“ I hereby declare that I have read through this report entitle “Controller Tuning By Using Optimization Technique For An Electro-Hydraulic Actuator System” and found that it has complied the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation & Automation) With Honors ”

Signature: ....

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CONTROLLER TUNING BY USING OPTIMIZATION TECHNIQUE FOR AN ELECTRO-HYDRAULIC ACTUATOR SYSTEM

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A report submitted in partial fulfilment of the requirements for the degree of Control Instrument and Automation

Faculty of Electrical Engineering

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YEAR 2015/2016

I declare that this report entitles "**Controller Tuning By Using Optimization Technique For An Electro-Hydraulic Actuator System**" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ....

Name: ....

Date: ....

To my beloved mother and father

ACKNOWLEDGEMENT

In the name of Allah, the Most Beneficent and The Most Merciful. It is deepest sense gratitude to the Almighty that gives me strength and ability to complete this final report.

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ABSTRACT

Nowadays, the application that use of Electro Hydraulic Actuator (EHA) system in the industrial sector has been widely applied. This is because the system produces high power to weight ratio, smaller size, and faster responds than existing CHA (Conventional Hydraulic Actuator) system. The EHA system has been developed to replace the CHA system that has some problem such as leakage of the working fluid, maintenance load, heavy weight and limited installation space. However, the system of EHA system has produced nonlinearities and uncertainty characteristic. Therefore, to improve the performance, the parameter require to compensate the changes in EHA system. In this project, PID and LQR control tuning using PSO (Particle Swarm Optimization) by using Matlab coding. Other than that, the transient of performance in term of settling time, rise time and overshoot will be determine by compare both controllers. The performance index, integral of time square error (ITSE) will be used in optimization technique in order to find suitable parameter for PID and LQR. The last chapter, will be discussed which controllers will gives are better performance between PID and LQR with more precision and flexibility.

ABSTRAK

Pada masa kini, aplikasi yang menggunakan Elektro Hidraulik Penggerak sistem dalam sektor perindustrian telah digunakan secara meluas. Kerana system ini menghasilkan kuasa yang tinggi kepada nisbah berat, saiz yang lebih kecil, dan tindak balas lebih cepat daripada Hidraulik Konvensional Penggerak sistem yang sedia ada. Sistem Elektro Hidraulik Penggerak telah dibangunkan untuk menggantikan sistem Hidraulik Konvensional Penggerak yang mempunyai beberapa masalah seperti kebocoran bendalir kerja, beban penyelenggaraan, berat dan ruang pemasangan yang terhad. Walau bagaimanapun, system Elektro Hidraulik Penggerak telah menghasilkan parameter tak lelurus dan ciri-ciri yang tidak menentu. Walaubagaimanapun, system EHA ini telah menghasilkan system tak terlelurus dan ciri-ciri yang tidak menentu. Oleh itu, untuk meningkatkan prestasi, memerlukan imbagi parameter kepada perubahan dalam system EHA. Dalam projek ini *Proportional Integral Derivative* (PID) and *Linear Qudratic Regulator* (LQR) telah digunakan pada *Particel Swarm Optimization* (PSO) dengan menggunakan kaedah Matlab. Selain itu,prestasi sementara akan dinilai dari segi peratusan terlajak waktu penyelesain, waktu naik dan ralat keadaan mantap akan dikenal pasti untuk pembandingan kedua-dua kawalan. Indeks prestasi, *Integral Time Square Error* (ITSE) akan digunakan dalam dalam teknik optimum untuk mencari parameter yang sesuai untuk kawalan PID dan LQR. Di bab yang terakhir, akan dibincangkan kawalan yang mana akan memberi percapain percapain yang terbaik diantara PID dan LQR dengan lebih fleksibel dan lebih tepat.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, the application Electro Hydraulic Actuator (EHA) has been widely used in the industrial sector. This is because the system produces high power to weight ratio, smaller size, and faster responds than existing CHA (Conventional Hydraulic Actuator) system. The EHA system has been developed to replace the CHA system that identified to cause a problem such as leakage of fluid during working with involve big and heavy equipment that applies with CHA or running the application, high maintenance cost part that applies in CHA heavy and limited space for installation. Moreover, the performance of the EHA system in term of position control requires an accurate EHA to determine the position and robustness of the controller. Besides that, the system need to develop and make sure that robustness and tracking accuracy is significant with desired output. However, the system with application of EHA system has produced nonlinearities and uncertainty characteristic. These effects emerge from the friction and internal fluid leakage system. To perform the performance of EHA, a suitable controller need to be designed in order to achieve the desired output of the system. The output response of two different type of controller will be applied to EHA system. The LQR and PID will be designed as a controller of the nonlinearities and uncertainties to improve the performance of the EHA system. Optimization technique Particle Swarm Optimization (PSO) technique will be use in this study to optimize the parameters of LQR and PID Controller.

1.2 Motivation

The application of EHA system technology has spread into many different fields including robotics, aircraft, manufacturing system and etc. Due to higher performance of the EHA system in term of position and pressure the nonlinearities and uncertainties characteristic have to be considered. The intelligent controller tuning will be used in the EHA system to improve the performance of the EHA system. Optimization technique will be used in this project to acquire the best parameter tuning. PID and LQR were chosen to apply in the Electrohydraulic Actuator system. The advantage of using PID which is having a wide range of application in industrial control while the advantages of LQR is the system always be stable and robust.

1.3 Problem Statement

An Electro Hydraulic System is one of important application in the industrial sector and engineering practice. The advantages of EHA system its high power to weight ratio and stiffness response being good, smooth and fast. However the EHA system has a problem in terms of friction and internal fluid leakage. It happen because the system is highly nonlinear [8]. Other than that, the effects of nonlinearities and uncertainties will degrade the performance of the system in terms of robustness and tracking performance. Hence proper selection of controller are crucial at which it will improve the performance since the performance of EHA will degrade the controller. The parameter required a change to compensate the changes in EHA system. Manual trial that still being used nowadays are not efficiency because trial and error method not good technique if the problems situation doesn't gives multiple changes to find a solution and sometime need to repeat many times to get best parameter. Hence this project will use the optimization technique to tune the selected controller parameter.

1.4 Objective of Project

The aim of this project is to obtain the parameter for the LQR and PID tuning for Electro Hydraulic System (EHA) using optimization technique. Therefore the objectives are.

1. To implement LQR and PID controller to EHA system and tune controller parameter using PSO.
2. To compare system performance in term of index, Overshoot, Settling Time, Rise Time and precision of the controller.

1.5 Scope of project

In order to achieve the objective of the project, several scopes of project have been outlined:

- The LQR and PID controller are chosen as the controller of the nonlinearities and uncertainty model of EHA system.
- The LQR and PID parameters will be tuned using optimization technique which is Particle Swarm Optimization.
- ITSE will be used as the performance index to the system performance for both LQR and PID will be compare in term of performance index response (Settling Time, Rise Time and Overshoot) and precision.
- All simulation work will be shown using MATLAB software.

1.6 Project outlines

This report basically divided into five chapters which is chapter 1 is an introduction, chapter 2 is a literature review, chapter 3 is a methodology, chapter 4 is a result and discussion and lastly chapter 5 is a conclusion and future works.

Chapter 1 will introduces the readers with the basic aspect of the research done, such as the overview of the electrohydraulic actuator system, problem statements, objective and scopes of the project. Chapter 2 will reviews the basic principle of the system, related previous work and other reviews related to this project. Chapter 3 will show the flow of the study and methodology related to this study. Chapter 4 will present the result of the system performance by using LQR and PID controller by using PSO. Both of the controllers will be tested with disturbance. Chapter 5 consist of the conclusion based on the overall works and results and include some future improvement that can be done in the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the literature review for Electro Hydraulic Actuator (EHA) system. This stage will review related previous work and other related to this project which are EHA system background, EHA system operation, control strategy in the EHA, application for EHA system, controller of EHA systems and lastly optimization technique. The observation from this chapter will determine for the next chapter is a methodology.

2.2 Electro Hydraulic Actuator (EHA) System Background

2.2.1 Description of EHA System Background.

An Electro Hydraulic Actuator (EHA) system is driven systems are central factors in industrial process and engineering practice. Electro hydraulic actuator system has been widely used in industry because of a like large dynamic system to guarantee the performance of the system [1]. It is because the system working under high speed condition and fulfil the requirement of standard industry ,include their ability to produce large force at high speed during durability and stiffness and their rapid response[2], [3]. However, the system is faster responding than the existing conventional hydraulic actuator (CHA) system [4]. The system that is being applied in CHA commonly used as power units. In addition, ability to generate very large power compared to their size. The basic function of CHA is to transfer the working fluid and an actuator. Devices that creates a mechanical motion by converting into various form of energy into mechanical energy known as actuator. The problem are faced in CHA system firstly is environmental. The leakage of the working fluid maintenance caused the pollution. In addition, the leakage occurs when high pressure during working fluid. It is between joint of pump, fluid conduits, manifold and fluid conduit. Secondly, the problem is heavy weight. Many parts of hydraulic system are more expensive. It is because the requirement to build and construct need a powerful pressure to operate the requirement system. Lastly is the limited space consumption system CHA. Basically, the system consists of many components and valves to operating. It necessity to improve the system of CHA like size, system maintenance and environmental pollution. EHA system was developed to replace the role of the CHA system with the best performance of the EHA in terms of position, force or pressure is needed [2].

2.3 EHA System Operation

The main components of EHA system include an electrical motor, pressure and position sensors, a bidirectional gear pump, a symmetrical actuator and an accumulator sub-circuit [5] based on Figure 2.1. The EHA uses a bi-directional, fixed displacement gear pump to supply oil to the actuator. The function of the electric motor to generate the flow rate by rotating the motor. The pressure that generated by flow rate will changes the position of the piston rod and also varying the speed of the motor. It is because when the flow encounter a resistance such as an actuator, the pressure on fluid will increase [6].The symmetrical actuator is connected with an external load. In addition, the motion of load can be control. The useful part to influence load is a motor, by controlling the speed of the electrical motor.

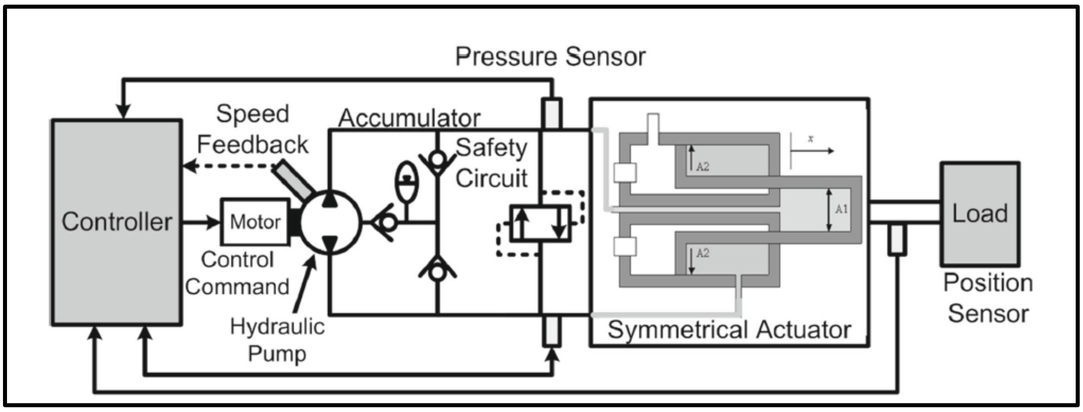

Figure 2.1: Schematic of the EHA hydraulic circuit [5].

2.4 Control Strategy in the EHA

The EHA position control system consist two hydraulic sub-circuit. Which is, outer loop and inner loop, as shown in Figure 2.2. Outer-circuit connected to the symmetrical actuator and an inner-circuit with low-pressure accumulator [6]. Inner loop for control the angular velocity control of the servo motor or pump and outer loop for the position control of the piston [4].Inner loop is an important process because it regulate the electric motor to provide an accurate control into the pump flow. In addition, the friction occurred at pump-motor interface when flow control strategy desensitizes the system into dead-band. The outer loop is an important part in EHA system and to improve the performance and robustness of EHA in term of the position control system.

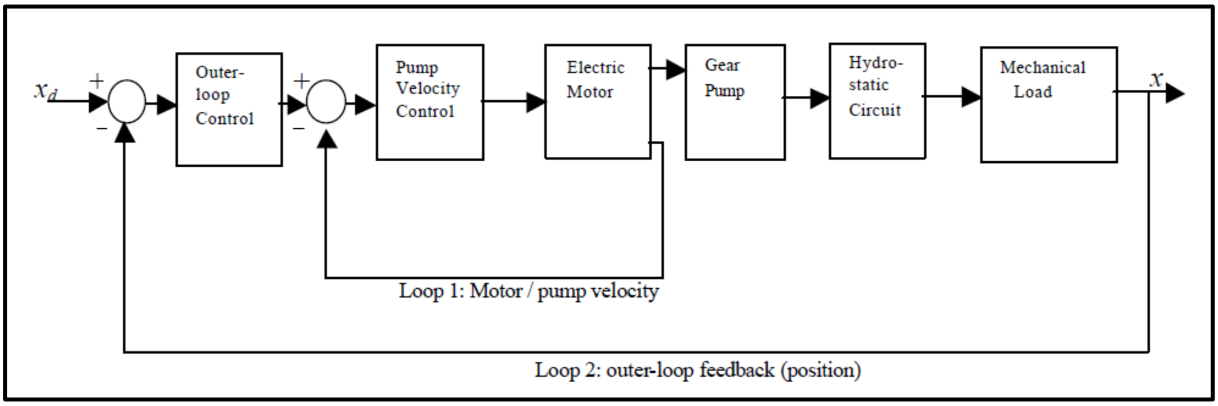

Figure 2.2: Control Block Diagram for the EHA [6].

2.5 Application for EHA System.

The use of EHA has spread into many different fields due to their advantages. Recently, with the research and development of the hydraulic control has been developed and used widely in many applications such as manufacturing system, material testing machineries, fatigue testing, flight simulation, paper machines, ship and electromagnetic marine, robotics, and steel and aluminums mill equipment [7].

The ability of EHA system such as high power to weight ratio, fast and smooth response characteristic, accurate positioning of heavy load, stiffness response and good power capabilities have increased the number use of EHA in industries. For an example injection molding machines as shown in Figure 2.3. Injection molding machines have several steps that needed to produce a product. The step is clamping, injection, dwelling, cooling, mold opening and removal of products. This method is suitable for production that produces with complicated shapes. Moreover, EHA system is the best way to implement in this method. This is because EHA produces high power to weight ratio and also accurate positioning for plastic processing. In addition, application of wind turbine also implement EHA system. The fundamentals and principles of hydraulic system used for wind turbines, such as for pitch control, yaw control, braking and cooling or filtration systems. For pitch control system, the function is to adjust the pitch turbine blade angle based on Figure 2.4. Basically, the technical feature electrohydraulic pitch control system is precision control, high level of integration, compact design, reliable fail-safe function, integrated safety function and high positioning forces.

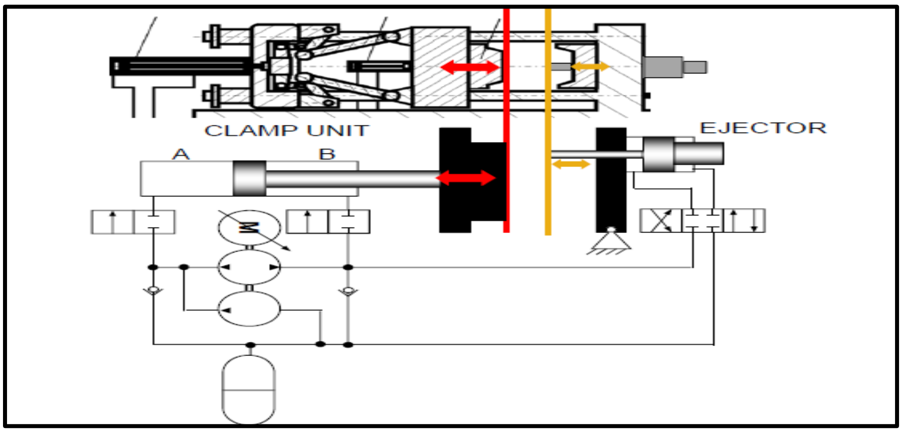

Figure 2.3: Injection Molding and Die Casting Machines [21].

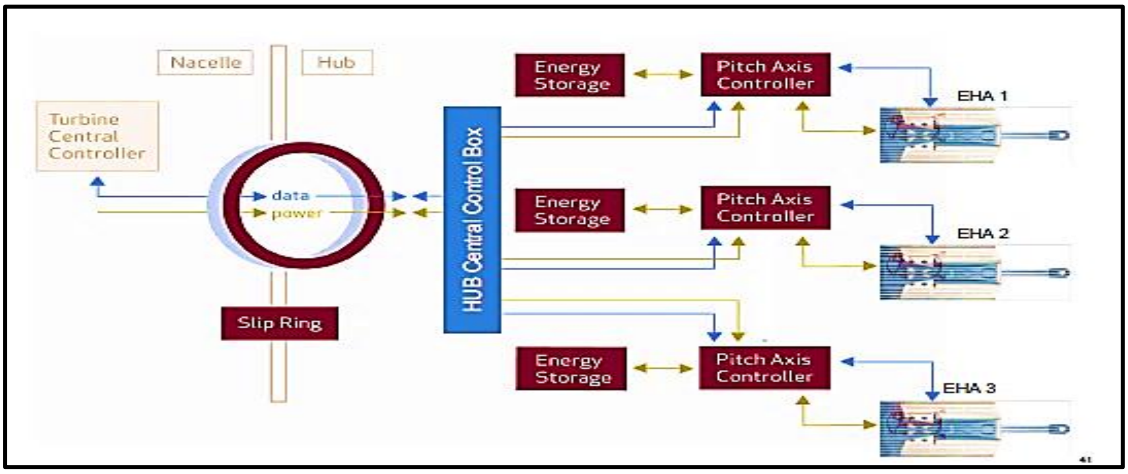

Figure 2.4: Wind turbine circuit diagram [21].

2.6 Control of EHA System.

The ability of EHA system, the system become one of the important drive system and play an important role to implement in application in industries. However, the constraints that appearing in EHA system will interrupt the application of the hydraulic control system. The internal and external disturbance that yields the nonlinearities and uncertainties in hydraulic control system. [8]. Thus, this effect will contribute disturbance of performance and degrade the system. To avoid the nonlinearities and uncertainties in EHA system, improve the control performance of EHA by designing a robust controller to compensate the nonlinear behavior of hydraulic system. Although EHA has uncertainty and nonlinearities problem, many researchers have conducted research on performance EHA, due to its advantages.

Examples of robustness controller that have been applied to EHA system have been reviewed. Many advanced control techniques have been used by researchers, but in this thesis only a few control systems will be discussed.

2.6.1 Proportional, Integral and Derivative (PID)

PID known as Proportional, Integral, and derivative or any combination controller. PID can be implemented in a wide variety of operating systems because of their functional simplicity and reliability. PID controller is designed for controlling the position of the actuator and potential to cope with physical uncertainties and external disturbances[9]. In [32] state that PID controller using tuning method are given better performance compare to conventional PID and it give good performance in term of give less overshoot and less setting time. The PID controller can be tune without approximately model .The ability of PID system can be improve the transient response of the system such as overshoot, rise time, settling time and steady error by tuning parameter PID.

$$\mathrm{u(t)} = \mathrm{KPe(t)} + \mathrm{KI}\int_0^t e(t)dt + KD\,\frac{d\,e(t)}{dt} \tag{2.1}$$

From the formula PID, e (t) is error, u (t) is the controller output and Kp, Ki and Kd are the parameter of PID based on equation (2.1). Based on Table 2.1, the comparison between Kp, Ki and Kd to the effect of controller applied on a closed loop system.

Table 2.1 Comparison between Kp, Ki and Kd

Types of controllers	**Rise Time**	**Settling Time**	**Steady State Error**	**Overshoot, Os**
Proportional	Decrease	Small Change	Decrease	Increase
Integral	Decrease	Increase	Eliminate	Increase
Derivative	Small Change	Decrease	Small Change	Decrease

The advantage of using PID which is simple control structure that easy to understand by plant operator and found relatively easy to tune. In addition, a system using PID has proven satisfactory and also have a wide range of application in industrial control.

2.6.2 Fuzzy Logic Controller

The new approach of controller, to overcome the uncertainties and nonlinear problem the fuzzy controller were applied to EHA system. A few of research toward on fuzzy logic control has been done and utilized such as fuzzy with PID and adaptive PID control using fuzzy [17]. Jun et. al [25] presented fuzzy logic self – tuning PID controller to a nonlinear characteristic system for regulating brushless DC motor (BLDC) of EHA system. The nonlinear characteristic that occur such as saturation of the motor power and dead zone due to the statistic friction. The results show, when the Fuzzy controller implemented in EHA system, it can achieve fast response ability without overshoot. In addition, representing, manipulating and implementing a human heuristic knowledge for formal methodology can be provided to control a system performance [8].

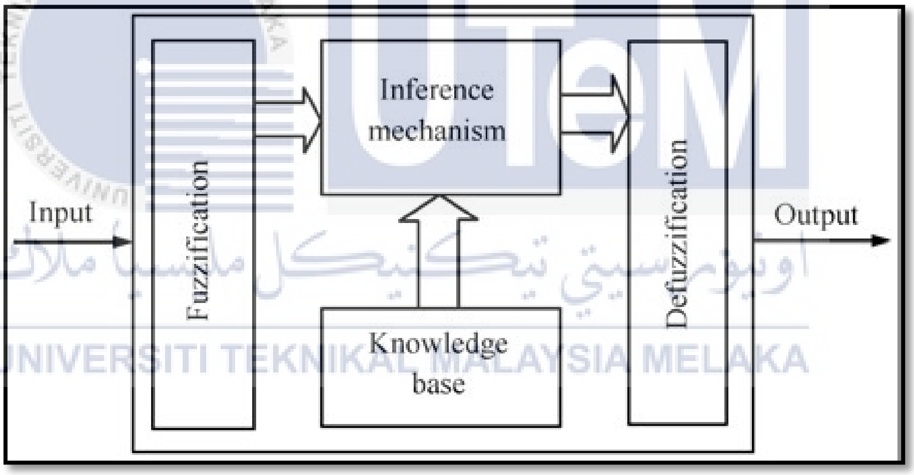

Figure 2.5: The fuzzy logic controller block diagram [8]

Four main components in fuzzy controller is Fuzzification, Inference Mechanism, Knowledge Base and Defuzzification based on Figure 2.5. The table is shown in Table 2.2 shows the every single function fuzzy logic controller block diagram.

Table 2.2 Function block diagram Fuzzy Logic Controller.

Function	Description
Rule based	Hold the knowledge in order to set a rules of how to control the system.
Inference mechanism	Evaluates which control rules are relevant at the current time and decide the input plant should be
Fuzzification interface	It modified the input so they can be interpreted and compare to the rules in the rule–base.
Defuzzification	Analyze the inference mechanism into the input to the plant

2.6.3 Sliding Mode Control (SMC)

In addition, the controller that's been used is sliding mode control (SMC). SMC has become as one of the powerful tools in terms of control positioning tracking performance of the EHA system [10], [11]. The SMC scheme consisted of two terms. Firstly is the equivalent term for linear system and secondly the robust term for unknown system uncertainties. It seemingly solution for eliminating uncertainties and disturbances. Besides, large parameter variations are available in these controllers. Perron et. al [12] proposed a sliding mode control scheme for showing volumetric capacity perturbation of the pump in terms of robust position control of EHA system.

However, in this controller have several lack of result achievement. Discontinuous control action in SMC result produces chattering phenomenon. Which is, it will reduce tracking accuracy, vibrates the system and may reduce the life cycle of the EHA system. Moreover, this control have limitation of control performance. This is because SMC is bounded information with uncertainties system. Other than that, there is discontinuous control signal that result in excites unmodel system and decrease its performance, this problem is partially reduce by Fung and Yang [16].

2.6.4 Adaptive Control System

Adaptive control system was adopted to solve the uncertainties problem in EHA system. It is a valid method, particularly uncertainties derived from uncertain parameters. Adaptive control system was proposed by researches and assuming this controller is linearized system models. This controller has an ability to manage with small change parameters. In addition, it potential to cope the valve flow coefficient, the fluid bulk modulus and variables loading [14]. But this controller, must consider to adapt the parameters which carry or are initially uncertain [3]. Kaddisi et. al. [13] applied a robust indirect adaptive back-stepping control (ASBC) scheme to EHA systems having perturbation of the viscous friction coefficient and the effective bulk modulus due to temperature variations. Furthermore, many control schemes have been used by researchers to apply in the EHA system to compensate uncertain parameter such as sliding mode adaptive control, feed-back-precise linearization adaptive control and nonlinear adaptive control based on back stepping techniques. However, adaptive control just only suitable for small changes parameter and not for large changes in the system parameters, as was demonstrated experimentally by Bobrow and Lum [15].

2.6.5 Linear Quadratic Regulator (LQR)

The LQR is technique in modern control theory that used the state space approach to analyze such a system. State space methods were used to relatively simple work with a multi-output system. Full-state feedback system in LQR give a system in stabilizing conditions. Besides, LQR also gives the best possible performance measure with respect to some given measure of performance. The performance measure is a state vector and control output. In addition, the LQR method was provides better performance such as of rise time, settling time compare with PID controller [26]. Moreover the LQR and H∞ are underlined for their controllability by giving out an optimal and robust performance depend on mathematical model-base. If the mathematical model were derived accurately and the performance of the controller will be improved [27].

In [29] LQR and Fuzzy Logic Controller were applied for controlling the pitch angle of an aircraft system. It shows that the LQR and fuzzy logic is capable to control the pitch angle of the aircraft system. From the simulation, it shows that the LQR gives better performance than fuzzy logic control system such as rising time, settling time and percent of steady state errors and also good in eliminating the error. In addition, Lal Bahadur Prasad, Barjeev Tyagi and Hari Om Gupta in [28] were applied LQR and PID to control the nonlinear inverted pendulum-cart system with disturbance input. The result from simulation show that response of LQR is better than PID. This is due to LQR controller are robustness and effective controller that capable to producing very small steady- state error.

In addition, the advantages of LQR is the system always be stable and robust. It is also tool for complex system that require high robust in the performance desired. Other than that, when using LQR controller it obtain precision, speed, recovery time, efficiency and safety. Therefore, there are several systems that used to improve the system of the performance.

2.7 Optimization Technique

In the real world, many problems are continuous and also difficult in finding the global solution. Although the development in computer technologies is increasing the speed of computations, but the lack of size is the problem. Applying the exact algorithm on such problem is necessitated. Heuristic are the best solution to tackling the problem within reasonable computational time and give an approximate solution.

The researches were development of the algorithm which have been based on natural phenomena. Nowadays have more the inclination to the meta-heuristic algorithms method and he major of advantages in using of meta-heuristic to search flexibility, speed and high performance and it is the features of global [18]. Many Meta – Heuristic algorithm have been implement base on the nature of which is Particle Swarm Optimization (PSO), Artificial Colony Bee (ABC), Firefly Algorithm (FA), Genetic Algorithm (GA) and Neural Network Algorithm. Many advanced optimization techniques have used by researchers, but only a few techniques will be discussed in this thesis.

2.7.1 Particle Swarm Optimization (PSO)

PSO is a population – based evolutionary computation technique and were prompted by social behavior among individuals. Kennedy and Eberhart were introduced PSO in 1995. PSO inspired by swarming behaviors such as observed in a flock of birds, schools of fish or a swarm of bees [8]. Each particle have position and velocity in order to decide the flying direction and tracking the current optimal particle in the search space. If the solution has found, all particles can share information and search next solution [19]. In [8] the optimized parameters are the factor of the scaling fuzzy inference system. Then after the optimized parameters are obtained, the performance will robustly the unoptimized and optimized FLC and lastly the system will compare. The result show that, optimized by PSO has been successfully implement which is does not introduce any delay and tracking error compare to the system are using PID controller.

2.7.2 Genetic Algorithm (GA).

Genetic programming is one of technique which base on the mechanics of natural genetics. Basically, GA were used for solving constrained and unconstrained optimization problem. In addition, GA technique is based on the Darwin theory of natural evolution that specified in the origin of species. An advantage of the GA is suitable for auto tuning. This is because, GA technique does not need gradient information and can operate to minimize naturally defined cost function without using complex mathematical operations. Genetic programming function like a probabilistic algorithm. Ability to searches the space of compositions from available functions and terminals under the guidance of a fitness measure [14]. Figure 2.6 show the flowchart of the parameters optimizing procedure using GA technique. The essential operation to create new population is by applying reproduction, crossover, mutation and architecture-altering operation.

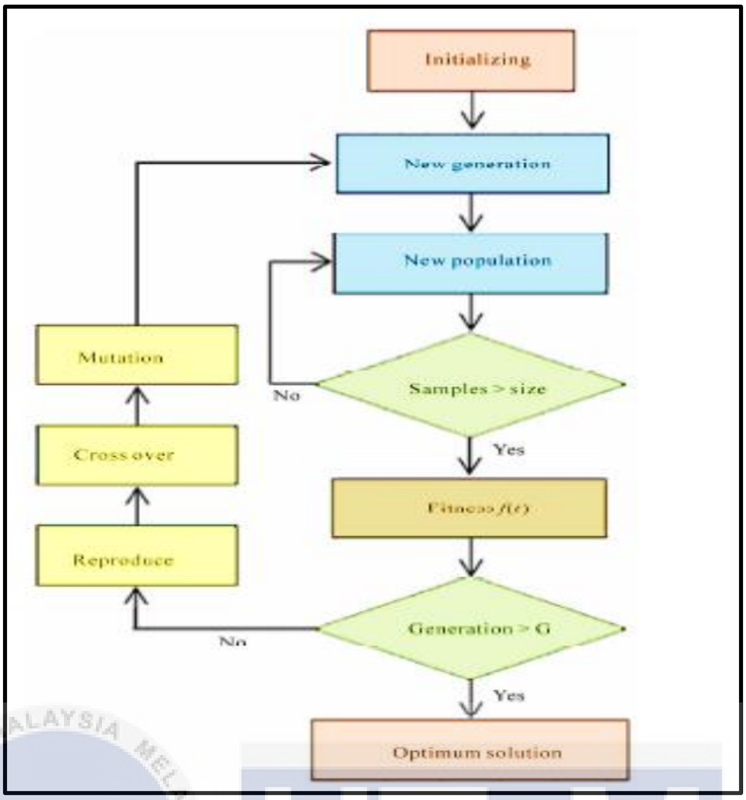

Figure 2.6. The optimization flowchart of GA technique [14]

2.7.3 Imperialist Competitive Algorithm (ICA).

The imperialist competitive algorithm is inspired by the imperialist competition. ICA equivalent to the chromosome in GA and PSO. Briefly, ICA starts with initial population. Population individuals are called countries are divided into two types first is colonies and the second is imperialist all together are the same empires. This algorithm concept, which empires powerful will take the possession and the weak empires will collapse. The competition among empires will happen until just one empire in the world and all the other countries are colonies of the empires. Figure 2.7 show the flowchart of the parameters optimizing procedure using ICA technique. This method were used to find optimal or suitable solution in term of the variables of problem. ICA technique was implemented with PID in [3] for controlling the position of a nonlinear. The result show that overshoot, settling time and steady error can be minimize.

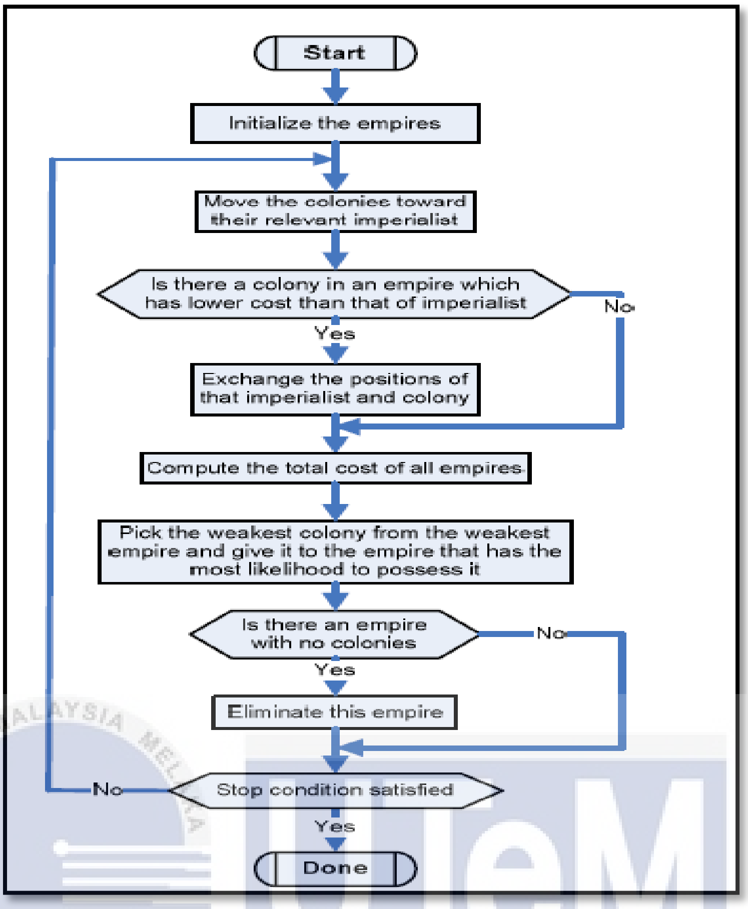

Figure 2.7: Flowchart of the propose algorithm [20].

2.8 Conclusion

To perform the performance of EHA, a suitable controller need to be designed in order to achieve the desired output of the system. In this report, PID and LQR were chosen as controller to improve the performance Electrohydraulic Actuator with uncertainties and nonlinearities problem. The other controller can obtain a good result, but using PID give simple control structure that easy to understand, easy to tune and wide range of application in industrial while LQR gives the system always be stable and robust. Optimization technique Particle Swarm Optimization (PSO) will be used in this study to optimize the parameter of LQR and PID controller. From the review researchers, PSO does not introduce any delay and most popular technique.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project. Each stage of work is divided into several parts which are flow of the study, transfer function model of EHA system and the controller that will be used for this project is LQR and PID controller using the PSO optimization technique.

3.2 Flow of the Study

The flow of this project had been developed to ensure the project finish at the right time and student able to conduct with systematically. After the selection of the title were done, in order to understand about the project, literature review were done first. The evaluation was focused on EHA system, intelligent controller, optimization technique and other linked topic. After chapter two done, the next writing is writing chapter one which is the introduction of the progress report. At this stage the research were started in order to understand and determine the performance of EHA system. Besides that, in chapter 3, the mathematical modelling of the EHA system is constructed from research material. The transfer function of the EHA system, it will be used for the system simulation. For this stage the system simulation were performed to obtain the preliminary result. The system performance of EHA system simulation with implementation of the LQR and PID controller. The controller of the parameter of this project will be determined by using optimization technique which is PSO.

3.3 Mathematical Model of EHA System.

The mathematical modelling of the EHA system is constructed from research material. In [30] transfer function of the electrohydraulic system should be identified primarily regarding to several physical laws. Merritt et. al [31] presented that a several physical laws such as the dynamic equation of servo valve, the flow equation and the continuity equation and the force balance equation. The electrohydraulic system can be described by a third-order system. Besides, the parameter of this transfer function can be calculated regarding to the manuals provide by the manufacturers, but the problem occurs because of difficult to obtain the leakage coefficient and the transfer function was determined based on the input-output data using MATLAB software.

$$\frac{XP}{u} = \frac{Kq\ Kv}{\frac{VtMT}{4\beta eAp} S3 + \left(\frac{KceT}{Ap} + \frac{VtBp}{4\beta eAp}\right) s2 + \left(Ap + \frac{KceBp}{Ap} + \frac{KVt}{4\beta eAp}\right) s + a\,\frac{KceK}{Ap}} \tag{3.1}$$

$$RMS(y,\ y_m) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y(i) - y_m(i)\right)2} \tag{3.2}$$

$$VAF(y, y_m) = [1 - \frac{var(\ y - y_m)}{var\ (y)}\ x\ 100\% \tag{3.3}$$

where:

x_p : Displacement of piston

U : Input voltage signal

k_q : Valve flow gain

k_V : K is the equivalent spring gradient

v_t : Sum of two volume

m_t : Total mass of piston and load referred to piston

A_p : The area of piston

β_E : Viscous damping coefficient of piston.

y : actual output of displacement

y_m : output of the obtain model

N : Number of data.

Var () : variance operation

This system were used in [30] to see the behavior of EHA system. The input signal is the control valve in the range of [-8 8] volt, and the output signal is the displacement of the piston is in the range of 0 0.45 meter. This work for EHA system were developed by using open loop system. The output of the system were recorded and several data from the experiment with 100ms sampling time, 1000 data are collected. The first data is 600 data are used to train the model while the other is 400 data are employed to validate the obtained model. In addition, in order to weight the performance of different models of the system, the Root Mean Square (RMS) is applied to measure the precision of model based on Eq (3.2) and the Variance Accounted For (VAF) were implemented to evaluate the quality of the model by comparing the measurement output of the system based on Eq (3.3). After transfer identification function (TF) of the system is obtained as equation (3.4) [30].

$$\frac{XP}{u} = \frac{4.01}{8.46s^3+863.91s^2+1802.17s+1} \tag{3.4}$$

3.4 Design LQR and PID Controller.

LQR and PID controller will be used to control the electrohydraulic control system and the parameter for the controller will be used MATLAB algorithm (coding) with the chosen optimization technique. The result for both controllers will be shown in the next chapter.

3.4.1 LQR Controller.

The LQR is a technique that uses a state space method to analyse such a system. The two matrices Q and R are considered to control the system in order to maintain the performance of the system. In LQR system, value gain K is important to select the best gain to minimize the performance of the performance index, J. The LQR controller schematic is shown in Figure 3.1.

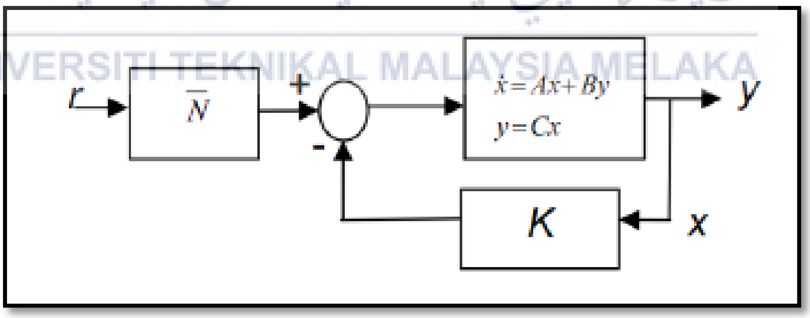

Figure 3.1: Schematic diagram for LQR

Below shows the state variable form to represent a system:

$$\dot{x} = Ax + Bu$$

The initial condition is x (0). Assume that all the state are measurable and seek to find a state-variable feedback (SVFB) control

$$U = -Kx + v$$

The closed-loop system using LQR control will be

$$\dot{x} = (A\text{-}BK)\,x + Bv = AcX + Bv \qquad (3.5)$$

Where *Ac* the close-loop plant matrix and *v (t)* is the new command input

Formula performance index (PI),

$$J = \frac{1}{2}\int_0^{\infty} x^T \; Qx + \; u^T Ru \; dt \qquad (3.6)$$

Substitute the SVFB control:

Performance Index (PI),

$$\text{J} = \frac{1}{2}\int_0^{\infty} x^T \; (Q + \; K^T RK)x \; dt \qquad (3.7)$$

It have procedure to find the LQR feedback, K:

I. Parameter matrices Q and R need to be design
II. The Algebraic Riccati Equation (ARE) for P need to be solved
III. Find feedback using K= $R^{-1}\,B^T$

Q is a positive semi-definite n x n matrix and R is positive definite m x m. If the value Q is choose larger and means keeps value J to become small.

To find the feedback, K value of P need to be determine. Below is the constant matrix P

$$\frac{d}{dt}\,(x^t Px) = -\,x^T(Q + K^T RK)x \qquad (3.8)$$

Now substitute the equation (3.8) into (3.7)

$$J = -\frac{1}{2}\int_0^\infty \frac{d}{dt}(x^T\, Px)dt = \frac{1}{2}\, x^T(0)Px(0) \qquad (3.9)$$

Then substitute the close loop equation (3.5) in (3.8)

$$\dot{x}^T\, Px + P\dot{x} + x^T\, Qx + x^T K^T RKx = 0$$

$$x^T\, Ac^T\, Px + x^T PA_c\, x + x^T\, Qx + x^T K^T RKx = 0$$

$$x^T(Ac^T\, P + PA_c + Q + K^T RK)x = 0 \qquad (3.10)$$

Assumed that external control v (t) is equal to zero. Thus, proceeding one sec that

$$(A - BK)^T p + p\,(A\text{-}BK) + Q + K^T RK = 0$$

$$A^T P + PA + Q + K^T RK - K^T B^T P - PBK = 0 \qquad (3.11)$$

This is a matric quadratic equation and exactly for the scalar case, must complete the squares. This procedure is a bit complicated for matrices, then select

$$K = R^{-1}B^{T}P$$

Then the results

$$A^{T}P + PA + Q + (R^{-1}B^{T}P)^{T}R(R^{-1}B^{T}P) - (R^{-1}B^{T}P)^{T}B^{T}P - PB(R^{-1}B^{T}P) = 0$$

$$A^{T}P + PA + Q - PBR^{-1}B^{T}P = 0 \quad (3.12)$$

Equation (3.12) as Algebraic Riccati Equation (ARE). In Matlab value ARX called LQR(A,B,Q,R). To reduce the steady state error of the system output, a value constant gain Nbar should add. The value of parameter LQR will be determined by using PSO.

3.4.2 PID Controller

PID known as Proportional, Integral and derivative and gives the simplest solution to various real-world control problems. The ability of a PID system can improve the transient response of the system such as overshoot, rise time, settling time and steady error by tuning of PID. Figure 3.2 shows the block diagram for PID controller. Besides, in this project the values of parameter Kp, Ki and Kd are determined by using optimization technique, PSO.

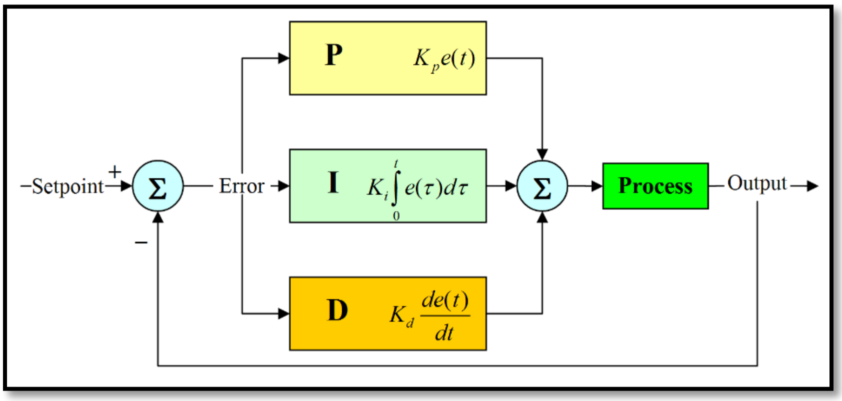

Figure 3.2: Schematic diagram for PID

3.5 LQR and PID Control Tuning using Optimization Technique.

This section will discuss about how LQR and PID controller work by using PSO in order to get better performance and result. LQR tuning method for finding Q1, Q2, Q3 and R while PID tuning method for Kp, Ki and Kd to achieve best parameter with the optimum value for the desired control response. Figure 3.3 and 3.4 shows diagram the LQR and PID controller with tuning block diagram.

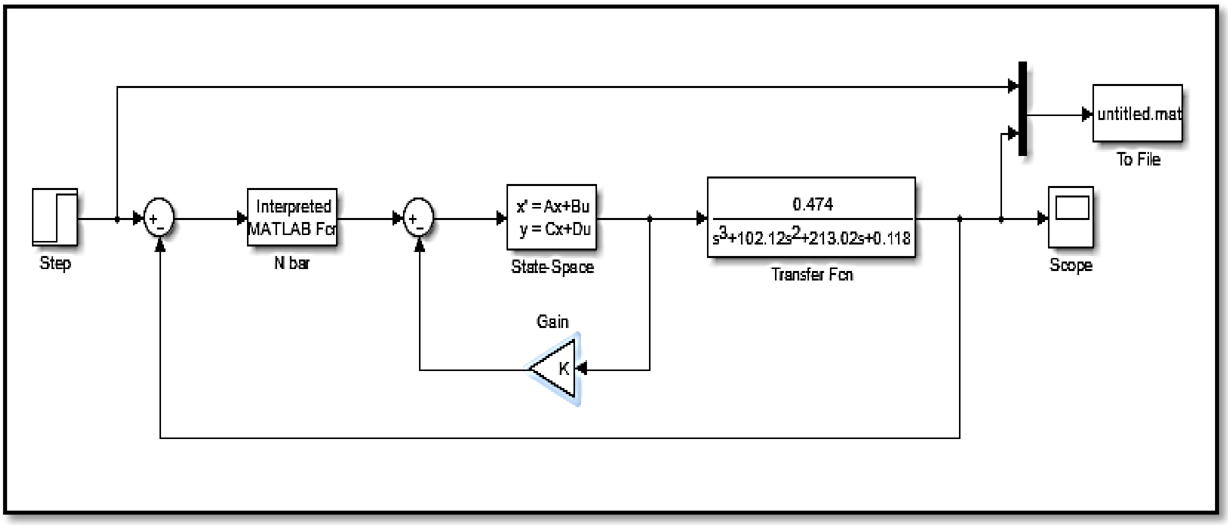

Figure 3.3: LQR Control Tuning block diagram

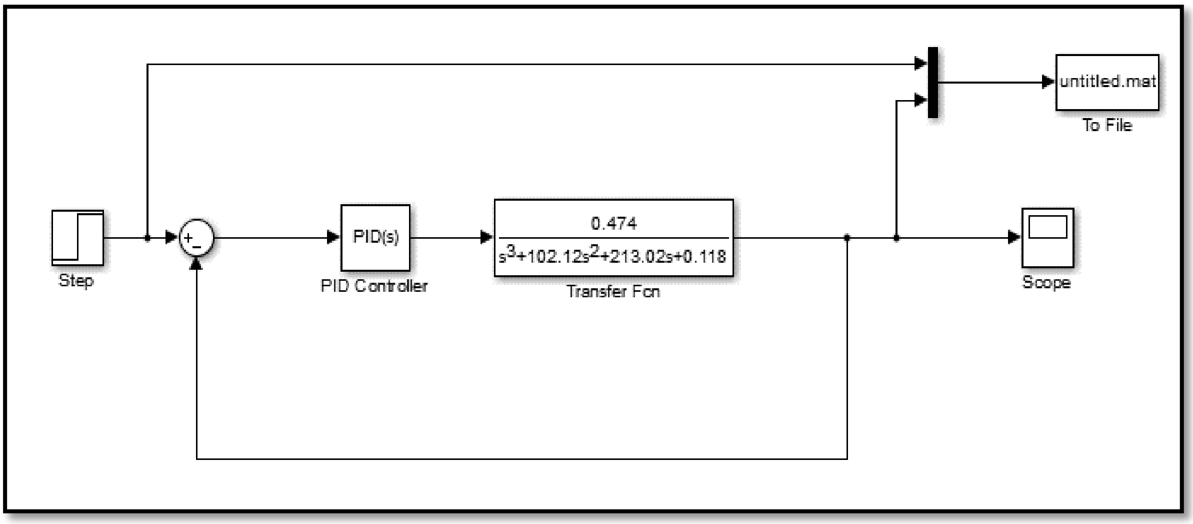

Figure 3.4: PID Control Tuning block diagram.

3.6 Optimization Technique

Optimization technique is a main part in this study. Therefore, this section explains briefly how the optimization technique algorithm being developed and also contains all the step and methods used. Particle Swarm Optimization was selected due to solve various function optimization problems and most popular technique.

3.6.1 Particle Swarm Optimization (PSO) technique

PSO inspired by swarming behaviours such as observed in a flock of birds, school of fish or swarm of bees [8]. Each particle have position and velocity in order to decide the flying direction and tracking the current optimal particle in the search space. If the solution has found, all particles can share information and search next solution [19]. The swarm of particle communication through adjustment of position and velocity. In this study, PSO was chosen to find optimal parameters to implement into both controllers based on Figure 3.5 so that the respond will improve in term of settling time, rise time, overshoot and performance index. Other than that, the system the effect of PSO makes the performance of controller more precision.

The general process on PSO works in a system for each execution:

1. The group of particles, including the random positions, velocity and acceleration of particles was initialized.
2. The fitness of each particle was evaluate
3. Compare the individual fitness of each particle with previous save data. If it is better update as a new data.
4. The velocity and position for each particle was update
5. Step 2 were repeat until the best stopping criteria is met

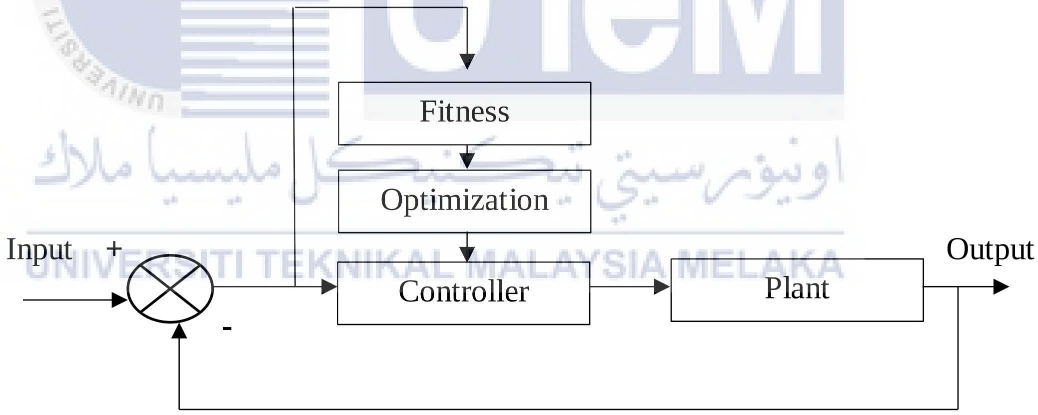

Figure 3.5: Diagram of controller with optimization technique

Figure 3.6 shows the flow of the PSO technique process with an optimization technique works in a system.

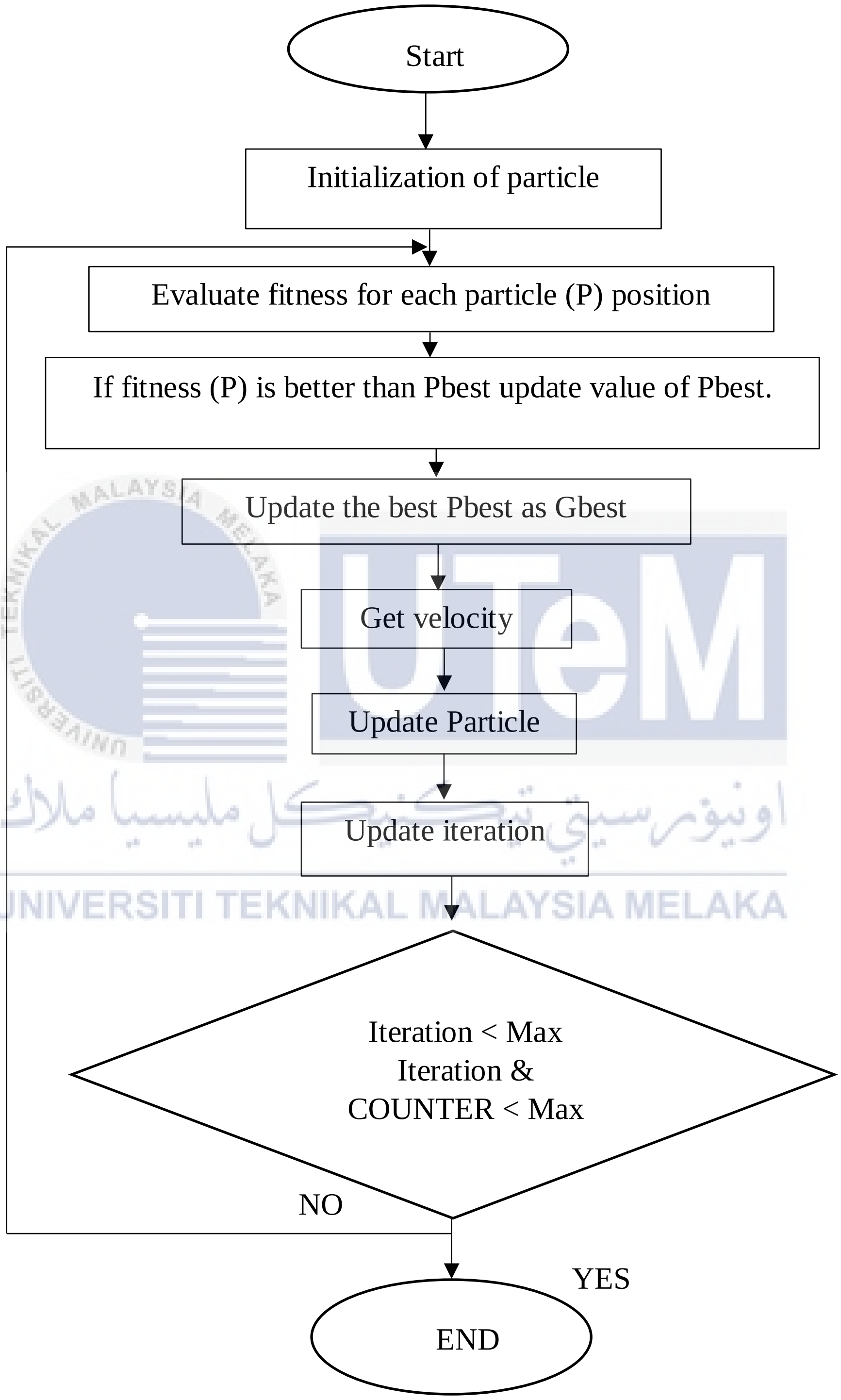

Figure 3.6: Flow of chart of PSO technique

There are several parameters that requirements to be initialized before executing the PSO algorithm. Each parameter is simulated using various numbers of criteria and the number of criteria will encouragement the performance respectively. Table 3.1 shows the set value of initialization in PSO.

Table 3.1 Parameter of PSO

INITIALIZATION	
Number of particles	20
Number of counter	9
Number of iteration	100
Search Range	0 - 100000
VELOCITY INITIALIZATION	
c_1, c_2	2
Maximum velocity	π /1000
Maximum weight	0.9
Minimum weight	0.4

In this project, there will be three tuning parameters method for PID which are Kp, Ki and Kd and for LQR have four parameters need to be tuning which are Q1, Q2, Q3 and R. Besides, the iteration of this project has two stopping criteria which is when 9 constants fitness values repeated during the range of iteration or when the iteration reach the maximum range. The initialization for iteration is evaluated based on the equation (3.11). The fitness of each parameter is evaluated during particle initialization.

$$Initialization = range_{min} + (range_{max} - range_{min}) \times random\_number \qquad (3.11)$$

The fitness is evaluated in order to find the particle best (Pbest). Each iteration Pbest will be updated based on better performance of performance index. The best performance index from Pbest will be updated as the global best (Gbest). The value of Gbest updated until stopping criteria meet. This process are iplements to find the best parameter for LQR and PID controller. Next phase is to evaluate the velocity and position of the particle. An inertia weight is added to the velocity equation in (3.13) in order to find the new velocity. The weight will act as a mechanism of exploration abilities of the swarm. The new particle position is obtained by summing the current position with the new velocity as in equation (3.14). These steps repeated until stopping criteria are met.

$$w_k = w_{max} - ((iteration\ x\ (w_{max} - w_{min}) / max\_iteration) \quad (3.12)$$

$$V_{i,k+1} = w_k V_{i,k+1} + c_1 r_1 (P_{pbest,i,k} - X_{I,k}) + c_2 r_2 (P_{Gbest,i,k} - X_{I,K}) \quad (3.13)$$

$$X_{i,k+1} = X_{i,k} + V_{i,k+1} \quad (3.14)$$

where:

V_i^k : Velocity of the i^{th} individual at iteration *k*

w_k : Inertia weight at iteration *k*

r1 and r2 :Uniform random number of [0.1]

c1 and c2 : Acceleration factor between 0 and 2

x_i^k : Position of the i^{th} individual at iteration *k*

$P_{Pbest,i,k}$: Best position of the i^{th} individual at iteration *k*

$P_{Gbest,i,k}$: Best position of the group until iteration *k*

3.7 Objective Function

The objective function is used to evaluate the performance index of the system. It represents system criteria that desired by the user and also can be found in various forms such as time-domain specifications, frequency domain specifications and time-integral performance. In this project, no specific criteria of the system as long gives the optimum value of the objective function. The smallest error of the objective function, the better the system of the performance index.

Time-Integral performance or Integral Time Square Error (ITSE) has been selected as the objective function. This selection used because ITSE behaviour has provided a better dynamic performance with good settling time. ITSE expression based on the equation (3.15) that refer from [32]. Based on the equation, ITSE only required system error and the answer will represent the area of the output and desired output.

$$\mathrm{I}TSE = \int_0^t (e_i\,(t))^2 \; t\,dt \tag{3.15}$$

$$e\,(t) = y(t) - r(t) \tag{3.16}$$

where:

e(t) = error

y(t) = output of system

r(t) = desired output

3.8 Simulation process

In this project, two controllers have been decided to implement in the EHA system by using PSO. For the information, the number of execution conduct for each simulation is 20 times and repeated for 10 times to get the best performance index. Every single execution were gives different value even though the same initial point used. After all executions done, the standard deviation will be calculated based on 10 values of fitness.

Secondly, that need to be considered is stopping criteria of the algorithm. Stopping criteria need to be introduced so that the system will know that it has found the best result. There will be two stopping criteria which is when 9 constant fitness values repeated during the range of iteration when iteration reach the maximum range for an example 100 iterations.

Lastly, all simulations will develop using Matlab coding for both controllers and PSO. The result obtains from the simulation will be discussed in the next chapter with shows the best parameter for LQR and PID controller. This Figure 3.7 shown flow of the simulation process.

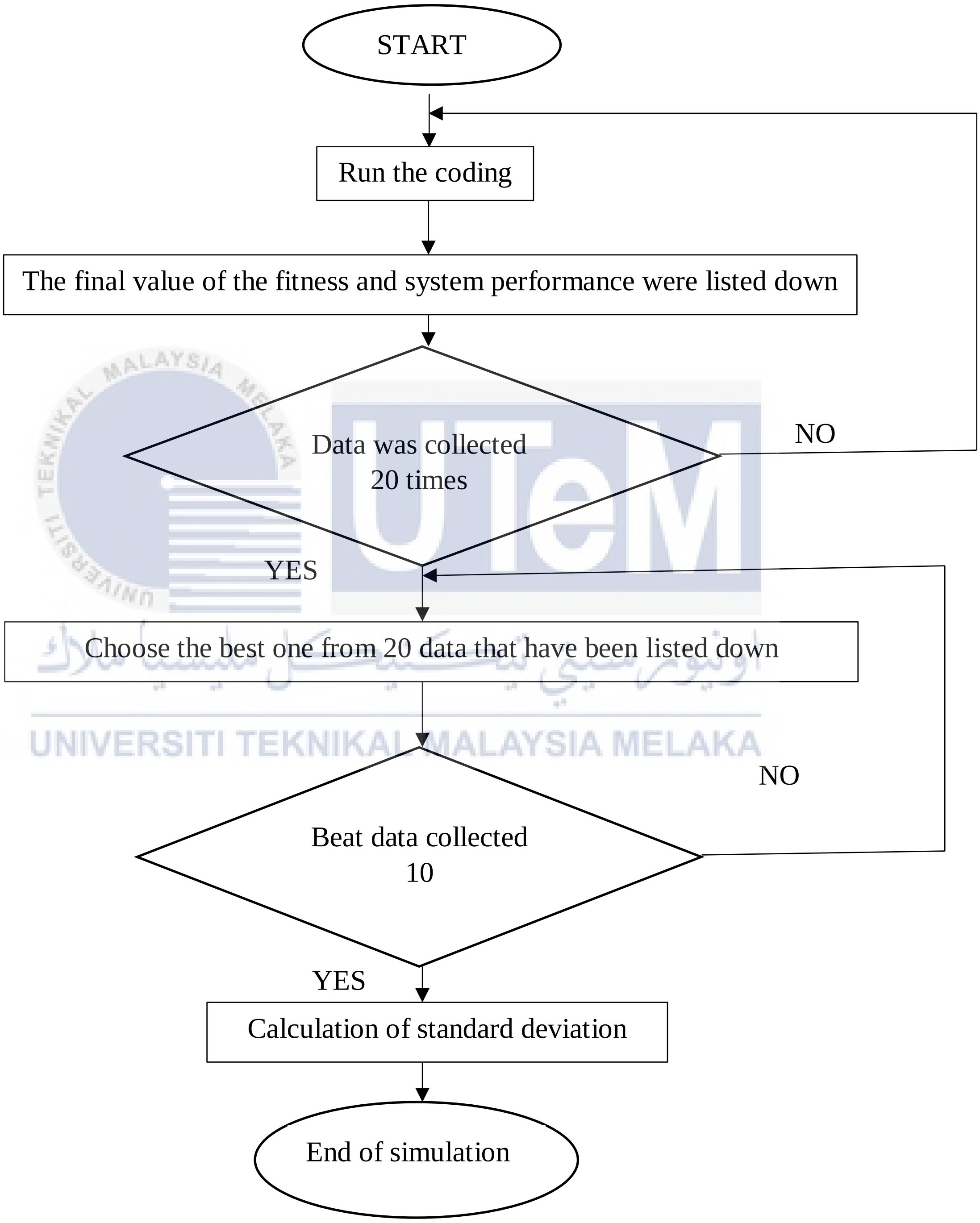

Figure 3.7: Flow of Process Simulation

3.9 Disturbance Test

For the part disturbance test, the system was applied with disturbance which is step input to test the effect of disturbance in obtaining the tuning parameter based on Figure 3.8 and Figure 3.9. Figure 3.10 and Figure 3.11 are Simulink model for both controller in Matlab when injected disturbance. This test are important in order to shows the ability of the controller to resist by any disturbance that might distort the system.

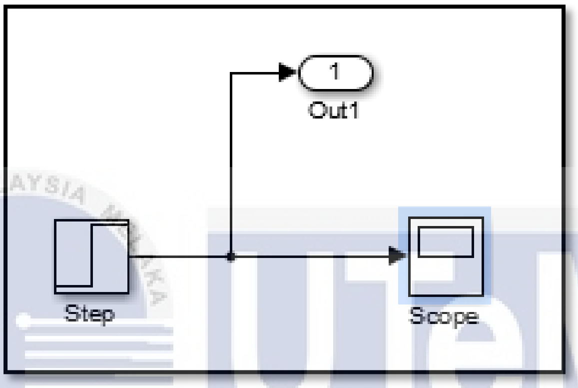

Figure 3.8: Disturbance Input

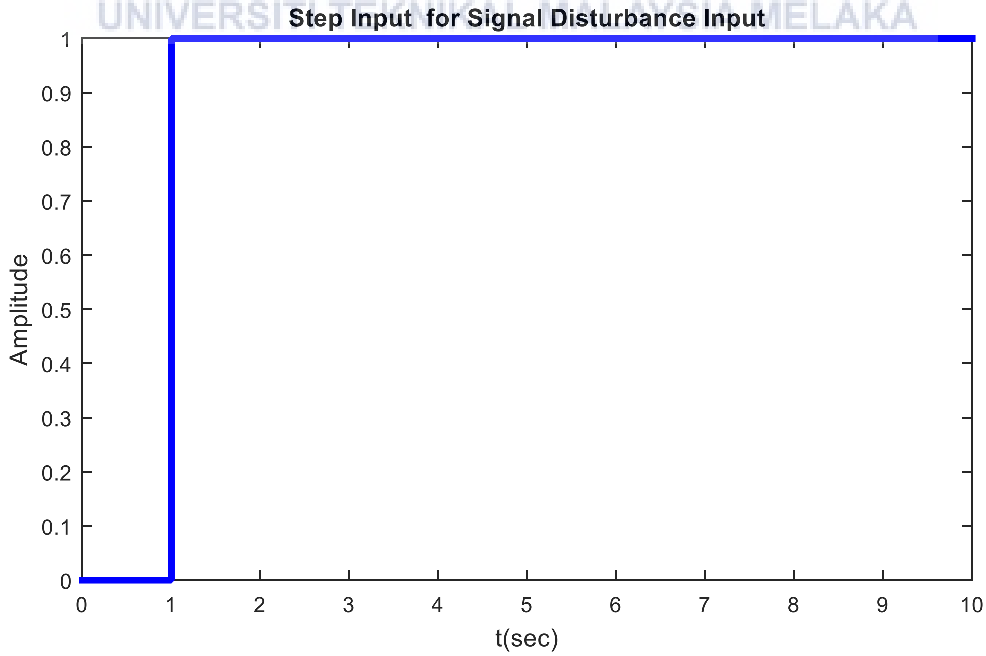

Figure 3.9: Disturbance for Signal Input.

The process for to collect data with injected disturbance is same as previous simulation which is executed the data for 20 times and repeat 10 times to select the best result. The result obtains from simulation will be compare with without disturbance and with disturbance and evaluated which controller is better.

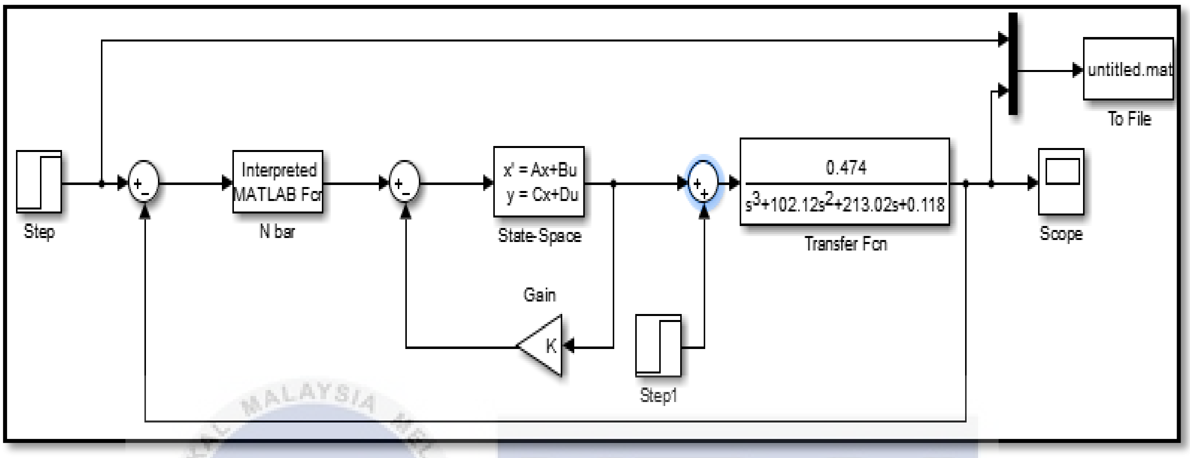

Figure 3.10: PID controller system with Disturbance

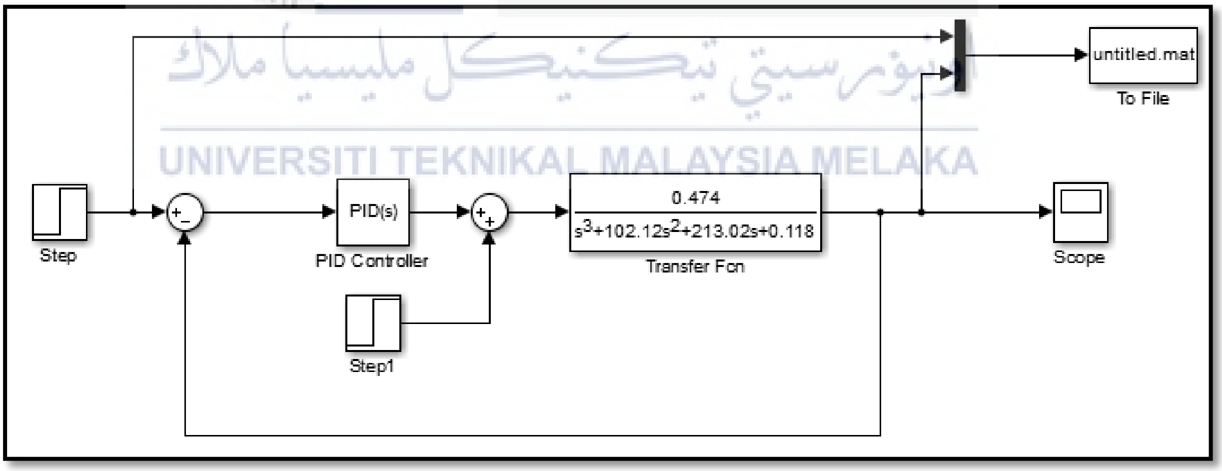

Figure 3.11: LQR controller system with Disturbance

3.10 Conclusion

As a conclusion, to improve the system performance EHA several step needs to be considered. The aim of this method was proposed is for obtain best parameter for PID and LQR controller. Several parameters need to be considered before executing the PSO algorithm such as number of iteration, search range and value velocity initialization. Objective function are used to evaluate the performance index of the system and time-integral performance (ITSE) has been selected as the objective function for provide a better dynamic performance. In addition, this process will be repeated 10 time to get the best performance index and best parameter for both controller. Lastly, the implementation of the disturbance into the system was used to test the robustness of the system.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will discuss the performance from PID and LQR controller by using optimization technique which is Particle Swarm Optimization (PSO). In order to analyze the performance of the system before the controller can be designed, open loop and closed loop with a unity feedback need to analyze. After analyzing result open loop and close loop the selection of initial parameter of PSO will be shown in this chapter to get the best parameter for both controllers. The result of performance index, statically estimation from ITSE and performance system for both controllers without disturbance and with disturbance will be shown for analysis.

4.2 Expected Open-Loop and Close–Loop from Simulation Result

This chapter presents the result of open loop with step input and close loop with unity feedback. By having an open loop test of the system, the dynamic and transient response of the system can be observed. This is the important part, in order to analyze the performance of the system before the controller can be designed. The transfer function obtained from the system that based on equation (4.1) will be used to observe the performance.

$$G = \frac{0.474}{S^3 + 102.12^2 + 213.02S + 0.118} \quad (4.1)$$

The system was obtained by injecting with a step input and unity feedback as shown in Figure 4.1 and Figure 4.2 respectively. From Figure 4.1 and Figure 4.2 shows the system performance of open loop and close loop which has not reach the desired value of respond.

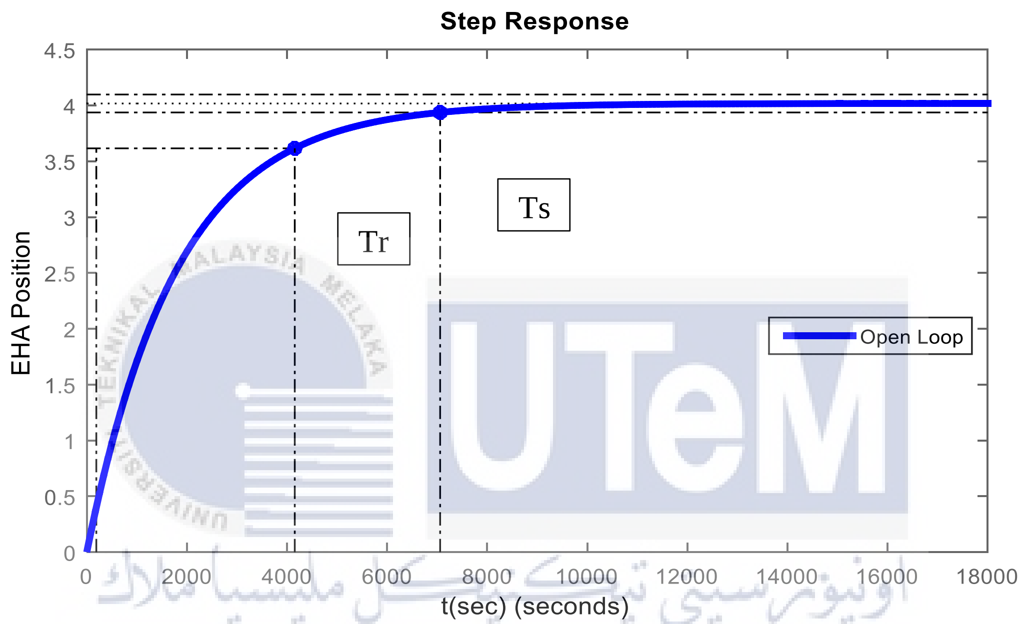

Figure 4.1: Response of the model with step input

Table 4.1 shows the performance response regarding the transient response of the system in open loop. The settling time is very long and the system does not have an overshoot. The performance of the system gives slow response for the transient response.

Table 4.1: Data transient response for model with step input

Output	Open Loop System
Settling time, Ts	7060.9s
Rise time, Tr	3965.1s
Overshoot, % OS	0

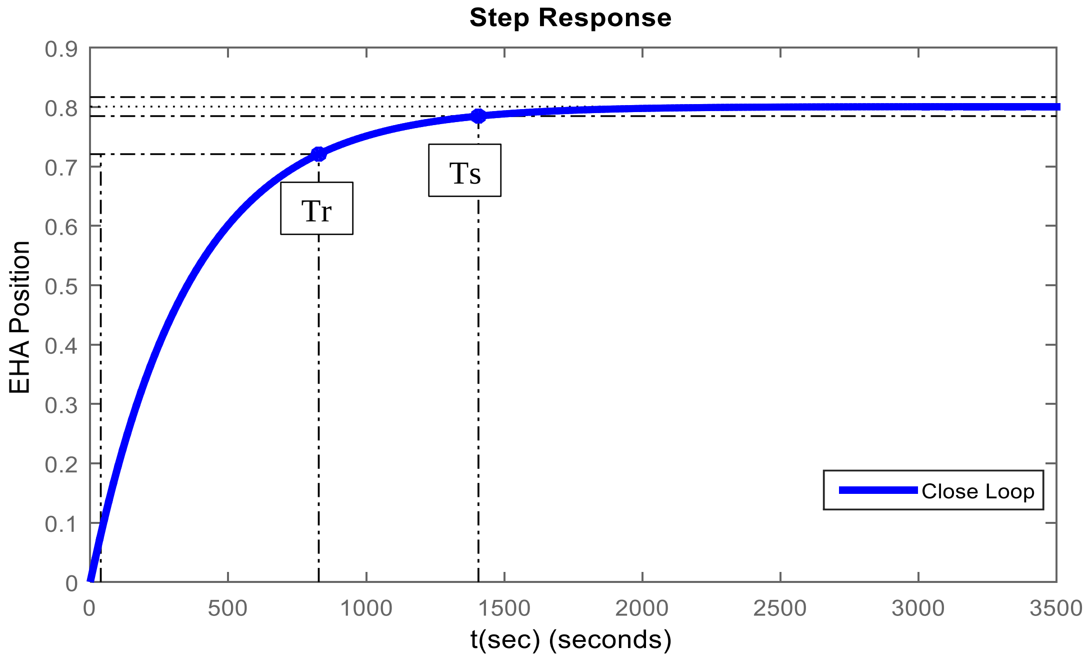

Figure 4.2: Response of the model with unity feedback.

Table 4.2 below shown the performance of close loop with unity feedback. From the observation, it shows the improvement performance system in term of rise time and settling time. Unfortunately, the performance of the system still gives slow response for the transient response. From the both performance result it show that the system performance need to be improve to make sure the performance system stable and precision.

Table 4.2: Data transient respond for model with unity feedback

Output	**Close Loop System**
Settling time, Ts	1406.3s
Rise time, Tr	789.5031s
Overshoot, % OS	0

4.3 Selection of PSO parameter

This stage will discuss the selection for the parameter in PSO. There are two parameters were selected for PSO in order to find the optimal parameter for LQR and PID controller, which are number of particle and number of iterations. Table 4.3 shows how the selection of number of particles for both optimization technique and it shows a different number of particles will give the different value of ITSE. Figure 4.3 and Figure 4.4 shows the graph ITSE versus the number of particles obtain from data Table 4.3

Table 4.3: Number of Particles Selection

	Performance Index, ITSE			
Number of particles	**10**	**20**	**30**	**40**
LQR	10.774	7.425	7.0200	8.514
PID	0.0325	0.0294	0.0673	0.0539

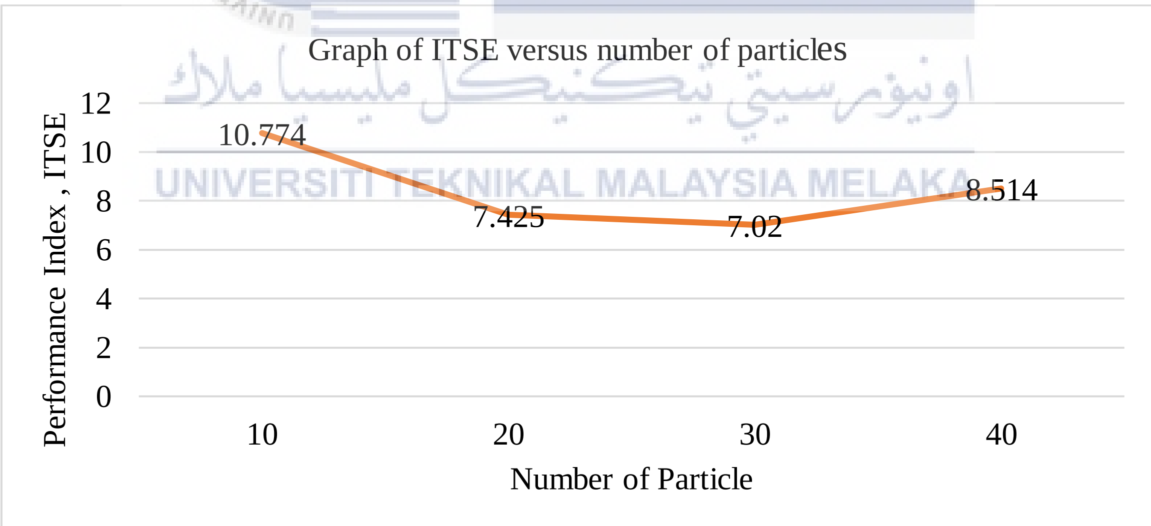

Figure 4.3: Graph of ITSE versus number of particle for (LQR) with EHA system

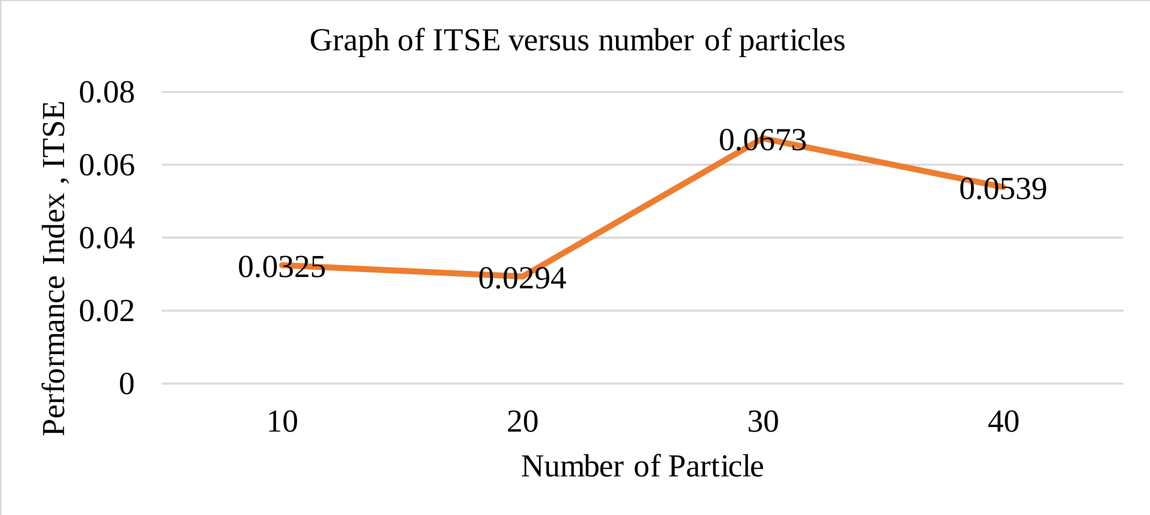

Figure 4.4: Graph of ITSE versus number of particle for (PID) with EHA system

Number of particle for Performance index LQR for parameter PSO was chosen is 7.425 while LQR is 0.0294 due to the minimum value among other number of particles. It shows that, the bigger number of particle applied the result does not give best value. Hence, several numbers of particle are used in this simulation to determine which the best performance index. Besides that, from Figure 4.4. The number of particles was selected is 20 because it gives the minimum value for LQR and PID controller which are 7.425 and 0.0294 respectively. Minimum value represents the best performance index. Therefore number of particle 20 was chosen as the best performance index compared to others.

4.4 PSO for LQR and PID

The purpose of this project shows a comparison between LQR and PID by using PSO in term of performance index. The parameter of PSO used is followed from the previous topic. The number of execution conduct for each simulation is 20 times and repeated for 10 times to get the best optimum result of performance index.

The result have been tabulated in Table 4.4 for LQR and Table 4.5 for PID

Table 4.4: LQR data with 10 executions using PSO

Number of execution	Performance index
1	7.426
2	8.514
3	8.352
4	8.558
5	8.7443
6	9.155
7	8.7443
8	8.552
9	8.573
10	9.454

For LQR the best performance index is 8.558 after the simulation repeatedly 10 times of selection as shown in Table 4.4. A graph of number of execution versus performance index is plotted in Figure 4.5.

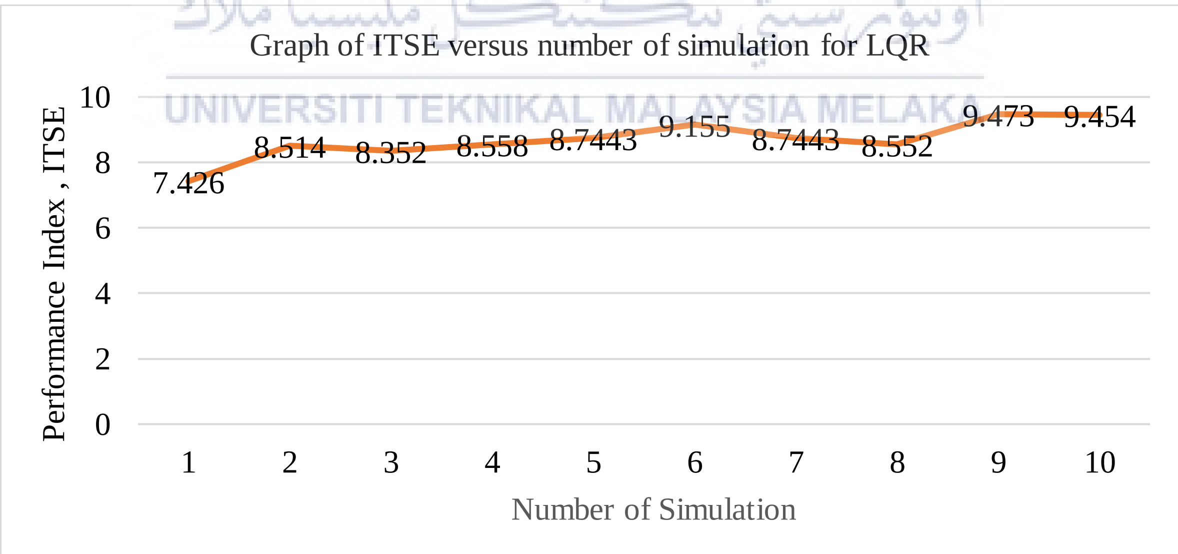

Figure 4.5: Graph of ITSE versus number of simulation for LQR

Table 4.5 shown the best performance index for PID controller with repeatedly 10 times and Figure 4.6 shows a graph number of execution performance index from data table 4.5.

Table 4.5: PID data with 10 executions using PSO

Number of execution	**Performance index**
1	0.02941
2	0.0295
3	0.0538
4	0.0539
5	0.0539
6	0.0544
7	0.0539
8	0.0542
9	0.0544
10	0.0541

Besides, based on Table 4.5 after simulation repeatedly, 10 times of selection the best performance index for PID is 0.0539 which is the lowest value obtained. A graph of number of execution versus performance index is plotted in Figure 4.6.

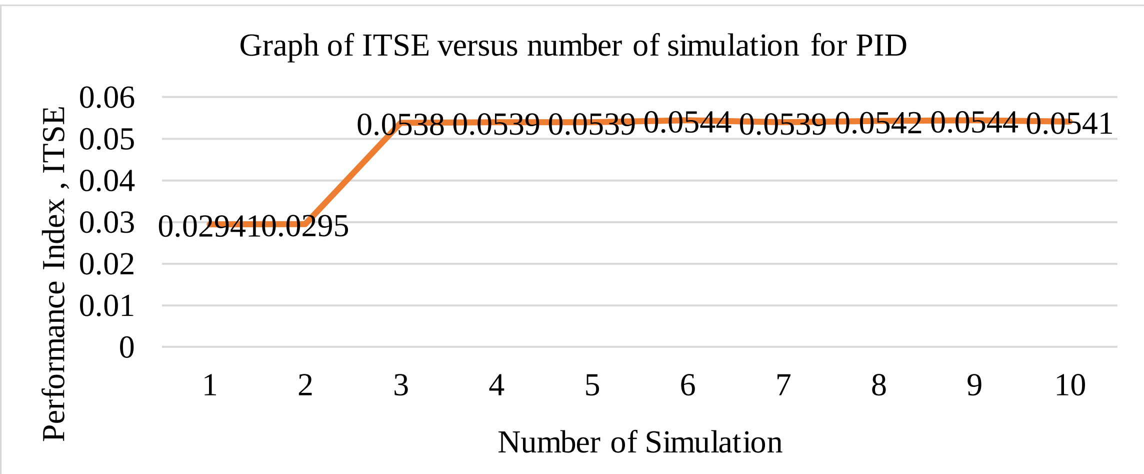

Figure 4.6 Graph of ITSE versus number of simulation for PID

The result of 0.0539 was repeated 8 times and it shows that the performance index of 0.0539 as the best value ITSE to be selected for PID.

As a conclusion from the result, each of run given a different value for parameter in LQR and PID. The performance index for LQR is higher compared to PID which is 8.5558 and 0.0539 respectively. Hence, PID controller gives better result in terms of performance index compare to LQR controller.

4.4.1 Parameter for PID and LQR

This section will discuss about the parameter that have been selected from PSO for PID and LQR. The performance criteria that include in this project are overshoot, rise time, settling time and steady-state error. The parameter of the controllers need to be obtained for LQR is Q1, Q2, Q3 and R while for PID the parameters are Kp, Ki and Kd. Table 4.6 shows the value of the parameter for LQR and PID based on the value of performance index obtained after finish 20 run for one execution. It shows the value ITSE PID smaller which is 8.558 compared to LQR which is 0.0539.

Table 4.6: Parameter value for LQR and PID

LQR				
ITSE : 8.558				
Parameter	**Q1**	**Q2**	**Q3**	**R**
	3525.53	253.753	68363.83	0.3048

PID			
ITSE : 0.0539			
Parameter	**KP**	**KI**	**KD**
	616.1031194	25949.8423	97235.288

The best parameter for LQR is Q1 (3525.53), Q2 (253.753), Q3 (68363.83) and R (0.3048) while parameter for PID is KP (616.1031194), KI (25949.8423) and KD (97235.288). After obtaining parameter for both controllers, comparison between LQR and PID will be analyzed in order to find better performance controller.

4.5 Comparison between LQR and PID

The parameter for LQR and PSO was determined by using same optimization technique, in order to find the suitable gain and small ITSE for controllers. Figure 4.7 and Figure 4.8 shown the respond for LQR controller and the respond for PID controller. While Figure 4.9 shown the combination between PID and LQR controller. The comparison between LQR and PID controller response are shown in Figure 4.7, 4.8, 4.9 and Table 4.7.

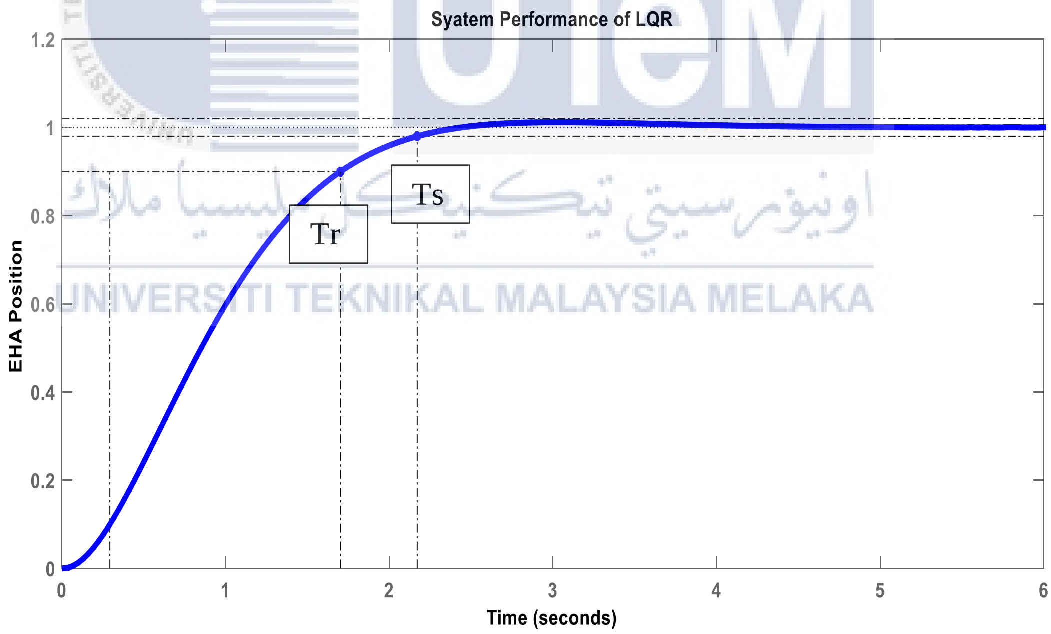

Figure 4.7 Respond for LQR controller

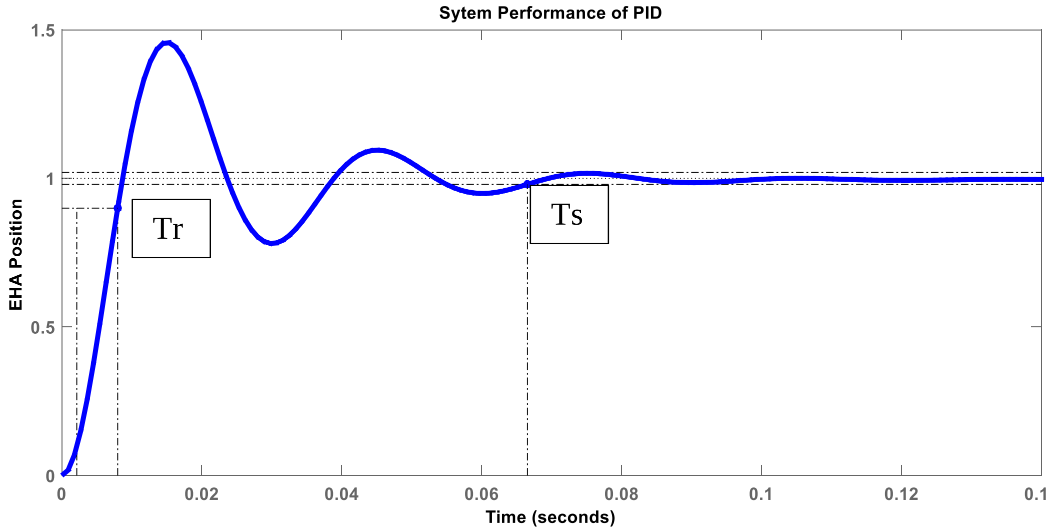

Figure 4.8 Respond for PID controller

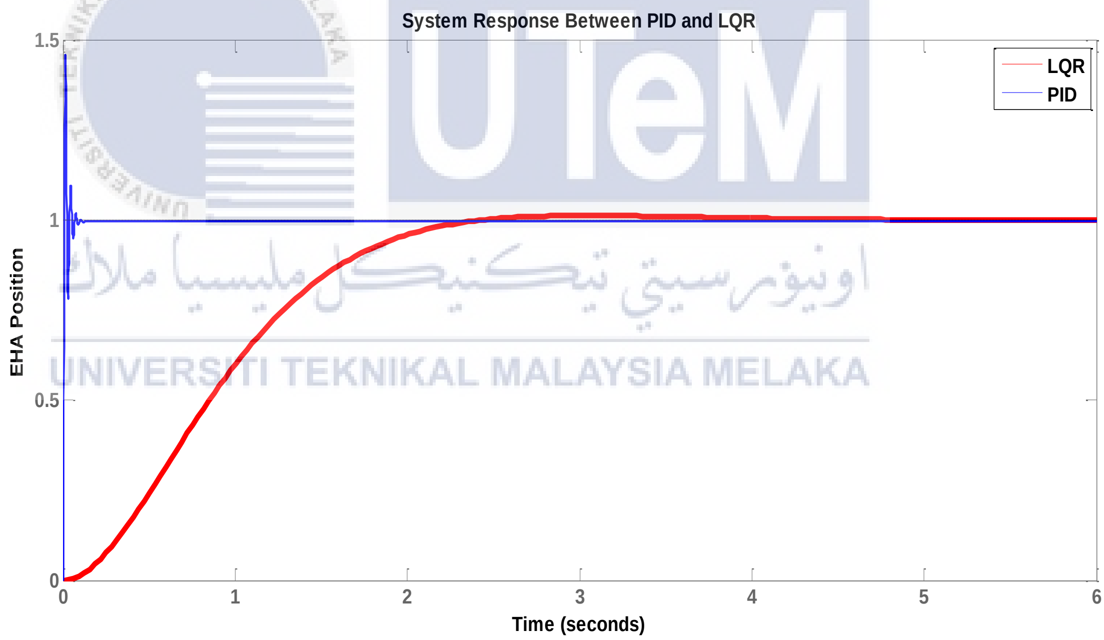

Figure 4.9: Combination System Performance between LQR and PID

From the observation, Figure 4.9, it shown that LQR controller gives better performance compare to PID in terms of the transient response. LQR controller gives less overshoot compared to PID controller and it show the LQR give more stable and precise than PID controller. Table 4.7 and Figure 4.10 shown the performance between for both controllers in term of rise time, settling time, overshoot and steady-state error.

Table 4.7: Comparison between LQR and PID

OUTPUT	**CONTROLLER**	
	LQR	**PID**
Rise time, Tr (s)	1.41	0.00585
Settling time, Ts (s)	2.17	0.0681
Overshoot, OS (%)	1.18	45.7
Steady-state error, Ess	0	0

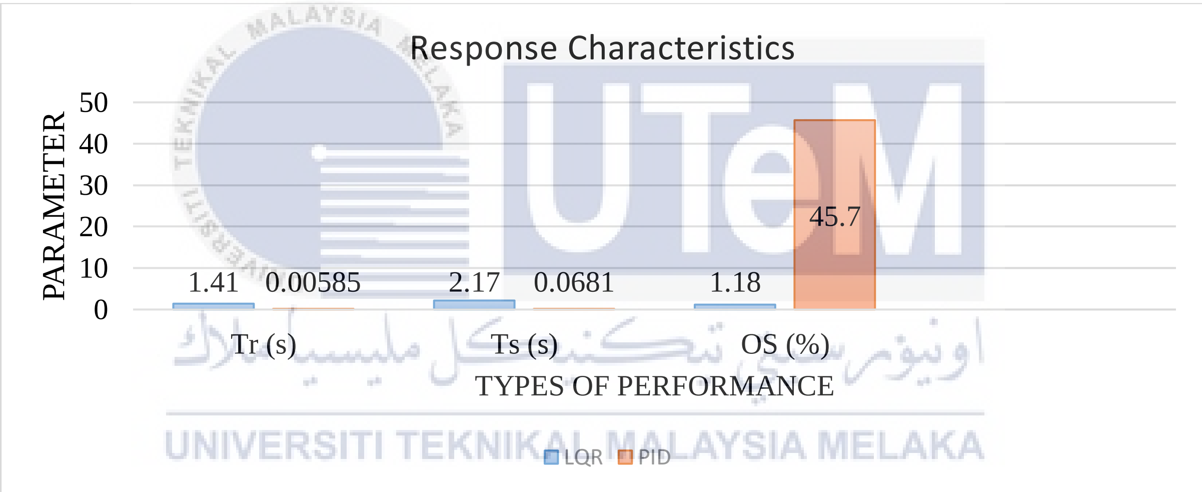

Figure 4.10: Performance comparison between LQR and PID controller.

From the observation on Table 4.7 and Figure 4.10, it shows that LQR gives less overshoot (1.18 %) compared to the PID controller (45.7 %). Beside, LQR shows that the system using LQR gives a long period of time to reach a desired output compared to PID give a short period of time to reach desired output. For the rise time, Tr PID response faster than LQR which is rising at 1.41 s and 0.00585 respectively. In addition, in terms of settling time, Ts the time taken for PID controller to reach the set point is shorter, which is 0.0681 s while LQR took longer time which is 2.17 s. While for steady state error for both controller is zero. From the observation, LQR controller gives better performance compared to the PID due to overshoot performance. It makes the system become more stable by giving lowest percentage of overshoot.

4.5.1 Statically Estimation from ITSE

[24] as PSO is known as stochastic algorithm where there is some randomness in the algorithm, the algorithm will usually reach at different point every time the algorithm execute, even though the same initial point is used. Hence, calculating the standard deviation will determine the precision of the controller tuned using PSO. Another method, in order to verify the performance of the system is by using statistical estimation method. In statistic, estimation refers to the process by which one makes inferences about a population, based on information obtained from a sample. It determines the tendency on the average for the statistic to assume values that are close to parameter. A small standard deviation gives an accurate data because it will give better estimation. The statically for LQR and PID are shown in Table 4.8. The value of standard deviation for LQR is higher compared to PID which is 0.53024 and 0.0104 respectively. Hence, PID is better in term of giving lowest value standard deviation.

Table 4.8: Comparison of statically estimation

Statically Estimation	LQR	PID
Average	8.6073	0.04912
Standard Deviation	0.53024	0.0104

4.6 Controller System Tuning Using PSO with Disturbance

Robustness is an important criteria that needed by any controller because it shows the ability of the controller to resist by any disturbance that might distort the system. To determine the robustness in term of the disturbance were injected the system with a step input ($\frac{1}{s}$). This stage of LQR and PID controller were compared with the disturbance and without disturbance in the system, to see the performance has improve or not.

The result have been selected and number of execution conduct for each simulation is 20 times and repeated for 10 times to get the best optimum result of performance index. The result have been tabulated in Table 4.9 for LQR and Table 4.10 for PID

Table 4.9: LQR data with 10 executions using PSO with disturbance

Number of execution	**Performance index**
1	8.124
2	8.352
3	8.451
4	9.767
5	8.4852
6	8.552
7	9.154
8	9.155
9	8.487
10	8.474

For LQR the best performance index is 8.558 after the simulation repeatedly 10 times of selection as shown in Table 4.9. A graph of number of execution versus performance index is plotted in Figure 4.11.

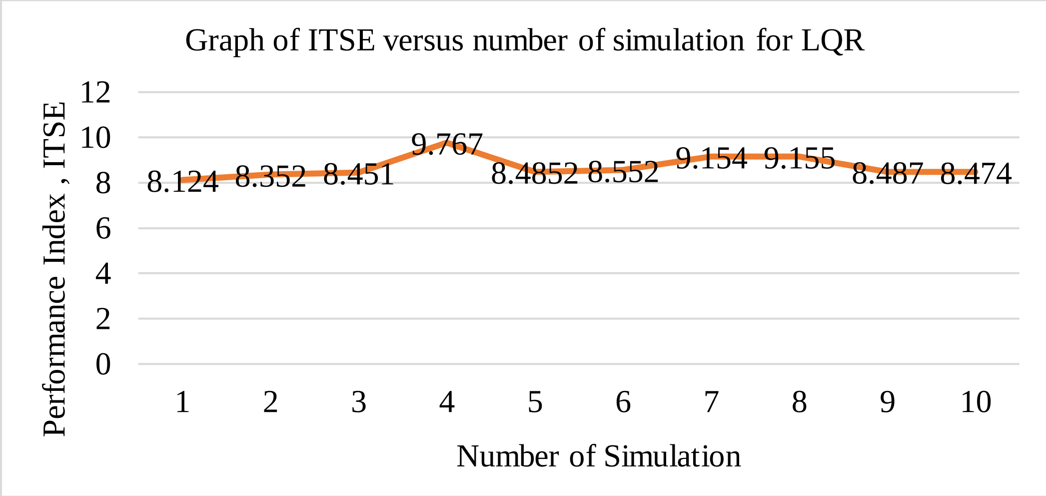

Figure 4.11: Performance index for LQR with disturbance.

For LQR, the best performance index with disturbance is 8.4852 which is the lowest value obtain from simulation with 4 time consecutive and hence shows that s the best value for LQR with disturbance.

Table 4.10: PID data with 10 executions using PSO with disturbance

Number of execution	**Performance index**
1	0.0325
2	0.0544
3	0.0543
4	0.0536
5	0.0549
6	0.0541
7	0.0538
8	0.0541
9	0.0673
10	0.0612

Based on Table 4.10 and Figure 4.12, after 10 times of execution the best performance index for PID with disturbance is 0.0541 which lowest value obtain with 5 times repeated. Hence shows that the best value for PID with disturbance.

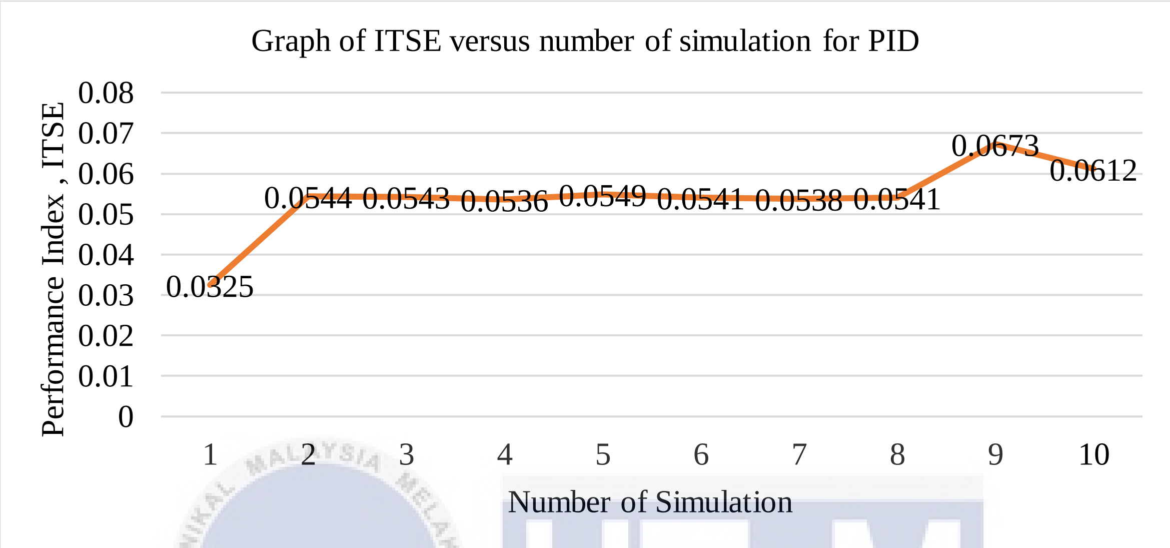

Figure 4.12: Performance index for LQR with disturbance.

As a conclusion from the result, each of run given a different value for parameter in LQR and PID with disturbance. The performance index for LQR is higher compared to PID which is 8.4852 and 0.0541 respectively. Hence, PID controller gives better result in terms of performance index compare to LQR controller.

4.6.1 Parameter for LQR and PID with disturbance

This section will discuss about the parameter with disturbance that have been selected from PSO for PID and LQR. The parameter for LQR and PID controller are based on the value of performance index obtained after finish 20 run for one execution. The parameter of controllers will be used for comparison of the system performance. Table 4.11 shows the value new value parameter when injected with disturbance. It shows the ITSE value for PID is smaller, which is 0.0541 compared to LQR is 8.4852.

Table 4.11: Parameter value for LQR and PID with disturbance

LQR				
ITSE : 8.4852				
Parameter	**Q1**	**Q2**	**Q3**	**R**
	198.7824	30156	94209	0.1942
PID				
ITSE : 0.0541				
Parameter	**KP**	**KI**	**KD**	
	11053	88584	92025	

4.6.2 Comparison between PID and LQR with disturbance

The parameter for LQR and PSO with disturbance was determined by using same optimization technique, in order to find the suitable gain and small ITSE for controllers. The comparison between LQR and PID controller response are shown in Figure 4.13, 4.14, 4.15, 4.16 and Table 4.12.

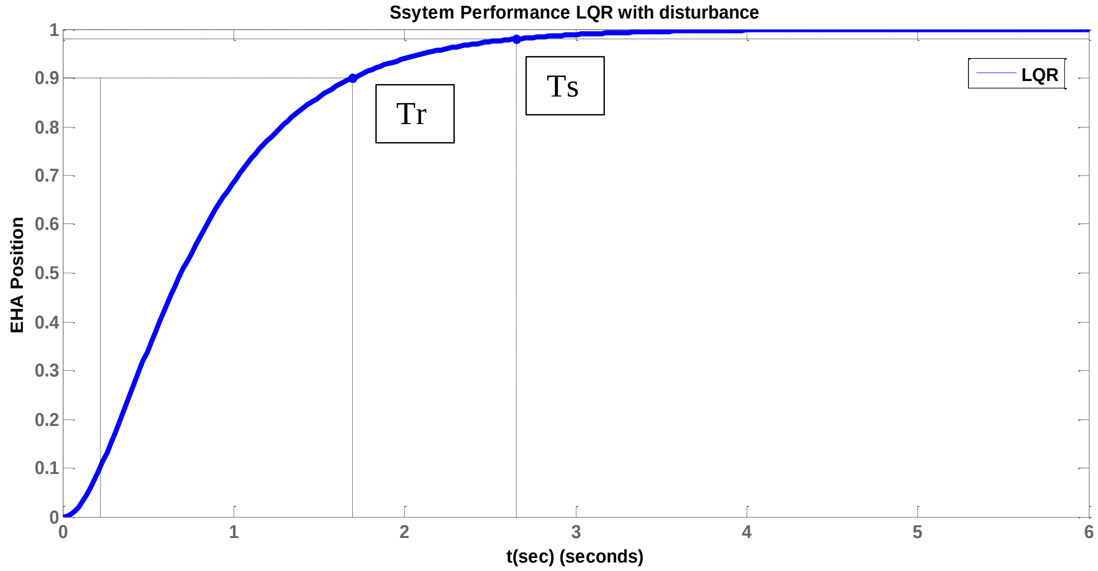

Figure 4.13 Respond for LQR controller with disturbance

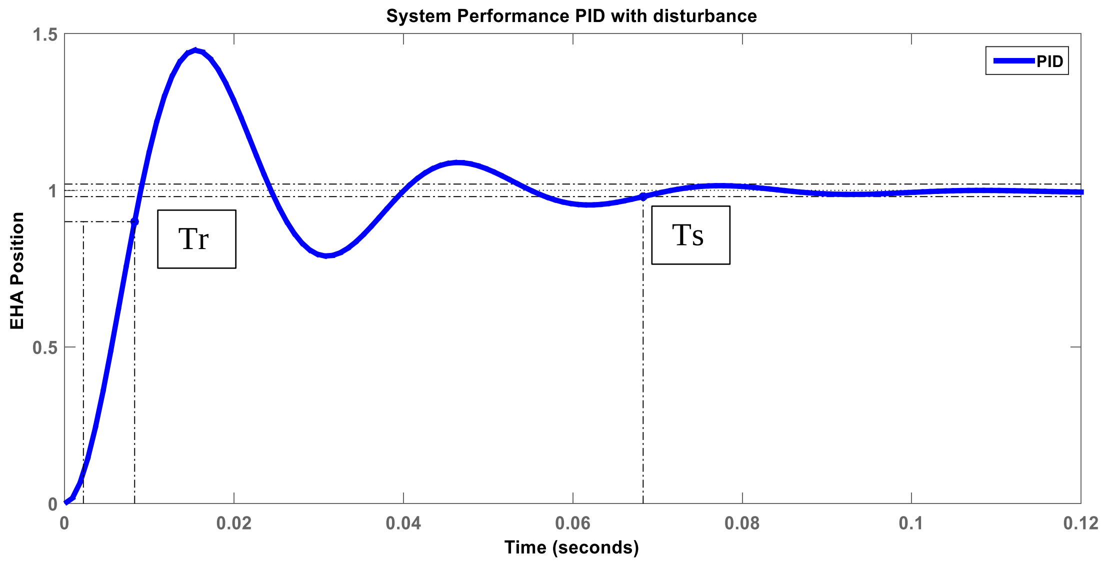

Figure 4.14: Respond for PID controller with disturbance

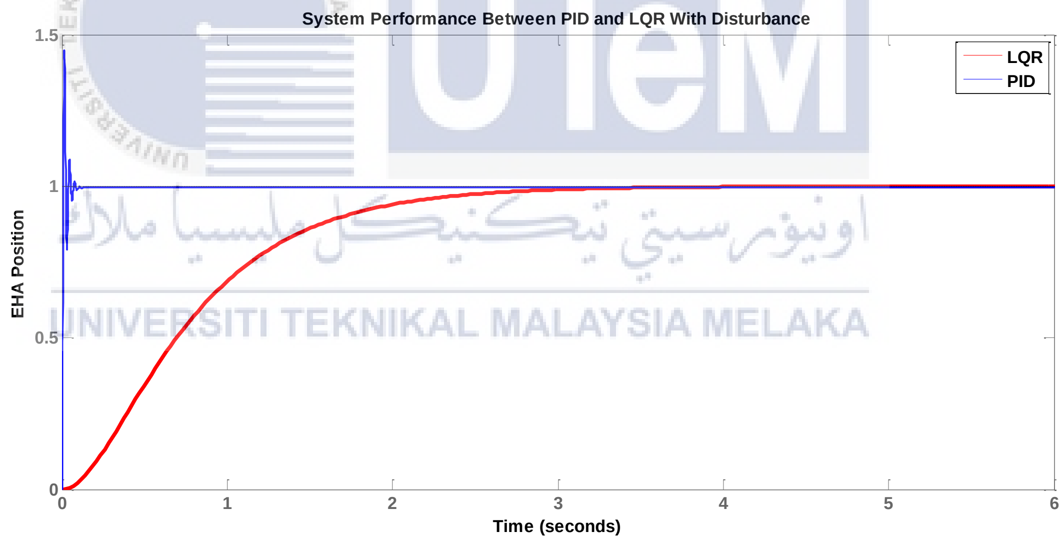

Figure 4.15: Combination Respond between PID and LQR controller with disturbance

From the observation, Figure 4.15, it shown that LQR controller gives better performance compare to PID in terms of the transient response. LQR controller gives less overshoot compared to PID controller and it show the LQR give more stable and precise than PID controller when the injected disturbance. Table 4.12 and Figure 4.16 shown the performance between for both controllers in term of rise time, settling time, overshoot and steady-state error with injected disturbance.

Table 4.12: Comparison between LQR and PID with disturbance

OUTPUT	CONTROLLER	
	LQR	PID
Rise time, Tr (s)	1.48	0.00605
Settling time, Ts (s)	2.65	0.0683
Overshoot, OS (%)	0	44.7
Steady-state error, Ess	0	0

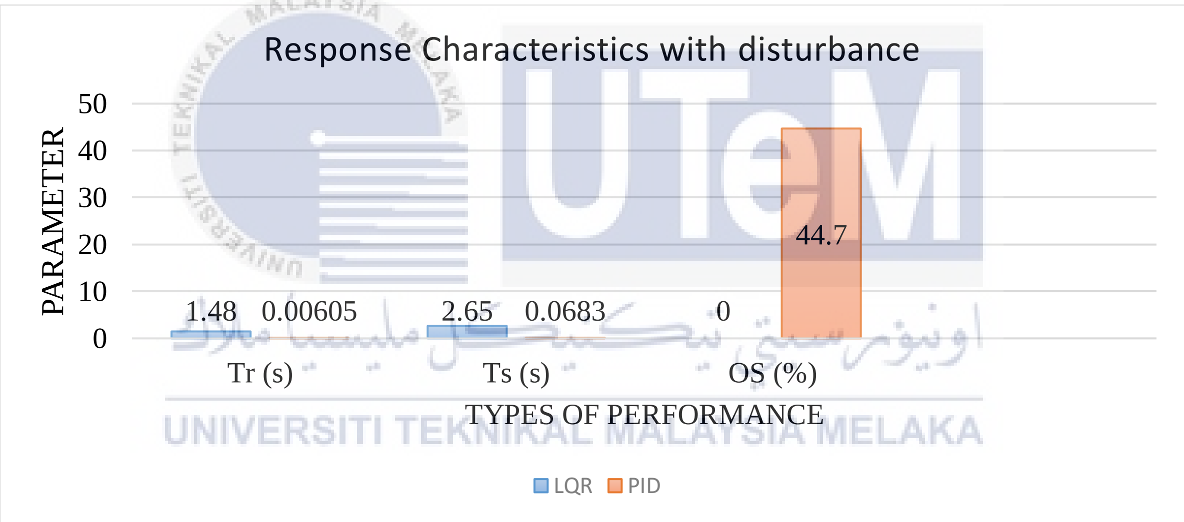

Figure 4.16: Performance comparison between LQR and PID controller with disturbance.

From the observation on Table 4.12, it shows that LQR and PID can resist with disturbance injected and give slightly different with the response without disturbance. It shows that system when injected the disturbance, response characteristic that improve only overshoot for LQR while PID improve in term of rise time and settling time. From Figure 4.16 controller LQR gives less overshoot (0 %) compared to the PID controller (44.7 %). Beside, LQR shows that the system using LQR gives a long period of time to reach a desired output compared to PID give a short period of time to reach desired output. For the rise time, it shows the PID gives faster response than LQR which is rising at 0.00605 s and 1.48

respectively. In addition, in terms of settling time, the time taken for PID controller to reach the set point is shorter, which is 0.0683 s while LQR took longer time which is 2.65 s. Both controller give better respond where gives zero steady- state error for the system. As a conclusion, the result shows that is PID give faster response while LQR gives less overshoot and both controllers prove that system design can resist with disturbance. Hence, the better response for controller with injected disturbance is LQR. Even though the rise time and settling time slower than PID, but the LQR produces (0%) overshoot. It makes the system become more stable and precision.

Table 4.13: Comparison of statically estimation

Statically Estimation	**LQR**	**PID**
Average	8.70012	0.11459
Standard Deviation	0.49788	0.19635

From the Table 4.13 the average value for LQR is 8.70012 while standard deviation is 0.49788. Besides, the average value for PID is 0.11459 while standard deviation is 0.19635. From the observation, PID gives the lowest value in term of average and standard deviation compare to LQR. The standard deviation for PID shows that the data is very good because roughly to 0.

4.7 System response comparison with disturbance and without disturbance.

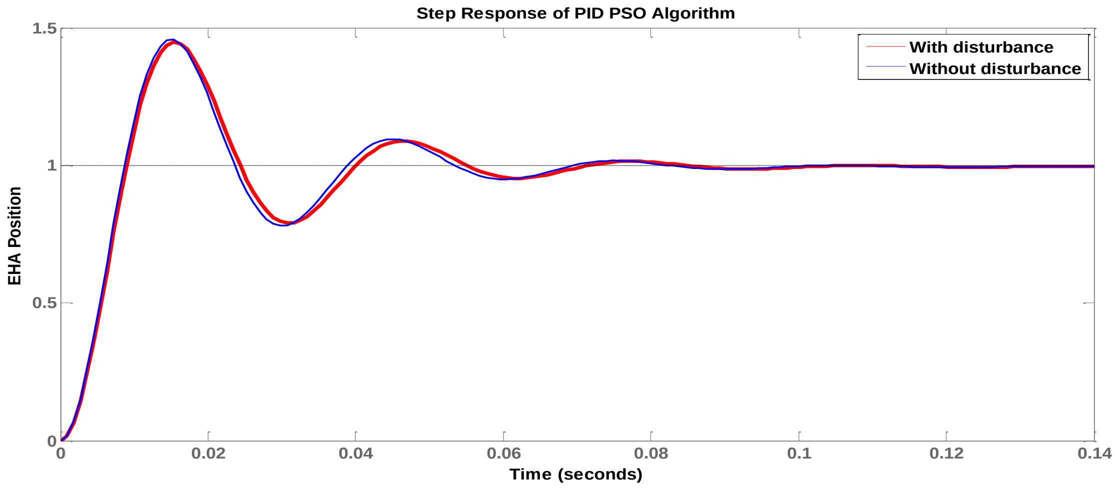

Figure 4.17: Step Response of PID PSO Algorithm

Table 4.14: System Response PID with disturbance and without disturbance.

Output	Without Disturbance	With Disturbance
Rise Time	0.00585	0.00605
Settling Time	0.0681	0.0683
Overshoot (%)	45.7	44.7

Based on the Figure 4.17 and Table 4.14, the settling time for without disturbance is 0.00585s while with disturbance is 0.00605. Other than that, the rise time without disturbance produce 0.00681 while with disturbance is 0.00683 which is faster 0.0002s than system without disturbance. Overshoot from without disturbance is 45.7%, while with disturbance is 44.7%. This shows that the system does not have a good performance index when disturbance is added to the system because the result shows almost same with and without disturbance.

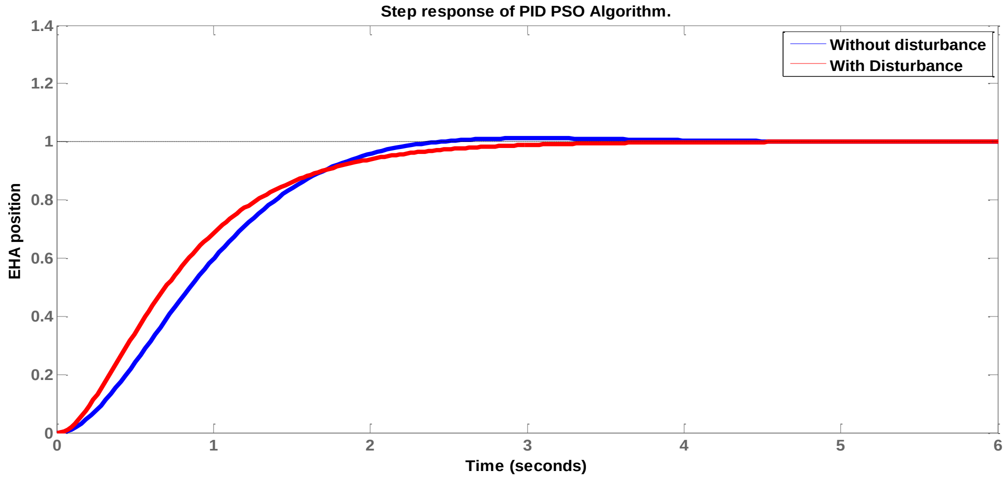

Figure 4.18: Step Response of PID PSO Algorithm

Table 4.15: System Response LQR with disturbance and without disturbance.

Output	Without Disturbance	With Disturbance
Rise Time	1.41	1.48
Settling Time	2.17	2.63
Overshoot (%)	1.18	0

Based on the Table 4.15 and Figure 4.18, the settling time for without disturbance is 1.41s while with disturbance is 1.48. Other than that, the rise time without disturbance produce 2.17s while with disturbance is 2.63s which is faster 0.0002s than a system without disturbance. Overshoot from without disturbance is 1.18% while with disturbance produces 0%. This shows that the system have improve the performance index when disturbance is added to the system. As conclusion, the implementation of disturbance in LQR give lower percentage overshoot. Hence, LQR gives system more stable and precision when implement the disturbance.

4.8 Conclusion

This chapter conclude the process of simulation Electrohydraulic System with LQR and PID controller by using PSO is succeeded. The data obtained from the simulation was discussed and have been tabulated and plotted in the graph. In the end of this chapter, the performance result when injected disturbance has analyzed and overall performance shows the LQR controller provide better result and suitable to handle uncertainties and nonlinearities problem in EHA system.

CHAPTER 5

CONCLUSION

5.1 Introduction

In this chapter will discussing about the conclusion from the overall steps and method that have been used while recommendation for future work will state in this chapter.

5.2 Conclusion

Electro Hydraulic Actuator systems have become an important driving element that extensively and have many advantages in the industry process. High power to weight ratio and stiffness response being good, smooth and fast makes this EHA system are preferable in the industry. However, the problem of EHA is highly nonlinearities and uncertainties characteristic due to a leakage, friction expression through the servo valve. With these nonlinear and uncertainties characteristic, it is difficult to model to control the position of the actuator. In addition, a good controller and optimization technique is needed in order to compensate and get a better position control of the EHA system. The implementation of PID and LQR using Particle Swarm Optimization (PSO) is done and it shows that by using optimization technique make easy to find parameter of controllers compare to used trial and error method. The advantage of used optimization technique because it gives a less error by selected the best parameter reflect to overall performance of settling time, rise time and overshoot.

From all the result that been presented in the previous chapter, implementation PSO to tune parameter of PID and LQR controller for electrohydraulic actuator system a success based on smaller integral square error (ITSE). However, PID is much better than LQR in term of produce smaller value ITSE and standard variance. In addition, the LQR controller gives much better performance than PID controller performance in term of produce less overshoot with implementing disturbance and without disturbance. PID with optimization control cannot withstand good value when the disturbance was implemented into the system. However, in terms of rise time and settling time shows that PID are better because faster respond compared to LQR. As a conclusion, LQR give much better compare to PID which is give less overshoot and can withstand the good value when disturbance is implemented in the system.

5.3 Future work

As we look forward, there is a lot of thing need to be improved in the future. One objective in this project to design of position control of the EHA using an intelligent control such as Fuzzy Logic Controller and optimize the parameter by using Genetic Algorithm and Imperialist Competitive Algorithm (ICA). This objective can be achieved through simulation via Matlab. It shows that Bat Algorithm will improve the system performance.

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