comparison chart

It is detected from the experimental review of research literature discussed above which is mention in the chart, that the frequency signal injection method and rotor slot harmonic methods are preferably recommended to where there is need of low speed procedure. EKF is recommended where many source of noise is in the drive system, for that reason it is designed to perform an optimal filter. Even though, when it comes to techniques of Artificial Intelligence demonstrate good criteria but it doesn't only suffers from the large computation time but also complexity. From the chart comparison, it is also notable that SMO method offers good behaviour with respect to all methods discussed above in literature review but it also have problem of chattering illumination.

CHAPTER THREE: METHODOLOGY

3.1 Basic Principles of Vector Control

For the modelling description in this section basic principle of vector control is explained in figure 3.1.

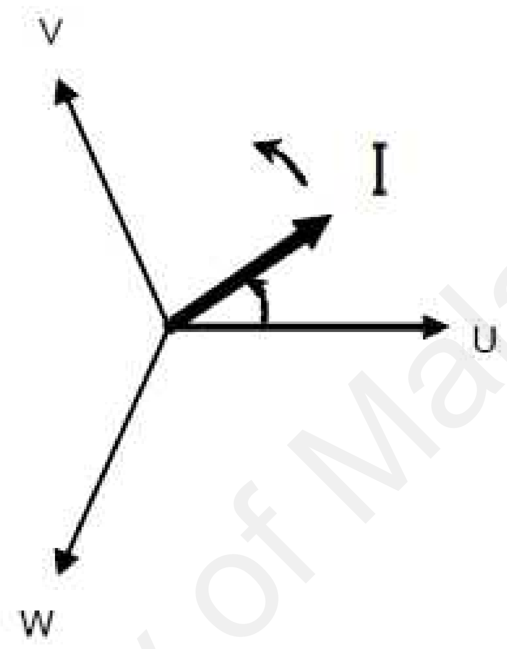

Figure 3. 1 Three-phase fixed coordinate system (Jun, Yuejiao et al. 2012)

If observed on the system of fixed coordinate with axis of UVW of which phases are angled off 120 degrees, armature current "I" of three phase induction motor can be detected as the rotating vector through power supply angular velocity ω. The current vector can be kept motionless if observed in synchronously rotating coordinate system with the power supply angular velocity. It can be considered as direct-current value. We can simplify the electrical equations by using coordinate transformation technique and the transformation angle can be arbitrary selected. In the case of induction motor, it is easy to treat the equations in synchronously rotating coordinate system (d-q frame) with rotor flux linkage vector λr. The equations on the three phase fixed coordinate system (UVW) are converted into two phase fixed coordinate axis (α-β) of which phase are deviated 90 degrees .And then, they are converted into d-q frame by the rotation angle θ in figure 3.2.

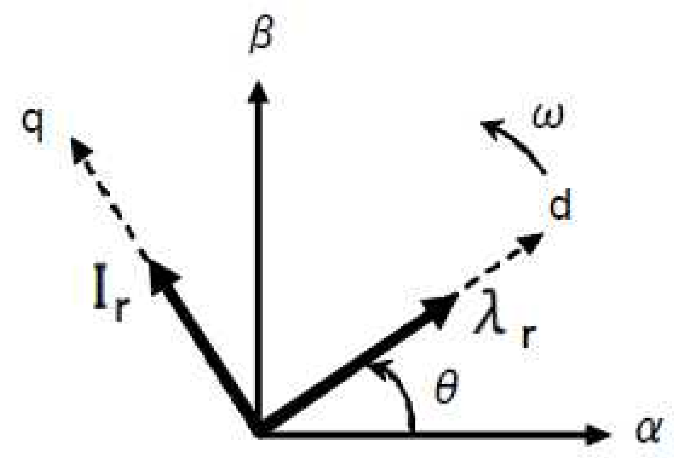

Figure 3. 2 Two-phase fixed coordinate system and rotating coordinate system (Jun, Yuejiao et al. 2012)

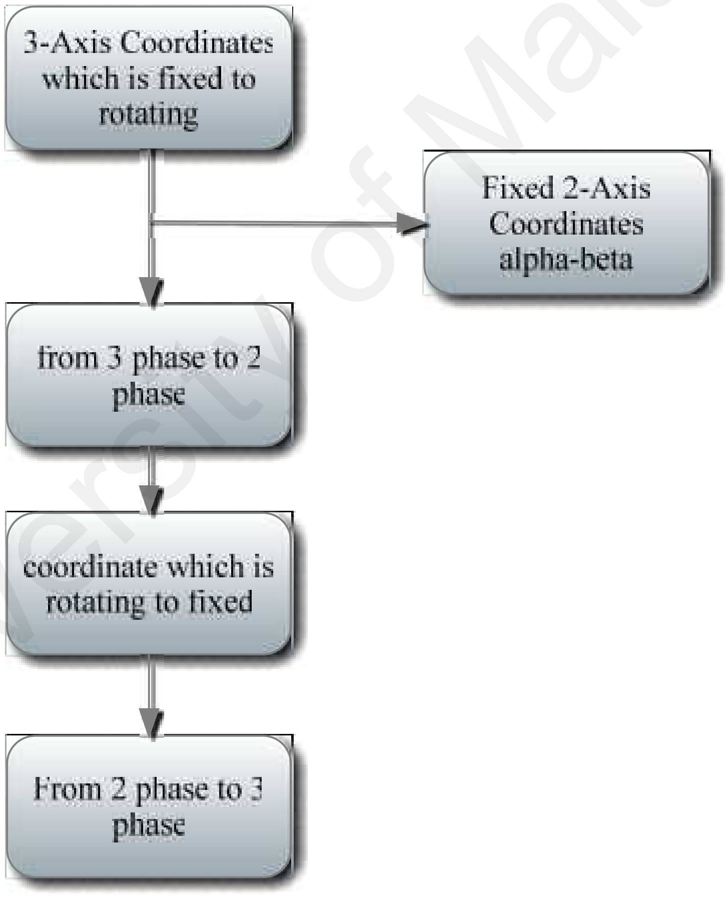

Figure 3.2.1 flow chart of basic vector principle

And so the electrical torque equation for induction motor can be expressed by outer product of flux vector and current vector below.

$$T_e = P_m\ (\lambda_r \times I_r) \tag{3.1}$$

Where,

P_m: Number of poles pares.

λ_r: Rotor flux vector $[\lambda_{dr} \quad \lambda_{qr}]^T$

I_r: Rotor current vector $[i_{dr} \quad i_{qr}]^T$

Therefore equation 3.1 also can be modified by treating the d axis as rotor flux vector.

$$T_e = -P_m \lambda_{dr} i_{qr} = P_m \lambda_{dr} (\frac{M}{L_r} i_{qs}) \qquad (3.2)$$

Where,

M: Coefficient of mutual induction.

L_r: Self induction of rotor.

With the constant rotor flux of equation 3.2, the torque of the motor can also be controlled by q-axis current of stator. Therefore, the flux of rotor can be expressed as;

$$\lambda_{dr} = \frac{M}{1+\tau_r s} i_{ds} \qquad (3.3)$$

Where,

Time constant: $\tau_r = \frac{L_r}{R_r}$

The above equation shows that by the d - axis current of stator, the flux of the rotor can be controlled to be constant. Using the constant target value of current in the similar way as traditional DC brush motor allows controlling the motor torque in coordinate conversion by phase of flux vector.

3.2 System Modelling

An accurate flux vector is very important to determine in induction motor. Detection of flux vector includes some methods such as; indirect detection, where slip angular frequency is added to the detected angular velocity, and the DTC (direct detection), where magnetic sensor by hall element is used. Here, we will consider the model that calculates rotating angle and flux vector by using flux observer. This is one of the sensorless methods which doesn't require magnetic and position sensors.

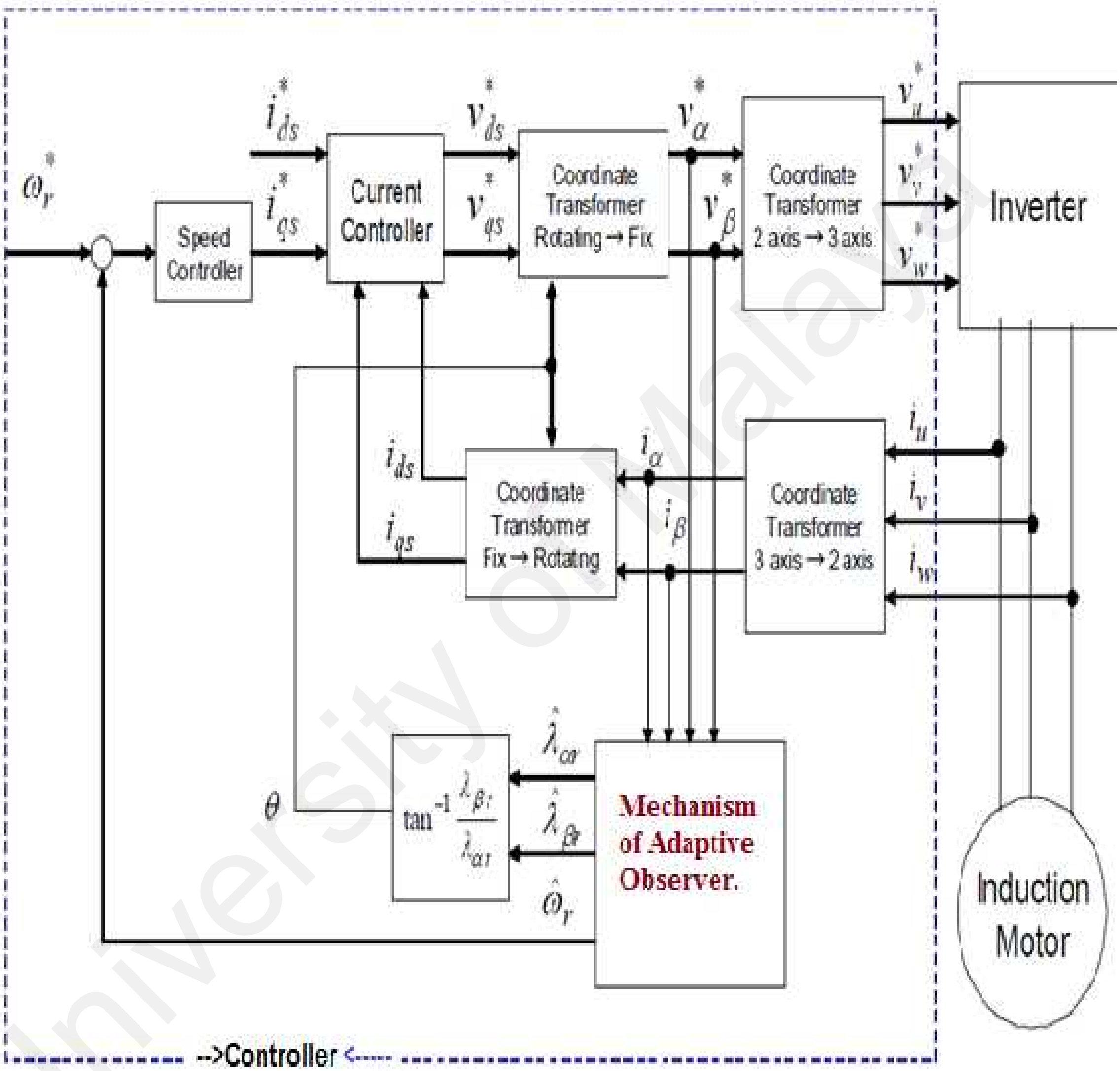

Figure 3. 3 Configuration Block diagram of position sensorless vector control

3.2.1. Description of Symbols

Self-inductance [H]	L
Resistor [Ω]	R
Laplace operator	S
number of pole pairs	Pm
current value [A]	I
Flux linkage	Λ
Electric torque [Nm]	Te
Rotor flux angle velocity [rad/sec]	Ω
voltage value [V]	V
Electric angular velocity [rad/sec]	Ωr
Rotor flux rotation angle [rad]	Θ
mutual inductance [H]	M

3.2.2 Subscript symbol description

Estimation value	^
Variables in three-phase fixed coordinate system	*U*, *V*, *W*
Variable in the rotor	*R*
Variables in orthogonal two-axis fixed coordinate system	α,β
Target value	*
Variables in orthogonal two-axis rotating coordinate system	*d*, *q*
Variable in the stator	*S*

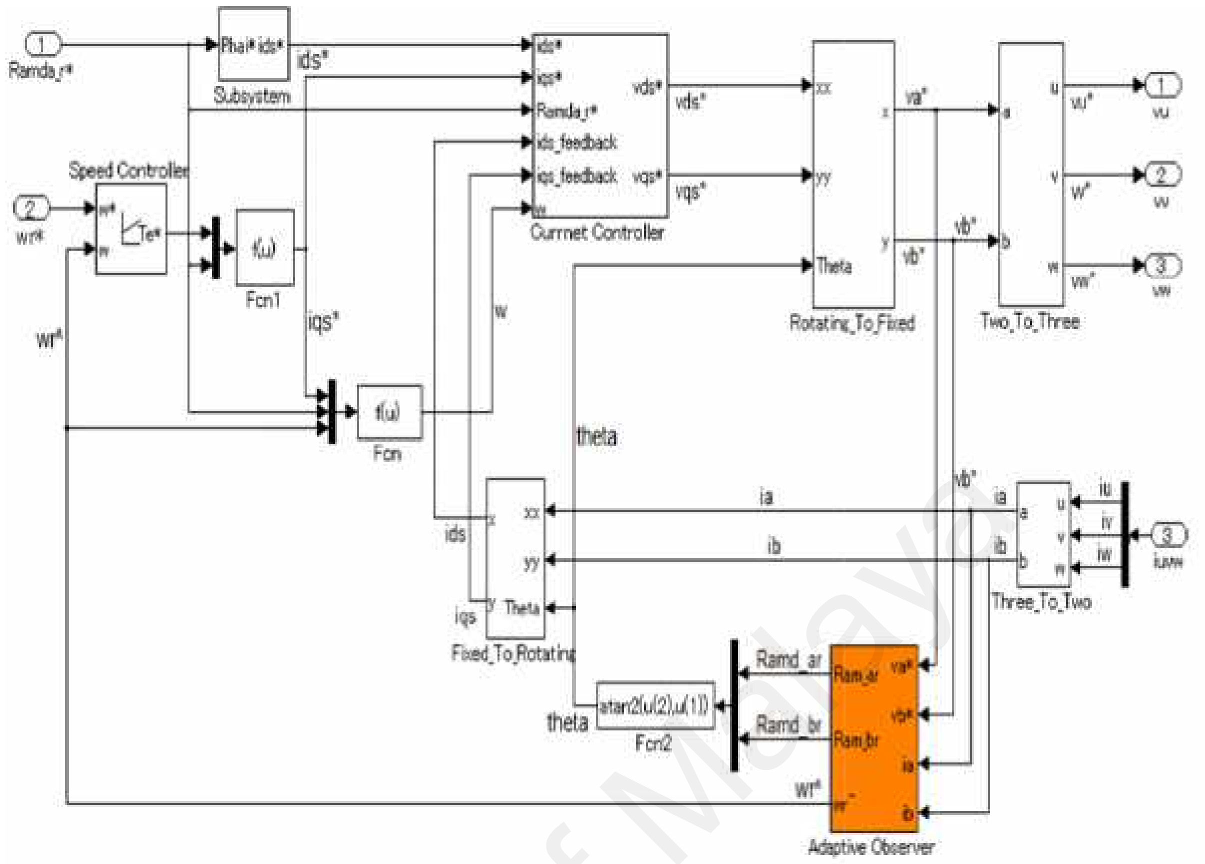

Figure 3. 4 Modelling of controller part

In the above figure, symbol * denotes "target value", and symbol ^ denotes estimate value. Configuration diagram of controller part in figure 3.3 is expressed as in figure 3.4 making each operator element subsystem.

3.2.3 Description of signal label

Subscript indicating target value	*
Voltage target values on α, β axes	va, vb
Current values on α and βaxes	ia, ib
Theta	power supply angle - Rotor flux rotation angle
Current value on UVW axis	iu, iv, iw
Voltage target values on UVW axis	vu, vv, vw
Voltage target value on d and q axes	vds, vqs
Current target values on d and q axes	ids, iqs
Rotor flux rotating angler velocity (power supply angler velocity)	W
Electric angler velocity estimation value	Wr
Rotor flux of α and β axes	Ramd_ar, Ramd_br

Below equation is the expression of coordinate transformation.

Transformation	Equation
From the coordinate which is fixed to rotating.	$\underline{i}^{e} = C\underline{i}$
From the coordinate which is rotating to fixed.	$\underline{v} = C^{T}\underline{v}^{e}$
Phases: from 3Φ to 2Φ	$\underline{i}2 = D\underline{i}3$
Phases: from 2Φ to 3Φ	$\underline{v}3 = D^{T}\underline{v}2$

Where,

Rotary matrix:

$$C = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

Three-phase to two-phase transformation matrix:

$$D = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos 0 & \cos\left(\frac{2\pi}{3}\right) & \cos\left(\frac{4\pi}{3}\right) \\ \sin 0 & \sin\left(\frac{2\pi}{3}\right) & \sin\left(\frac{4\pi}{3}\right) \end{bmatrix}$$

Where,

_ Denotes vector

e Denotes direct-current value

T	denotes transpose
Subscript 2	denotes two-phase
Subscript 3	denotes three-phase

Internal model of coordinate transform can easily be expressed by mathematical formula definition of function block in simulink.

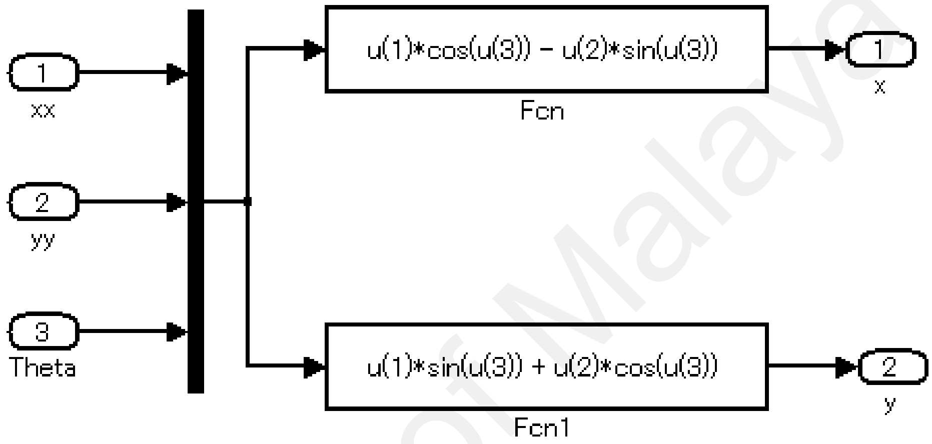

Figure 3. 5 Internal model of coordinate transformer subsystem "Rotating_to_Fixed"(Sun and Zhao 2010)

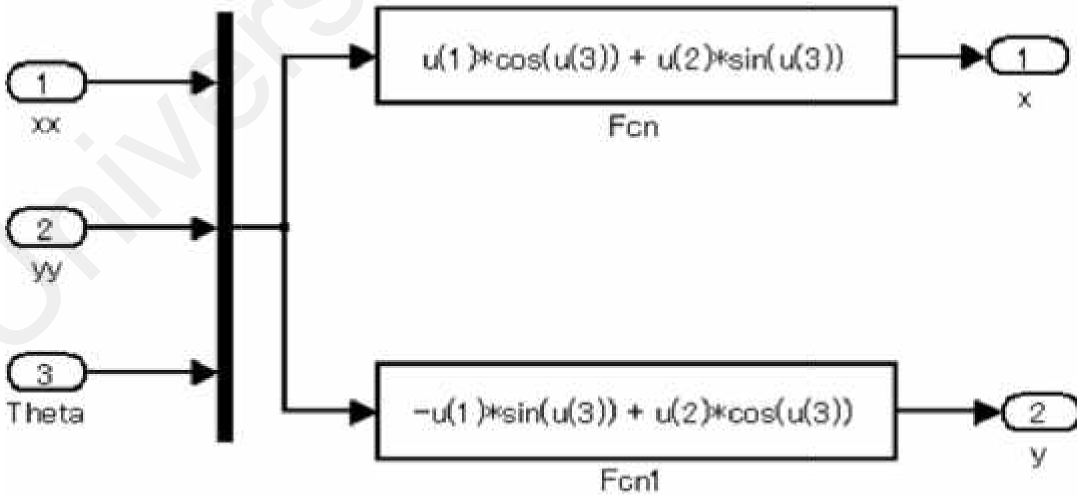

Figure 3. 6 Internal model of coordinate transformer subsystem "Fixed_to_Rotating"(Sun and Zhao 2010)

With feed-forward compensator the PI control loop is the current controller which synchronously deliberates in the coordinate system. Compensation of current model is by the method of feed-forward. From the formula of electric motor's analogous circuit we can receive the non stable term of power supply frequency ω , in the two coordinate system axis of two orthogonal.

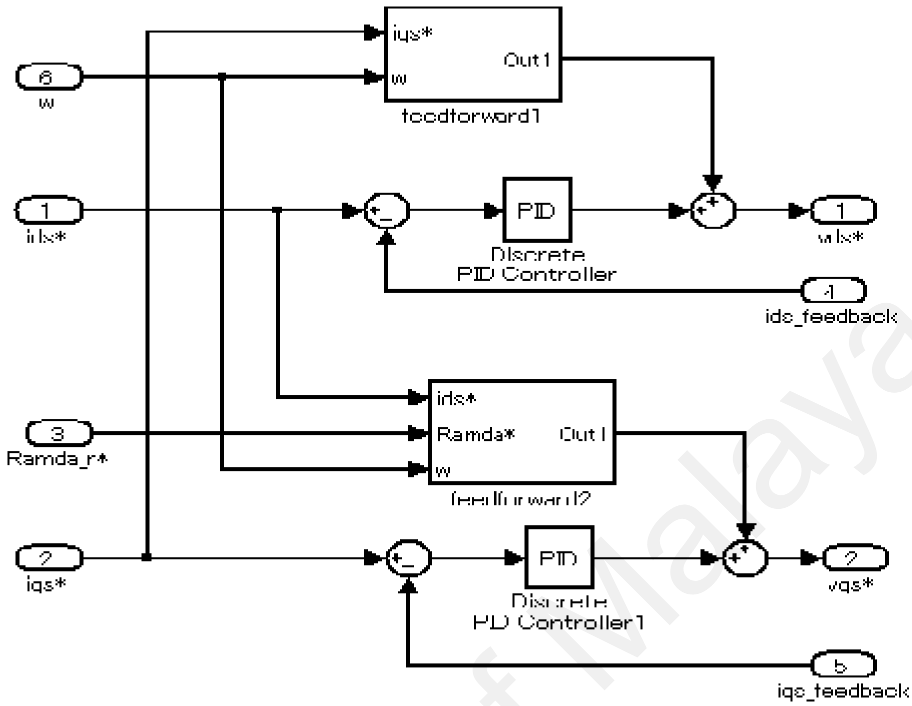

Figure 3. 7 Internal model of current controller subsystem(Tajjudin, Rahiman et al. 2012)

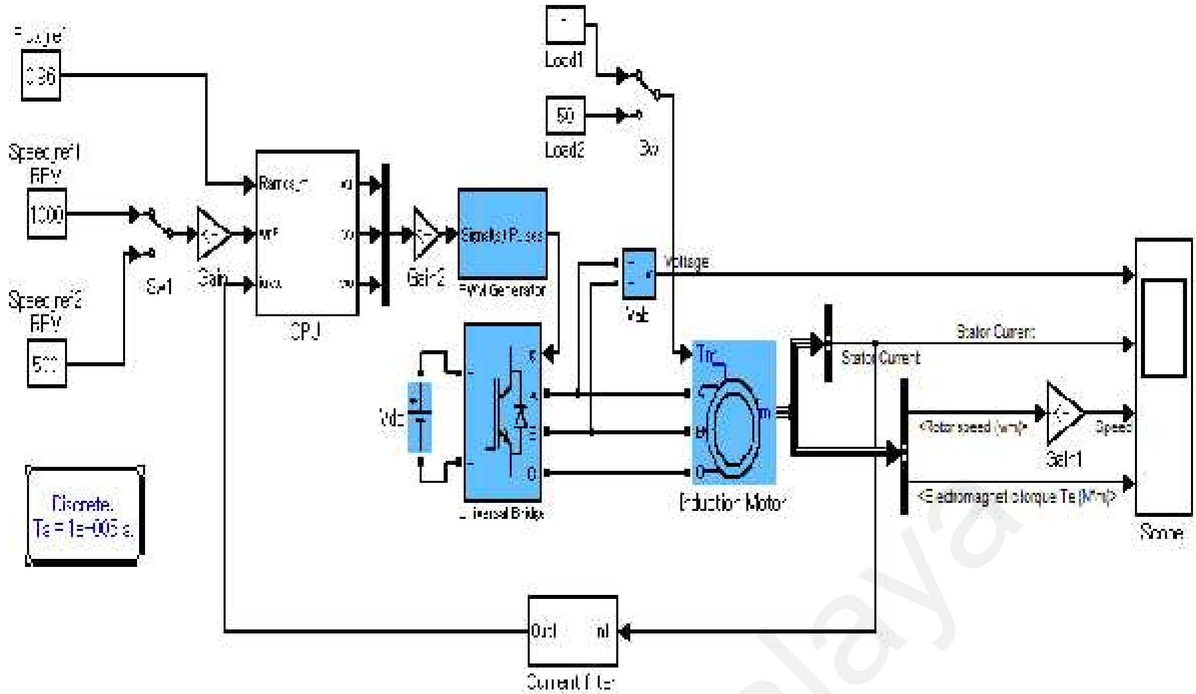

Figure 3. 8 Modeling Example using SimPowerSystem tool

Using the Simpowersystems Motor, Inverter of carrier wave and PWM Generator comparison can be modelled by using simulink. If time saving of modelling is preferred, SimPowerSystem, extended option of simulink, is available. Induction Motor Drive, Synchronous Motor, DC Motor and others are prepared in the block library. Figure above is the model of the overall system which has subsystems in which have internal model of the controller. The reference voltage from the Subsystem in the diagram named block “CPU” is compared with PWM Generator block with carrier wave that is equipped in SimPowerSystem and it gives the six PWM pulses. Universal Bridge block is the mechanism and switches each gate of IGBT (i.e. three arm bridge circuits) and drive connected induction motor block. Switching of MOSFET, GTO, Thyristor, ideal switch from menu are also allowed by Universal Bridge.

The prominent attributes of the SimPowerSystems are listed as below:

- Using block of symbolized element for modelling in circuit topology.
- Stiff ordinary differential equation solver in simulink is provided for continuous and discrete simulation and faster simulation in discrete mode is achieved.

- Block inside almost can be referenced.
- Automatic code generated tools are supported, RTW and real time-simulation is accomplishable.
- Many models as sample demo are available which are related to motor control included vector control is provided which makes easy further development work for sensorless control of motor.

3.3 Principles and Analysis Model Sensorless velocity by Adaptive Secondary Flux Observer

If the same input voltage as actual voltage is applied to the mathematical simulator model that is implemented on the processor, then Rotor flux should be estimated. Nevertheless, when building the velocity sensorless system, changes of none stable velocity term can not be formed by actual velocity sensor output and the calculated value of flux will deviate from the actual value. Thus, by using the technique adaptive observer that modifies the mathematical model of incorrect constant term with function of the output deviation is applied. In this case, the electric angular velocity terms are considered as the incorrect terms.

State-space formula of induction motor in orthogonal type two axis fixed coordinate system can be expressed as below:

$$dx/dt = Ax + Bvs \,.\, i_s = Cx \tag{3.4}$$

Where,

$x = [i_{\alpha s} \quad i_{\beta s} \; \lambda_{\alpha r} \quad \lambda_{\beta r}]^T$

$v_s = [v_{\alpha s} \quad v_{\beta s}\;]^T$

$i_s = [i_{\alpha s} \quad i_{\beta s}\;]^T$

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix},$$

$$J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

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

$$B = \left[\left(\frac{1}{\sigma L_s}\right)I \quad 0_{2X2}\right]^T$$

$$C = [I \quad 0_{2X2}]$$

$$\sigma = 1 - \frac{M2}{(L_s L_r)}$$

$$\varepsilon = \sigma L_s L_r / M$$

Note: reference: equation of basic vector control are applies.

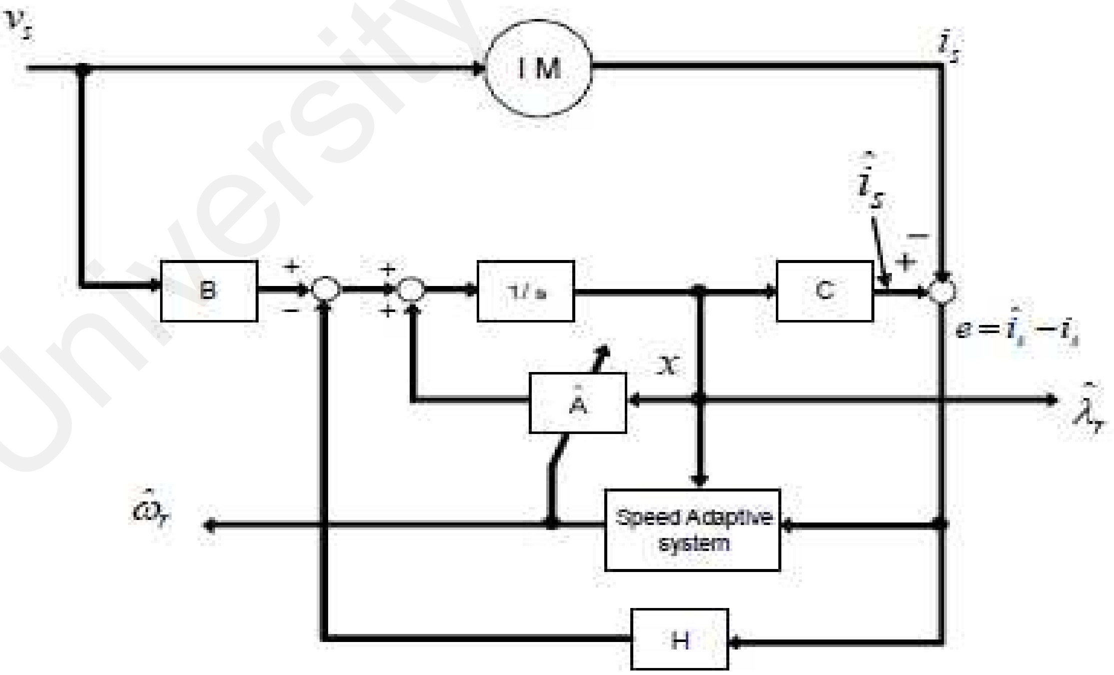

Figure 3. 9 Adaptive Flux Observer Configuration Diagram (Savoia, Verrelli et al. 2012)

For the above figure of observer, State-space expression can be expressed in the equation below:

$$\frac{d\hat{x}}{dt} = \hat{A}\hat{x} + Bv_s - H \text{ , } \hat{i}_s = C\hat{x} \quad (3.5)$$

Where, H denotes the gain of observer

^ is the estimation value

e is the current error **e=** $\hat{i}_s - i_s$

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

Then, parameter adjusting the law of calculation the electric angular velocity (ωr), are supplied by the below equation using size of outer product of current error vector (e) and the value of estimation flux:

$$\hat{\omega}_r = K_p(J\,\hat{\lambda}_r)^T{}_e + K_i \int (J\,\hat{\lambda}r)^T\, edt \quad (3.6)$$

Gain of the observer H is planned in such way to ensure the adaptability of control system consisting of adaptive observer and the induction motor that is $\mathbf{lim}_{t\to\infty}\, \boldsymbol{e} = \mathbf{0}$.

The term value other than the velocity estimation value, we assume as true value, equation concerning current error can be showed by subtracting the formulae a3.4 from a3.5, and define the matrix B_ω by separating the term of ω from matrix system.

Therefore,

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

$$= G_{(s)}\left(-\Delta\omega_r J\hat{\lambda}_r\right) \quad (3.7)$$

Where,

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

I_4: 4 X $4_{\text{unit matrix}}$.

$B_\omega = \left| {}^{I}/_{\varepsilon} \quad -I \right|^T$

And so, we consider feedback system comprising LTI (linear time invariant) block G(s) and block of nonlinear time variation similar to the following figure. Applying Popov's hyper stability, the below are necessary to be satisfied to ensure the stability $\lim_{t\to\infty} e = 0$.

1. The Transfer function G(s) of feed forward LTI (Linear – Time – Invariant) is strictly positive real (SPR).

2. Input v1 and the output w1 of non-linear time variation block satisfy the Popov's equation for all the time t1 greater than t0 (t1>t0).

$$\int_{t0}^{t1} v_1^T\, w_1\, dt \geq -\gamma_0^2 \tag{3.8}$$

Where,

γ_0: is constant independent of time.

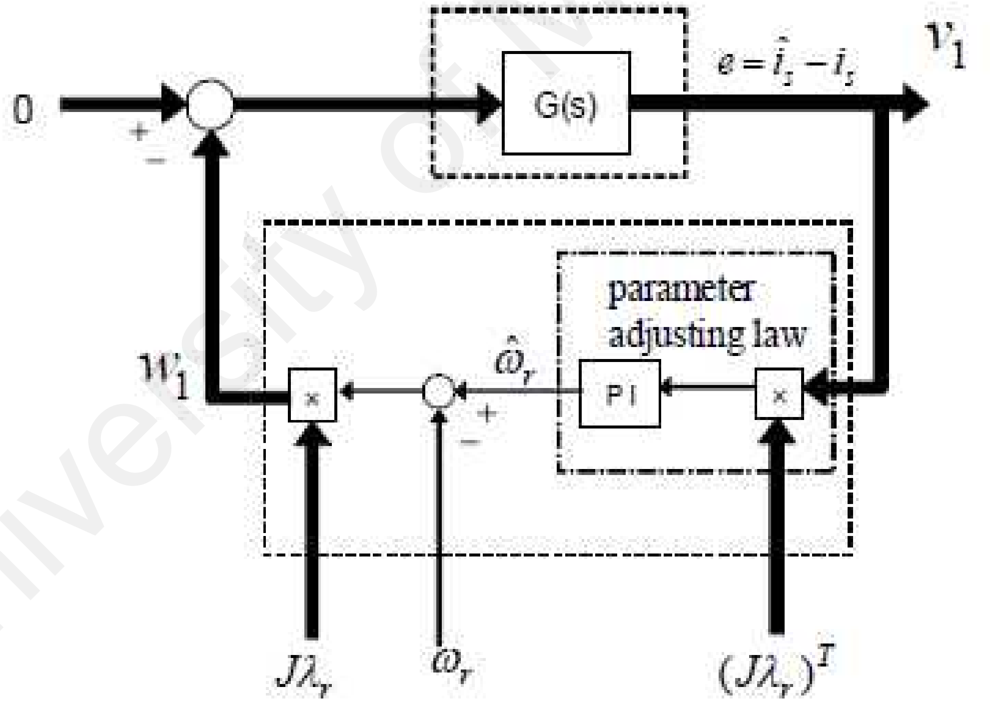

Figure 3. 10 Current error block feedback system (Tarek BENMILOUD 2011)

The above figure is proved to be satisfied by using equation 3.6. Riccati equation is applied for obtaining the optimal feedback gain to make G(s) SPR as a condition which we mention above.

$$H = PC^TR^{-1} \tag{3.9}$$

Riccati equation:

$$PA^{T} + AP - PC^{T}R^{-1}CP + B_{\omega}QB_{\omega}^{T} = 0 \qquad (3.10)$$

Where,

P	solution of Riccati equation
Q,R	weight matrices

The weight matrices Q=1 and R=yI, respectively, however, y is a small positive number.

3.4 Modeling of Adaptive observer

Program (M-file) of matlab language is used to set the all parameters of motor and each matrix of state-space expression, and the formula 3.10 is solved with the help of using the Control System Tool box , and we obtain the optimal feedback gain as well.

Where,

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

The function of Iqe is provided in Control System ToolBox for designing the Kalman filter estimator and it returns the feedback gain, H, solution of Riccati equation, P, and pole of estimator E= eig (A-H*C). M-file can be loaded in to the memory (workshop) once executed in Matlab and define as each block parameter of Simulink model in it. Adaptive observer subsystem in figure b is defined in figure (3.11) below.

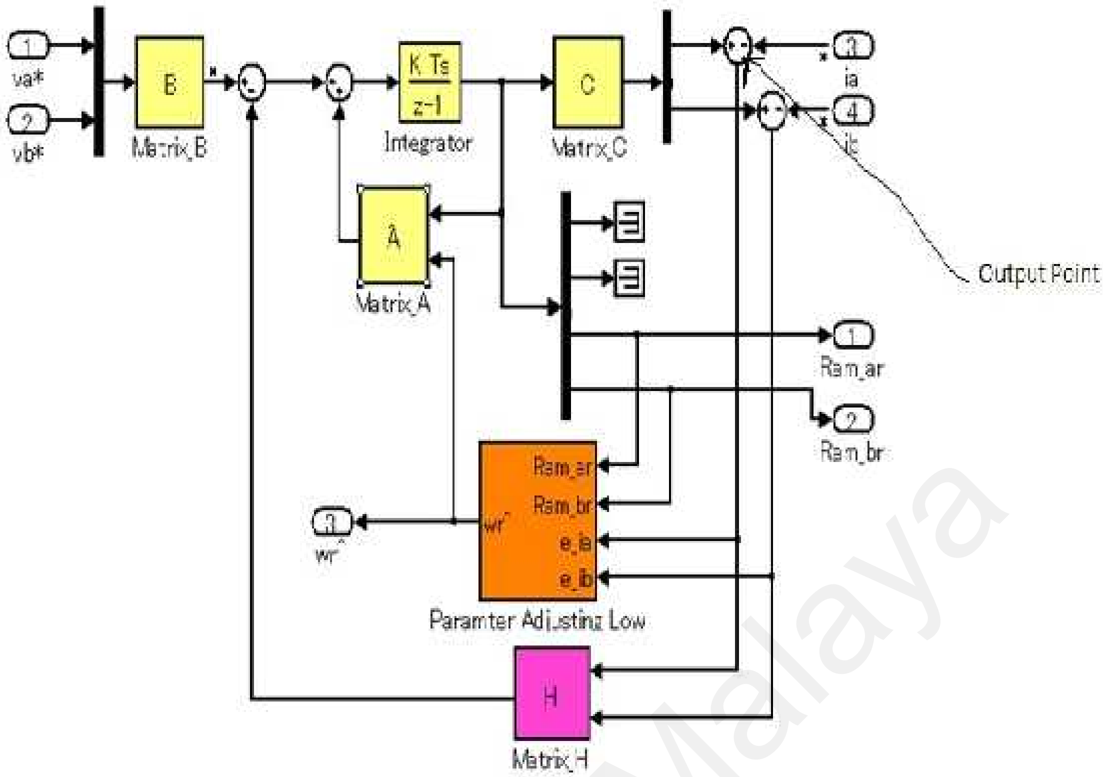

Figure 3. 11 Model of Adaptive Observer

Separate and add none stable term which is ωr that is included in system Matrix A, is the key to the modelling. Model can be easily done by using the Integrator block in case motor system is expressed in state-space.

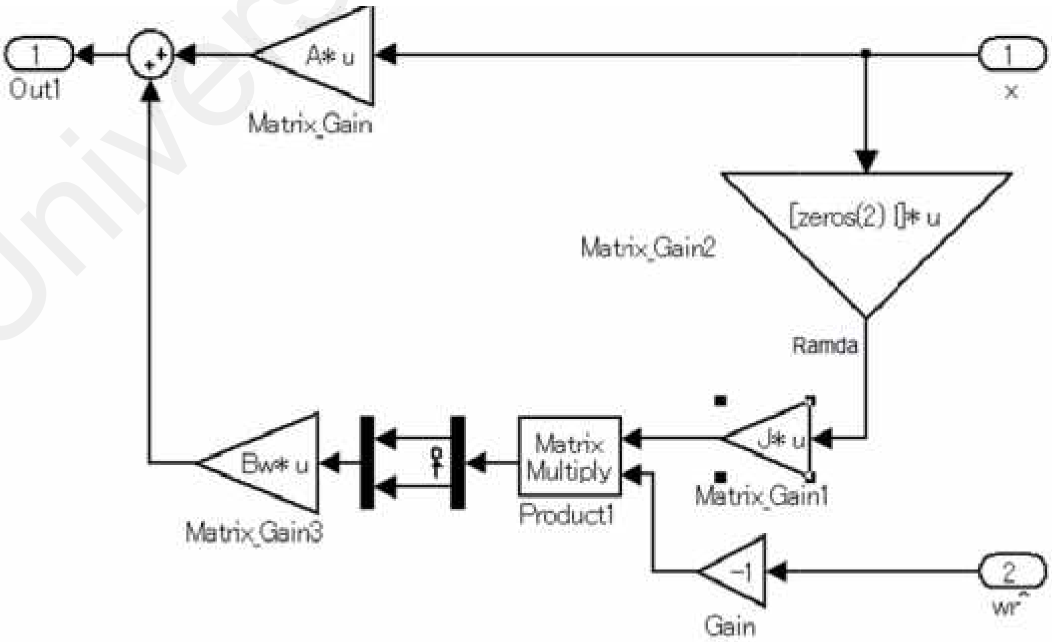

Figure 3. 12 Block diagram inside the Matrix A

Adaptive observer operates stably if the absolute value of the phase difference between input and out is within 90 degrees. Subsequently it is verified the stableness of the transfer function G(s) of linear stationary term. Linearization point is indicated as mark of arrow below in the figure 3.11 is provided by simulink control design is located in the relevant input and output points.

Hence, stability of transfer functions G(s) is verified. Adaptive observer operates stably if the absolute value of phase difference between input and output is within 90 degrees.

Figure 3.13 is a bode diagram if linear time-invariant block G(s) drawn the LTI Viewer of the Control System Toolbox. Referring to the phase diagram, you can see that weight factor of formula (3.8) γ=1, γ=0.006, are within ±90° across the whole frequency range, and they are stable.

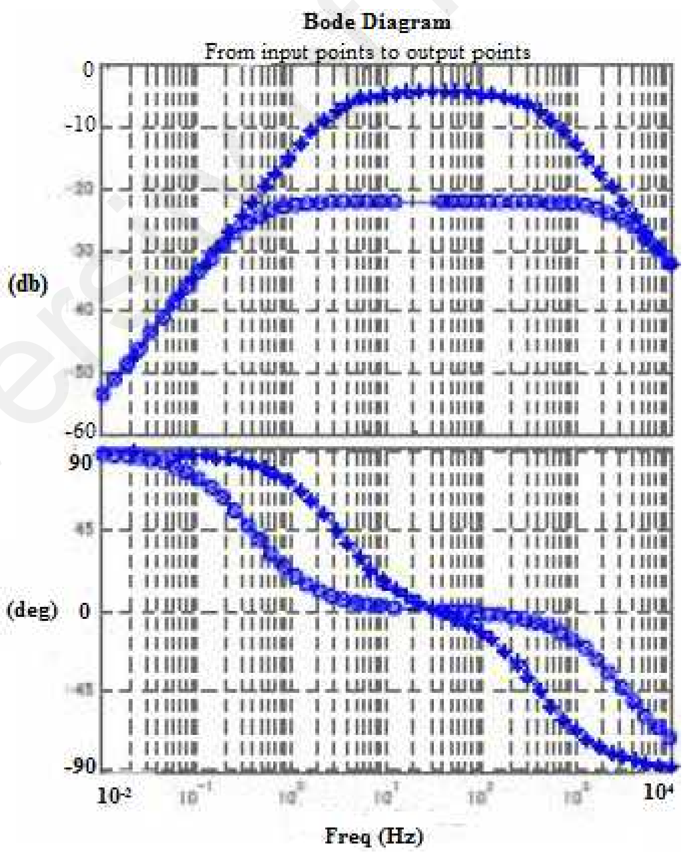

Figure 3.13 Bode diagram of linear time-invariant block

Upper: gain characteristics Lower: phase characteristics, 0 mark line: γ=0.006, * mark line: γ=1

CHAPTER FOUR: RESULTS AND DISCUSSION

Simulations, using MATLAB Software Package, have been carried out to show the effectiveness of the proposed observer. Model which we discussed in methodology chapter includes the PI gain that requires tunning for the velocity control, current controller and velocity estimator.

Each control parameter is adjusted for the better functioning by trial-and-error from the response result of simulation. The IM parameters and value for M-file which is used in simulation are given below.

Table 4. 1 IM parameters and value for M-file

Paramter	Notation	Value
Mutual Inductance (H)	M	69.31e-3
Stator resistance (Ohms)	Rs	0.435
Sampling Time (sec)	Ts	2e-6
Stator leakage inductance (H)	Lls	2.0e-3
Rotor leakage inductance (H)	Llr	2.0e-3
Rotor self inductance (H)	Lr	M+Llr
number of pole pairs	P	2
Inverter voltage (V)	Ed	1000
Stator self inductance (H)	Ls	M+Lls
Rotor resistance (Ω)	Rr	0.816
Time Constant of flux	tr	Lr/Rr
Maximum terminal voltage (V)	Emax	Ed/√3

For getting the value of sigmaσ, use the formula discussed in previous chapter of methodology.

That is, $$\text{sigma} = 1 - M2/(L_s L_r).$$

Value for the State Space Matrix:

$$I = [1 \quad 0 : 0 \quad 1]$$

$$J = [0 \quad -1 : 1 \quad 0]$$

Compute the variable for state space matrix value with the help of below formulas in M-file.

$$A11 = -\frac{\left(R_s + M^2 * \frac{R_r}{{L_r}^2}\right)}{(\text{sigma} * L_s) * I}$$

$$A12 = \frac{M}{(\text{sigma} * t_r * L_s * L_r) * I}$$

$$A21 = \frac{M}{t_r * I}$$

$$A22 = -\frac{1}{t_r * I}$$

Assigning the variables for memory to workspace variables of space vector:

$$A = [A11 \quad A12 : A21 \quad A22]$$

$$B = \left[\frac{1}{(\text{sigma} * L_s)} * I; \text{zeros}\ (2)\right]$$

$$C = [I \quad \text{zeros}(2)]$$

$$Bw = [\frac{M}{(\text{sigma} * L_s * L_r) * I}; -I]$$

Value of weight matrix:

$$ep = 0.006;$$

$$R = ep * I;$$

$$Q = I;$$

For obtaining the optima feed back gain, we can use the formula in M-file, discussed previously in methodology.

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

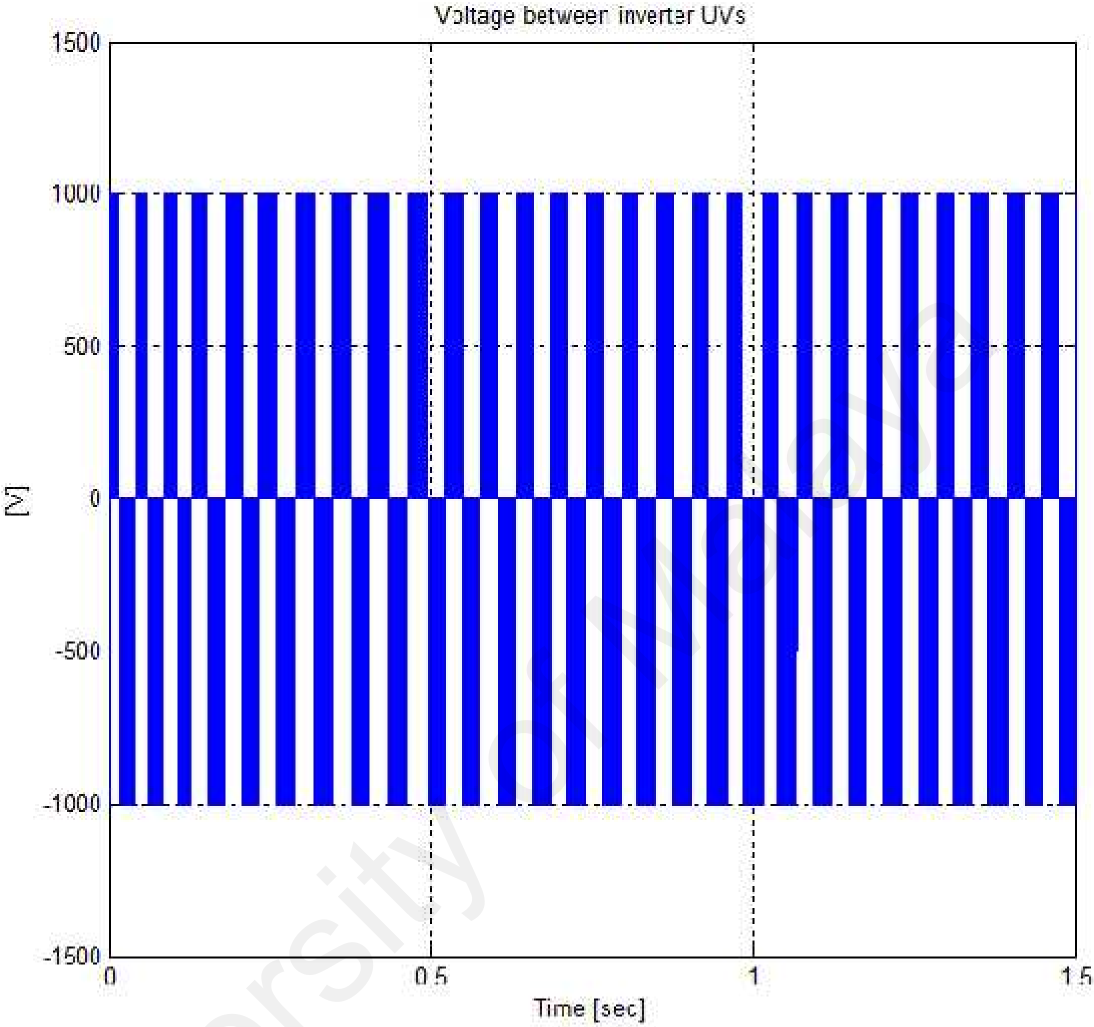

Figure 4. 1 Voltage between inverter UVs[V]

Figure shows the simulation result of voltage which is reference voltage from the Subsystem in the fig.3.8 named block "CPU" which is compared with PWM Generator block with carrier wave that is rendered in SimPowerSystem and it gives the six PWM pulses.

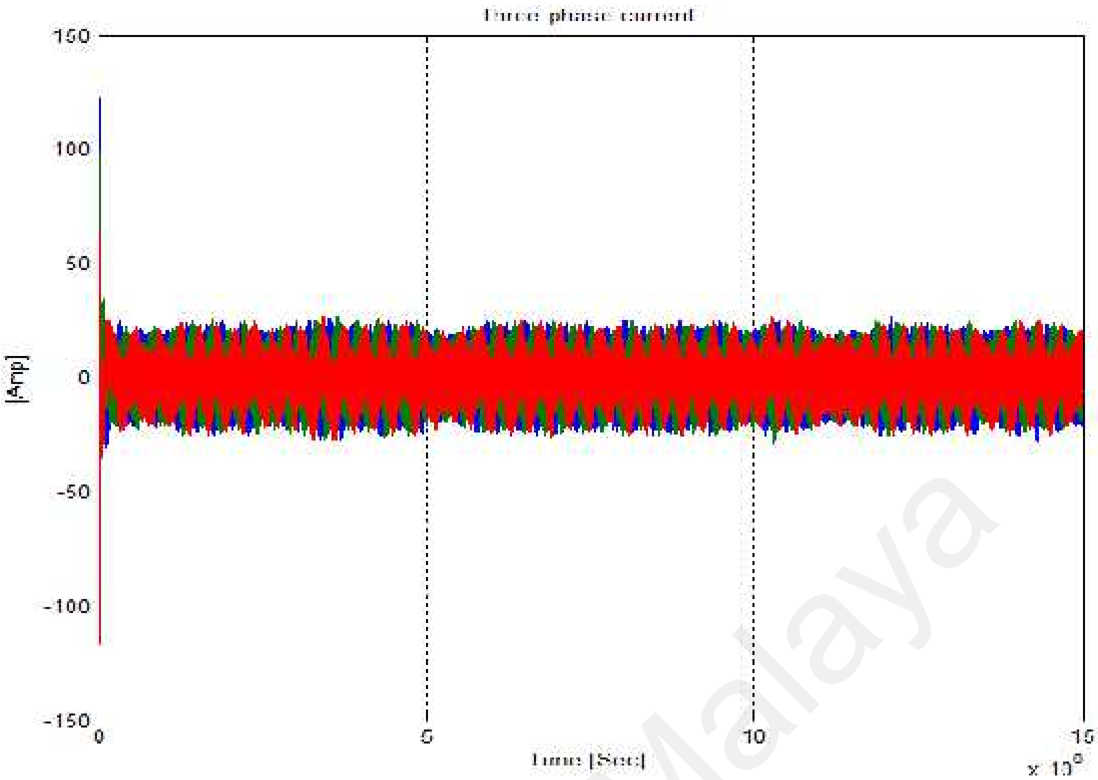

Figure 4. 2 Three-phase stator current of motor [A]

Three phase stator current of the motor can be seen, that the current is regulated correctly to the value of nominal which means that the fed current is controlled in the amplitude. In that type of control of phase current will prevent the system from being heat up. Fig 4.2.1 is the expended view of figure 4.2 to verify the controlled amplitude of three phase stator currents.

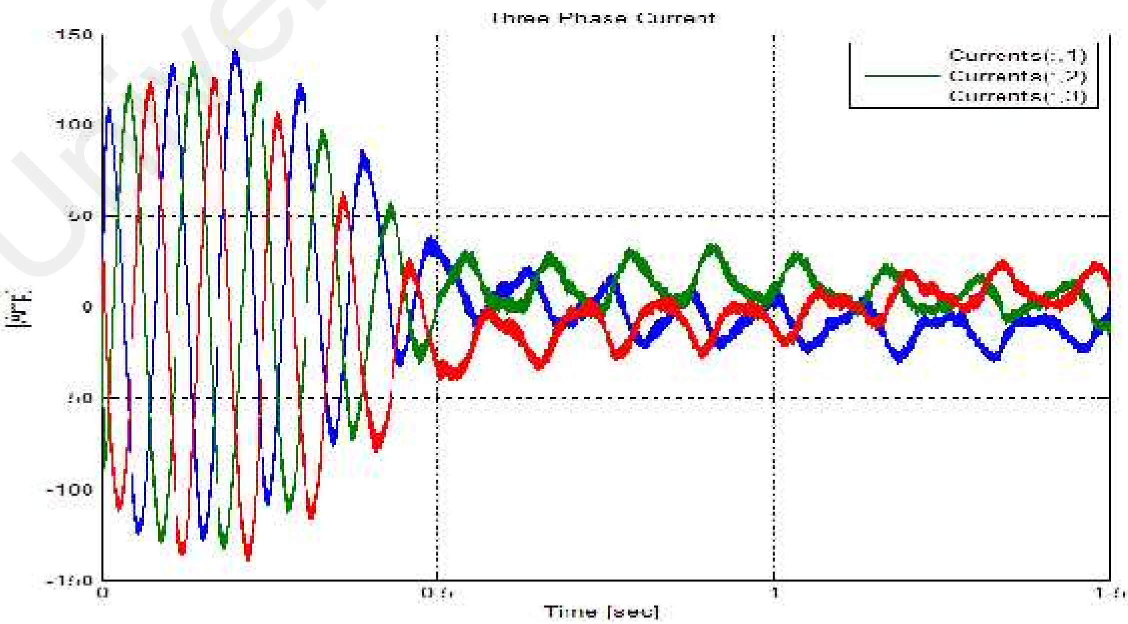

Figure 4.2. 1 Three-phase stator current of motor [A]

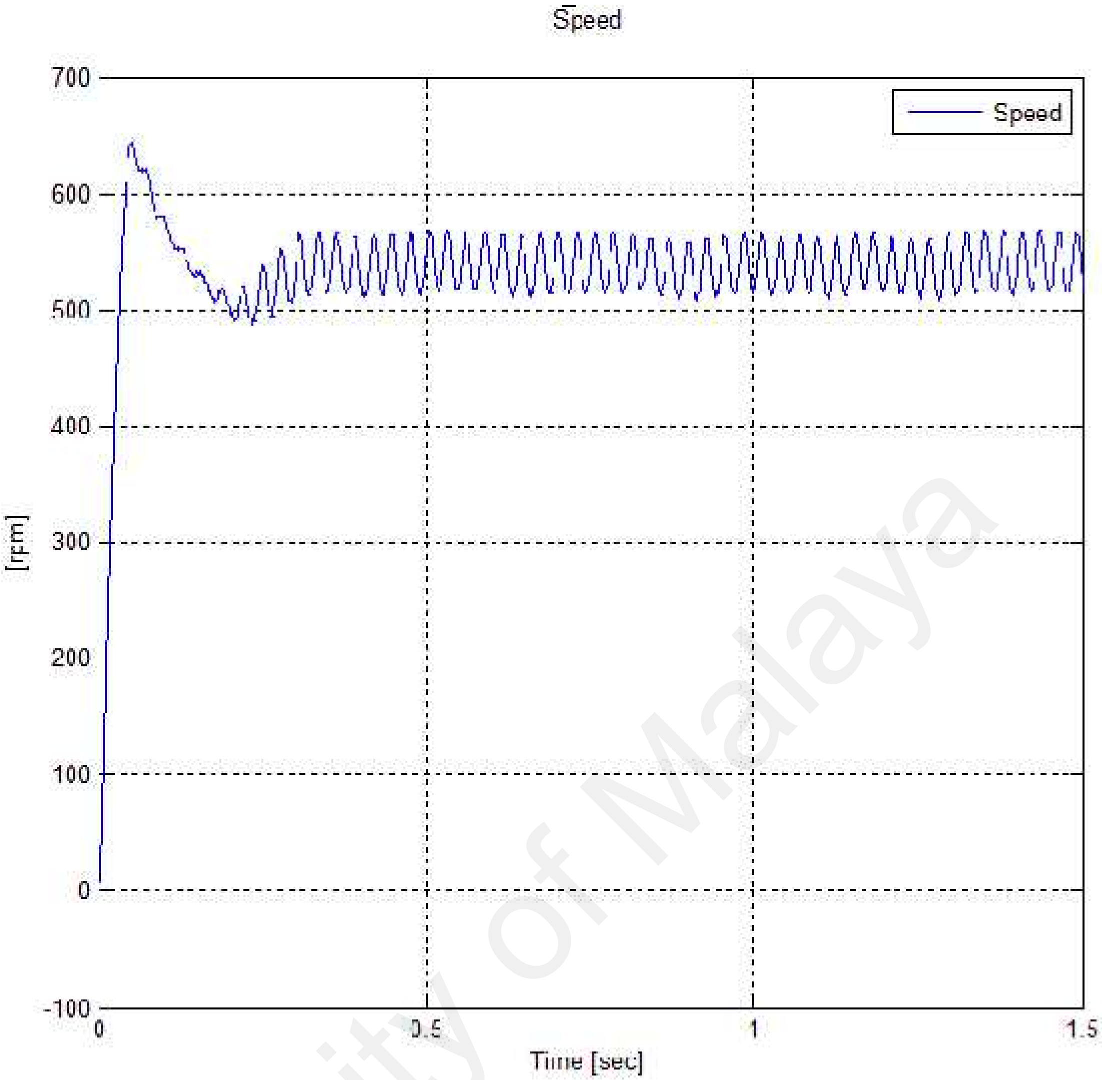

Figure 4. 3 Motor rotating velocity [rpm]

Simulation result of rotating speed is at 1st reference speed at 500 [rpm], Torque load Tm constant 1.

Figure illustrates simulation result, transient time (0 to 0.2) ,we can check in the group from 0 to 1.5 in which we can check at very short time, our required referenced speed is suppose to be constant from 0.2 to onwards but system is unstable here reason of that is adaptive settings are not matched.

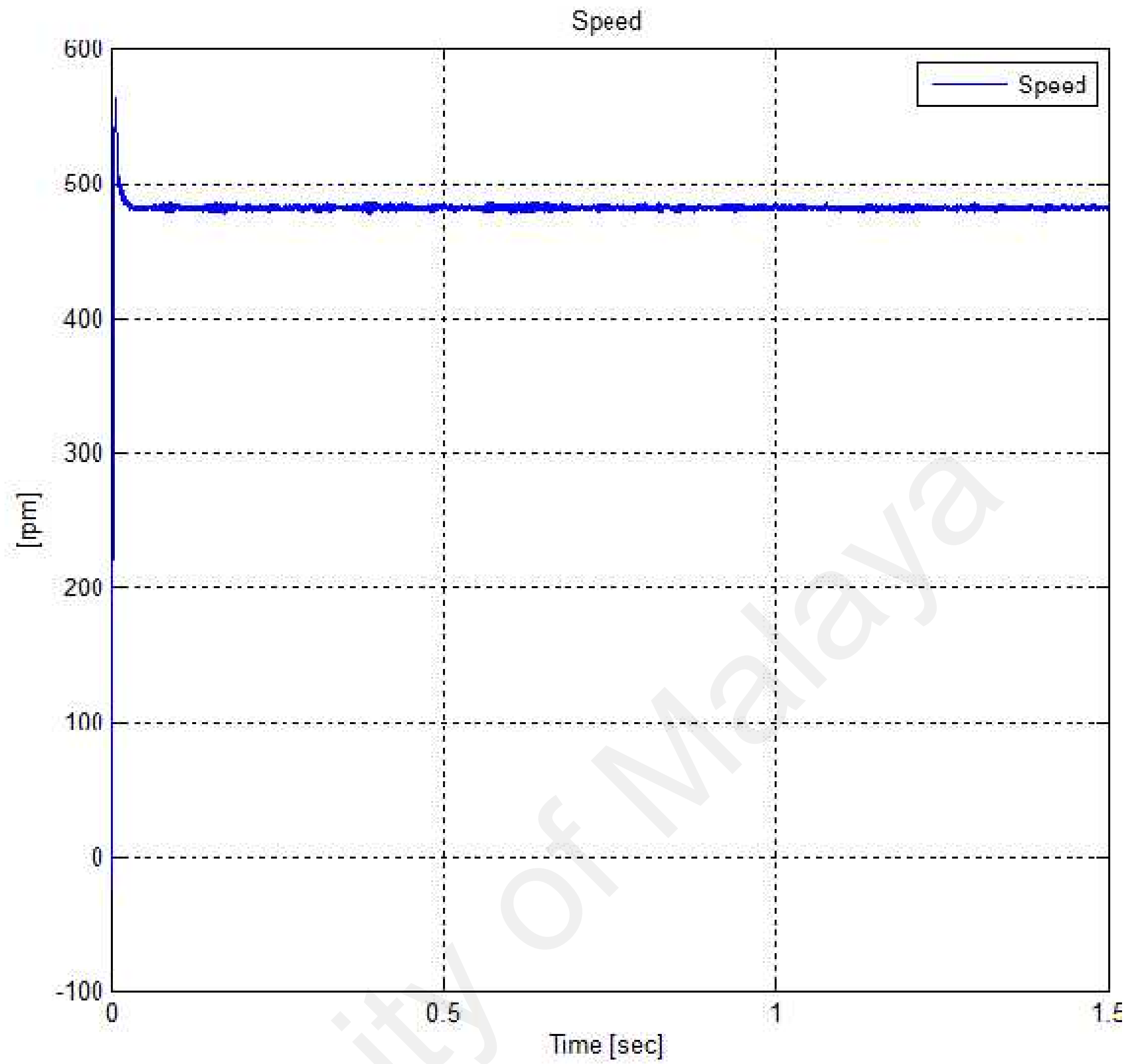

Figure 4. 4 Motor rotating velocity [rpm]

Simulation result of rotating speed is at 1st reference speed at 490 [rpm], Torque load Tm constant 50.

Figure illustrates simulation result, transient time (i.e 0 to 0.1) we can check in the group from 0 to 1.5 time, in which we can check at very short time our required referenced speed is constant from the 0.1 to 1.5. The step velocity is changed from rpm 0 to 550 rpm and that is between 0 to 0.1 which is transient period after immediately our constant velocity response is from 0.1 to 1.5 which is 490 rpm and the result is achieved in simulation with adaptive observer technique.

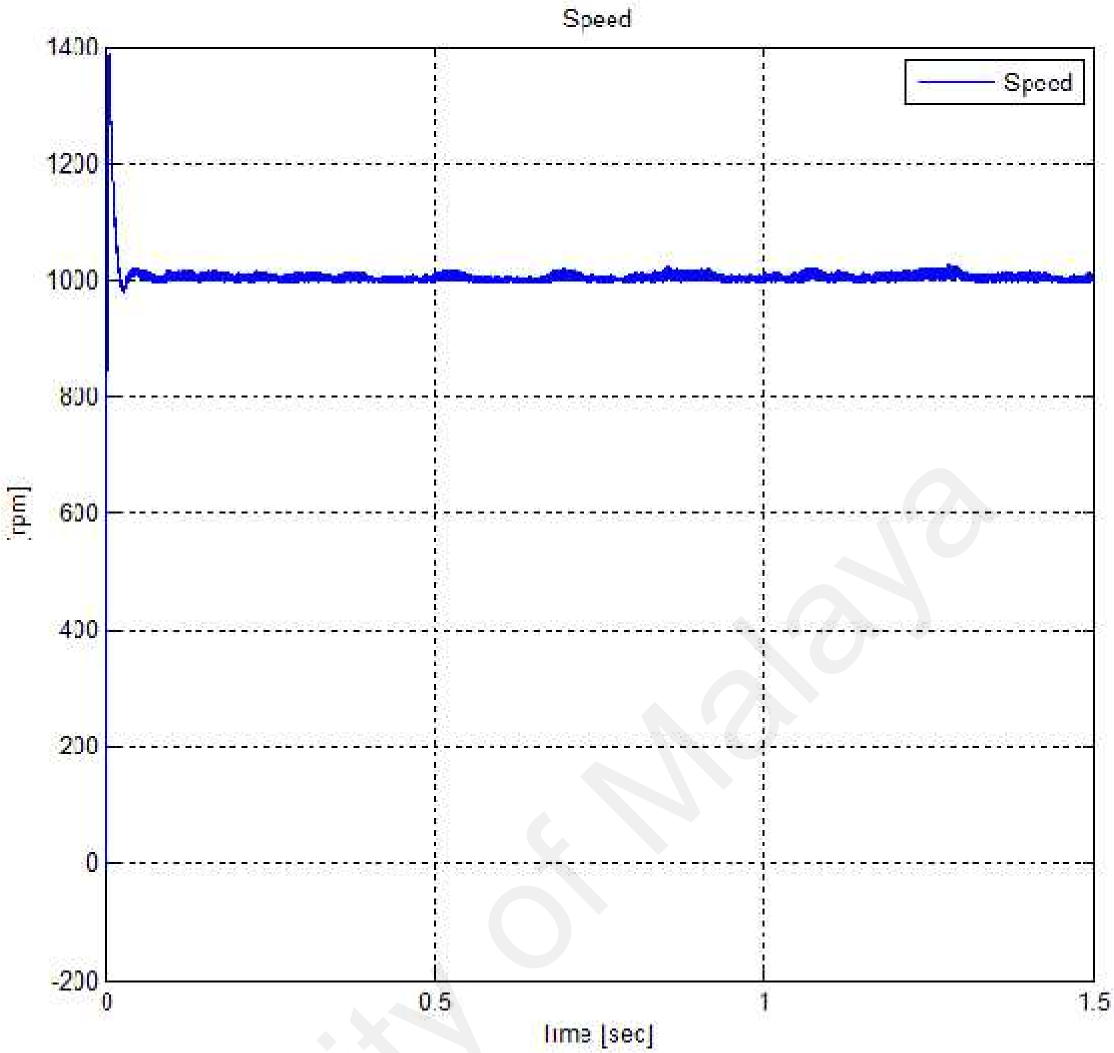

Figure 4. 5 Motor rotating velocity [rpm]

Simulation result of rotating speed is at 2nd reference speed at 1000 [rpm], Torque load Tm constant 1.

Figure illustrates simulation result, transient time we can check in the group from 0 to 1.5 in which we can check at very short time. Our required referenced speed is constant from the 0.1 to 1.5. The step velocity is changed from rpm 0 to 1400 rpm very short transient period which is 0 to 0.1. After that, we have constant required speed according to which we set as reference that is 1000rpm.

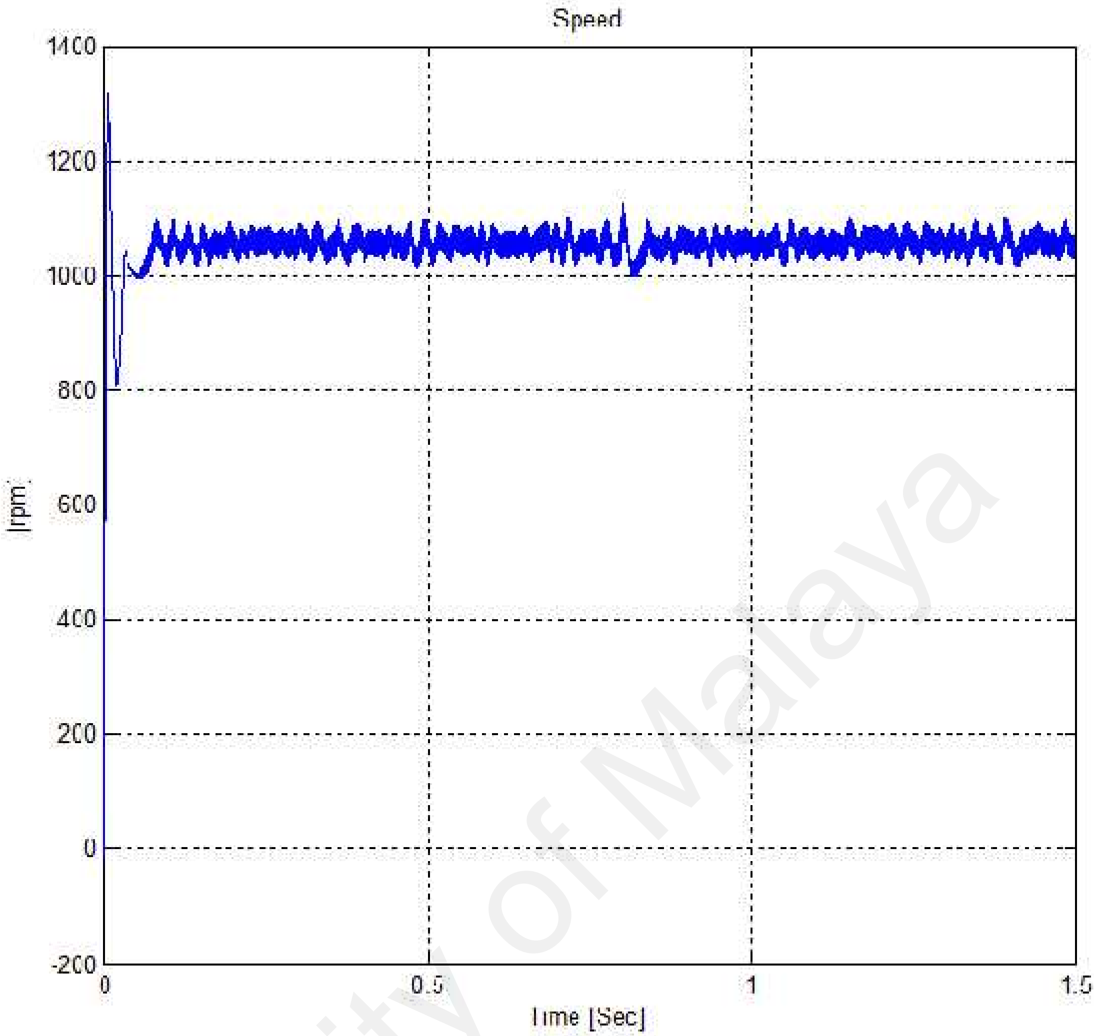

Figure 4. 6 Motor rotating velocity [rpm]

Simulation result of rotating speed is at 2nd reference speed at 1000 [rpm], Torque load Tm constant 50.

Figure illustrates simulation result, transient time ,we can check in the group from 0 to 1.5 in which we can check at very short time our required referenced speed is suppose to be constant from 0.2 to onwards but system is unstable here reason of that is adaptive settings are also not matched.

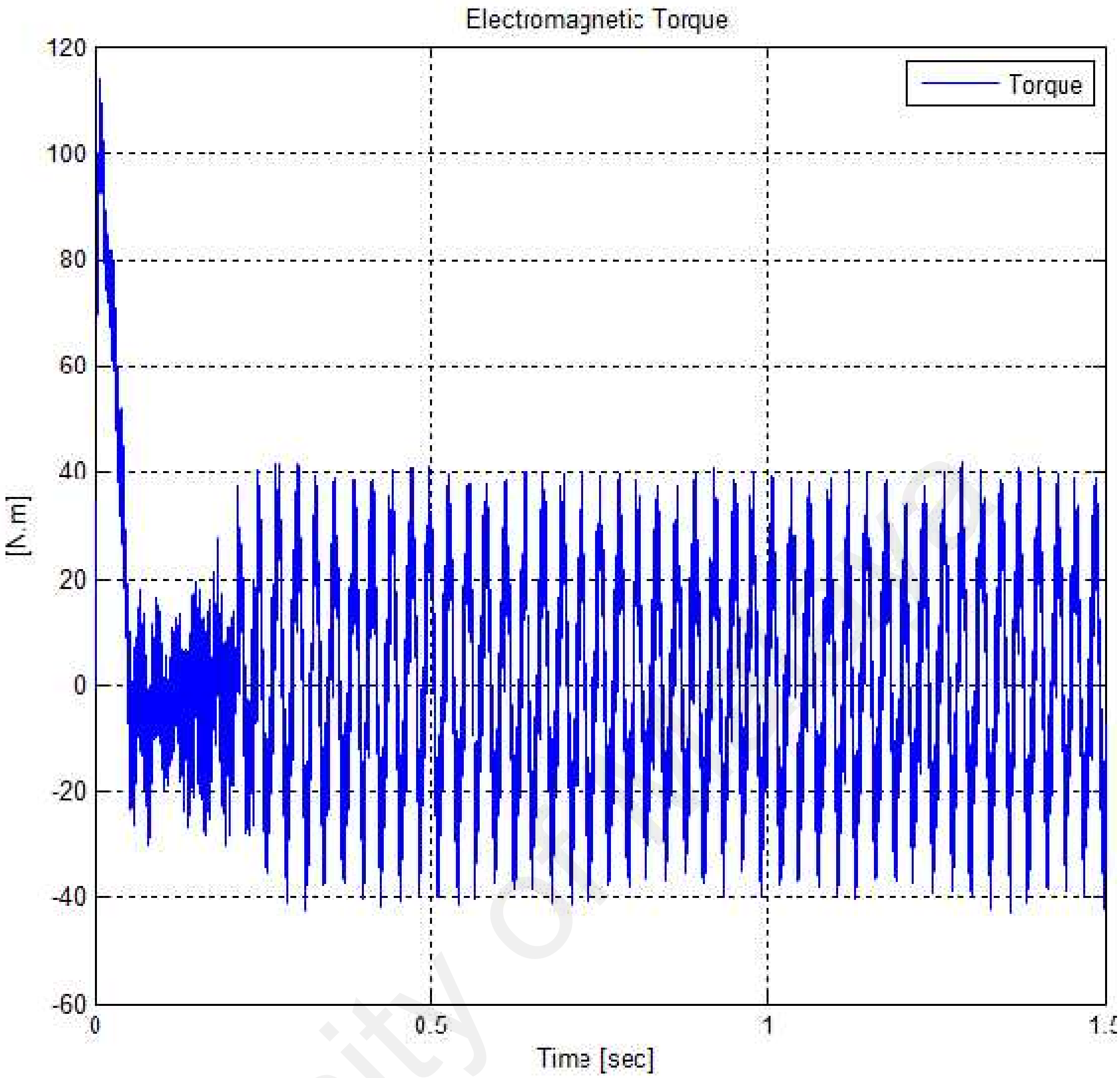

Figure 4. 7 Electromagnetic Torque to 1 Nm

Electromagnetic torque value is based on the 1 Nm constant of applied external load torque at the speed of 500rmp.

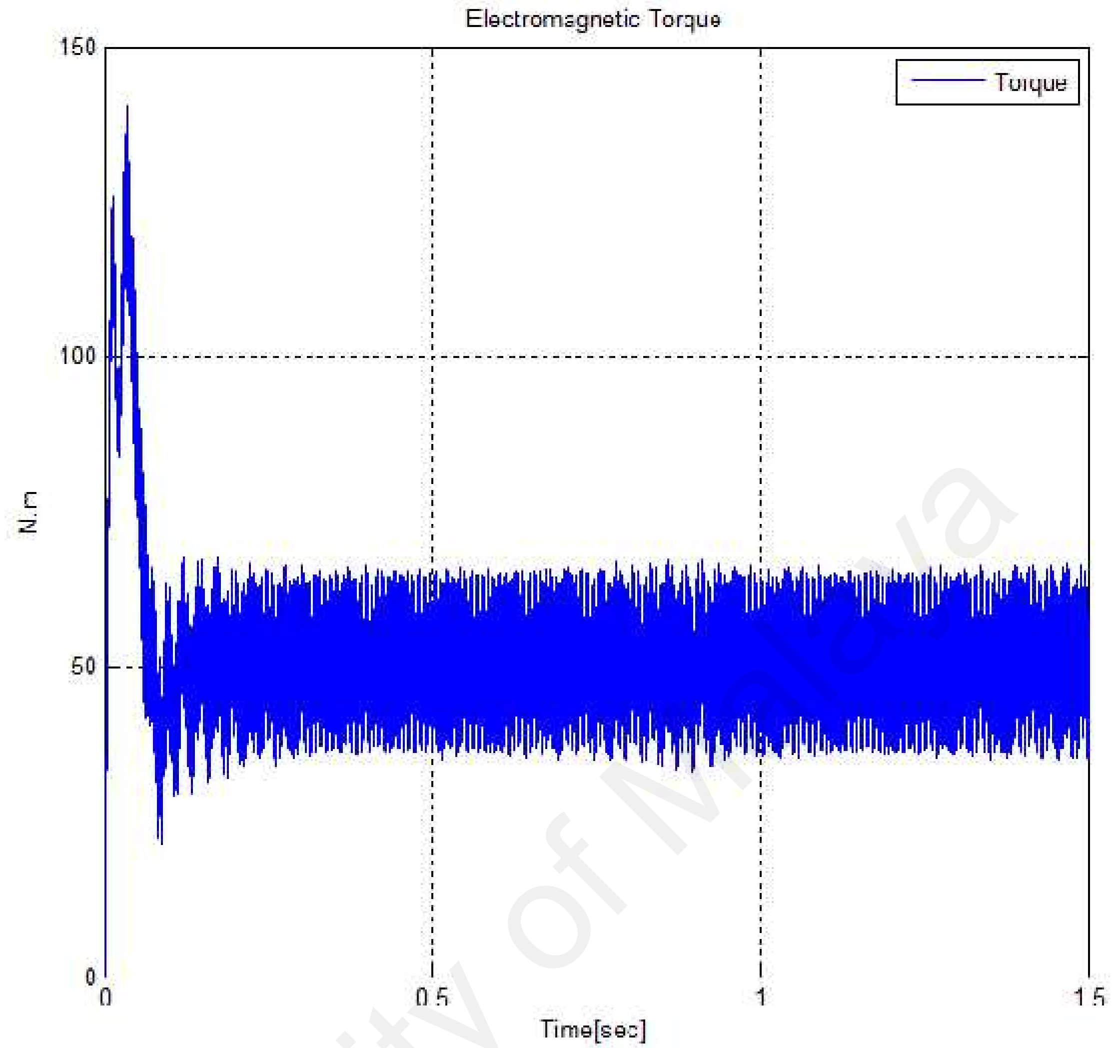

Figure 4. 8 Electromagnetic Torque to 50 Nm

Electromagnetic torque behaviour at 50 N.m external torque load for speed of 490 rpm.

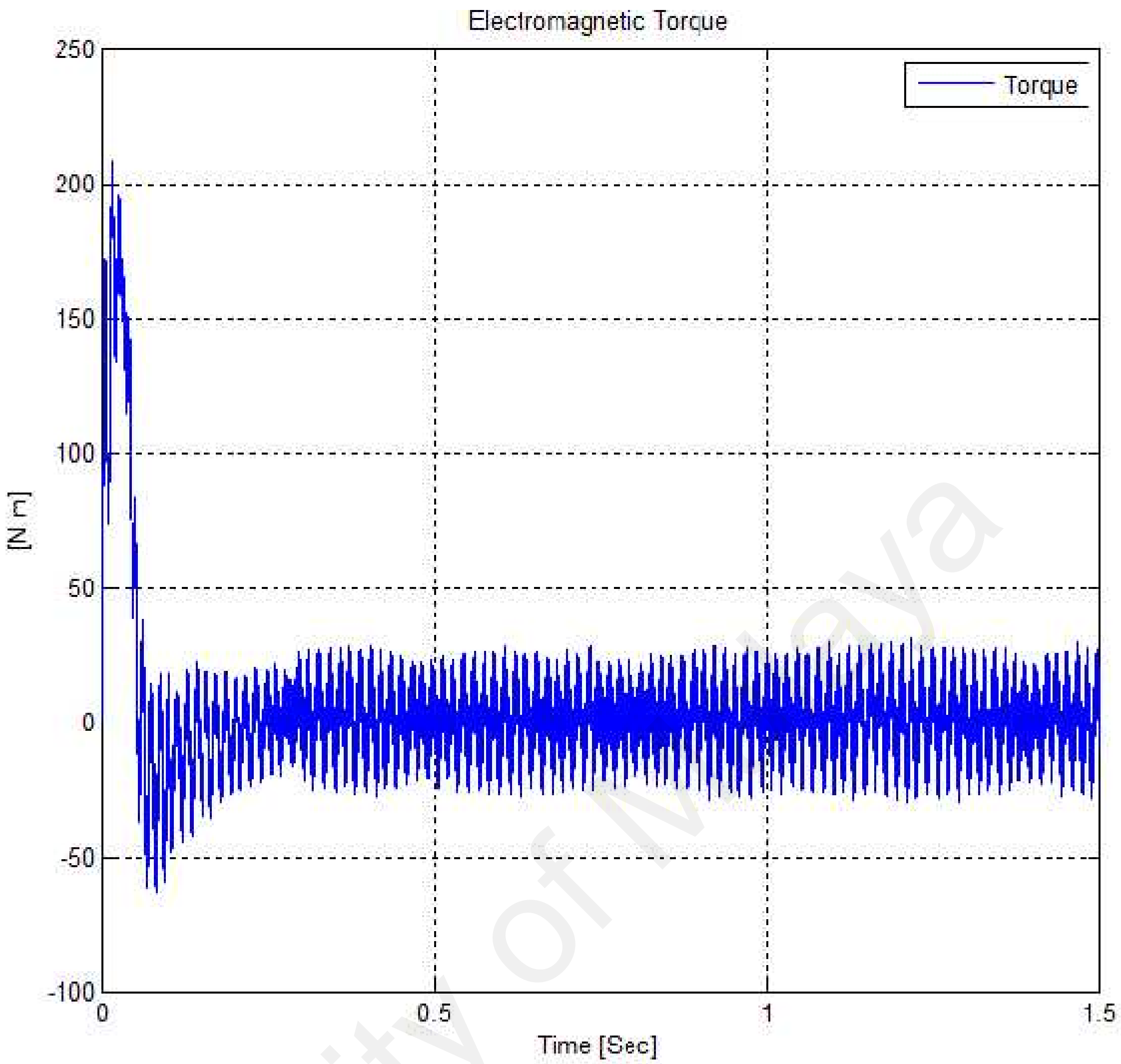

Figure 4. 9 Electromagnetic Torque to 1 Nm

Electromagnetic torque behaviour at 1 N.m external torque load for speed of 1000 rpm.

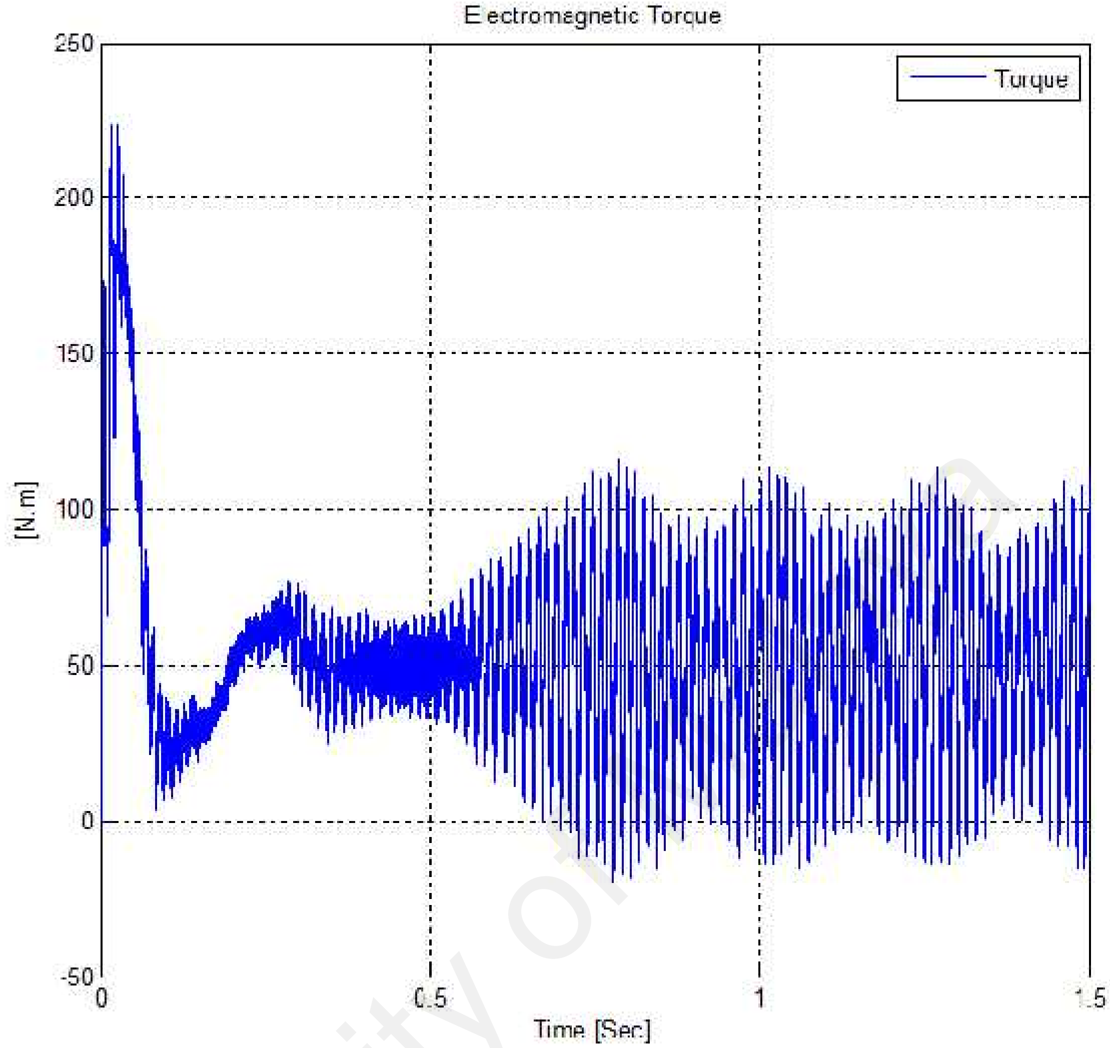

Figure 4. 10 Electromagnetic Torque to 50 Nm

Electromagnetic torque behaviour at 50 N.m external torque load for speed of 1000 rpm.

4.1 Discussion of results

Adaptive observer scheme is tested on different values of external load torque, and the reference speeds. From tested results in Matlab simulink, it gives the best result of Electromagnetic torque on the value of external load torque 50Nm with the reference speed of 490rpm which is constant at very low transient. Higher speed up to 1000rpm is also tested on which external load 1 Nm gives also good result of speed which is stable also at very low transient time.

System is configured at the speed starts from 490 [rpm] to [1000rpm] with external load form 1 [Nm] to 50 [Nm]. Results as per required speed can achieved at required external torque; for that there is need of change in variations parameter of induction motor, adaptive flux until the system becomes stable. For adaptive observer it is confirmed from the results that for getting the value which is required are depending on the accurate parameters variations. As speed 490rpm is stable on external load 50 N.m, 0.96 flux value; any variation in other parameters of induction motor will make the system disable. Any required speed with respect to external load using adaptive observer can be attained by adjusting the parameter of induction motor until the system becomes stable.

CHAPTER FIVE: CONCLUSION AND RECOMENDATION

5.1 Conclusion

The design and analysis of adaptive observer for controlling the performance of induction motor has been presented. Different types of sensorless techniques were discussed and reviewed together with the adaptive observer technique. The objective of reviewing all techniques was to arrange the speed sensorless method techniques along with the importance of merits and demerits for each method. The comparison between different estimation of speed methods based on devised set of criteria was also introduced. Mostly the exchanges which occur are between the simplicity regarding implementation and the behaviour of over all system. Nevertheless, for the justification of the certain scheme regarding specific applications from the results of each method is considered a useful tool and all techniques are considered yet as powerful according to the needs of specific requirements for the system.

For low speed procedure there is a need of introducing low speed application technique such as; the technique of frequency signal injection method and rotor slot harmonic methods, system which have high noise; mostly Extended Kalman Filter (EKF) is preferable, due to noise reason EKF is designed as like in which can perform most desirable filtration. Slide Mode Observer (SMO) gives better speed estimation although it is required to remove the chattering problems from the system. Artificial Intelligence technique has the problem of complexity and the large time in computation although it also demonstrates the better results.

Adaptive flux observer technique is presented in new way, as improved technique for the induction motor, based on the correction of the value of the stator resistance and the estimation of the load torque. The estimation of the torque is based on the use of the error between real and estimated speed of induction motor, this will have to improve the performances of the adaptive flux observer. The results show that the proposed adaptive observer offers better performances while tracking the speed and the flux, even in presence of stator resistance variation.

5.2 Recommendation

As there are advantages and disadvantages of sensorless techniques, due to that all techniques are important for specific application purpose; none of them would be discarded for any disadvantage reason, all are useful. For example as Artificial Intelligence (AI) system has better results but has problem of computation time and complexity. However, AI techniques using with adaptive observer criteria can make system more stable. It is highly recommended idea which comes after review of all sensorless technique that by using the advantages of all sensorless techniques according to needs such as; variation to parameters , configure system according to requirement , reduce complexity and try to reduce disadvantages for making the system more reliable and accurate. Such adaptive observer scheme is preferred and possible by using combination of techniques, SMO technique together with AI can give better results just by eliminating chattering problem from SMO and reduce the complexity and computation time of AI system together with variation in parameters.

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