MULTIVARIABLE PID CONTROLLER DESIGN TUNING USING OPTIMIZATION TECHNIQUE FOR ACTIVATED SLUDGE PROCESS

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“Hereby declare that I have read through this report entitle “Multivariable PID Controller Design Tuning using Optimization Technique for Activated Sludge Process” and found that it has been comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)”.

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Date	: 15 JUNE 2017

I declare that this report entitle "Multivariable PID Controller Design Tuning using Optimization Technique for Activated Sludge Process" 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.

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ABSTRACT

The designing of a multivariable PID control for multi input multi output is being concerned in this project by applying four multivariable PID control tuning which are Davison, Penttinen-Koivo, Maciejowski and Proposed method. The determination of this study is to investigate the performance of selected optimization technique to tune the parameter of MPID controller. The selected optimization techniques are Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Bat Algorithm (BA). The best MPID method which is Proposed has been choose to be as a controller tuning method from the all methods of MPID result tuning that have been compared and analyzed. Later, the Proposed has been compared between PSO, GA and BA in order to determine which optimization techniques are better based on the system performances in terms of transient response. The result obtained for the best optimization techniques to be used in Activated Sludge Process (ASP) was the Bat Algorithm with the Proposed control tuning method. This project also was done by simulated the algorithm in a different types of ASP system which are linear and nonlinear system.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Activated sludge process (ASP) is biological process that suspended growth secondary treatment process of Wastewater Treatment Plant (WWTP). It is a primarily removes dissolved organic solids while involving in controlling the concentration of microorganisms and sludge particles that are naturally found in unsettled wastewater. Besides, the controller parameters stay remained constant once after the plant been commissioned and this process involves a number of interacting controls. Therefore, a proper tuning of multivariable PID will improves the performances of WWTP while the parameter tuning can be obtained using optimization technique.

1.2 Motivation

Wastewater treatment plant (WWTP) is become very important nowadays due to the increasing of environmental awareness around the world. This situation cause the improvement of WWTP is driving enforcement because of the tightened requirements for the effluents before being released into the river. Activated Sludge Process (ASP) is secondary treatment process of WWTP and quite popular to be known as biological process. The complexity process of ASP make it becomes difficult to be handled. Thus, it can affect the performance of WWTP producing high quality effluent. With the proper tuning of multivariable PID, the performances of WWTP will be improved. Bat Algorithm (BA) technique of optimization was used in this project to gain the parameter tuning of MPID.

1.3 Problem Statement

Lately much of the efforts are giving an attention on new sources of clean energy, transportation and of course, wastewater treatment. An accurate treatment of the wastewater is a common issue in all metropolises before its discharge into the receiving water. Besides, since the ecological awareness is more important for people and politicians nowadays, the quality standards for Wastewater Treatment Plants (WWTP) becoming constricted [7]. WWTP also is categorized as a complex system. Therefore, an effective control methods need to be implemented for economic and environmental reasons, especially its Activated Sludge Process (ASP) because it involve a biological process. Unfortunately, an increasing claim for a more stable effluent water quality [6] makes a scalar PID based control systems are become insufficient anymore due to complexity of the system such as interrelated and highly nonlinear of its biological, physical and chemistry phenomena. Hence, as the system becomes more complex, the process of tuning controllers also becomes more difficult [8].

Then, the multivariable control systems are really needed to overcome that problem by using the suitable tuning method of its controllers and optimization techniques that can helps obtained an optimal solution to get the best values of parameter tuning in order to have good transient response performances of the system.

1.4 Objectives

The aim of this project is to gain parameter tuning based on selected optimization technique. So, the goals of this project are:

1) To implement the Multivariable PID (MPID) control tuning method of Activated Sludge Process.
2) To tune MPID parameter using optimization technique, Bat Algorithm (BA), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for MPID control tuning method.
3) To compare the system performances in term of transient response between selected optimization techniques

1.5 Project Scope

This project implements MPID controller design for activated sludge process. Davison, Penttinen-Koivo, Maciejowski and Proposed Combined method are the four types of MPID tuning that will be used in this project. Then, the scalar parameter MPID controllers are being adjusted by the selected optimization techniques which are Bat Algorithm (BA), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) in the system. All the simulation steps are done by using MATLAB/SIMULINK software and the results of this project are presented based on the performances of linear and non-linear system in terms of transient response and performances index.

1.6 Project Report Summary

This thesis basically is distributed into five chapters and this section delivers a brief overview of the chapters comprised in it.

Chapter 1: Introduction

This section guides readers to the elementary of this project, such as overview of activated sludge process, objectives, problem statement and project scope towards it.

Chapter 2: Literature Review

This part provides a simple explanation on the concept and previous work of related literature studies. The activated sludge process flow, controllers, MPID tuning and optimization techniques are being reviewed.

Chapter 3: Methodology

In this section, the project flow and methodology along to accomplish this project are being presented. Davison, Penttinen-Koivo, Maciejowski and Proposed Combined method are the types of MPID tuning that will be explained. Instead, the process of implementation of optimization technique will be stated in this chapter

Chapter 4: Result and Discussion

This section shows the results of system performance in term of transient response by using MPID tuning method. Its scalar parameter is being obtained via tuning with selected optimization technique. The results are compared and the specific discussions will also include in this section.

Chapter 5: Conclusion and Future woks

This section contains of conclusion based on the whole methodologies and outcomes. Then, some suggested work that can be done for a future is also mention in it.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explained about the definition of related subject or issues for this project. From this review, a several MPID methods and optimization technique will be chosen for additional studies. Hence, this section also reviews the related previous researches that have been done and other topic connected with this project.

2.2 Activated Sludge Process

Wastewater treatment plant (WWTP) is a place where the wastewater treatment process being carried out. The wastewater treatment process is designed in order to achieve enhancement in the quality of the wastewater that including three stages of processes [1] which are primary, secondary and tertiary as shown in Figure 2.1. The primary stage is also known as mechanical process, was aimed to eliminate gross, suspended and floating solid from raw sewage by including screening to trap solid object and sedimentation. Secondary stage is biological process. While, tertiary or advanced stage is a last stage where from this stage, almost all the impurities from the sewage will be removed.

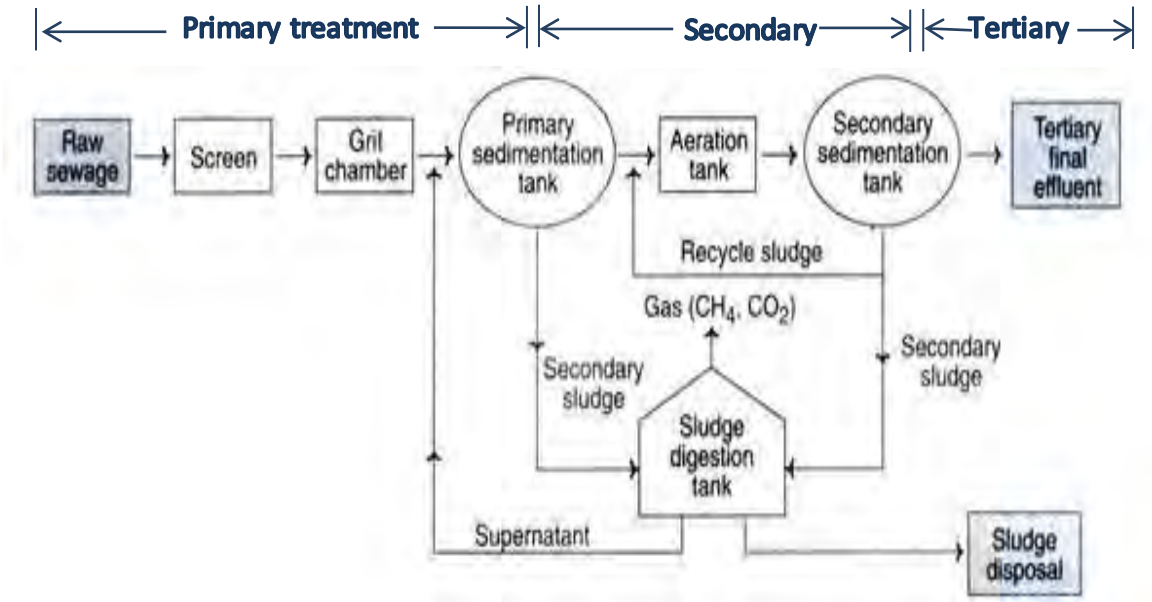

Figure 2.1: The Wastewater Treatment Process

Activated sludge process is the most widely used for biological wastewater treatment plant [2] and a type of secondary treatment where a high level of elimination of biodegradable organic pollutants are given to keep receiving water quality that clarification alone cannot provide. The activated sludge process also can speeds up decomposition by adding an activated sludge into the wastewater where the activated sludge particles hold many living organisms that can feed on the incoming wastewater [3]. This process is divided into two parts; an aerator tank which where the growth of organisms take place and a secondary settling tank, in where the leaving of clear liquid free of organic material happened [4].

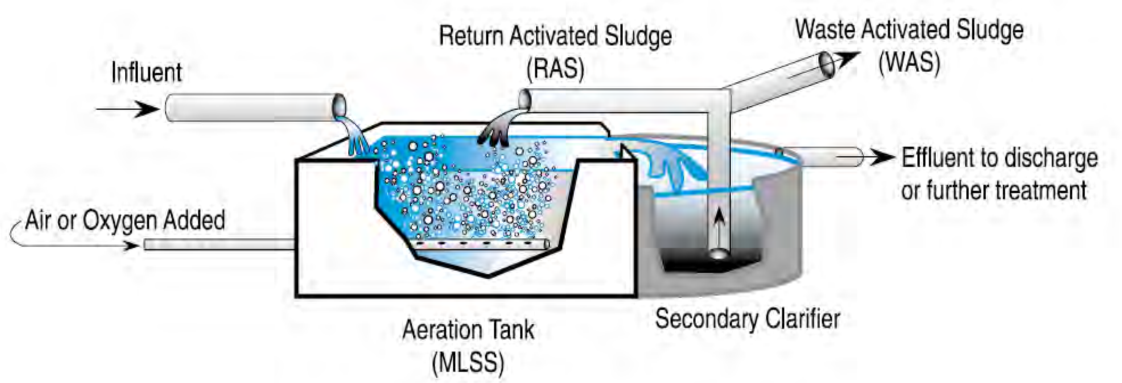

Figure 2.2: Activated Sludge Process

Figure 2.2 illustrated on how the process of activated sludge system takes an action [5]. This process starts with the incoming of influent to the aeration tank. Aeration tank is where the place of biological react occurred to segregate wastes from water and form waste decomposition. During that time, microorganisms are inject in and being contact in the wastewater; they feed and grow by the source of oxygen supplied into the tank. Then, the mixed liquor which is the mixture of wastewater and microorganisms will flow into secondary clarifier and begin to aggregation together. During the bio-flocculation process, the particles start to clump together, called floc and it will be settle to the bottom tank of the clarifier as sludge (separated completely from water). From the secondary clarifier tank, the relatively clear liquid above the sludge will flow on for further treatment while the sludge is driven back to the aeration tank, named Return Activated Sludge process (RAS). Lastly, the sludge that is intentionally eliminated from the ASP is denoted as Waste Activated Sludge (WAS).

2.3 Activated Sludge Process Controller

Nowadays, the health of natural ecosystems has been giving more attention cause of the effect from the human development in very different ways [6] by increased environmental awareness in terms of water pollution anticipation. The constricted laws and requirements toward quality of water are fortunately acting like a driving force for the development of wastewater treatment plants (WWTPs) [7]. The complex, interrelated and highly nonlinear of its biological, physical and chemical phenomena make the WWTP become more difficult to be controlled while optimizing operating and management costs [8].

Meanwhile, the activated sludge process (ASP), a biological processes are usually popular methods used to remove carbon as well as components of nitrogenous from wastewater beforehand it being released [9]. ASP has been widely case study in the automatic control perspective, for example by Yong et al. [10] the concentration of ammonia in the fluent of the wastewater plant is reducing by implementation of cascading PI-like controllers with feed-forward actions. Different with the model predictive control (MPC) by Holenda et al. [11] proposed that MPC method determining and controlling the dissolved oxygen concentration only. A decreasing of more than 25% in power usage and an increasing in plant efficiency are the significant benefits that can be obtained of using the MPC system [12].

A previous study done by Shen et al. [13] where a multiple input approach is implemented, by the recycle flow rates, the oxygen transfer coefficient of three aerated tanks and a complementary carbon source. Fuzzy controller has proved its efficiency to be implemented at WWTPs for improving the denitrification or nitrification process but these methods gives a highly cost and behaves relatively rough toward its control actions [14].

Rojas et al. [15] proposed that in order to be able to actuate based on the measurements of the disturbance, a three degree of freedom controller, tuned with the Virtual Reference Feedback Tuning (VRFT) is offered and applied to the WWTP. The three degree of freedom controller is an extended from a two degree of freedom PI which where control of nitrate concentration by manipulating the internal recycle flow rate, plus disturbance feed-forward action that can control ammonia using ammonia measurements from the influent. This methodology viewing the usability of model-free approach for WWTP control although there are no clear rules to select neither an appropriate close-loop target function nor the correct parameterization of the controllers

2.4 Multivariable PID

PID stands for Proportional Integral Derivative is a type of controller that encouraging to be used with more than 90% of industrial controllers due to its well-known robustness and its straightforwardness where the structure is easy to understand [16]. The structure of PID a combination of "three terms" and the transfer functions are given by (2.4.1) and (2.4.2) where proportional term represented gain factor, integral term by an integral and derivative term by a differentiator. Each of them has their own specific character to make sure better system performance. P-term decreases error but does not remove it. I-term eliminates the error but have a tendency to make the system oscillate while D-term improves the speed of the responses [17].

$$G(s) = K_p + \frac{K_i}{s} + K_d s \qquad (2.4.1)$$

$$G(s) = K_p\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \qquad (2.4.2)$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \qquad (2.4.3)$$

Along the implementation of PID controller due to the popularity of its advantages, this controller has limitation to control multivariable system. Multivariable process is a system with combination more than one variables at the input or output to be controlled in a system and a type of MIMO system which means multi-input, multi-output system. Figure 2.3 shows a multivariable system with PID controller and its transfer function matrix is stated at (2.4.3).

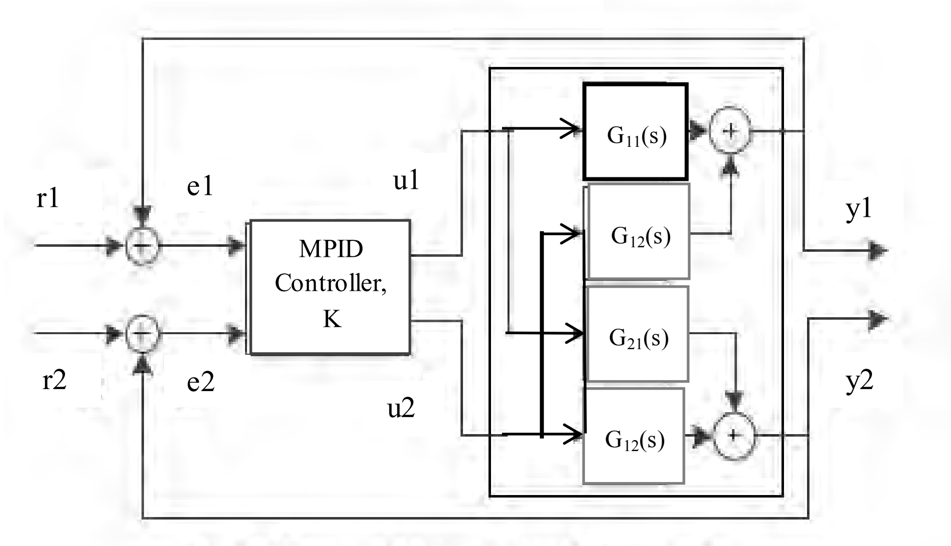

Figure 2.3: Multivariable System with PID Controller

MIMO system can be divided into two, centralized and decentralized controller. Centralized controller only involves one loop while decentralized controller involves several loops. The multivariable system is the system that apply centralized controller since its deal with MIMO by using single controller. Then, the decentralized controller was applied to another system called Multi-loop where each control variables are controlled by different controller [18]. Figure 2.4 shows a centralized controller for multivariable system, while Figure 2.5 shows a decentralized controller for multi-loop system.

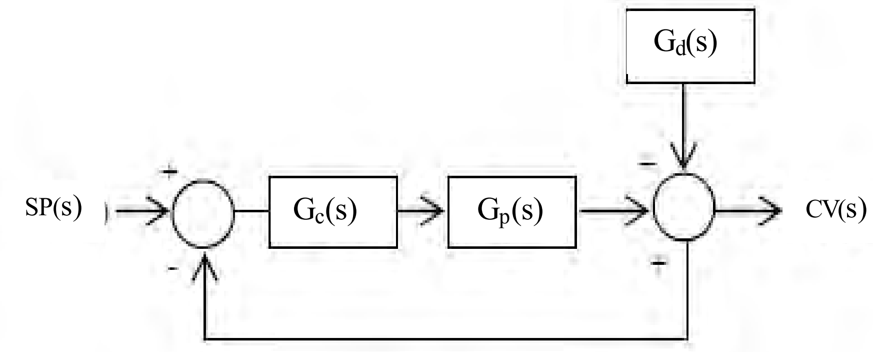

Figure 2.4: Centralized Controller for Multivariable System

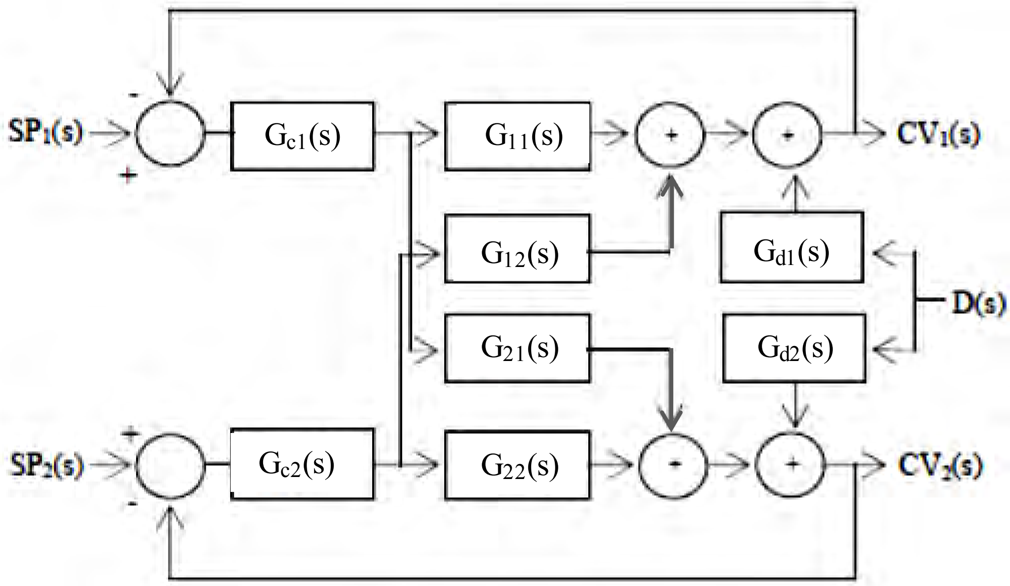

Figure 2.5: Decentralized Controller for Multi-loop System

Unfortunately, sometimes interactions phenomena can be occurred in MIMO system and it happen when loop gain in one loop also depends on other loop gains, particularly multivariable system [19]. Differ to the multi-loop system that does not acknowledge the interaction phenomena due to the structure of loop control which base on a single loop basis [20]. An interaction effect can be shown in (2.4.4) and (2.4.5). Besides, another factor which is quite important in multivariable system is *input/output* pairing problem. A number of quantitative techniques can be used to determine the right pairing of the manipulated and controlled variables [19]. So, the MPID is challenging to build rather than PID that implement in SISO system because it is does not involved an interaction [21].

$$y_1 = u_1 G_{11}(s) + u_2 G_{12}(s) \quad (2.4.4)$$

$$y_2 = u_1 G_{22}(s) + u_2 G_{21}(s) \quad (2.4.5)$$

2.5 Multivariable PID Tuning Method

Multivariable PID tuning method can be classified into two parts; parametric and non-parametric methods. Parametric methods use whichever model or experiment data to determine the controller parameters and are mostly defined as offline tuning methods, through online approaches have also been tested. While, non-parametric methods only partly use models such as critical states and are suitable for online use as well as for application without previous extensive plant studies [22]. The example of parametric tuning methods are Biggest Log modulus Tuning (BLT), gain and phase margin, minimum variance control, internal model control, and robust decentralized method whereas Davison, Penttinen-Koivo and Maciejowski are categorized on non-parametric tuning methods. Figure 2.6 shows the PID turning method classification.

Virtual Reference Feedback Tuning (VFRT) is an example of one-shot technique which means only one set of data required to define the controller. Campi et al. said that VRFT method converts the model reference control problem into an identification problem, where the controller is the transfer function to be identified based on some “virtual signals” figured from a batch of data taken directly from an open loop system [23]. This method has been implemented to a variety of cases [24, 25, 26] including in the field of WWTPs [27] because of its easiness of implementation, flexibility to be used in different kind of control systems and the characteristic of using