WATER LEVEL IN TANK USING LEVEL SENSOR AND PID CONTROLLER

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ABSTRACT

Water level in tank control using level sensor and PID controller system is an implementation of PID controller application into designing an intelligent and automatic level control of water/liquids/solids. While people especially in engineering fields have difficulties to measure and control the desired level in smooth transitions, this system provides the features which allow people to control and maintain water level in tanks as accurately and as steady with smooth transition process. This system is able to continuously maintain and doing necessary processes non stop day and night. The design will be implemented into a model built for a FKEE process laboratory in UMP (University Malaysia Pahang).

CHAPTER 1

INTRODUCTION

1.1 Overview

This thesis uses the PID controller in designing an actual real life plant to be future used in the process control laboratory in UMP (Universiti Malaysia Pahang). PID algorithm is among the latest technology used in industry application. A plant of controlling water level will implement PID controller in it's system. The PID controller will be able to control the inlet and the smooth transition of water into the tank to satisfy the set parameters by the handler (human). The program is from the PID controller itself. PID controller is programmed and the tunings of other manual settings on the whole system uses human interface. Each steps of designs and verifications process is documented here.

1.2 System Overview

The Water Level Control Using PID Controller is a design of an intelligent automatic level measurement system using PID controller. The system will allow users to measure and set the desired level of water with the PID controller controlling the process of water flowing into the tank. The system will be connected with a control valve and level sensor for the control section.

The system is able to show the trend of water flowing into the tank and the responses of the measurements. The PID controller has the ability to control the trend and specific responses for a smooth transition of the water reaching the desired level point with the tunings and algorithm parameters entered by the handler (human) together with safety aspects monitored by the PID controller especially in hazardous plant.

1.3 Problem Statements

Measurements have been on the world since the beginning of humans. Every creation since the beginning starts with measurements. The world today has developed complex and un-imaginable technologies to fulfill the ever demanding of necessities and needs thus creating at almost possible control of a system. Measurements have become crucial and higher accuracy is most wanted by now. For an example of oil refinery plant, overflows of oil can be hazardous, dangerous and costly. Empty vessels lead to pumps or drain stream processes running dry. Inaccurate measurements in mixtures processes can lead to product defects and higher costs. Accurate liquid level is vital in the process industries where inventories, batching and process efficiency are critical measurements.

Human supervision is limited for several hours and the accuracy is almost not perfect. Hazardous contents of a vessel must be watched carefully everyday without break and human are not capable of it. Extra workers thus to higher cost are results of these. Continuous monitoring and adjustments are necessary and important in this type of situation. Plants have become bigger or smaller and higher or shorter for lower cost and these developments are above humans' capabilities. Monitoring and measurements of these modern processes are almost impossible done by humans.

Recent years has shown the difficulties of controlling the process of contents reaching the desired / specified level point. Smooth transition and graph responses are now a goal of every high cost modern plants. Human senses and body control are in large scale to be able to control for example the opening of the valve into the tank.

In this project, the PID controller is proposed and built into actual plant with model of water level to be monitored. It introduces a better solution in accurate level measurements and automatic process in bringing water to the specific given level point (set-point). Not only that, the other crucial figure of smooth transition of level control can be controlled by the PID controller.

1.4 Objectives

The project is called water level control suing PID controller. The PID controller is used and applied into the system to measure and control the water level in a tank automatically. The objectives of the project are:

i. to fabricate an automatic model water level control using the PID controller.
ii. to build a real scale project model for the usage of FKEE process control laboratory in UMP (Universiti Malaysia Pahang).
iii. to implement the existing PID controller into a control process.

1.5 Scopes of Project

The span of the project is narrowed down in identifying the details of parameters, settings, tunings and method(s) used in controlling the desired water level. Devices and engineering of physics in facilitates the required and necessary sensing to the system for the only purpose of controlling water level in a tank. With the aim of designing real scale water level control system, this project is facilitated with:

i. Endress+Hauser model type level sensor to sense the water level in a tank.

ii. Flowvalve 3000series model type control valve to control the intake of water inserting into the tank.

iii. Yokogawa PID controller model type YS1700 for controlling the opening percentage of the control valve for optimum feedback responses on the plant.

CHAPTER 2

LITERATURE REVIEW

2.1 Level Measurements

Measurement is the estimation of the magnitude of some attribute of an object, such as its length or weight, relative to a unit of measurement. Measurement usually involves using a measuring instrument, such as a ruler or scale, which is calibrated to compare the object to some standard, such as a meter or a kilogram [1]. Measurements are crucial in purposes such as in science and in engineering. Measurements always have errors and therefore uncertainties. In fact, the reduction—not necessarily the elimination—of uncertainty is central to the concept of measurement. Measurement errors are often assumed to be normally distributed about the true value of the measured quantity [2] . Since accurate measurement is essential in many fields, and since all measurements are necessarily approximations, a great deal of effort must be taken to make measurements as accurate as possible [3] . These errors even though seemed neglectable are crucial in determining the accumulating costs, the perfections of each products produced and the quality of any creations. For example, every section of the metal manufacturing process can benefit from the use of infrared thermometry. These

6 Aug 2008 , Citing Internet Resources :

1 http://en.wikipedia.org/wiki/Measurement Para 1, line 1,2,3
2 http://en.wikipedia.org/wiki/Measurement Para 4, line 1,2,3
3 http://en.wikipedia.org/wiki/Measurement Para 1, line 1,2
4 http://www.allbusiness.com/primary-metal-manufacturing/foundries/704860-1.html Para 3, line 1,2,3

benefits include higher quality products, increased productivity, reduced energy costs, enhanced worker safety, reduced downtime, and easy data recording [4] .

2.1.1 Types of Level Measurement Sensors.

Various systems in sensors developments have been introduced to assist in crucial measurements of level. These sensors are most likely incorporates business obligation though there are certain sensors provided for non-business or profitable usage and for the usage in education purposes. There are many physical and application variables that affect the selection of the optimal level monitoring solution for industrial and / or commercial processes. Selection is categorized to contact and non-contact sensor. The selection criteria include the physical: state (liquid, solid or slurry), temperature, pressure or vacuum, chemistry, dielectric constant of medium, density or specific gravity of medium, agitation, acoustical or electrical noise, vibration, mechanical shock, tank or bin size and shape; and the application constraints: price, accuracy, appearance, response rate, ease of calibration or programming, physical size and mounting of the instrument, monitoring or control of continuous or discrete (point) levels. The selection criteria selected in this project is non-contact point level detection or continuous monitoring of solids and liquids. The sensor types to assist in this particular criterion are as follows:

i. **Capacitance level sensor (also called RF)**

   Possible when the tank wall are metal, to use a single bare or insulted rod as one capacitor plate and the tank walls as the other. An interesting application of this type of capacitance probe is in aircraft fuel quantity indicators. Capacitance switches can be utilized to provide non contact point measurements of liquid level [5].

ii. **Ultrasound**

Ultrasound echo ranging transducers can be used in either wetted (contact) or non wetted (non-contact) configurations for continuous measurements of liquid level. An interesting application of wetted transducers is as depth finders and fish finders for ships and boats. Non wetted transducers can also be used with bulk materials such as grains and powders [6]

iii. **Radar**

Microwave sensors are ideal for use in moist, vaporous, and dusty environments as well as in applications in which temperatures vary. Microwaves (also frequently described as RADAR), will penetrate temperature and vapor layers that may cause problems for other techniques, such as ultrasonic. Microwaves are electromagnetic energy and therefore do not require air molecules to transmit the energy making them useful in vacuums. Microwaves, as electromagnetic energy, are reflected by objects with high dielectric properties, like metal and conductive water. Alternately, they are absorbed in various degrees by low dieletric or insulating mediums such as plastics, glass, paper, many powders and food stuffs and other solids. Microwave-based sensors are not affected by fouling of the microwave-transparent glass or plastic window through which the beam is passed nor by high temperature, pressure, or vibration. These sensors do not require physical contact with the process material, so the transmitter and receiver can be mounted a safe distance from the process, yet still respond to the presence or absence of an object.

5,6 Jerry C.Whitaker, “The Electronic Handbook Second Edition”. (Taylor & Francis,2005), pg 1932-1935

Microwave transmitters offer the key advantages of ultrasonic: the presence of a microprocessor to process the signal provides numerous monitoring, control, communications, setup and diagnostic capabilities. Additionally, they solve some of the application limitations of ultrasonic: operation in high pressure and vacuum, high temperatures, dust, temperature and vapor layers. One major disadvantage of microwave or radar techniques for level monitoring is the relatively high price of such sensors.

2.1.2 Selection of Level Sensor in This Project

Below level sensor is initially selected to be used in this project:

Figure 2.1 Prosonic M FMU40 Ultrasonic Level Sensor

Areas of applications:

- The Prosonic M is used for continuous, non-contact level measurement of liquids, pastes, and slurries.
- The measurement is not affected by changing media, temperature changes, gas blankets or vapours.
- The FMR240 with the small (1½") horn antenna is ideally suited for small vessels. Additionally, it provides an accuracy of ±3 mm.

<u>Benefits at a glance:</u>

- 2-wire technology, low price: A real alternative to differential pressure, floats and displacers. 2-wire technology reduces wiring costs and allows easy implementation into existing systems.
- Non-contact measurement: Measurement is almost independent from product properties.
- HART or PROFIBUS PA respectively FOUNDATION Fieldbus protocol.

2.2 P.I.D Controller

P.I.D is a term for **P -Proportional, I - Integral, D – Derivative.** These terms describe three basic mathematical functions applied to the error signal , Verror = Vset - Vsensor. This error represents the difference between where you want to go (Vset), and where you're actually at (Vsensor). The controller performs the PID mathematical functions on the error and applies the their sum to a process (motor, heater, etc.). If tuned correctly, the signal Vsensor should move closer to Vset. Example of P.I.D application analogically is when a person in a bath operating the water heater. The person will feel the initial heat dissipated by the heater. The brain will command the desired temperature. The hand will adjust the water heater adjuster to obtain the desired heated water. This process is continuous throughout the person bathing. P.I.D controls this type of process but in automatically conditions. Tuning a system means adjusting three multipliers Kp, Ki and Kd adding in various amounts of these functions to get the system to behave the way you want. The table below summarizes the PID terms and their effect on a control system:

Table 2.1 Effects of P.I and D

Term	Math Function	Effect on Control System
P Proportional	KP x Verror	Typically the main drive in a control loop, KP reduces a large part of the overall error.
I Integral	KI x $\int$ Verror dt	Reduces the final error in a system. Summing even a small error over time produces a drive signal large enough to move the system toward a smaller error.
D Derivative	KD x dVerror / dt	Counteracts the KP and KI terms when the output changes quickly. This helps reduce overshoot and ringing. It has no effect on final error.

1..SET Kp : Starting with Kp=0, KI=0 and KD=0, increase KP until the output starts overshooting and ringing significantly.

2. SET Kd : Increase Kd until the overshoot is reduced to an acceptable level.

3. SET Ki : Increase Ki until the final error is equal to zero [7].

i. **The Proportional term (Kp):**

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain.

The proportional term is given by:

$$P_{\mathrm{out}} = K_p e(t)$$

Where

- P_{out}: **Proportional output**
- K_p: **Proportional Gain**, a tuning parameter
- e: **Error** = $SP - PV$
- t: **Time** or instantaneous time (the present)

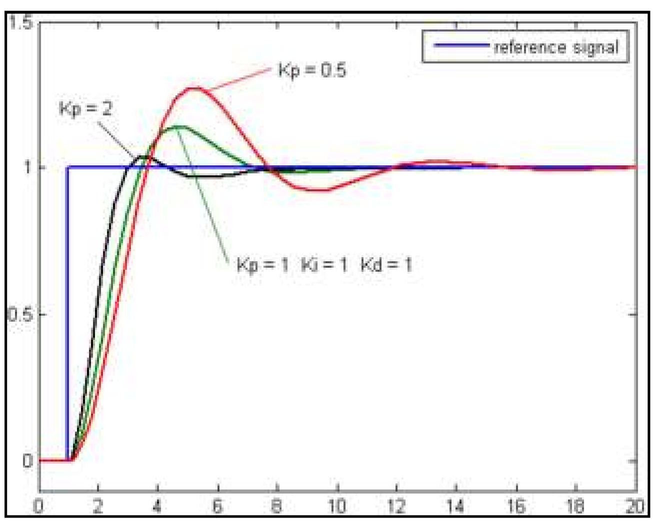

Figure 2.2 Graph response due to P value alterations

Change of response for varying Kp

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

In the absence of disturbances pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady-state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

ii. <u>**The Integral term (Ki)**</u>

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i.

The integral term is given by:

$$I_{\mathrm{out}} = K_i \int_0^t e(\tau)\, d\tau$$

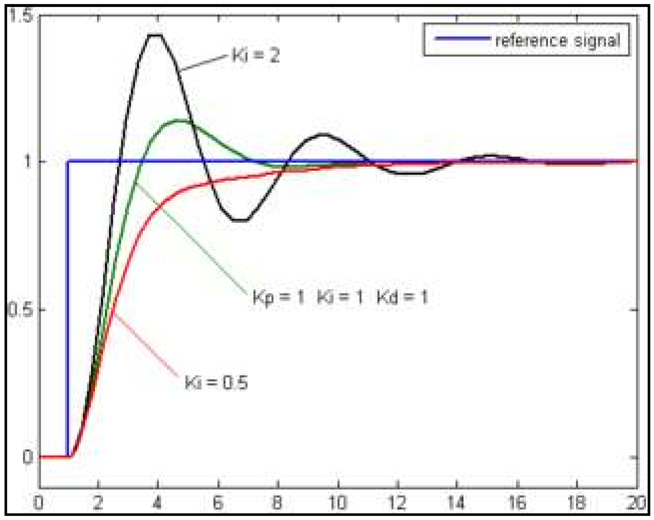

Figure 2.3 Graph response due to I value alterations

Change of response for varying Ki

Where

- I_{out}: **Integral output**
- K_i: **Integral Gain**, a tuning parameter
- e: **Error** = $SP - PV$
- τ: **Time** in the past contributing to the integral response

The integral term (when added to the proportional term) accelerates the movement of the process towards setpoint and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to **overshoot** the setpoint value (cross over the setpoint and then create a deviation in the other direction). For further notes regarding integral gain tuning and controller stability

iii. **The Derivation term (Kd)**

The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d.

The derivative term is given by:

$$D_{\text{out}} = K_d \frac{de}{dt}$$

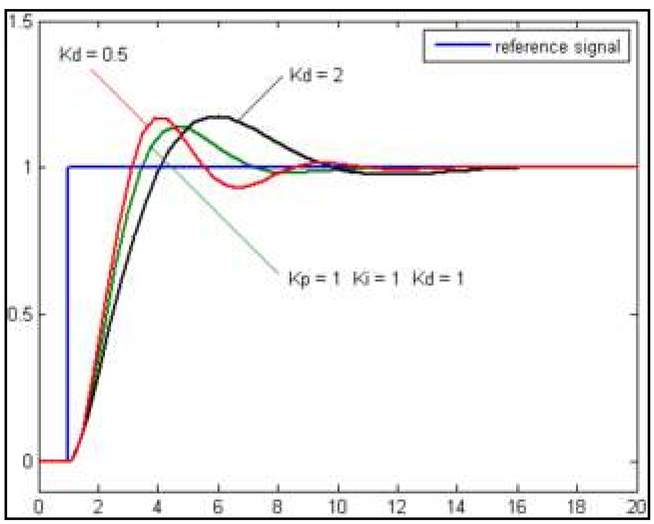

Figure 2.4 Graph response due D value alterations

Change of response for varying Kd

Where

- D_{out}: **Derivative output**
- K_d: **Derivative Gain**, a tuning parameter
- e: **Error** = $SP - PV$
- t: **Time** or instantaneous time (the present)

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller setpoint. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise in the signal and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

2.3 Valve

A **valve** is a device that regulates the flow of materials (gases, fluidized solids, slurries, or liquids) by opening, closing, or partially obstructing various passageways. Valves are technically pipe fittings, but usually are discussed separately. Below are specific types of valve easily obtained in the market:

Specific Valve Types

- 4-stroke cycle engine valves: an application of piston valve.
- Aspin valve, a cone-shaped metal part fitted to the cylinder head of an engine.
- Ball cock: often used as a water level controller (cistern).
- Bibcock, provides a connection to a flexible hosepipe
- Blast valve, used to prevent rapid overpressures in a fallout shelter or a bunker.
- Cock, colloquial term for a small valve or a stopcock.
- Demand valve on a diving regulator.
- Double check valve
- Duckbill valve
- flow control valve: an application which maintains a constant flow rate through the valve.
- Foot valve: a check valve on the foot of a suction line to prevent backflow.
- Freeze valve: in which freezing and melting the fluid creates and removes a plug of frozen material acting as the valve.
- Gas pressure regulator regulates the flow and pressure of a gas.
- heart valve: regulates blood flow through the heart in many organisms.
- leaf valve: one-way valve consisting of a diagonal obstruction with an opening covered by a hinged flap.
- Pilot valve: regulate flow or pressure to other valves.

- A poppet valve is commonly used in piston engines to regulate the fuel mixture intake and exhaust. The sleeve valve is another valve type used for this purpose.
- A pressure reducing valve (PRV), also called *pressure regulator*, reduces pressure to a preset level downstream of the valve.
- A pressure sustaining valve, also called *back-pressure regulator*, maintains pressure at a preset level upstream of the valve.
- Presta and Schrader valves are used to hold the air in bicycle tires.
- A Reed valve consists of two or more flexible materials pressed together along much of their length, but with the influx area open to allow one-way flow, much like a heart valve.
- A **regulator** is used in SCUBA diving equipment and in gas cooking equipment to reduce the high pressure gas supply to a lower working pressure
- Rotary valves and piston valves are parts of brass instruments used to change their pitch.
- A Rupture Disc is a one time use replaceable valve for rapid pressure relief used for protecting piping systems from excessive pressure or vacuum. Its is more reliable than safety valves.
- A saddle valve, where allowed, is used to tap a pipe for a low-flow need.
- A safety valve or relief valve operates automatically at a set differential pressure to correct a potentially dangerous situation, typically over-pressure.
- Schrader valves are used to hold the air inside automobile tires.
- Solenoid valve, an electrically controlled hydraulic or pneumatic valve.
- Stopcocks restrict or isolate the flow through a pipe of a liquid or gas.
- Tap (British English), faucet (American English) is the common name for a valve used in homes to regulate water flow.
- Thermostatic Mixing Valve
- Some trap primers either include other types of valves, or are valves themselves

- **Vacuum breaker valves** prevent the back-siphonage of contaminated water into pressurized drinkable water supplies.
- A Heimlich valve is a specific one-way valve used on the end of chest drain tubes to treat a pneumothorax.
- Rocker valves
- Flipper valves

2.3.1 Selection of valve in this project

Below is the type of valve selected to be used in this project:

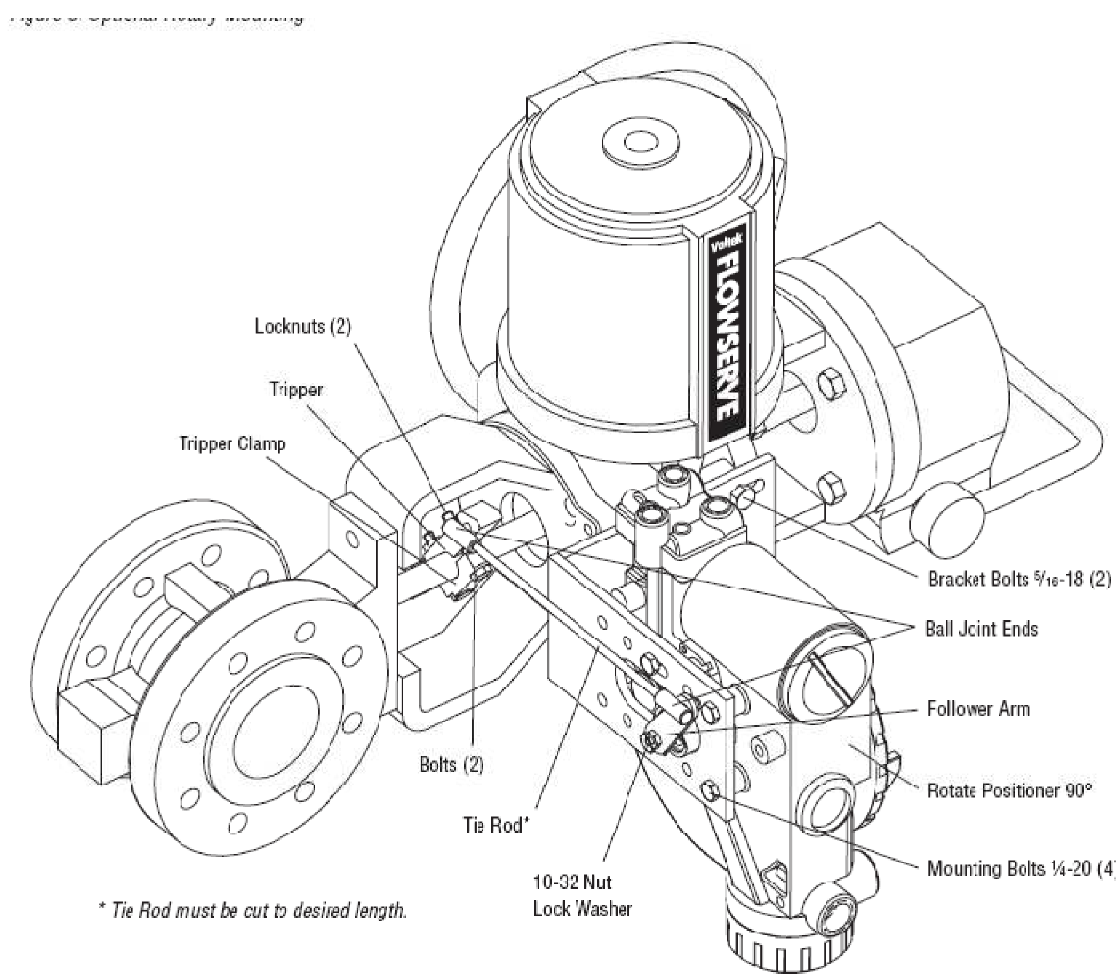

Figure 2.5 Flowserve 3200IQ control valve

Features of the LOGIX 3200IQ control valve :

i) Utilizes the HART protocol for two-way communications with the positioner.

ii) Fully powered by 4-20mA current.

iii) Position of actuator defined in either analog or digital signal. In analog source, the 4-20mA signal is converted to percentage. During loop calibration, the signals corresponding to 0% and 100% are defined and setting of 0% = 4mA / 100% = 20mA is selected.

iv) It is set to ATO (Air-to-open) setting which means giving pressured air to open the valve.

CHAPTER 3

METHODOLOGY

3.1 Project flow and block diagram

After research and studies have been made, this project is carried on based on the process control flow diagram. The flow diagram in figure 3.1 explains the process of the water level control using PID controller. At startup, the system will quickly determine the type of process loop. Selection of the loop is closed single loop process (refer figure 3.2). New set point is given by the handler (human). This set point is the desired level for the water to reach. Draining valve which is type open/close valve is put on open at selected degree of opening thus constantly draining the water at presumably constant rate. This draining valve is placed underneath the tank flowing into the reservoir tank beneath it as in figure 3.3. The sensor will then measure the current water level in the tank thus sending the current ampere signal to the PID controller. Depending with the set point given, actions of percentage of opening on the control valve can be determined. If the set point is higher than the current water level, the PID controller will send signal to the inlet valve to let the water into the tank. If the current water level is above the set point (overflow), the opened drain valve which is constantly draining the water will send feedbacks to PID controller via differential level sense of its rate of drainage. The data received will then make the PID controller to give signal of percentage of closing to the control valve. The process of draining and flowing of water into the tank is continuous to reach the desired set point with the aim of ideal process response such as in figure 3.4.

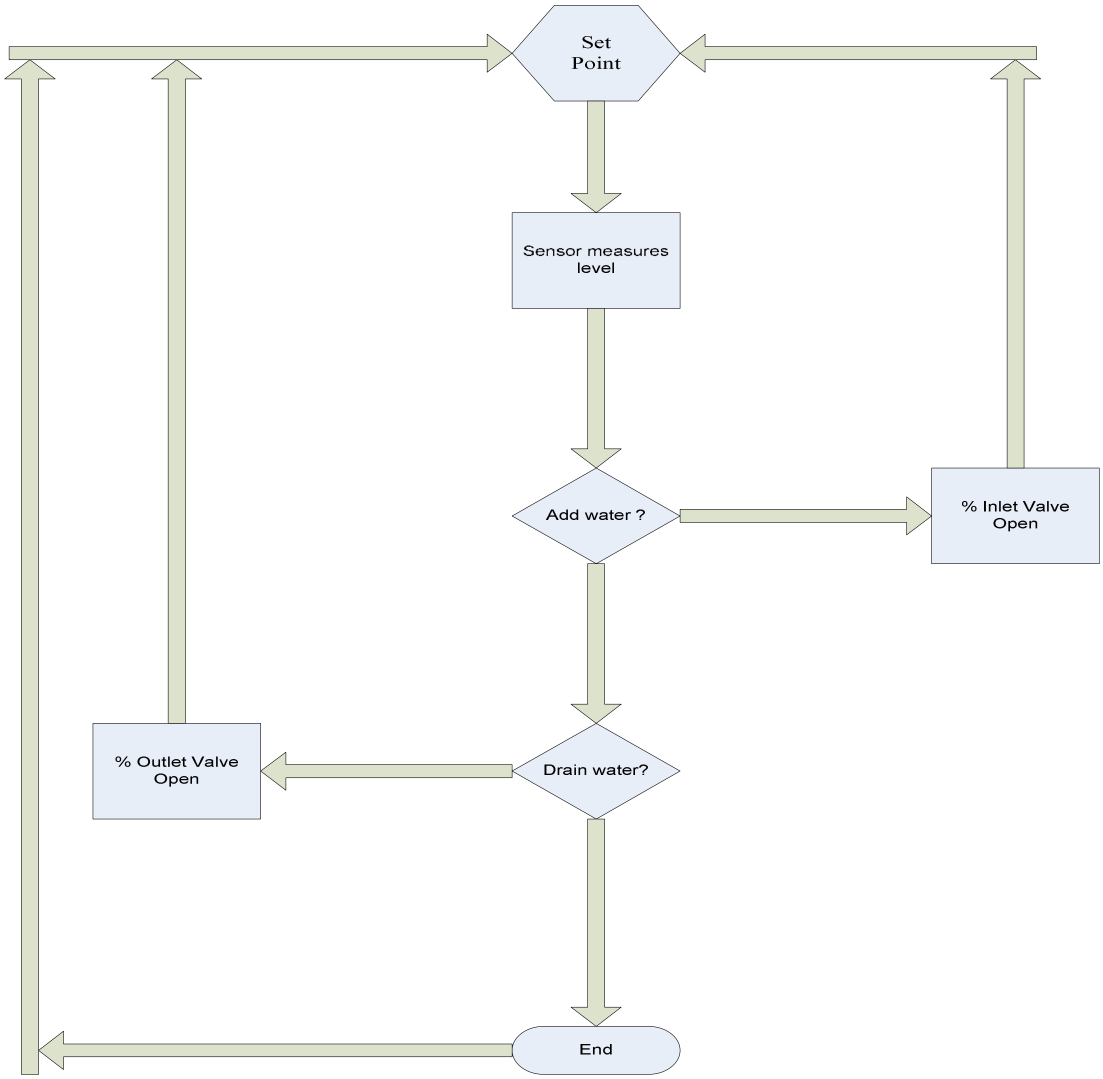

Figure 3.1 Flow diagram of PID controller on water level

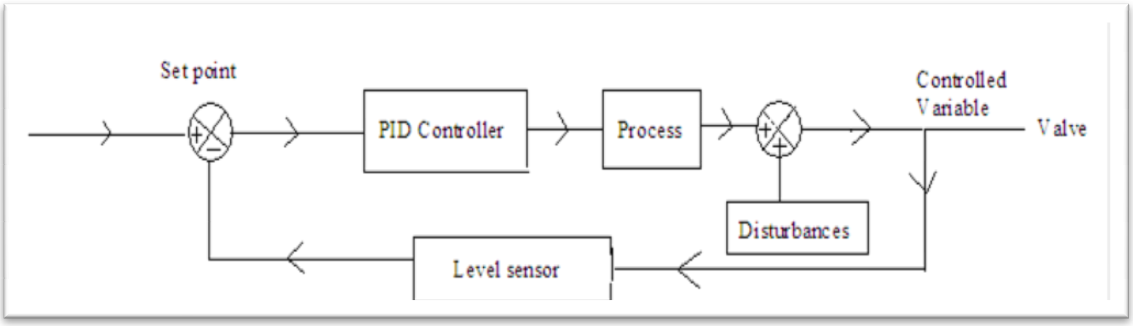

Figure 3.2 Closed single loop block diagram

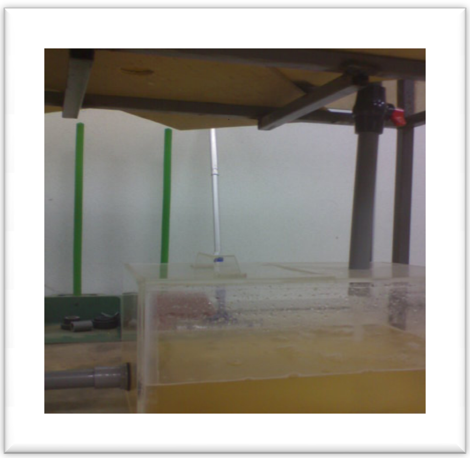

Figure 3.3 Placement of drainage valve type open/close

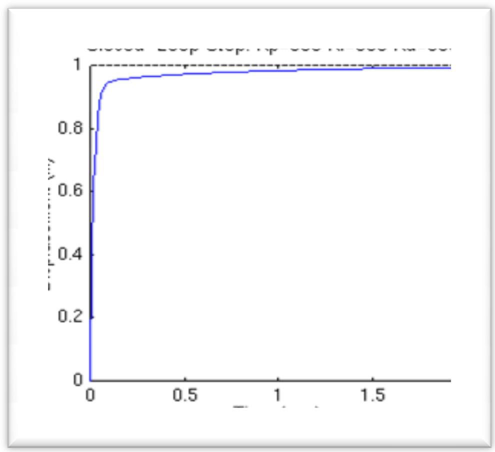

Figure 3.4 Ideal process response

3.2 Project Procedure

This project has a distinctive type of process. It is because of the requirements on operating procedure from the PID controller unit. As shown from figure 3.5 which also can be refer to YS1700 user's manual **title: YS1500 indicating controller YS1700 programmable indicating controller operation guide, page 10**, hardware has to be installed and wired before commencing the tuning and program. Options of two either to create own user program or uses the factory settings of multifunction modes which are the single loop, cascade mode or selector mode. The next procedure needed the user to set-up operation engineering constant before commencing the tuning of the PID controller YS1700. The nature of this system is constantly online. All process and tuning has to be done while the plant is online meaning the whole plant is moving for the PID to acknowledge all the equipments, field devices connected to the plant. No other means can be done to tune and design the system without the plant being online.