PWM-DRIVEN INDUCTION MOTOR CONTROLLER: STATE SPACE APPROACH

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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December 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MUHAMMAD NAJIB BIN MOHD NASRUDDIN)

ABSTRACT

In adjustable-speed drive applications, the range of speed and torque achievable is very important. A power electronic converter is needed as an interface between the input AC power and the drive. A controller is needed to make the motor (drive), through the power electronics converter meets the drive requirements. The widely used conventional control that is based on mathematical model of the controlled system is very complex and not easy to be determined since it requires explicit knowledge of the motor and load dynamics.

This final project report is a design and implementation of a state space controller from a for a PWM-driven variable-voltage variable-frequency (VVVF) speed control of an induction motor and the analysis, evaluation and improvement of the control strategies. A simulation model in MATLAB/Simulink is developed using state space approach to perform verification of the controller. To provide stability in response to sudden changes in reference speed and/or load torque, details study on the pole placement method used in the system will be conducted.

Detailed evaluations of the controller's performance based-on a pre-defined performance indices under several conditions are presented. The findings demonstrate the ability of the control approach to provide a viable control solution in response to the different operating conditions and requirements.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Motor drives are used in a very wide power range. In adjustable-speed drive applications the ranges of speed achievable is very important in applications such as controlling of a boiler feed-water pump, fan and a blower. In all drives where the speed and position are controlled, a power electronic converter is needed as an interface between the input power and the motor. A controller is also needed to make the motor, through the power electronic converter, meet the drive requirements. Notably, the extensive automation in modern industries demand several strategies that have high reliability and robustness to be introduced and one of the main requirements is the control technique used.

Most of electromechanical actuator driving the industrial process use induction motors (IM). It replaces the role of previous motor i.e. direct current (DC) motor. The induction motor offers simple design, low maintenance and cost competitive compared to DC motor but the control of induction motor is more complex than a DC motor.

Basically the basic relation on IM allows controlling the speed using either number of poles or frequency of applied voltage. Since the design of IM is fixed, changing the number of poles is not feasible and applicable. Thus varying frequency at the voltage applied becomes an alternative.

Varying the frequency at an applied voltage is feasible and applicable by implementing power electronics control. The circuit implementing power electronic provides variable electrical properties is usually called power electronic converter. The electrical properties can be voltage, current and frequency.

In order to vary the IM speed the converter will provide the variable frequency. In order to avoid flux saturation on the IM, the voltage applied to the IM should be varied as well. The variable-voltage variable-frequency (VVVF) technique is usually considered as an effective method to achieve this control.

The popular method in implementing the VVVF is the pulse width modulation (PWM). It is based on level comparison between modulating signal input and triangle signal. The average output at one switching period will be the same as the ratio between modulating signal and peak of triangle time DC input voltage [2]. If the modulating signal waveform is sine wave then average output will be sine wave as well.

In the implementation, the PWM inverter functions as an interface between the induction motor and power line. The power line is rectified, filtered and then fed to the inverter circuit using power electronics components. The inverter circuit is controlled by the PWM modulator. The modulating signal determines waveform, voltage and frequency of inverter output. In order to maintain the constant torque on induction motor, a pattern of voltage and frequency fed to induction motor should be maintain. This is known as V/Hz ratio. This ratio is constant. But at low frequency, voltage should be boosted due to drop voltage at the stator winding.

In order to provide a stable output at the induction motor speed, a control system is required to maintain the speed when the disturbance exists. A method of providing the required input of PWM inverter will be handled by a controller.

1.2 Problem Statement

The state space approach in control is a basic and widely used in industry for a long time. In order to obtain high performance, suitable control technique using pole placement method should be conducted based on the mathematical model of the plant. The plant model is sometimes not easy to be obtained, ill-defined and complex. The other situation is the changing of parameter values caused by the changes in environment condition, which requires the parameters to be adjusted.

In relation to the induction motor speed control in an industrial automation, a PLC is easily found in industries. Implementing state space control approach to the existing devices will optimally utilize the devices and improve the performance. This will contribute to the quality and cost effective product that is also efficiency.

1.3 Objectives and Scope of Study

The objective and scope to this thesis are outlined below:

-Develop a method of modelling and designing a state space controller for Pulse Width Modulation (PWM) driven Induction Motor

-Evaluate the control performance of state space controller using suitable control technique, pole placement method through simulation in MATLAB/Simulink using the plant transfer function.

-To evaluate the characteristics of pole placement for three directions: vertical direction/ horizontal direction / and constant radial line at constant reference speed 600 rpm, no load condition.

-To determine best pole placement that which one of them gives the best control performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, Industrial competition in the world is on the rise and getting tougher. Hence, the efficiency due to shortened product life cycles, rising manufacturing costs, and the globalization of market economics is a critical issue and a key word to success. All industries put efforts to increase the efficiency and to reduce the losses. Increasing the efficiency could be done by increasing the production speed, automating the system, reducing the material cost, increasing the quality, reducing the rejected product, lessening the downtime and reducing the maintenance cost [3].

Reducing the human interventions in a process is commonly known as automation. An automated system is a collection of devices working together to accomplish task or produce a product or family of product [3]. An industrial automated system can be a machine or a group of machines. Automation plays an increasingly important role in increasing the efficiency. Obviously, the automation is applicable in a process with high volume production [4]

2.2 Induction Motor

The earliest electric machine used as the drive in industrial process is the direct current (DC) motor. It has some disadvantages such as high cost, volume and weigh, reliability and maintainability problem, limited high speed and cannot operate in dirty and explosive environment [3]. Despite that drawback, the DC motor has high inertia, inherently fast torque response and simple converter and control.

Nowadays, the trend is using induction motor to replace the DC motor position in industry. Most of electromechanical actuator in industries is driven by induction motor. It provides simple way to control and cost competitive, [4].

The fundamental theory of the induction motors is that the synchronous speed (*ns*) of induction motor depends on the frequency at the voltage applied (*f*) and number of poles (*p*). The relation between frequency, number of poles and synchronous speed is expressed as:

$$Ns = {}^{120}/_{p}\, f$$

The air-gap flux (Φag) rotates at synchronous speed relative to stator winding. The number of turn on the stator winding is indicated by *Ns*. As a result of changing magnetic in a winding, induced voltage on the stator winding (*Eag*) is developed, where *Vs* is per-phase voltage, *Rs* is resistance of stator winding, *Lls* is leakage inductance of stator. winding, *Lm* is magnetizing inductance, *Rr* is resistance of equivalent rotor winding, *Llr* is leakage inductance of equivalent rotor winding, *s* is slip, the different between synchronous speed and mechanical speed of rotor.

2.3 Pulse Width Modulation (PWM)

In this work the IM speed control is using variable-voltage variable-frequency (VVVF) converter. The main objective is to have the ratio between voltage and frequency at the converter output be kept constant. By this concept, as the air-gap voltage is kept constant the torque would also be constant. In order to maintain a constant flux at low operating frequency, the drive based on VVVF should perform voltage boosting.

The VVVF is usually achieved using a pulse width modulation (PWM) technique. Figure 3.3 shows block diagram of basic PWM. It consists of a comparator and a triangle wave generator. The carrier signal, coming form triangle generator, operates at a certain frequency that is usually called switching carrier frequency (*fc*). The two signals are then compared. If the modulating signal level is higher than carrier signal level then the comparator output will be high. It then turns on the power switch in inverter circuit. Figure 3.4 illustrates the signals on PWM circuit.

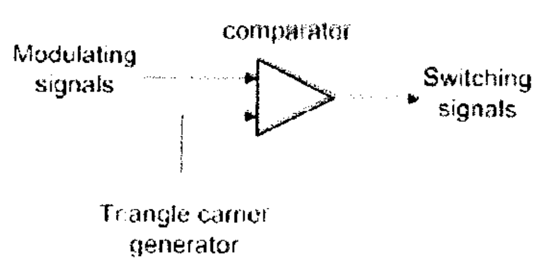


Figure 2.1: basic PWM model

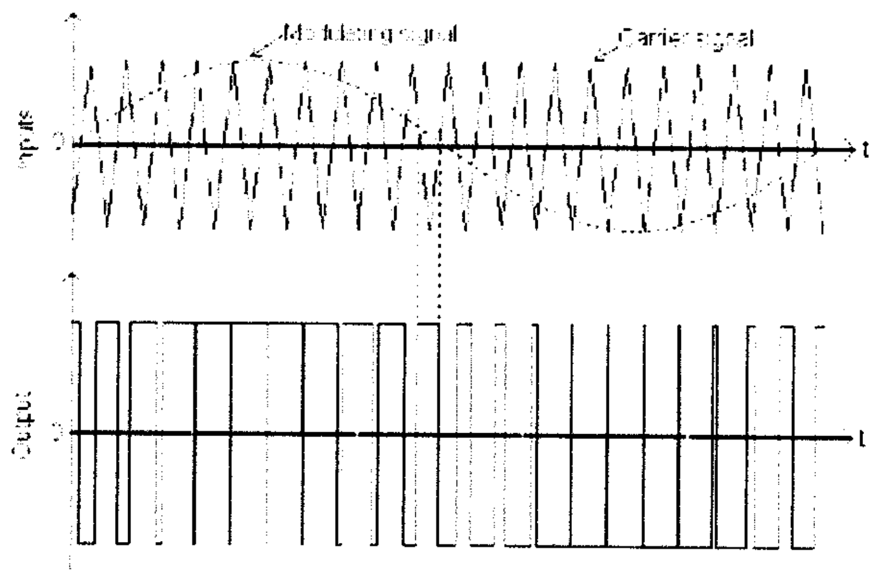


Figure 2.2: PWM signals

The comparator output is then connected to power switch in inverter circuit that receives DC power from rectifier. The block diagram of basic PWM inverter is depicted in Figure 3.5. For a three phase inverter, there will be six power switches to provide the AC signal. The common power semiconductor switch implemented can be either IGBT or MOSFET. The power semiconductor switches in the inverter will turn-on and off following the signal given by PWM. As the result, the current flowing in the inverter will be having the same waveform as the modulating signal.

2.4 State space approach

Modern state-space design is a comprehensive term referring to modeling and control of complex systems. The standard representation of a system is shown below.

$$\dot{x} = Ax + Bu \qquad y = Cx + Du$$

State-space design filled the void in that it compactly represents large systems in matrix form, as well as being able to handle time-varying and nonlinear systems. Furthermore, the model's B and C can be matrices allowing the 2 model to readily handle multiple inputs and outputs. Also, because the system is represented compactly by matrices, it is easily manipulated by computers [2].

In year 1997, Carnegie Mellon [20] from University of Michigan presented the procedure of designing state space controller in MATLAB for a system. It was implemented by using the pole placement method. The proposed method was applied, and simulation results show that substantial improvement in the performance was achieved compared with other local observers.

IEEE control systems magazine in October 2004 describes a new approach to teaching feedback to relevant engineering topics. The magazine also describe the special emphasis is given to state-space methods for analysis and synthesis, since these techniques are needed for systems that are nonlinear and asynchronous.

2.5 Pole Placement Method

Pole placement also known as pole-assignment technique or Full state feedback (FSF) is the method that control the system. It is one of the modern technique that can control not only single input and single output but can control the complex equation that have multiple input and multiple output. The pole placement design can place all closed-loop poles at desired locations. It means that, if the system considered is completely state controllable, then poles of the closed-loop system may be placed at any desired locations by mean of state feedback through an appropriate state feedback gain matrix, K. [4]

It also can define as a method employed in feedback control system theory to place the closed-loop poles of a plant in pre-determined locations in the s-plane. Placing poles is desirable because the location of the poles corresponds directly to the eigenvalues of the system, which control the characteristics of the response of the system. [11]

Pole Placement has been used as a control method in many fields, but it is remarkable the number of applications in the aerospace field that can be found in the literature [Manness and Murray-Smith (1992), Andry et al. (1983)].

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project work

The project activities flow is shown in Figure 1.

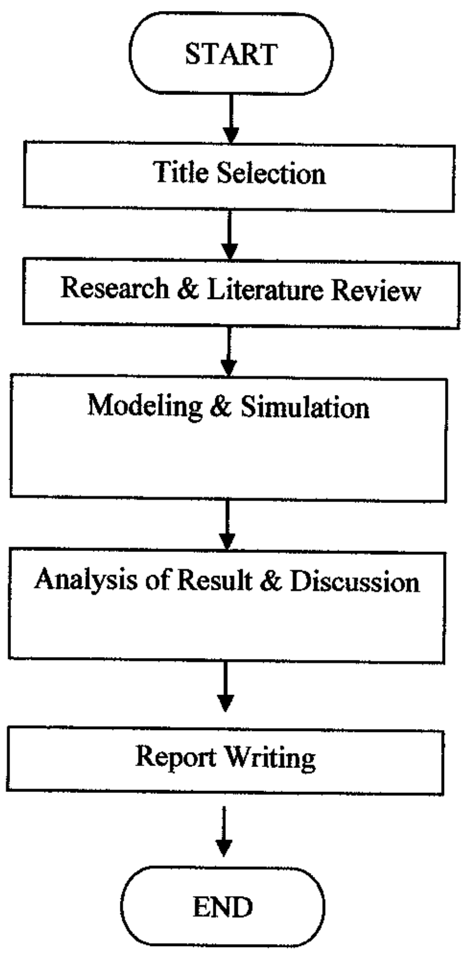


Figure 3.1: Project Activities Flow

The project is a modeling and simulation based project. Specifically, it is a study of state space controller for PMW driven Induction motor. First and for most, the project will begin with the research on several issues which had been mention in the research methodology. With the collective information, the project will proceed with the literature review.

The next step is to have modeling steps undertaken to produce a simulation model of a plant. The plant discussed is an induction motor (IM) driven by a variable speed drive (VSD) and loaded by a dynamometer. The plant model consists of several sub-models that include the VSD, IM and dynamometer. The modeling is based on input-output empirical data. There are seven sets of input output data used in the modeling. The input data set applied to obtain the output data is a multi-level periodic perturbation signals (MLPPS). The model is then evaluated using fifty input-output data that have not been used in the identification process. The final model is expressed in terms of transfer function[1].

Where, Y(s) = G_1(s) + G_2(s) + offset

$$G\_1(s) = \frac{0.72527\ (1+351.21s)\ e^{-0.069926s}}{(1+326.38s)(1+0.090062s)(1+0.10037s)}$$

$$G\_2(s) = \frac{0.12728\ (1+13.363s)\ e^{-0.025044s}}{(1+13.85s)(1+0.03672s)(1+0.038175s)}$$

Offset= -53.86

Then, the model identified then is used to represent the plant in simulation. Simulation is carried out on Matlab/Simulink. The simulation simulates the controller process using nearly the same situation in the experiment. The simulation includes using different kind of pole placements. The objective of simulation here is to provide a picture and a guide in the best controller setting of using pole placement method. The comparisons of the result are also presented in tables and graphs. Apart from that, the new simulation modeling will be further explained and justified.

CHAPTER 4

RESULTS AND DISCUSSION

After obtaining the modeling of plant transfer function, simulation will be conducted to determine the correctness of the technique used and system operation. This chapter concentrates on the model building for the integrated VSD and IM, and the simulation and investigation of the effectiveness of the proposed control method i.e., the PWM-driven VVVF, to achieve the control objective.

First, an introduction the ordinary model for plant, G1, consisting of VSD and IM is presented. Next, an explanation on the performance criteria is deliberately discussed. Then the test results focusing on the following poles conditions: first, to study the system response at when poles moving at vertical direction; secondly, to study the system response when poles moving at horizontal direction; thirdly, to study the system response when poles moving at constant radial line.

4.1 Plant Model of Simulink diagram

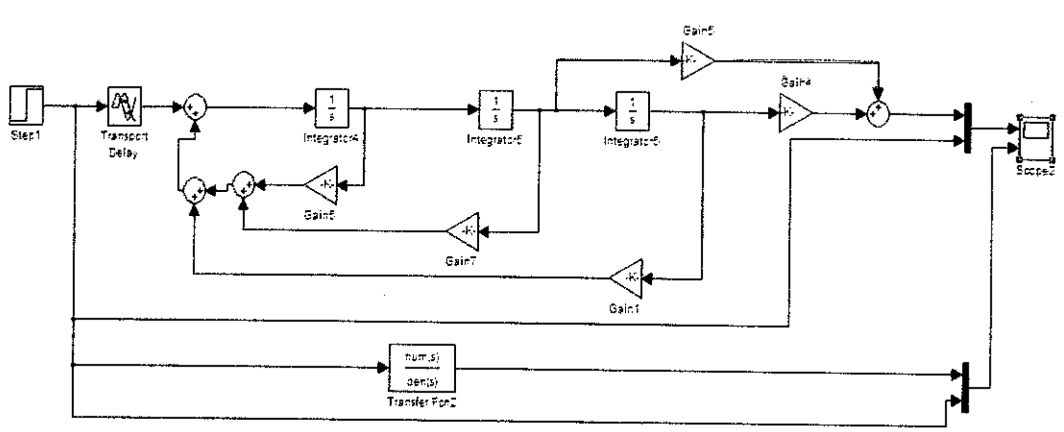


Figure 4.1: Simulink diagram of the G1 transfer function in state space without controller

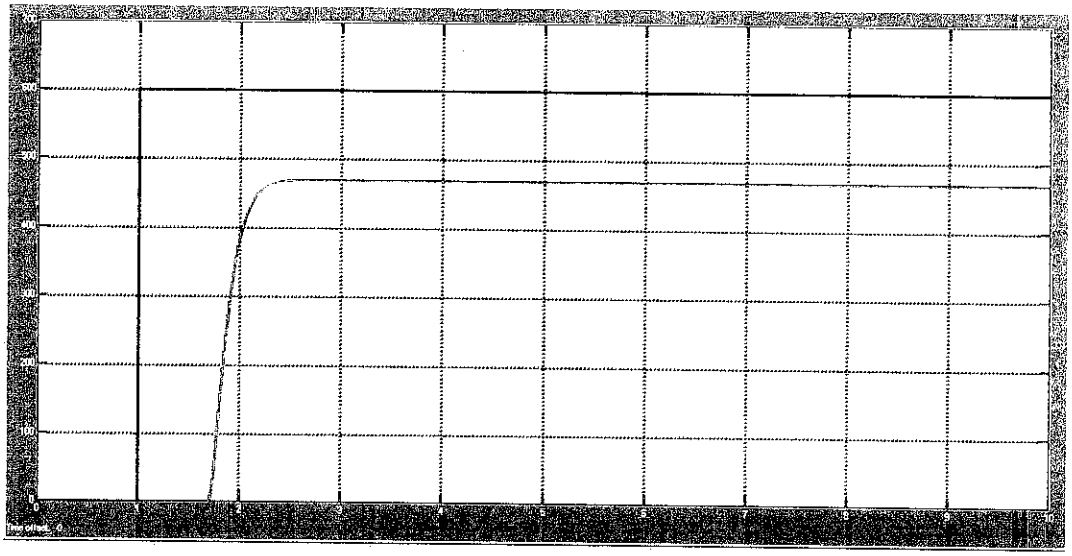


Figure 4.2: The output response of the state space system given a step input of 600rpm is applied.

Based on figure, we can conclude that the output response of state space system does not reach the set point applied. The concept of controllability plays an important role in the design of control systems in state space. In fact, the conditions of controllability may govern the existence of a complete solution to the control system design problem. Since the system is controllable, designing the state feedback controller can be done.

In order to design the state feedback controller, we first need to determine the state feedback gain K to shape the transient response, by solving the regulator problem. The feedback gain, K with u (k) = Kx (k) gives a closed loop system whose dynamics are manage by (A – BK).

4.2 System poles characteristics without controller

Pole placement locations are related to output response characteristics such as percent overshoot, rise time, and settling time [5]. By evaluating the location of poles, control performance characteristics can be optimized.

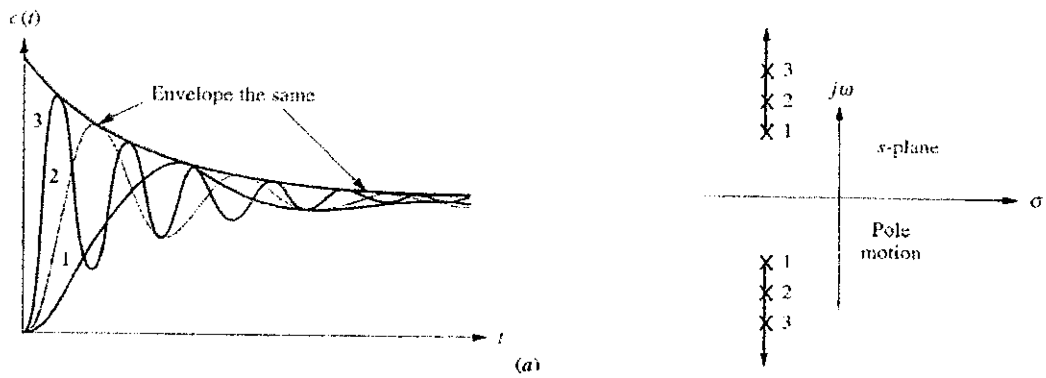


Figure 4.3: Poles moving in vertical direction

In Figure 4.3, are the step responses as the system poles are moved in vertical direction, keeping the real part same. As the poles move in a vertical direction, the frequency increases, but the envelope remains the same since the real part of the pole is not changing. The figure shows a constant exponential envelope, even though the sinusoidal response is changing frequency. Since all curves fit under the same exponential decay curve, the settling time is virtually the same for all waveforms. Note that as overshoot increases, the rise time decreases [5].

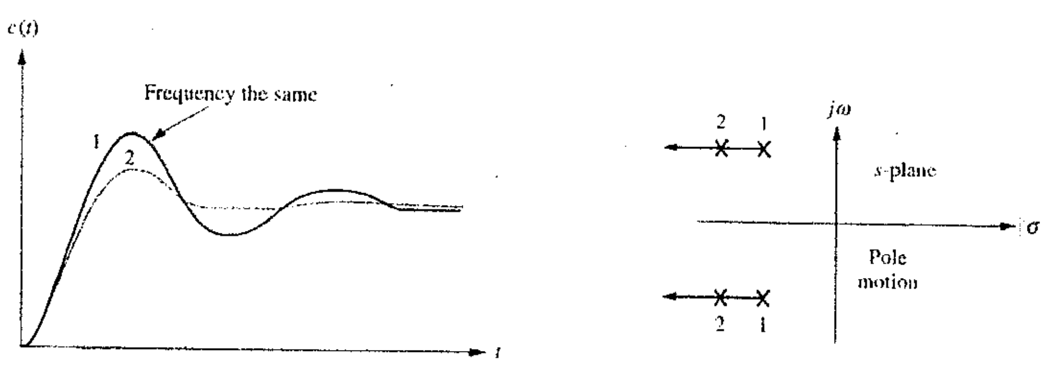
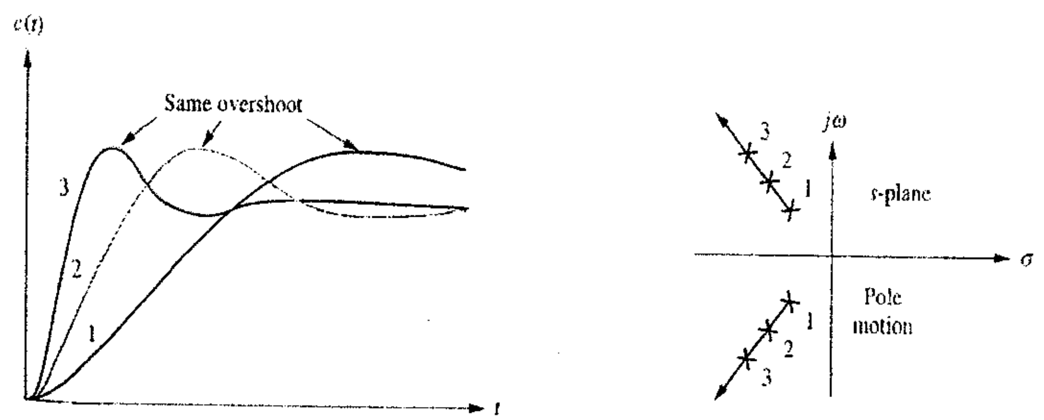


Figure 4.4: Poles moving in horizontal direction

Based on the figure shown, since the imaginary part is now constant, movement of the poles yields the responses correspondingly. Here the frequency is constant over the range of variation of the real part. As the poles move to the left, the response damps out more rapidly, while the frequency remains the same. Notice that the peak time is the same for all waveforms because the imaginary parts remain the same [5].



(c)

Figure 4.5: Poles moving in constant radial line direction

Moving the poles along a constant radial line yields the responses shown in figure. Here the percent overshoot remains the same. Notice also that the responses look exactly alike, except for their speed. The farther the poles are from the origin, the more rapid the response [5].

4.3 State feedback controller poles characteristics

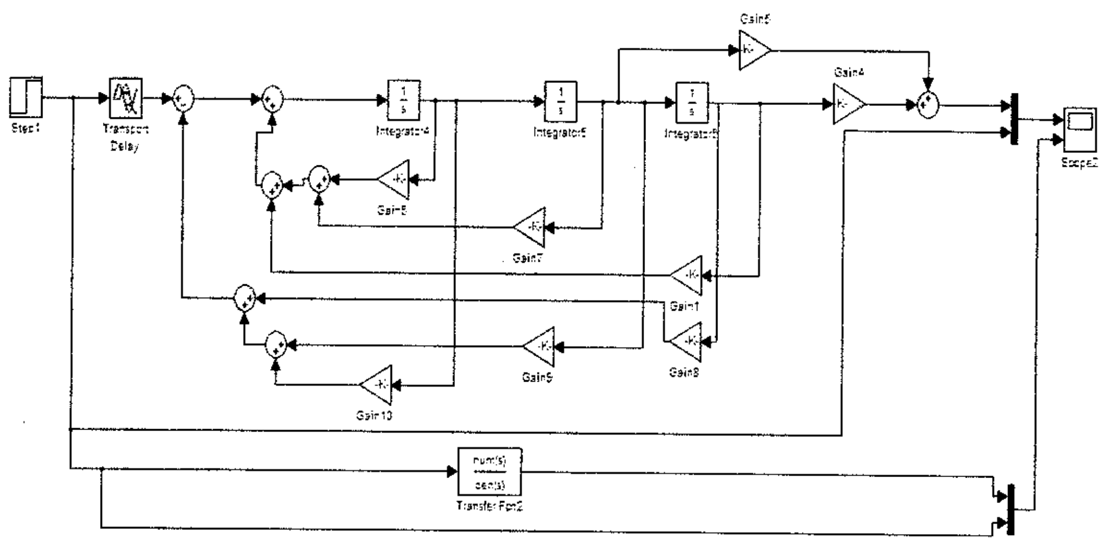


Figure 4.6: Simulink diagram of the G1 plant in state space with state feedback controller

The first part of simulation is to study the system responses as the controller poles are placed in vertical moving direction, at 600rpm reference speed. It is also conducted in no load condition. Since the plant model has a dead-time, the response has time lag exists at the early part. Figure 5.14 shows the step response of the system at 600rpm.

Calculations

$$G\_1(s) = \frac{0.72527\ (1+351.21s)\, e^{-0.069926s}}{(1+326.38s)(1+0.090062s)(1+0.10037s)}$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.339 & -110.7 & -21.07 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u$$

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.339 & -110.7 & -21.07 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$(A - BK) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.339 & -110.7 & -21.07 \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} [K_1 \;\; K_2 \;\; K_3]$$

$$= \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.339 & -110.7 & -21.07 \end{bmatrix} - \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ k_1 & k_2 & k_3 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.339 - k_1 & -110.7 - k_2 & -21.07 - k_3 \end{bmatrix}$$

Finding the eigenvalues of (A-BK):

$$|\lambda \mathbf{I} - (\mathbf{A\text{-}BK})| = \begin{bmatrix} \lambda & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & \lambda \end{bmatrix} - \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.339 - k_1 & -110.7 - k_2 & -21.07 - k_3 \end{bmatrix}$$

$$= \begin{bmatrix} \lambda & -1 & 0 \\ 0 & \lambda & -1 \\ 0.339 + k_1 & 110.7 + k_2 & \lambda + 21.07 + k_3 \end{bmatrix}$$

The characteristic equation;

$\lambda\,(\lambda^2 + 21.07\,\lambda + K_3\,\lambda\,) - 1(-110.7\,\lambda - K_2\,\lambda - 0.339 - K_1) = 0$

$\lambda^3 + \lambda^2\,(21.07 + K_3) + \lambda\,(110.7 + K_2) + (0.339 + K_1) = 0$ ....(1)

$K = [K_1 \;\; K_2 \;\; K_3]$

Since the system is third order, another closed-loop pole must be selected. The closed-loop system will have a zero at -0.00284688, the same as the open-loop system. Therefore, selecting the third closed-loop pole to cancel the closed-loop zero is necessary.

Case Study: Vertical direction Poles

For the first case study, take the eigenvalues to be = -1+j, -0.00284688, and -1-j. Hence,

$$(\lambda + 1\text{-}j)\ (\lambda + 0.00284688)\ (\lambda + 1\text{-}j) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3333 K_2 = -108.6943 K_3 = -19.0672

K = [-0.3333 -108.6943 -19.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-1+j,-0.00284688,-1-j];
>> K=acker(A,B,eigenvalues)


K =

      -0.3333    -108.6943    -19.0672
```

Figure : State feedback gain K obtained using MATLAB

For the second sample, take the eigenvalues to be = -1+2j, -0.00284688, and -1-2j. Hence,

$$(\lambda + 1\text{-}2j)\ (\lambda + 0.00284688)\ (\lambda + 1\text{+}2j) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3248 K_2 = -105.6943 K_3 = -19.0672

K = [-0.3248 -105.6943 -19.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues= [-1+2j,-0.00284688,-1-2j];
>> K=acker(A,B,eigenvalues)


K =

      -0.3248    -105.6943    -19.0672
```

Figure : State feedback gain K obtained using MATLAB

For the third sample, take the eigenvalues to be = -1+3j, -0.00284688, and -1-3j. Hence,

$$(\lambda + 1\text{-}3j)\ (\lambda + 0.00284688)\ (\lambda + 1\text{+}3j) = 0 \qquad \text{......(2)}$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3105 K_2 = -100.6829 K_3 = -15.0672

K = [-0.3105 -100.6943 -19.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues= [-1+3j,-0.00284688,-1-3j];
>> K=acker(A,B,eigenvalues)


K =

      -0.3105    -100.6943    -19.0672
```

Figure : State feedback gain K obtained using MATLAB

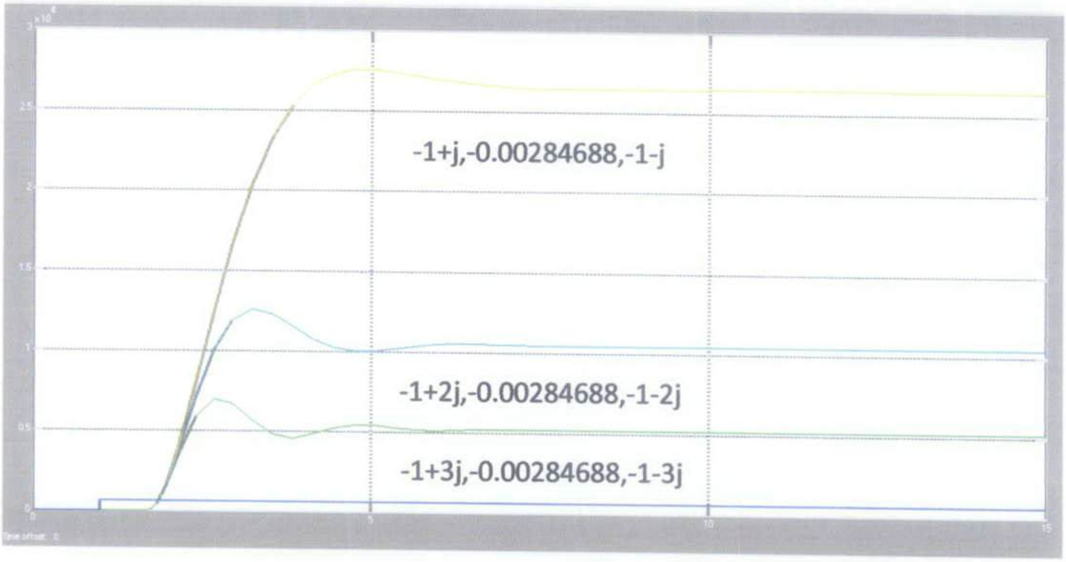


Figure 4.7: system response for vertical moving direction poles

Based on the figure shown, since the real part is now constant, movement of the poles yields the responses correspondingly. Here the frequency is constant over the range of variation of the imaginary part. As the poles move to far vertical, the response damps out slower, while the frequency remains the same. Notice that there is higher overshoot when it goes far vertical.

Case Study: Horizontal direction Poles

For the second case study, where the poles are moved in horizontal direction, take the eigenvalues to be = -1+j, -0.00284688, and -1-j.

Hence,

$$(\lambda + 1\text{-}j)\ (\lambda + 0.00284688)\ (\lambda + 1\text{-}j) = 0 \quad \ldots\ldots(2)$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3333 K_2 = -108.6943 K_3 = -19.0672

K = [-0.3333 -108.6943 -19.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-1+j,-0.00284688,-1-j];
>> K=acker(A,B,eigenvalues)

K =
       -0.3333   -108.6943   -19.0672
```

Figure : State feedback gain K obtained using MATLAB

For the second sample, take the eigenvalues to be = -2+j, -0.00284688, and -2-j. Hence,

$$(\lambda + 2\text{-}j)\ (\lambda + 0.00284688)\ (\lambda + 2\text{-}j) = 0 \qquad \ldots\ldots(2)$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3248 K_2 = -105.6886 K_3 = -17.0672

K = [-0.3248 -105.6886 -17.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-2+j,-0.00284688,-2-j];
>> K=acker(A,B,eigenvalues)

K =
       -0.3248   -105.6886   -17.0672
```

Figure : State feedback gain K obtained using MATLAB

For the third sample, take the eigenvalues to be = -3+j, -0.00284688, and -3-j. Hence,

$$(\lambda + 3\text{-}j)\ (\lambda + 0.00284688)\ (\lambda + 3\text{-}j) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3105 K_2 = -100.6829 K_3 = -15.0672

K = [-0.3105 -100.6829 -15.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-3+j,-0.00284688,-3-j];
>> K=acker(A,B,eigenvalues)


K =

     -0.3105   -100.6829   -15.0672
```

Figure : State feedback gain K obtained using MATLAB

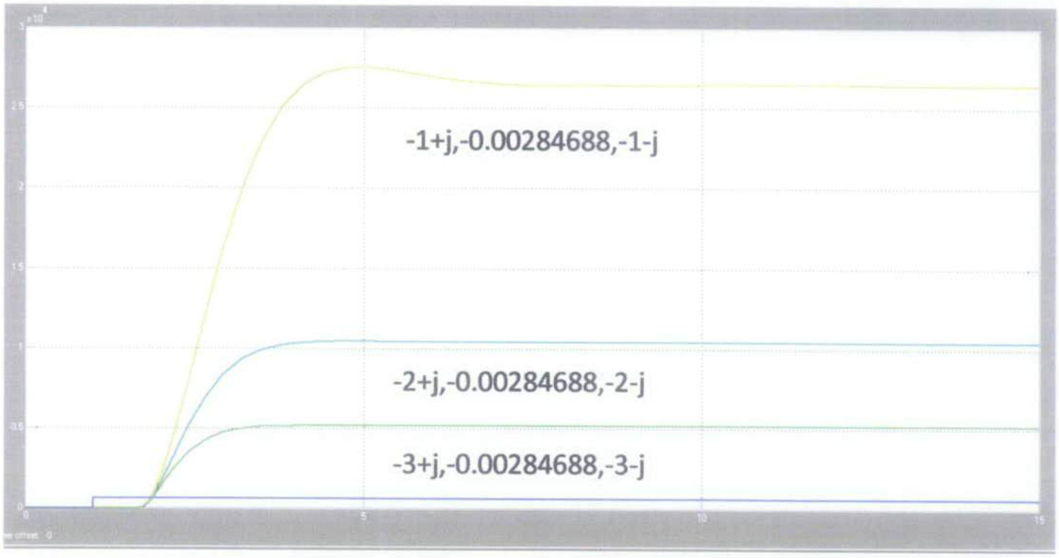


Figure 4.8: system response for horizontal direction poles

Based on the figure shown, since the imaginary part is now constant, movement of the poles yields the responses correspondingly. Here the frequency is constant over the range of variation of the real part. As the poles move to far horizontal, the response damps out rapidly, while the frequency remains the same. Notice that there is lower overshoot when it goes far horizontal.

Case Study: Constant radial line direction Poles

For the second case study, where the poles are moved in constant radial line direction, take the eigenvalues to be = -1+j, -0.00284688, and -1-j.
Hence,

$(\lambda + 1\text{-}j)\ (\lambda + 0.00284688)\ (\lambda + 1\text{-}j) = 0$……………………………….(2)

Comparing the characteristic equations of (1) and (2), we get

$K_1 = -0.3333\ K_2 = -108.6943\ K_3 = -19.0672$

K = [-0.3333 -108.6943 -19.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-1+j,-0.00284688,-1-j];
>> K=acker(A,B,eigenvalues)

K =

      -0.3333   -108.6943   -19.0672
```

Figure : State feedback gain K obtained using MATLAB

For the second sample, take the eigenvalues to be = -2+2j, -0.00284688, and -2-2j. Hence,

$$(\lambda + 2\text{-}2j)\ (\lambda + 0.00284688)\ (\lambda + 2\text{+}2j) = 0 \quad \ldots\ldots (2)$$

Comparing the characteristic equations of (1) and (2), we get

K_1 = -0.3248 K_2 = -105.6886 K_3 = -17.0672

K = [-0.3162 -102.6886 -17.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-2+j,-0.00284688,-2-j];
>> K=acker(A,B,eigenvalues)

K =

      -0.3162   -102.6886   -17.0672
```

Figure : State feedback gain K obtained using MATLAB

For the third sample, take the eigenvalues to be = -3+3j, -0.00284688, and -3-3j.
Hence,

$$(\lambda + 3\text{-}3j)\ (\lambda + 0.00284688)\ (\lambda + 3\text{+}3j) = 0 \quad \ldots\ldots (2)$$

Comparing the characteristic equations of (1) and (2), we get

$K_1 = -0.2878$ $K_2 = -92.6829$ $K_3 = -15.0672$

K = [-0.2878 -92.6829 -15.0672]

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues= [-3+3j,-0.00284688,-3-3j];
>> K=acker(A,B,eigenvalues)


K =

      -0.2878   -92.6829   -15.0672
```

Figure : State feedback gain K obtained using MATLAB

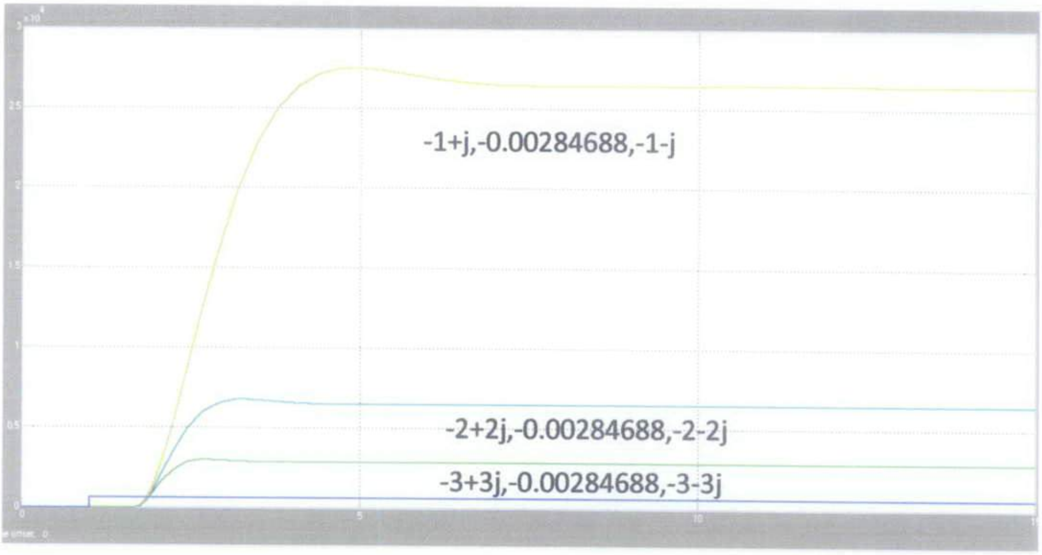


Figure 4.9: system response for constant radial line direction poles

Based on the figure shown, movement of the poles yields the responses correspondingly. Here the frequency is constant over the range of variation of the real part and imaginary part. As the poles move to far constant radial line, the response damps out rapidly, while the frequency remains the same. Notice that there is lower overshoot when it goes far horizontal. The constant radial line response is the response combination when the poles are moving vertical and horizontal.

Case Study: Designing best state feedback controller response

For the case study, heuristic method is used and it results in the best pole placement which the eigenvalues to be = -6.790678585+6.342106097j, -0.00284688, and -6.790678585-6.342106097j.

Hence,

$$(\lambda +6.790678585-6.342106097j)(\lambda + 0.00284688)(\lambda+6.790678585+6.342106097j) = 0 \quad \text{.......(2)}$$

Comparing the characteristic equations of (1) and (2), we get

$K_1 = -0.09312$ $K_2 = -24.31553$ $K_3 = -7.48545$

$$\mathbf{K = [-0.09312\ \ -24.31553\ \ -7.48545]}$$

The feedback gain K can also be determined by using MATLAB:

```
>> A = [0,1,0;0,0,1;-0.339,-110.7,-21.07];
>> B =[0;0;1];
>> eigenvalues = [-
6.790678585+6.342106097j,-0.00284688, -
6.790678585-6.342106097j];
>> K=acker(A,B,eigenvalues)

K =   -0.09312       -24.31553    -7.48545
```

Figure : State feedback gain K obtained using MATLAB

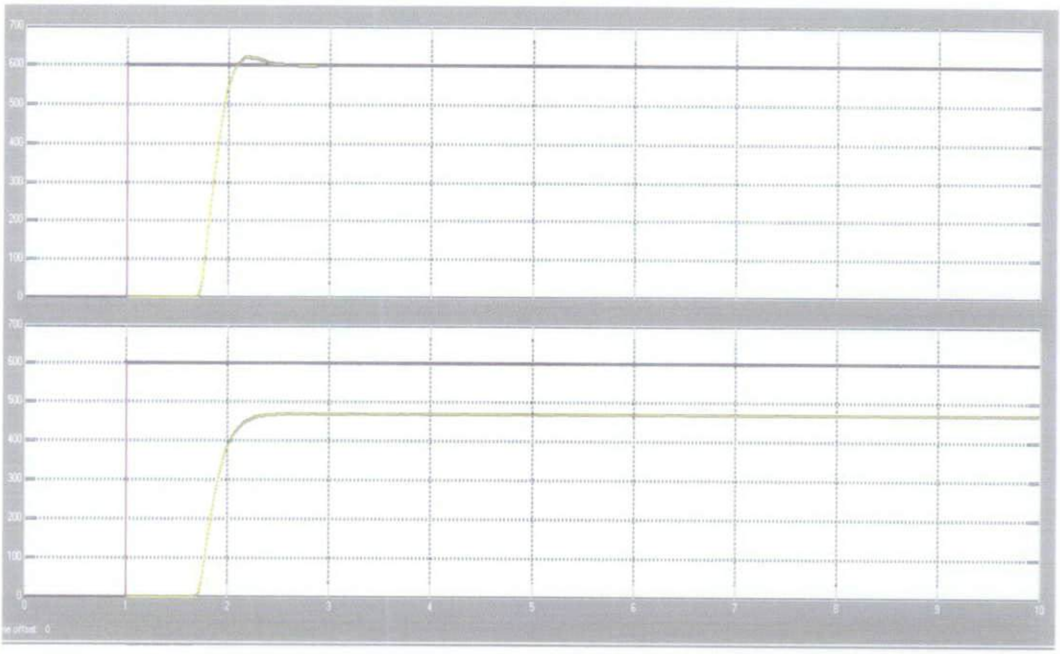


Figure 4.10: System response using the best pole placement

Based on the figure shown, using heuristic method, movement of the poles yields the response correspondingly. Poles at -6.790678585+6.342106097j, -0.00284688, and -6.790678585-6.342106097j are the best pole placement which produce system response that meets the set point Here, lower overshoot is produced 3.2% and it has good settling time at 2.63s although the system has dead-time which contribute to time lag exists at the early part.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In a conclusion, this project is a comprehensive research study about PWM-driven induction motor system model which is developed in MATLAB/Simulink using the plant transfer function. This project has met the objectives which are to develop a method of modelling and designing a state space controller for Pulse Width Modulation (PWM) driven Induction Motor. It has succeeded to evaluate the control performance of state space controller using suitable control technique, pole placement method through simulation in MATLAB/Simulink using the plant transfer function.

For future research, detail study on the suitable control technique using pole placement method is conducted to investigate the best output response for higher order system and to evaluate the performance at the controller under various load conditions and for three speed regions: LOW – low upto 300 rpm/MEDIUM – 500 up to 800 rpm/HIGH – 900 – 1200 rpm. It is expected system response improvement by having real-time implementation of the controller in regulating the speed of the motor drive in response to the operating conditions. ‘.

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3.3 Activities/Gantt Chart and Milestone

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues															
2	Submission of Progress Report															
3	Project Work Continues															
4	Pre-EDX															
6	Submission of Draft Report															
4	Submission of Dissertation															
8	Submission of Technical Paper															
9	Oral Presentation															
10	Submission of project dissertation(hardbound)															

Table 1: Gantt chart and Key Milestone