DEVELOPMENT OF OPTIMAL PID CONTROLLER FOR WASTEWATER TREATMENT PLANT

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DEVELOPMENT OF OPTIMAL PID CONTROLLER FOR WASTEWATER TREATMENT PLANT

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering
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2021

DECLARATION

I declare that this report entitled "Development of Optimal PID Controller for Wastewater Treatment Plants" is the result of my own work except for quotes as cited in the references.

Signature : ....

Author : SIA YOK KIT ....

Date : 25/06/2021 ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature : …………………………

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Date : 25/06/2021

DEDICATION

I would like to dedicate this thesis to my dear family, who have been my source of inspiration and have provided support and motivation to undertake and complete this research. Thanks for their dedication and giving me a loving and caring parenthood and let me face everything in my life with a positive attitude

ABSTRACT

The goal of this work is to develop an optimal PID controller for a wastewater treatment plant. Although PID control strategies are frequently applied to WWTP, the limitation of PID is still available. The limitations of the fixed-gain PID is time consuming and inefficient especially when applied to complex dynamic system, while poor plant performance is resulted. Therefore, in this study, the PSO algorithm optimization technique is used in a PID controller to identify the optimum optimal parameters for a wastewater treatment plant (WWTP).By using this method, the gains of the PID controller and the non linear gains are well optimized. Comparison between the classical non linear PID and the PSO-PID will be analyzed. The performance of nonlinear system and the output will be only observed and analyzed in the time domain. As a result, the lowest IAE and ISE error between the input and output of the WWTP will be the best performances. The analysis of the system will be one of the research's outcomes. The simulation is conducted in MATLAB SIMULINKplatform.

ABSTRAK

Tujuan kerja ini adalah untuk membangunkan pengawal PID yang optimum untuk kilang rawatan sisa air kumbahan. Walaupun strategi pengendalian PID sering digunakan di WWTP, tetapi had pengawal mempunyai kelemahannya dan tidak dapat dinafikan. Had gandaan tetap pengawal PID mengambil masa yang panjang dan tidak efisien apabila digunakan kepada sistem dinamik yang kompleks, rawatan pretasi sistem yang buruk dihasilkan. Oleh itu, dalam kajian ini, teknik pengoptimuman algoritma PSO digunakan dalam pengawal PID untuk mengenal pasti parameter optimum optimum untuk loji rawatan sisa air (WWTP). Dengan menggunakan kaedah ini, gandaan pengawal PID dan gandaan tidak linear akan dioptimumkan dengan lebih baik. Perbandingan antara PID bukan linear klasik dan PSO-PID akan dianalisis. Prestasi sistem tidak linear dan keluaran hanya akan diperhatikan dan dianalisis dalam domain waktu. Hasilnya, ralat IAE dan ISE terendah antara input dan output WWTP akan menjadi pretasi sistem terbaik. Analisis sistem akan menjadi salah satu hasil kajian. Simulasi dijalankan dengan platform MATLAB / SIMULINK.

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List of Symbols and Abbreviations

WWTP	:	Wastewater Treatment Plant
ASP	:	Activated Sludge Process
PID	:	Proportional-Integral-Derivative
PSO	:	Particle Swarm Optimization
ISE	:	Integral Square Error
IAE	:	Integral Absolute Error
ITSE	:	Integral of Time Squared Error
ITAE	:	integral of Time squared error
DO	:	Dissolve Oxygen

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CHAPTER 1

INTRODUCTION

This thesis proposes development of optimal PID controller for a wastewater treatment plant. This chapter will present the project background, problem statement, objectives, the scope of works, and the organization of the chapter.

1.1 Background of Project

Water is very important for the plants, animals and human to survive. If there was no water there would be no life on earth. In our modern society, demand of the clean water by the people become increase for daily purposes. This will cause the growing imbalance between the clean water and the people's demand. The access to clean and safe water is one of the major challenges and concerns in our society as water pollution problems have been increased[1]. Therefore, the wastewater treatment process (WWTPs) that takes place at the wastewater treatment plant play an vital role in minimizing of the discharge many water pollutants.

Wastewater treatment plant (WWTP) is a process which is to treat the wastewater to improve the water quality by separating the organic waste and the nutrients[2]. The process treatment in WWTP includes three stage, which are primary, secondary and tertiary treatment. Activated Sludge Process (ASP) is fall off secondary stage which to control the concentration of pollutant substrate and dissolved oxygen in the process treatment[3]. However, WWTP present many challenging control problem due to the system is complicated and strongly non linear because too many parameter is needed to control. Therefore, the PID controller is proposed in this research to overcome the problems in the WWTP.

Proportional-Integral-Derivative (PID) controller, is a feedback loop system that widely used in the industrial for system controlling. This PID controller is used for control subtract and dissolve oxygen concentration in the WWTP function for long period of time with parameter tune once at the beginning[4]. The PID controller are not complex and pragmatic. It can provide faster and good performance for most system in a specific operating conditions. Therefore, a PID controller will improve the system performances. Other by the self tuning method, the PID controller also can be enchanted by general fuzzy logic, and neural network strategy.

PSO Optimization Algorithm will be used in this study to obtain the gains of the non linear PID controller. If compared to the conventional tuning method such as Ziegler-Nichols Tuning approach, PSO-PID parameter design approach was having faster time responses and robust of the control system[5]. This Thesis proposes the PSO algorithm will be applied in WWTP through simulation to optimize the control parameter of the controller and improve treated water quality[6].

1.2 Problem Statement

The wastewater treatment plant (WWTP) is a process of treating the water by separating the waste and nutrients. Activated Sludge Process (ASP) in the secondary treatment of the WWTP is a play an important role to maintain the concentration of pollutant substrate and dissolve oxygen. The control design of WWTP is important to provide a clean water to human for daily use. Models of wastewater treatment processes are very complicated and strongly nonlinear because the process involves numbers of interacting controls.

A proper PID tuning is a crucial to overcome these problems. Even nowadays the PID controller have been used in control strategies in industrial still using try and error tuning method. The disadvantages of this method are time wasting and not efficient when applied in the modern process with complex dynamic, poor plant performance is observed[7]. WWTP involves a multivariable process which is highly complex thus tuning of the controller is still challenging. Therefore, the optimization technique of Particles Swarm Optimization (PSO) to find the tuning parameter is implemented in this research.

1.3 Objectives

The project aims to development of optimal PID controller for a wastewater treatment plant. Some objectives are needed to be accomplished to achieve the aim of this study.

i. To design the optimal nonlinear PID controller for wastewater treatment plant

ii. To apply the PSO algorithm to find the optimal parameter of the controller

iii. To investigate the system performance of the optimal nonlinear PID control for the wastewater treatment plant.

1.4 Scope of Project

The goal of this project is to construct the finest possible PID controller. The optimization technique will be basic Particle Swarm Optimization (PSO), and this control algorithm will be evaluated on a multivariable Wastewater Treatment Plant (WWTP). The results will be based on the performance of a nonlinear system, and the output will only be observed and evaluated in the time domain.

1.5 Thesis Outline

There will be five chapters in all in this thesis. The first chapter, Introduction, will quickly discuss the background of this project based on past research as well as material gathered on the internet, the research issue statement, the scope of the study, and the project objectives.

Chapter 2 will go over the fundamentals and explain how to conduct a literature review using the method and strategies that will be employed in this study. The gain of Kp, Ki, Kd, and Kn of the system, as well as the PSO optimization method technique, have been updated.

The technique is discussed in Chapter 3; this chapter will provide a thorough overview of the project as well as the strategy used in this proposed system. This chapter will also cover the experiment setup, system identification, and mathematical modelling, as well as an optimization technique for parameter adjustment seeking.

The results and discussion are offered in Chapter 4; all of the results may be shown in graphs, tables, or words to clearly demonstrate the reader what was done in this research, and the results are discussed by comparing them to earlier research. Furthermore, the results of the PID's control performance before and after applying optimizations techniques are briefly discussed with a summary comparison.

Finally, chapter 5 will be the conclusion, which will summarise the project's results. It finishes by stating what is believed to be the essence of each chapter, as well as the relevance of the project's accomplishments. In addition, some proposals for future work are discussed.

CHAPTER 2

BACKGROUND STUDY

A literature review has been conducted on journals and papers to collect useful information for this project deigning purpose. This chapter will review in detail about the element that corresponding to this project.

2.1 Waste Water Treatment Plant

Wastewater treatment is a process used to treat the wastewater or sewage before it returned to the natural bodies with acceptable impact on the environment. The wastewater is the water that has been used may comes from many sources. Some wastewater are difficult to treat especially due to chemical substances that produced by the industries and agricultures. In the water, the concentration of impurities is found and this will distinguish between the clean water and the polluted water. Therefore, wastewater treatment plant (WWTP) were built to clean wastewater for discharge into river or other receiving water or for public daily use such as drinking, showering and dishwashing.

The contaminants in the waste water need to be removed to ensure it safety to use and environmental friendly. If the water is not be treated well, numerous contaminants will be negatively influence the water quality and might exhibit toxic or poisonous impact that could harm aquatic life and also the public. Besides, efficiency of WWTP can be increased by using the automatic control methods. Figure 2.1 shows the general WWTP.

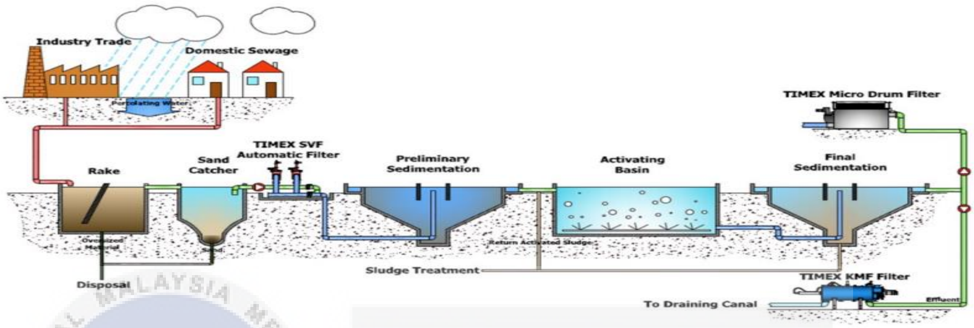

Figure 2.1: General Wastewater Treatment Plant (WWTP)

2.2 Process Stage in Waste Water Treatment Plant

The wastewater treatment plants consist of the three stages, from primary to tertiary treatment. Secondary treatment (Active Sludge Process) is one of the key component of a wastewater treatment plant[8]. Figure 2.2 shows the schematic representation for the stages of a typical WWTP.

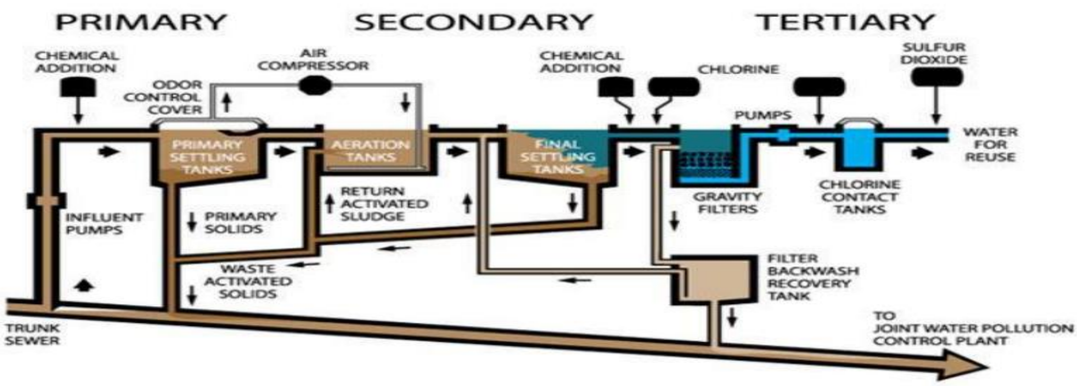

Figure 2.2: Schematic representation of a typical WWTP

2.2.1 Preliminary Treatment and Primary Treatment

The removal of coarse particles and other big objects commonly found in raw wastewater is the goal of preliminary treatment. This technique is required in order to improve the operation and upkeep of following treatment units. Coarse screening, grit removal, and comminuting of big objects are among the preliminary treatment activities. Bar screens can be used to remove screening. Bar screens and other devices developed for this purpose can be used to remove screening. Grit is made up of inorganic materials such as sand, gravel, eggshells, and so on. The efficient operation of the raw sewage pumps necessitates screening and grit removal. These materials can cause internal parts to wear out and stop working. These raw sewage pumps transport the flow to the next stage of the treatment process.

The primary treatment's goal is to remove floatable organic and inorganic solids by sedimentation and to remove floatable organic and inorganic solids by skimming. Round or rectangular basins can be used as primary sedimentation tanks or clarifiers. The wastewater flows into the primary settling tank (or clarifier), where it sits for many hours to allow the sludge to settle and a scum to form on the surface. The scum is skimmed off the top, the sludge is skimmed off the bottom, and the partially treated wastewater is sent to the secondary treatment level..

2.2.2 Secondary Treatment

The secondary treatment's goal is to remove the residual organics and suspended particles from the partially treated wastewater from the primary treatment. Secondary treatment, which is usually performed after primary treatment, entails the removal of biodegradable dissolved and colloidal organic materials utilizing aerobic biological treatment techniques. The bacteria and oxygen are mixed together in the effluent. The oxygen aids the microorganisms in digesting contaminants more quickly. The water is then pumped to settling tanks, where the sludge settles and the water becomes 90 to 95 percent pollutant-free. To complete the secondary treatment, sedimentation tank effluent is normally disinfected with chlorine before being discharged into receiving waters. To complete the secondary treatment, sedimentation tank effluent is normally disinfected with chlorine before being discharged into receiving waters. Chlorine is added to the water to eliminate dangerous bacteria and reduce odour. The trickling filter and the activated sludge process are the two main secondary treatment procedures used in secondary treatment. The untreated sewage is pumped to another sedimentation tank, where it is treated to eliminate microorganisms from a trickling filter.

2.2.3 Tertiary Treatment (Advance Treatment)

The tertiary treatment's goal is to remove dissolved contaminants like colour, metals, organic chemicals, and nutrients like phosphorus and nitrogen from the water. In the case of nitrogen removal, biological methods are used. Biological Nutrient Removal (BNR), which takes place in bioreactors, is one of the biological treatment processes. Chemical additives are usually required for phosphorus removal. The BNR procedure takes place in the bioreactor for tertiary treatment. In the bioreactor, there are three tanks, each with a different amount of oxygen. Phosphorus is removed from the water as it goes through the three tanks, and ammonia is broken down into nitrate and nitrogen gas, which is something that other bacterial processes can't do. Then, as the following phase of treatment, tertiary treatment will begin. Then, as the following phase of treatment, tertiary treatment will begin.

2.3 Activated Sludge Process

An aeration tank and a secondary clarifier make up the activated sludge treatment system. In the aeration tank, the settled sewage is mixed with fresh sludge that has been recovered from the secondary clarifier. The mixture is then injected with compressed air through porous diffusers at the tank's bottom. The diffused air supplies oxygen and a quick mixing action as it bubbles to the surface. The churning movement of mechanical propeller-like mixers situated at the tank surface can also be used to supply air. Microorganisms flourish in such oxygenated environments, generating an active, healthy suspension of biological solids—mostly bacteria—known as activated sludge. In the aeration tank, there is around six hours of detention. This provides adequate time for the bacteria to consume dissolved organics from the sewage, lowering the BOD. The combination then moves from the aeration tank to the secondary clarifier, where gravity separates the activated sludge. The clear water from the clarifier's surface is skimmed, disinfected, and discharged as secondary effluent. The sludge is pumped out of the tank through a hopper at the bottom. About 30 percent of the sludge is recovered and mixed with the principal effluent in the aeration tank. The activated sludge process relies heavily on recirculation.

2.3.1 Bioprocess Modeling in ASP

The activated sludge process (ASP), which is part of the WWTP's secondary treatment, comprises of an aerated bioreactor and a settler. The microorganisms in the aerated bioreactor act on the organic substrate to eliminate pollutants from the wastewater. The solids will be separated from the wastewater in the setting, and the clean water will be delivered to the effluent, while the sludge will be returned. Solids will be separated from wastewater in the setter, clean water will be transferred to the effluent, removed sludge will be returned to the aeration bioreactor, and everything else will be sent to the waste sludge.

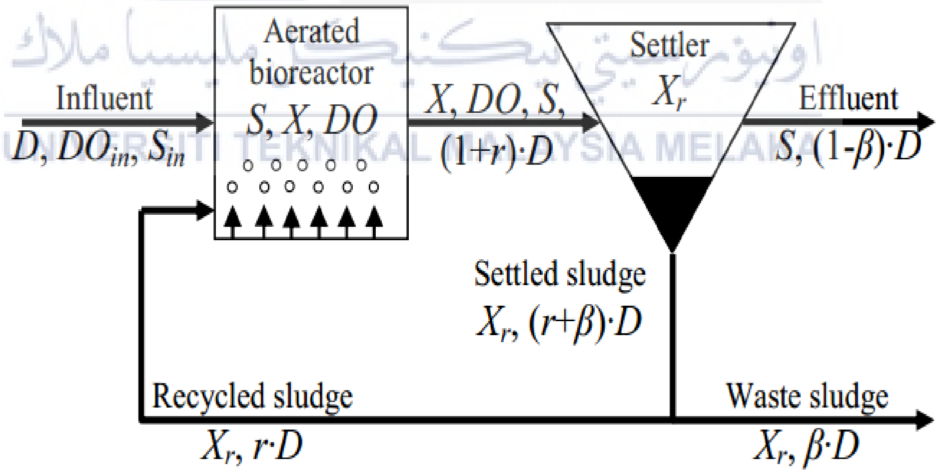

Figure 2.3 : Diagram of the activated sludge process

The equation below is the mass balance equations : [8].

$$\dot{X}(t) = \mu(t)X(t) - D(t)(1 + r)X(t) + rD(t)Xr(t) \tag{1}$$

$$\dot{S}(t) = - \frac{\mu(t)}{Y} X(t) - D(t)(1 + r)S(t) + D(t)Sin \tag{2}$$

$$\dot{C}(t) = - \frac{Ko\mu(t)}{Y} X(t) - D(t)(1 + r)C(t) + KLA(Cs - C(t)) + D(t)Cin \tag{3}$$

$$\dot{Xr}(t) = D(t)(1 + r)X(t) - D(t)(\beta + r)Xr(t) \tag{4}$$

The state variables $\dot{X}(t)$,$\dot{S}(t)$, $\dot{C}(t)$ and $\dot{Xr}(t)$ represent the concentrations of biomass, substrate, dissolved oxygen and recycled biomass respectively. D(t), μ(t), $Sin(t)$, $Cin(t)$, Cs, Y, Ko, KLa, r and β represent the dilution rate, specific growth rate, substrate concentrations influent steams, dissolved oxygen concentration of influent steams, constant of maximum dissolved oxygen, rate of microorganism growth, model constant, constant of oxygen transfer rate coefficient, ratio of recycled and ratio of waste flow to the influent flow rate respectively.

2.4 Multivariable System

The activated sludge process in secondary treatment is chosen as a benchmark to control the concentration of substrate and dissolve oxygen near to achieve the level that is intended. Therefore, there are two state variables to be controlled, the system considered multi-input multi output system (MIMO).

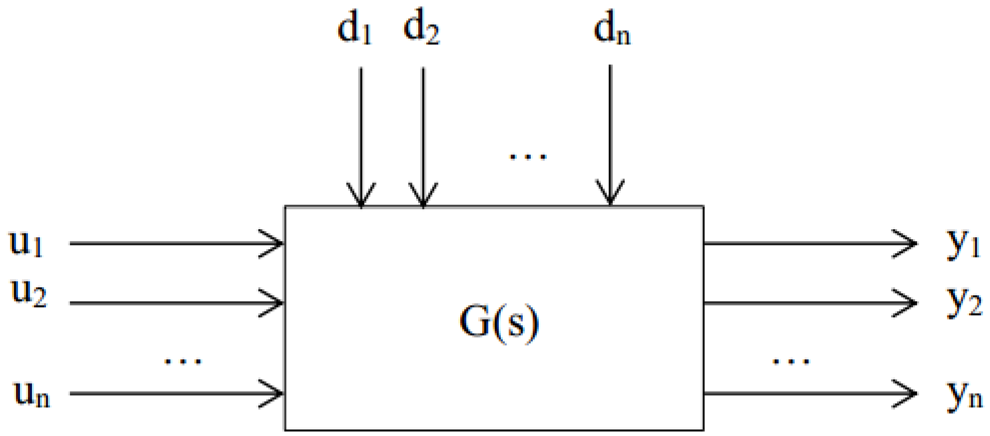

Figure 2.4 Multivariable System

Multivariable control tuning is becoming the preferred tuning control because to the numerous industrial process controls based on MIMO systems. PID, model predictive control (MPC), internal model control (IMC), linear-quadratic-Gaussian (LQG), and inferential control are some of the existing multivariable control techniques. PID controllers are still widely used today[9]. Due to the presence of process interaction and diverse dynamic characteristics in a multivariable system, tuning PID parameters has always been a difficult and necessary task for optimum operations[10]. Thus, MPID control tuning for WWTP is shown in this thesis.

2.5 Proportional Integral Derivative (PID) Controller

Proportional Integral Derivative (PID) controller have been used in industry control technique since many years.

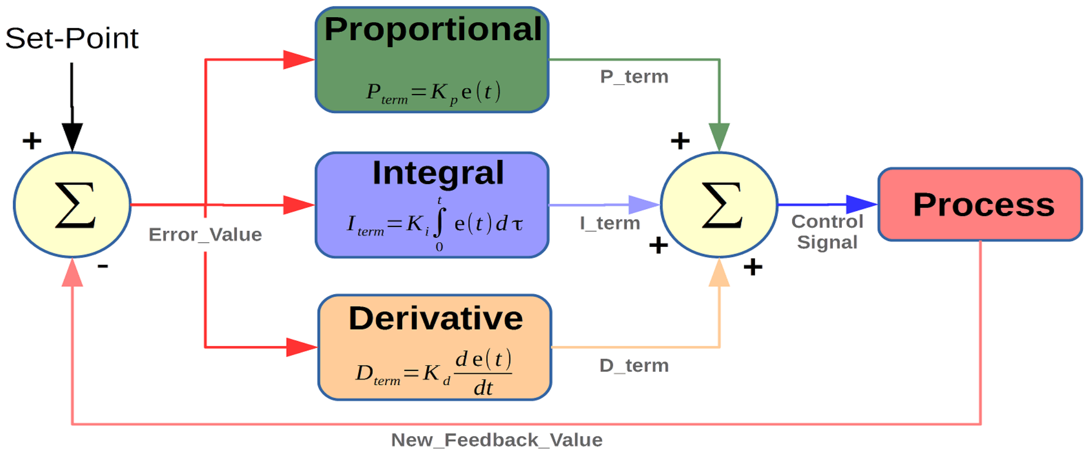

Figure 2.5 : Block Diagram of PID Controller

The standard form PID controller generates its control action according to the error by the given equation is

$$u(t) = Kpe(t) + Ki \int e(t)dt + Kd \frac{de(t)}{dt}$$

The PID controller transfer function is

$$H(s) = Kp + \frac{Ki}{s} + Kd\ s$$

The proportional, integral, and differential gains are denoted by Kp, Ki, and Kd, respectively. The proportional part is used to improve system response, the integral part is used to reduce steady-state error, and the derivative part is used to improve system stability. The linear PID controller is useful for controlling a normal physical process and can reach the desired operating condition, but because WWTP is a multivariable system, it is typically beyond the capabilities of standard PID controllers due to its significantly non linear and convoluted nature. The classic gain tuning of PID controllers, such as Ziegler-Nichols and many other traditional techniques, still creates a huge overshoot and is ineffective. Non-linearity, temporal delays, and the high order of practical systems cause issues for traditionally tuned controllers in real systems[3]. Optimization algorithms are widely proposed to tune the control parameter in previous works to discover the optimal performance[11][12]to increase the capabilities of standard PID parameter tuning procedures.

2.6 Optimization Technique - Particle Swarm Optimization (PSO)

Several intelligent approaches, such as those based on particle swarm optimization, have been proposed to augment the capabilities of traditional PID parameter tuning techniques (PSO). Optimization algorithms are frequently proposed to modify the control parameters in order to find an optimal performance with the advancement of computational technologies in recent time[13].

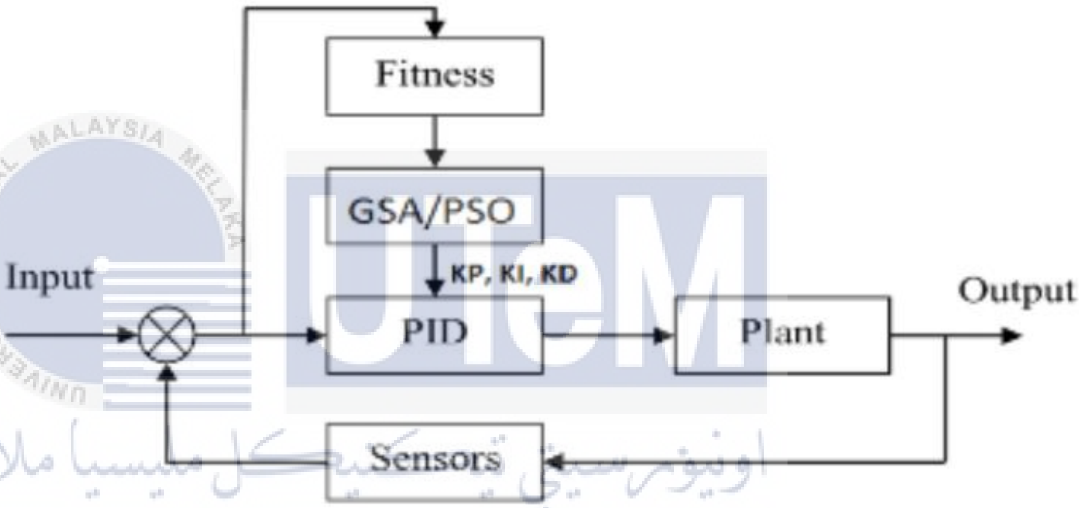

Figure 2.6 Typical PID Controller with PSO Implementation

PSO is an evolutionary computation-based optimization algorithm. The basic PSO is based on studies of swarms like fish schooling and bird flocking[14]f. After its initial release in 1995, a modified PSO was released in 1998 to improve the original PSO's performance. The inertia weight parameter has been introduced. This is a popular PSO in which the weight of inertia is taken into account. The inertia weight parameter has been introduced. In addition to another prevalent type of PSO disclosed by Clerc[5,] this is a commonly used PSO in which inertia weight is linearly decreasing during iteration.

The PSO concept is based on the random acceleration of each particle as it moves toward the pbest and gbest positions. Particles are individuals that offer a potential solution to a problem. Each particle changes its flight in accordance with its own and its companion's flying experiences. Its particle can be said to have velocity because of its movement. Each particle tries to discover the best solution in the solution space, which is referred to as the personal best or ‘pbest.' Any particle in the vicinity can also offer a different best value, which is referred to as global best or ‘gbest'[8]. A good nonlinear gain function may be achieved with the PSO algorithm with minimum parameterization adjustment.

The tracking response of substrate level and dissolve oxygen is projected to be much enhanced with proper tuning of nonlinear PID controller gain using the PSO algorithm, resulting in better treated water.

2.7 Performance Index

Performance index will indicates the effectiveness of the system performances. It can be called as fitness function. For a PID- controlled system, there are often four indices to depict the system performance: ISE, IAE, ITAE and ITSE.

The Integral of Absolute Magnitude of Error (IAE) is a mode of error that improves the system's stability. The time it will take to reach steady state is denoted by T.

$$\text{IAE} = \int_0^T |e(t)|dt \quad (2.7.1)$$

The Integral of Time of Absolute Error (ITAE) method is used to reduce large errors in a system, which is defined as the integration of absolute error with regard to time.

$$\text{ITAE} = \int_0^T |e(t)|tdt \qquad (2.7.2)$$

In applications of optimal control and estimation, the Integral of the Squared Error (ISE) is used to quantify system performance. It is defined as the error of an output squared and added (integrated) across continuous time.

$$\text{ISE}= \int_0^T e^2(t)dt \quad (2.7.3)$$

To minimize the huge error, the integral of time squared error (ITSE) is applied. It is defined as the integral of the absolute square error, or the integration of a huge error in order to reduce the unstable state.

$$\text{ITSE} = \int_0^T te^2(t)dt \qquad (2.7.4)$$

There are benefits and drawbacks to using time-integral performance indices. IAE gives good reaction but lacks good selection performance, whereas ITSE provides higher dynamic performance with good settling time. Aside from that, ISE are appropriate for analytical and computational purposes, IAE are appropriate for computer simulation studies, and ITAE can reduce big initial errors by emphasising errors that occur later in the response. The PID controller is used to reduce error signals, and it can be configured more precisely based on the error criteria in order to reduce the value of the performance indices discussed before. The smaller the value of the related particles' performance indices, the more fit the particles are, and vice versa[15].

CHAPTER 3

METHODOLOGY

This chapter briefly describe the methodology used in this project. Each phase of the work is divided into several sections which are wastewater treatment plant, nonlinear PID, optimization technique and objective function.

3.1 Flow of Project

This project is separated into two parts FYP1 and FYP2. Planning is important in order to accomplish and achieved the objectives for this project. FYP1 is started with the title briefing with the project supervisor and proceeds with the literature study for the chosen title. Literature study is the most crucial part as to guide the project in a right direction. The reading is focusing on the latest research of PID controller tuning method, optimization technique and wastewater treatment plant as the multivariable plant.

The next process is to find the suitable and appropriate nonlinear gain functions from established papers and at the same time, the process is familiarizing with the simulation tools (MATLAB). For this project, two main MATLAB tools that must be familiarized with, is Simulink and m-File coding. This process is delivered by self-study with multimedia-based guidance video hosting channel (Youtube).

After selected the suitable nonlinear gain function, the nonlinear function gains is applied to simple wastewater treatment plant with MIMO and SISO (Activated Sludge Process, ASP). During this process, it is required to observe either the output can track the input with minimum overshoots or vice versa. If the condition is satisfying, optimization technique is implemented.

Then FYP2, proceeds to compare between initial gain function and optimized gain function after the optimization is completed. When the value of optimized gain has better performance, next process is to verify and validate. Finally, the result will be analyzed. The system will be developed and evaluated completely by using MATLAB Simulink software.

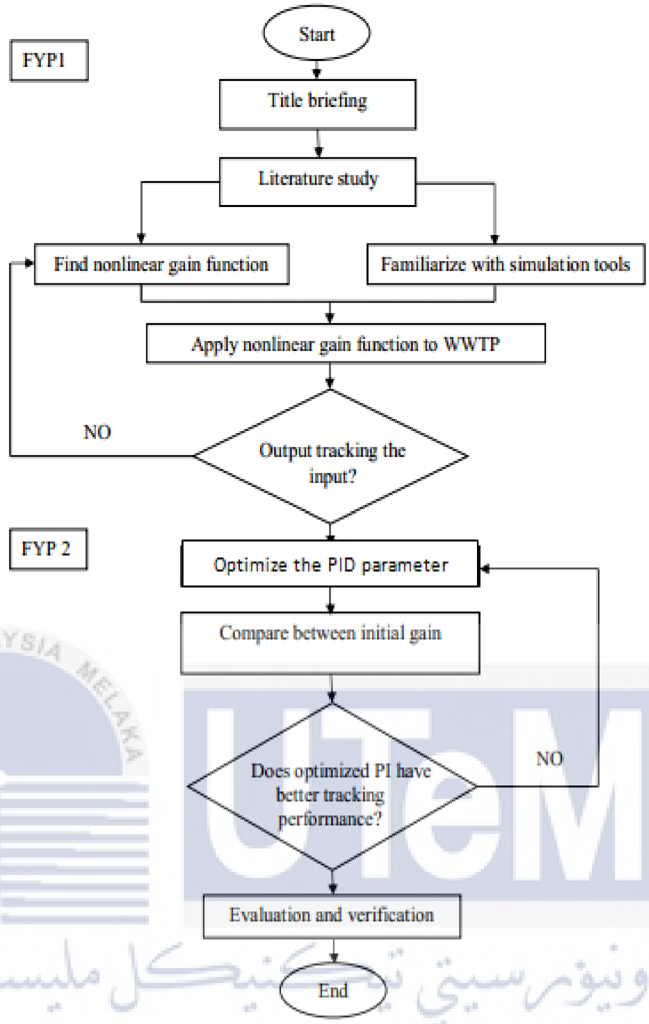

Figure 3.1 Project Flow Chart

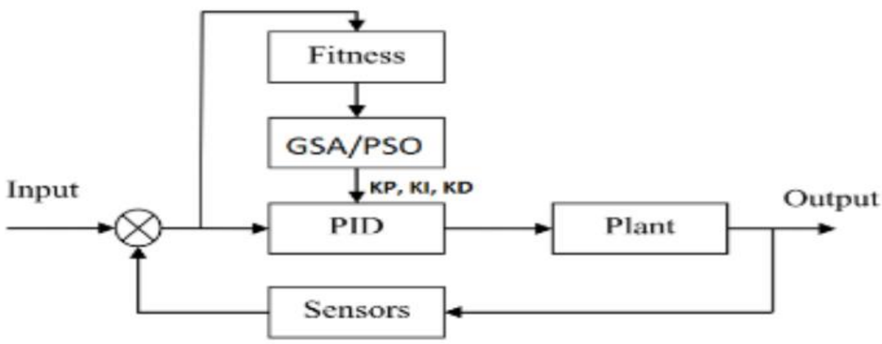

Figure 3.2: Block Diagram of a PID Controller with PSO Optimization Technique

3.2 Modeling of Wastewater Treatment Plant

For the purposes of this study, there are four inputs and outputs. The dilution rate and air flow rate are two inputs. Two outputs will be considered: substrate and dissolved oxygen.

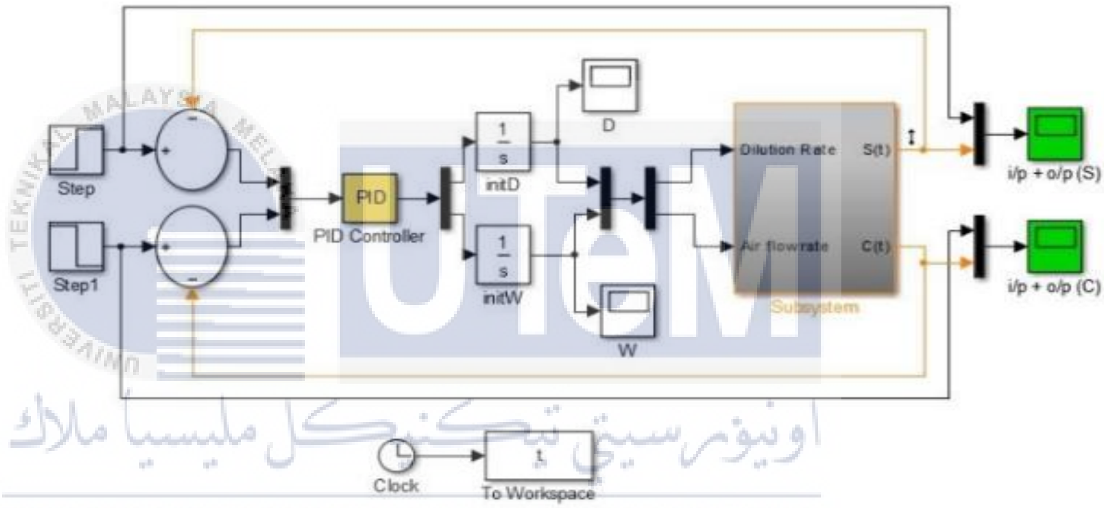

Figure 3.3 Plant modeling of activated sludge process

To linearize the non linear model, Table 3.1 and Table 3.2 show the initial condition value of the plant, and kinetic parameter value of the plant.

Table 3.1 Value of Initial Condition

Variable	Initial value
$X(o)$	$215mg/l$
$C(o)$	$6mg/l$
$S(o)$	$55mg/l$
S_{in}	$41.2348mg/l$
$X_r(o)$	$400mg/l$
C_{in}	$6.1146mg/l$
W	$90m^3/h$
D	$0.0825/h$

Table 3.2 Value of Kinetic Parameter

Parameter	Value
Y	0.65
r	0.6
α	0.018
K_c	$2mg/l$
μ_{max}	$0.15/h$
K_0	0.5

The state variables X(t),S(t),Xr(t), and C(t) denote biomass, substrate, dissolved oxygen, and recycled biomass concentrations, respectively. The substrate and dissolved oxygen concentrations in the fluent stream are represented by and. r and are the influent flow rate's recycled and waste flow ratios. Y. K0 is a constant, whereas signifies the specific growth rate that leads to cell mass. r and are the influent flow rate's recycled and waste flow ratios. Y. K0 is a constant, while Cs and KL are the maximum dissolve oxygen concentration and oxygen mass transfer coefficient, respectively. The Monod equation of microorganism growth m describes the relationship between maximum growth rate and dissolve oxygen concentration. The Monod equation of microorganism growth mathematical model describes the relationship between maximum growth rate to substrate and dissolving oxygen content. The maximal specific growth rate is represented by max, the affinity constant is represented by Ks, and the saturation constant is represented by Kc.

3.3 Nonlinear Gain Function

There are two types of PID: linear and nonlinear PID (NPID). Nonlinear PID control is used to tolerate nonlinearity and to achieve system performance that a linear PID cannot. NPID[16] features increased dampening, reduced rise time for step or quick inputs, greater tracking accuracy, and friction compensation.

The advantage of NPID controllers is that they have a high initial gain for a quick reaction, followed by a low gain to avoid oscillatory behaviour. By incorporating a sector-bounded nonlinear gain into a linear fixed gain PID control architecture, a performance boost to the typical linear PID controller is provided in this study[17].

The suggested enhanced nonlinear PID (NPID) controller is divided into two components in this work. The first component is a nonlinear gain Kn(e) with a sector bound, while the second portion is a linear fixed-gain PID controller (Kp, Ki and Kd). The error e is a sector-bounded function of the nonlinear gain Kn(e) (t). In prior studies, the nonlinear gain Kn(e) has been given a single scalar value.

The Kn(e) functions as a row vector in this study and may be represented as Kn(e) = [Kn1(e) Kn2(e) Kn3(e)] to improve the NPID controller. The following is a description of the proposed NPID control method:

$$u(t) = Kp[Kn1(e).\, e(t)] + Ki \int_0^T [\mathrm{Kn2(e).\, e(t)}]\ \mathrm{dt}\ + Kd\ [Kn3(e).\frac{\mathrm{de(t)}}{\mathrm{dt}}]$$

Kn1(e), Kn2(e), and Kn3(e) are nonlinear gains. Any general nonlinear function of the error e that is bounded in the sector 0 Kn(e) Kn(e)max is represented by the nonlinear gains. For the nonlinear gain Kn(e), a variety of alternatives are possible. The nonlinear gain function can be represented in one simple form as follows:

$$Kni(e) = ch(wie) = \frac{\exp(wie) + \exp(-wie)}{2}$$

Where i = 1, 2, 3.

$$e = \begin{Bmatrix} e \quad |e| \leq\ emax \\ emaxsgn(e)\ |e|\ > emax \end{Bmatrix}$$

Where wi and emax are positive constants defined by the user. When e = 0, the nonlinear gain Kn(e) is lower bounded by Kn(e)min = 1 and higher bounded by Kn(e)max = ch(wi emax). As a result, emax denotes the maximum range of variation, while wi denotes the rate of variation of Kn(e).

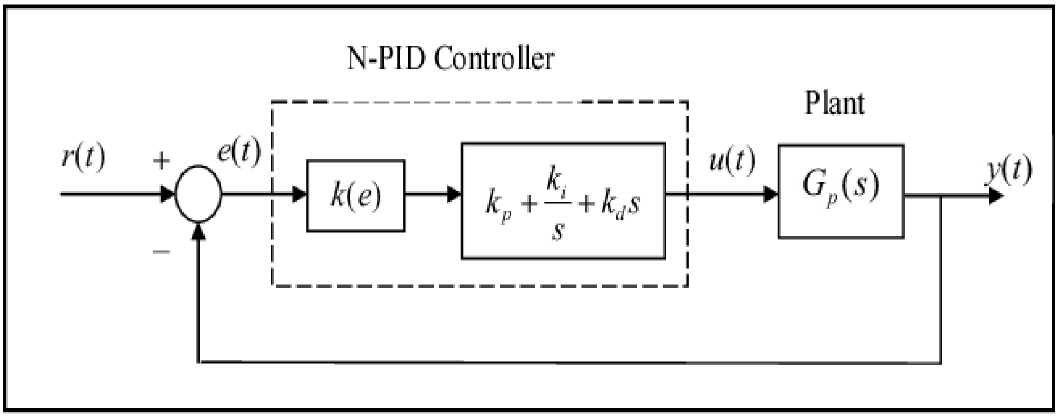

Figure 3.4: Nonlinear PID Controller Structure

As mentioned in Scope of the Project, the nonlinear gain functions that will be used to the PID controller are obtained from established paper. For better understanding of the methodology to design the PID controller, Figure 3.6 depicted flow chart of designing the PID controller.

The steps of designing NPID controller :

1. Find the nonlinear gain functions from an established papers

2. Simulate the respective functions in the MATLAB m-file coding to view the characteristics of the function. The preferred characteristics are nonlinear and continuous gain function.

3. Apply the function into Wastewater Treatment Plant (WWTP) for this project, which is Activated Sludge Process (ASP) plant and then simulate.

4. Determine whether the controller (now NPID) is able to track the output of the system. If NO, then the gain function is ineffective for the system. If YES, advances to the next procedure.

5. NPID is then tuned and optimized by using PSO algorithm. The algorithm methods are briefly discussed in section 3.4.

6. Compare and analyze the performance characteristics of the NPID controller before and after optimization.

7. End process.

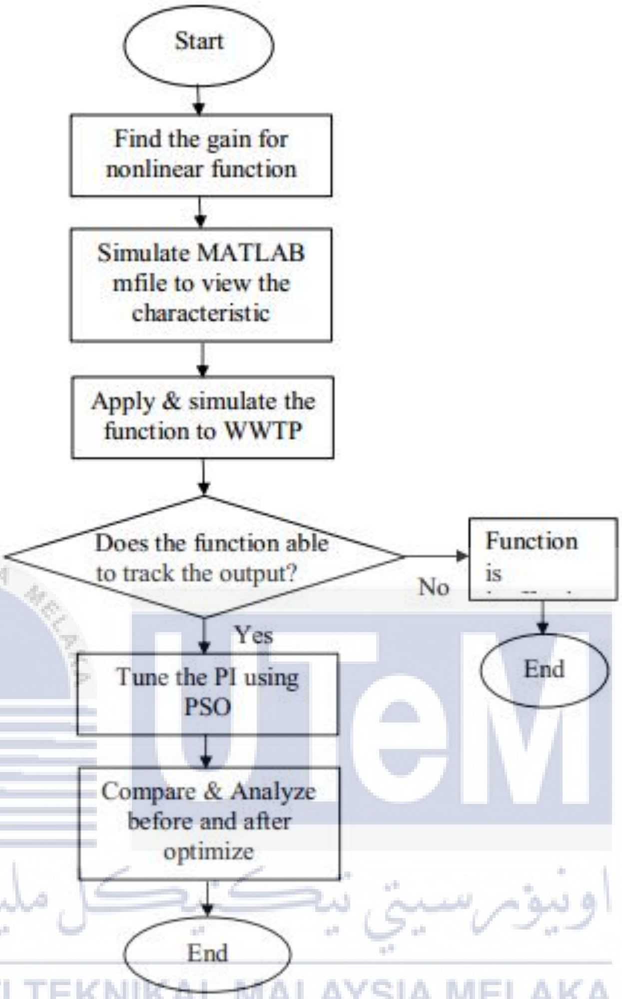

Figure 3.5: Flow Chart of NPID Design

3.4 Optimization Technique - PSO

The PSO algorithm flow chart is shown in Figure 3.4. Each particle can be seen as a bird, whereas the swarm model can be visualised as a group of space particles., as discussed in literature review. Particles in a swarm communicate by adjusting their velocity and position.

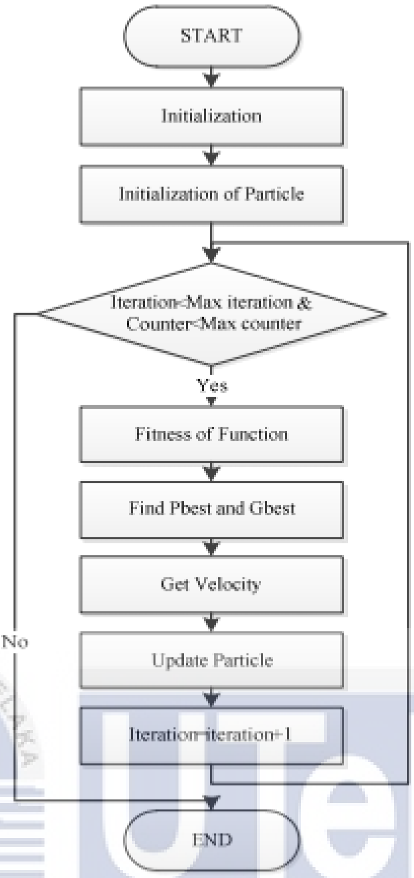

Figure 3.6: PSO algorithm flowchart

The PSO algorithm steps:

1) Create a set of particles with randomly generated locations, velocities, and accelerations.

2) Evaluate each particle's fitness.

3) Compare each particle's individual fitness to the preceding pbest. Update as new pbest if it is better.

4) Compare each particle's individual fitness to the preceding gbest. Update as new gbest if it is better.

5) Each particle's velocity and position should be updated.

6) Return to step 2 and repeat the process until the ending criteria are met.

The Particle Swarm Optimization algorithm starts by initializing all related parameters that will be used in the algorithm. Table 3.4 shows the values for the parameters. Depending on the number of tuning parameter, a set of particles will be initialized.

Table 3.4 Parameter Value of PSO

Initialization	
No of Particles=50	No. of counter=10
Search range=0-10	No. of iteration=100
Velocity initialization	
$c_1, c_2 = 2$	Max. weight=0.9
Max. velocity=$\pi/100$	Min. weight=0.4

The initialization will be based on random values with the search range defined earlier in the process, and the equation is (3.12), where the random numbers range from 0 to 1. The fitness of each parameter was also tested during particle initialization.

$$\text{initialization} = \text{range}_{min} + (\text{range}_{max} - \text{range}_{min}) \text{x random number} \quad (3.41)$$

The equations for velocity and position are given as below respectively.

$$V_{i,k+1} = w_k V_{i,k} + c_1 r_1 (P_{pbest,i,k} - X_{i,k}) + c_2 r_2 (P_{gbest,i,k} - X_{i,k}) \quad (3.42)$$

$$X_{i,k+1} = X_{i,k} + V_{i,k+1} \quad (3.43)$$

where

$w_k = w_{max} - ((i_k * (w_{max} - wmin)/max_k)$

V_i^k	At iteration k, the velocity of the ith individual
w_k	Iteration k inertia weight
r1 and r2	[0,1] is a uniform random number.
c1 and c2	between 0 and 2 acceleration factor
X_i^k	at iteration k, the position of the ith individual
$P_{pbest, i ,k}$	The ith individual's best position at iteration k
$P_{gbest,i , k}$	Until iteration k, the group's best position

[18]has mentioned a number of options for terminating criterion. There are two stopping conditions for this study: when there is no improvement after a certain number of iterations and when the maximum number of iterations is achieved. In PSO, better the fitness function the better the performance index with smaller errors (IAE and ISE value).

3.5 Objective Function

Performance index will indicates the effectiveness of the system performances. The objective function will be chosen in this research are Integral square error (ISE) and Integral absolute error (IAE). ISE behavior that provides a better tracking performance and suitable for analytical and computational purpose and IAE provides good response and useful for computer simulation studies. There are no precise system criteria in this study as long as the target function is maximized. The better the system or performance index, the less the error or objective function.

$$\text{IAE} = \int_0^T |e(t)| dt$$

$$\text{ISE} = \int_0^T e^2(t) dt$$

$$e(t)=y(t)-r(t)$$

where e(t) is the error, y(t) is the system output, and r(t) is the desired output.

3.6 Simulation

Some criteria were taken into account during simulating the algorithm. PSO is a stochastic method that produces different results each time it is run, although using the same starting point. The outcome is determined by the execution that yields the highest performance index.

There are two stopping conditions in this project: when there is no improvement after a certain number of iterations and when the maximum number of iterations is achieved. The first stopping criteria is implemented to speed up the algorithm's computation time and ensure that the best result is produced.

The result of the best performance index will come with the value of the scalar tuning, depending on what PID are used. Parameter tuning will be replaced to the non linear system in order to observe the system performance. To execute the nonlinear model, an m-file is required to be executed first.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter emphasizes on the design of Nonlinear Proportional Integral Nonlinear PID controller for the Activated Sludge Processes (ASP) Wastewater Treatment Plant (WWTP) and the optimization of the PID controller for ASP using Particle Swarm Optimization (PSO) technique. The first part of the results will show the response of the system of the classical PID controller. After that, the second part of the result will show the nonlinear gain function characteristics and the output is analysed. Then, the third part is the result when the nonlinear gain function being implemented to the PID controller, which forming the Non-PID controller and the response of the system is analysed. Lastly, the result response of system from classical PID and PSO-PID will be compared in this study.

4.1 Linear PID Controller

The linear PID controller response is retrieved by simulating the Simulink model of ASP wastewater treatment plant with linear PID controller with different gains. The input for this plant is Random Integer, and it is purposely chose to observe the difference level of input signal. The initial conditions of the plants are as shown in the Table 4.1 below.

Table 4.1 Initial Condition of the Plant

Variables	Initial Vale
Substrate, S_{in}	*41.2348mg/l*
Dissolve Oxygen, C_{in}	*6.1146mg/l*

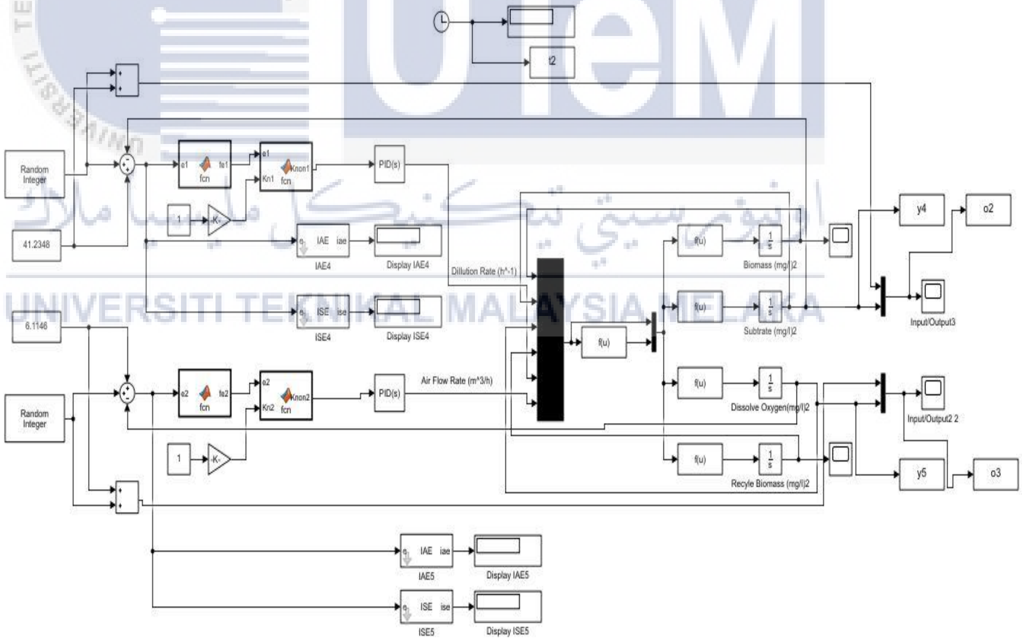

Figure 4.1: Wastewater Treatment Plants of Nonlinear Model in MATLAB/SIMULINK

4.2 Nonlinear Gain Function Characteristics

The enhanced nonlinear PID(NPID) is proposed in this research paper. The design of the NPID has a linear Kp, Ki, Kd gains of the PID controller is cascaded to a bounded nonlinear gain function with a non linear gain(Kn). A non linear gain function will be used to the PID controller are obtain from the established paper which can be described as[13]:

$$Kni(e) = ch(wie) = \frac{\exp(wie) + \exp(-wie)}{2}$$

Where $i = 1, 2, 3.$

$$e = \begin{Bmatrix} e \quad |e| \leq emax \\ emaxsgn(e)\ |e| \ > emax \end{Bmatrix}$$

Where wi and emax are positive constants defined by the user. When e = 0, the nonlinear gain Kn(e) is lower bounded by Kn(e)min = 1 and higher bounded by Kn(e)max = ch(wi emax). As a result, emax denotes the maximum range of variation, while wi denotes the rate of variation of Kn(e). When k0 = 0.125 and emax = 10, Figure 4.2 depicts a typical fluctuation of k(e) with regard to e.

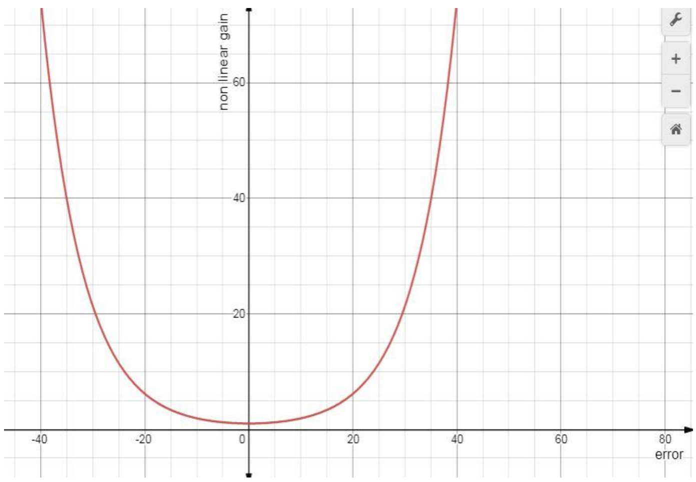

Figure 4.2: Graph of the Nonlinear Gain, k(e) with the Error, e

4.2.1 Non-PID Output Response for Enhanced Nonlinear Gain Function Equation

The gains of the classical non linear PID is obtained by using auto tune in PID Controller. Figure 4.3 shows that Non-PID controller for equation with enhanced non linear gain function is able to detect the input reference, albeit the overshooting at the starting of each toggle level for Substrates Level tracking. The controller achieved its steady state when T=51s. Substrates tracking show that the maximum value is at 43.39 mg/l, while maximum reference input reading which 42.23 mg/l; and minimum value of this controller is 40.44 mg/l while the minimum reference input reading is 41.23 mg/l.

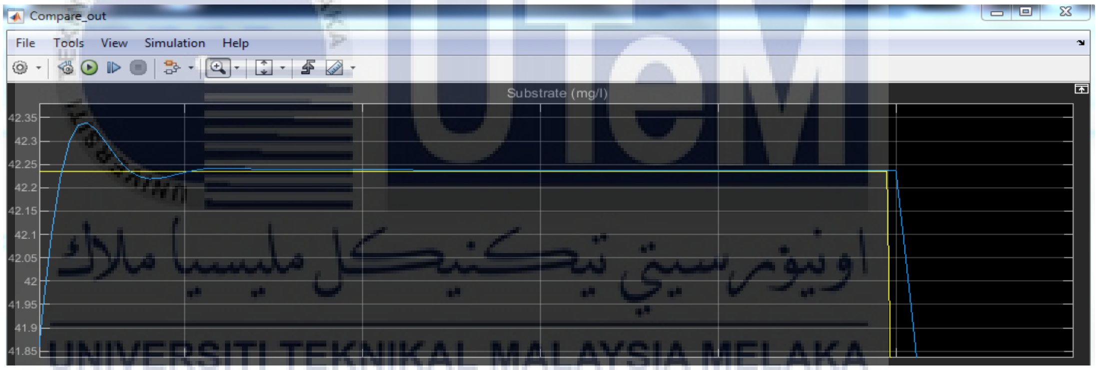

Figure 4.3: Response of Non-PID for Substrate Level

In Figure 4.4, tracking shows that the controller is able to track the reference input for Dissolve Oxygen with similar characteristics. The maximum tracking of Dissolve Oxygen is at 7.1 mg/l, equal with maximum reference input reading, which is 7.1 mg/l; and minimum detection of this controller is 6.121 mg/l while the minimum reference input reading is 6.121 mg/l.

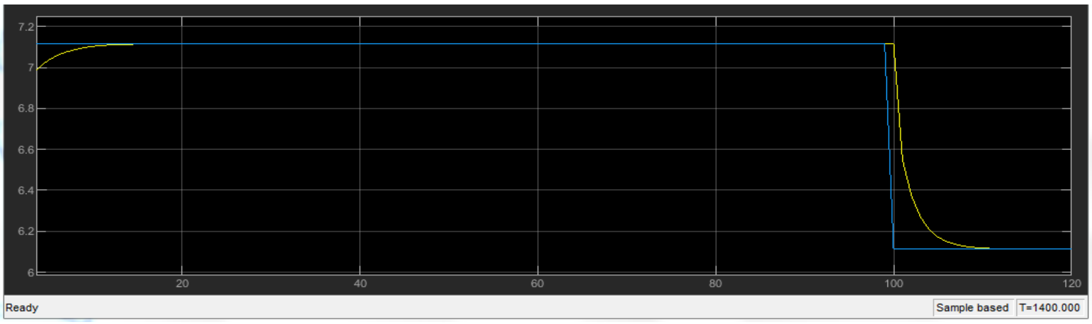

Figure 4.4: Response of Non-PID for Dissolve Oxygen Level

4.2.2 Classical Nonlinear PID Controller

Table 4.2 and 4.3 shows the summary of IAE and ISE reading for Substrate and Dissolve Oxygen tracking for classical Non-PID respectively.

Table 4.2 Transient Response of Output Substrate

Controller	Rise Time	Over shoot	Setting Time	IAE	ISE
PID	0.113	0.01	1.53	3.077	15.8

Table 4.3 Transient Response of Output Dissolve Oxygen

Controller	Rise Time	Over shoot	Setting Time	IAE	ISE
PID	0.297	0.03	0.512	67.3	121.4

Based on the given equations. It can be conclude that based from the readings, the IAE and ISE value quite high for Dissolve Oxygen Output, (67.3) and (121.4) however it is acceptable for Substrate output, (15.8) and (3.077).

4.3 Nonlinear PID Controller with PSO Response

Simulation studies are performed in this section to show the performance of the Non-PID controller with a Particle Swarm Optimization (PSO) algorithm. The number of particles and the iteration in PSO algorithm will be set to PSO-PID2(p=20,i=5), and PSO-PID3(p=100,i=25) in this research. The search range in PSO is between 0-10 because refer to the value of the gains obtained in the classical PID.

Table 4.4 PSO-PID2,3 parameters

	PSO-PID2	PSO-PID2
Epoch/ iteration	5	25
No. particles	20	100

The process start by PSO optimizing the gain of Kp of the substrate first and fixing the Kp for Dissolve Oxygen. After the optimization done, the Kp for substrate is fixed and the Kp of the Dissolve Oxygen is optimized by the PSO. After that, the same steps is repeated for the Ki, Kd of the substrate and dissolve oxygen. Therefore, the PID controller will be optimized. Then the steps is to optimized the non linear gains of Kn for each substrate and dissolve oxygen. As a result, the optimal PID controller for the WWTP is developed with the best performance index.

4.3.1 Optimization of PID gains using the PSO

Table 4.5 The simulation work optimize PID gains for PSO-PID2,3

	Case 1(fix pid gains substrate but pso pid gains DO)	**Case 2**(fix pid gains DO but pso pid gains substrate)	**Case 3**(pso pid gains substrate& pid gains DO)
Kp1,Ki1, Kd1	0.028, 0.024, 0.025	PSO	PSO
Kp2,Ki2, Kd2	PSO	1.89, 7.72, 0.028	PSO

Table 4.6 Comparative performance for Substrate of PSO-PID2,3

	Substrate				
	error	**ISE**	**IAE**	**% overshoot**	**Settling Time**
PSO-PID2	0.00	4.64	0.119	3.5770e-08	0.9814
PSO-PID3	0.00	5.39	0.23	9.4102e-09	0.09789

Table 4.7 Comparative performance for Dissolve Oxygen of PSO-PID2,3

	DO				
	error	**ISE**	**IAE**	**% overshoot**	**Settling Time**
PSO-PID2	0.00	58.64	193	2.6785e-04	0.9360
PSO-PID2	0.00	61.31	76.7	2.4156e-04	0.9502

4.3.1 Optimization of non linear gains using the PSO

Table 4.8 The simulation work optimize Kn for PSO-PID2,3

	Case 1(fix Kn substrate but pso Kn DO)	**Case 2**(pso Kn substrate but fix Kn DO)	**Case 3**(pso Kn substrate &Kn DO)
Kn1	1	PSO	PSO
Kn2	PSO	1	PSO

Table 4.9 Comparative performance for Substrate of PSO-PID2,3

	Substrate				
	error	**ISE**	**IAE**	**% overshoot**	**Settling Time**
PSO-PID2	0.00	2.59	0.018	0.00	18.7e-08
PSO-PID3	0.00	2.3	0.017	0.00	4.7e-08

Table 4.10 Comparative performance for Dissolve Oxygen of PSO-PID2,3

	DO				
	error	**ISE**	**IAE**	**% overshoot**	**Settling Time**
PSO-PID2	0.00	38.64	143	0.00	68.4e-05
PSO-PID3	0.00	41.51	56.7	0.00	2.85e-05

The input value of substrate and dissolve oxygen is set 41.2348mg/l and 6.1148mg/l respectively. Based on the result, the PSO-PID with highest number of iteration and particles (PID3) for performance index of the substrate has the lowest

IAE(0.018) and ISE(2.3) error. Moreover, the dissolve oxygen of PID3 has the lowest IAE(56.7) and ISE(45.41) error. The rise time of the PID3 also is fastest and the overshoot lowest compare to the PID2. The overshoot value for PSO nearest to the zero after optimize the gain of non linear kn and the gains of PID control. This can conclude as the number of iteration and the particles setting in the PSO algorithm will affect the value of the error between the input and output of WWTP. The lowest the error, the better the performances index of the WWTP. PID3 is chosen as the optimal PID controller for WWTP.

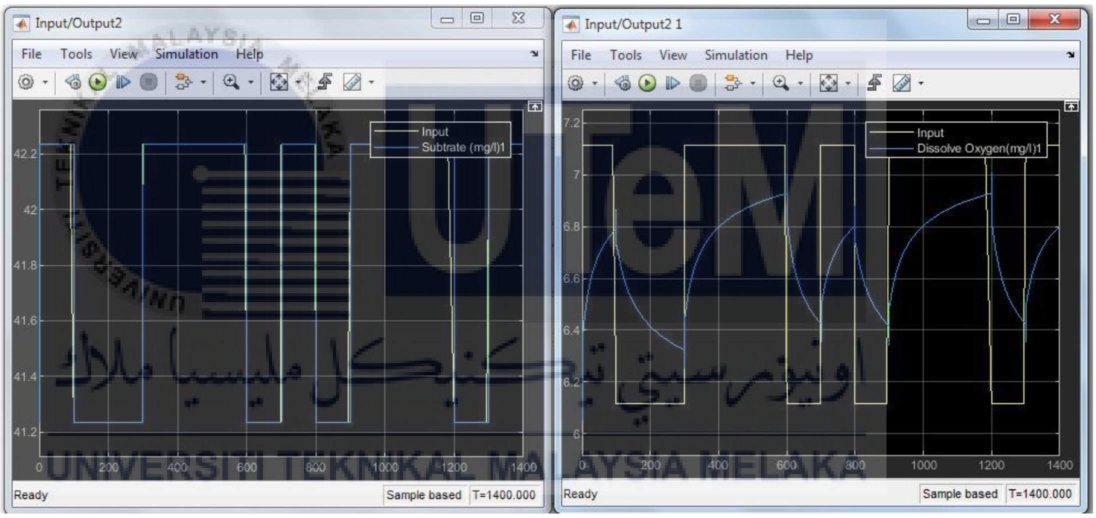

Figure 4.5: Response of PSO-NPID2 for and Substrate, Dissolve Oxygen Level

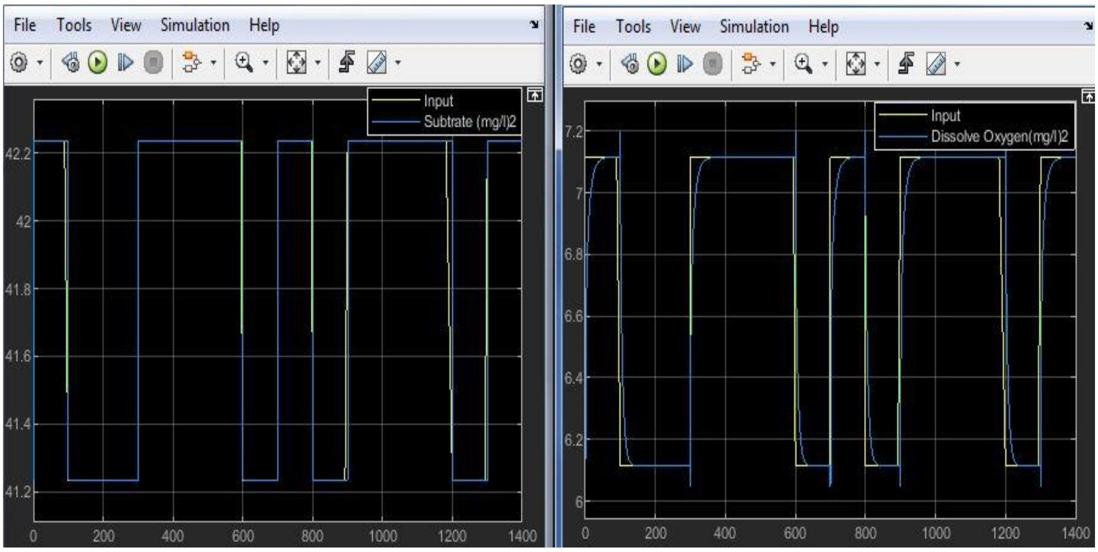

Figure 4.6: Response of PSO-NPID3 for and Substrate, Dissolve Oxygen Level

4.3 Comparison of Performance Index Between Classical PID and PSO-PID

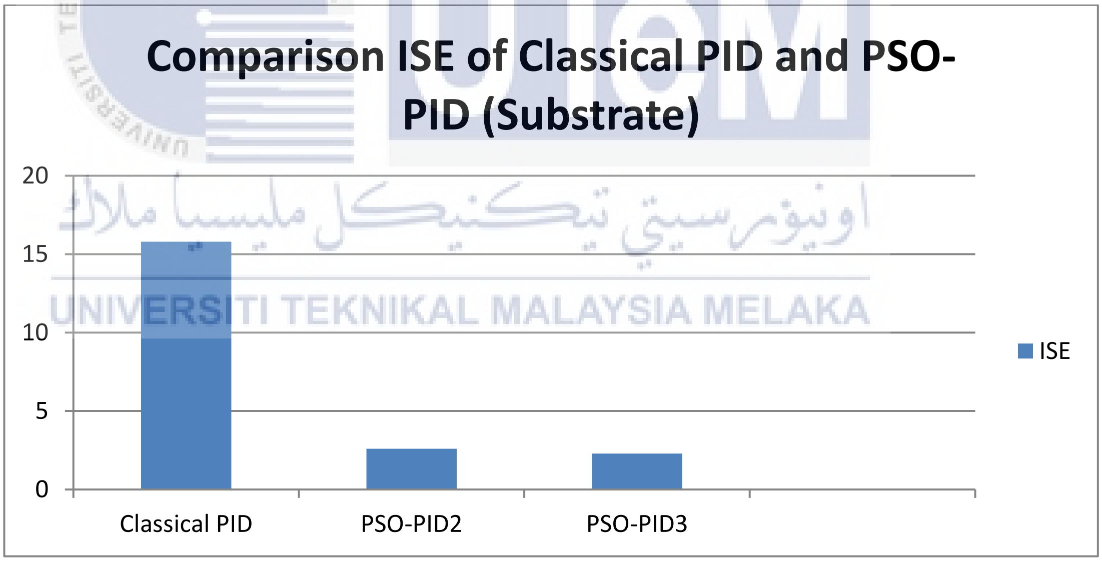

Figure 4.7: Comparison ISE of Classical PID and PSO-PID (Substrate)

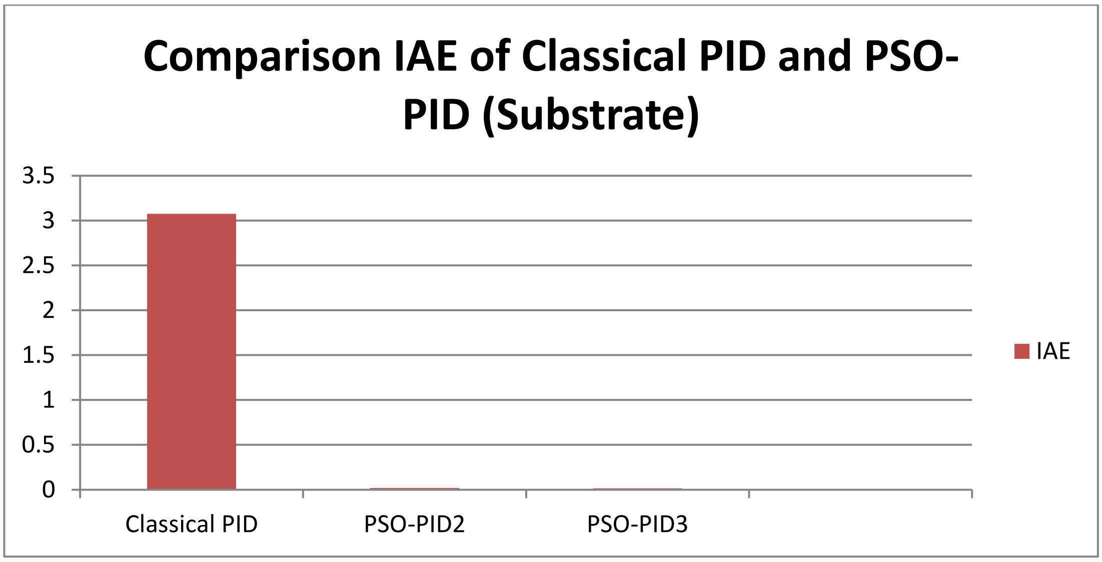

Figure 4.8: Comparison IAE of Classical PID and PSO-PID (Substrate)

Based on the result above, the performances index of ISE and IAE for the Substrate of the classical PID is reduced after the PSO optimization technique applied in the WWTP. For IAE of the PSO-PID, value is quite significant because it is nearest to the zero. The results shows the classical PID have been improved.

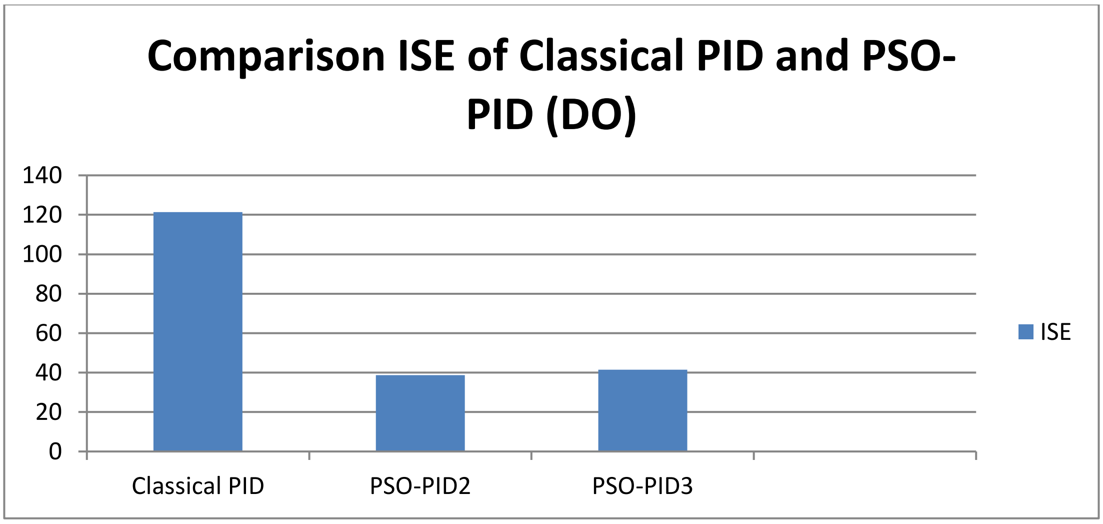

Figure 4.9: Comparison ISE of Classical PID and PSO-PID (DO)

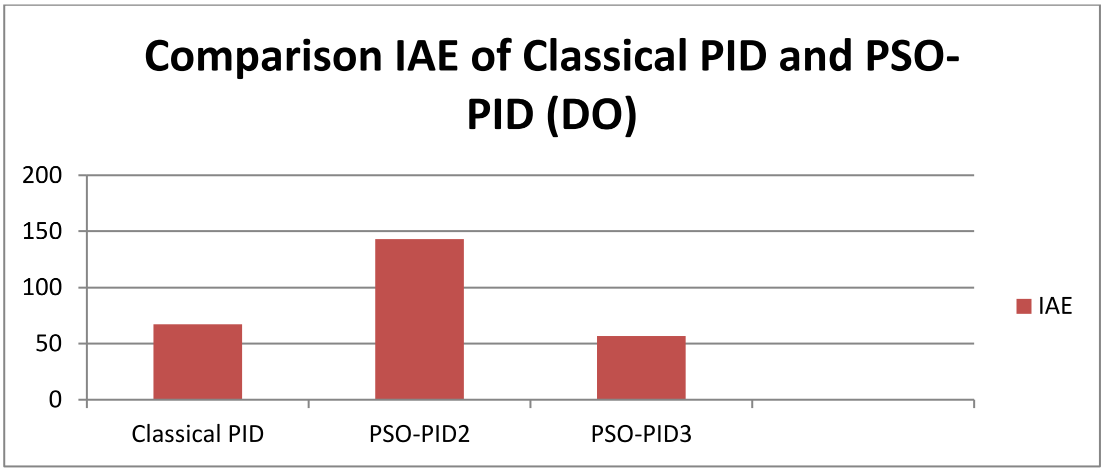

Figure 4.10: Comparison IAE of Classical PID and PSO-PID (DO)

Based on the result above, the performances index of ISE for the DO of the classical PID is reduced after the PSO optimization technique applied in the WWTP. However, even ISE is lower in PSO-PID2 compare to classical PID, but the IAE for DO is quite higher. This because the Kp gain value optimized by the PSO-PID 2 a quite higher and cause system is faster and unstable. Therefore, the solution is increase the iteration and the number particles for simulation. The results shows lower IAE in PSO-PID3. The results shows the classical PID have been improved, and the optimized PSO-PID3 gains and non linear gains have been tabulated in the table below.

Table 4.11 Optimized Gains (Substrate)

	Kn1	Kp1	Ki1	Kd1
PSO-PID3	8.7994	3.0523	5.364	6.7485

Table 4.12 Optimized Gains (DO)

	Kn1	Kp1	Ki1	Kd1
PSO-PID3	1.9775	6.1525	6.3358	0.0669

By using PSO algorithm, the optimal gains parameter of the nonlinear PID will be obtained. In the result of the simulation, the IAE and ISE are obtained lowest error and the transient responses can be analyzed. The optimal gains parameters are tuned in the simulation is better rather than before test in real plant to avoid the risk of damage.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter summarizes the conclusion of the project and recommendations for the future works that can be improved based on this project.

5.1 Conclusion

This study demonstrates an optimization technique for controller parameter adjustment in a multivariable WWTP plant. Before it is discharged to a receiving water body, a WWTP goes through various steps. The Non-PID controller is utilised in this project to manage S and dissolved DO concentration levels in the WWTP's secondary treatment (ASP). The system becomes complicated when there are too many characteristics to control, and obtaining the best treated water is difficult.

The optimization technique utilised in this research is Particle Swarm Optimization (PSO), and the findings are based on the performance of a nonlinear system. However, the output is only observed and analysed in the time domain. The

MATLAB/Simulink software is used for all simulation work. Based on the findings, it can be concluded that employing optimization techniques, the Non-PID controller has been successfully improved. The integral square error (ISE) and integral absolute error (IAE) performance values are lowered, and the ideal value is obtained using PSO.

5.2 Future Works

This project has been implemented based on simulation results. It seems that it is not entirely solved if the design is not to be implemented for real model of wastewater treatment plant activated sludge process. Due to this matter, implementation of hardware for experimental setup is needed in order to validate the simulation results that have been done previously. Indirectly, the performance of Non-PID controller of the WWTP can be observed in real time situation.It is suggested that in future works, additional works that can be done is first -variation of the nonlinear function gain, either it is obtained from established papers or derived by the researcher themselves. The next idea is to implement more advanced optimization technique for the Wastewater Treatment Plant to perceive the efficiency of optimization technique being used such as Firefly Algorithm (FA).

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APPENDICES

Appendix A : MATLAB PSO Coding

```
clear all
close all
clc

tic;
%% Initialization

Ts=0.01;
MAX_INPUTS = 3; %no input to be optimized
MAX_PARTICLES = 5;
V_MAX = 0.001;
W_MIN=0.4;
W_MAX=0.9;

MAX_EPOCHS = 5;  % can try higher
START_RANGE_MIN_1 = 0;
START_RANGE_MAX_1 = 10;
START_RANGE_MIN_2 = 0;
START_RANGE_MAX_2 = 10;
START_RANGE_MIN_3 = 0;
START_RANGE_MAX_3 = 10;
mData=zeros(MAX_PARTICLES,MAX_INPUTS,MAX_EPOCHS+1);
mVelocity=zeros(MAX_PARTICLES,MAX_INPUTS,MAX_EPOCHS+1);
mWeight=zeros(MAX_PARTICLES,1,MAX_EPOCHS+1);
Particle_result=zeros(MAX_PARTICLES,1,MAX_EPOCHS+1);
gBestvalue=zeros(MAX_EPOCHS+1,4);
gBest =1;
epoch = 1;
%Tol=0.2;
```

```
%% To find gBest

if  Particle_result(winner,1,epoch)<Particle_result(gBest,1,epoch)
    gBest = winner;
    real_counter=1;
    gBestvalue(epoch,1)=Particle_result(gBest,1,epoch);
    gBestvalue(epoch,2)=gBest;
    gBestvalue(epoch,3)=mData(gBest,1,epoch);
    gBestvalue(epoch,4)=mData(gBest,2,epoch);
    gBestvalue(epoch,5)=mData(gBest,3,epoch);

else
    real_counter=real_counter+1;
    gBestvalue(epoch,1)=gBestvalue(epoch-1,1);
    gBestvalue(epoch,2)=gBestvalue(epoch-1,2);
    gBestvalue(epoch,3)=gBestvalue(epoch-1,3);
    gBestvalue(epoch,4)=gBestvalue(epoch-1,4);
    gBestvalue(epoch,5)=gBestvalue(epoch-1,5);

end

fmin=gBestvalue(epoch,1);
%% Velocity and Position Calculation
%% Velocity

for i = 1: MAX_PARTICLES
    mWeight(i,1,epoch)=W_MAX-((epoch*(W_MAX-W_MIN))/MAX_EPOCHS);
```

```
%% Fitness Function calculation
    %Particle_result(i,1,epoch+1)=coupled_tank_ain(mData(i,1,epoch+1),
Kp=mData(i,1,epoch+1)
Ki=mData(i,2,epoch+1)
Kd=mData(i,3,epoch+1)
options = simset('SrcWorkspace','current');
sim('sia_pso_pid',[],options)
result = open ('results.mat');
%       size(result)
%apa = result.ans(3,:);
t = result.ans(1,:);
y = result.ans(2,:);
yy = result.ans(3,:);

%apa4 = result.ans(4,:);
%plot(t,y)
e_1=y(:)-yy(:);
e_1 = e_1';
%sum(e_1);

W_G_out1_in1 = 1;

%ITSE
temp=(e_1.*W_G_out1_in1).^2.*t;
%ITAE
%temp=abs(e_1.*W_G_out1_in1).*t;
%IAE
%temp=abs(e_1.*W_G_out1_in1);
%ISE
```

```
    %ITSE
    temp=(e_1.*W_G_out1_in1).^2.*t;
    %ITAE
    %temp=abs(e_1.*W_G_out1_in1).*t;
    %IAE
    %temp=abs(e_1.*W_G_out1_in1);
    %ISE
    %temp=(e_1.*W_G_out1_in1).^2;
    out_1_error=sum(temp);

    z=out_1_error;
    Particle_result(i,1,epoch+1)=z;

    end
    %% Update iteration and counter
    epoch =epoch + 1;
    %real_counter=real_counter+1;
end

epoch=epoch-1
Best_errors=gBestvalue(epoch-1,1);
Best_particle=gBestvalue(epoch-1,2);

Kp=gBestvalue(epoch-1,3)
Ki=gBestvalue(epoch-1,4)
Kd=gBestvalue(epoch-1,5)

Time=toc;
plot(t,yy')
stepinfo(yy',t)
```