University of Southern Queensland

Faculty of Engineering and Surveying

Power Station Operations
Millmerran Power Station Feed water Dissolved Oxygen Control

A dissertation submitted by

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towards the degree of

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ABSTRACT

This project investigated the operation of a coal fired power station. The project developed and analysed some operational control system engineering problems faced by Millmerran power station. The main area covered in this project is on feed water dissolved oxygen control. This involved feeding of oxygen gas at required amounts into the boiler water to protect boiler tubes from corrosion effects. Millmerran power plant uses a supercritical once through boiler which operates at extremely high temperatures of about $540^{\circ}c$ and pressure of 24 Mega Pascal which can accelerate corrosion of the boiler tubes.

Oxygen injection process, which is known as oxygenated treatment performed well in high purity feed water with a pH ranging from 8.0 to 8.5. The OT process control of Millmerran power plant utilized an advanced proportional integral and derivative controller (A-PID) which regulates the opening and closing of the servo control valve. The control process encountered some stability problems during load changes due to the effect of large dead time. The dead time was mainly the time between injecting oxygen gas and detecting the dissolved oxygen in the feed water. Dead time of the OT process of Millmerran power plant ranges from 12 to 15 minutes. Oxygen is injected at the polisher outlet and detected downstream at the economizer inlet.

In this dissertation, simulation models for the behavior of the advanced PID controller and a servo DC motor under various time delays were carried out using simulink and matlab software. The simulation models showed that by varying the process dead times, the process variable was becoming stable. This was only experienced during small time delays of less than 6 minutes. To obtain a quick and more stable response of the OT process control, the dead time can be reduced by simply moving the injection point closer to the oxygen sensor. This will help in maintaining the protective oxide layer hence reducing chances of oxide exfoliation which can lead to boiler tube failures and power plant shut down. A proper OT control will help protect the boiler hence saving millions of dollars for the power plant.

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Chapter 1 Background

1. Introduction

This project defines the Millmerran power station operations. The main focus is on feed water dissolved oxygen control system operations of the power plant. This power plant is located in southern Queensland. The project will be looking at the dissolved oxygen control engineering problems of Millmerran power station and possible solutions and recommendations to these problems. Millmerran power station uses a sophisticated supercritical boiler technology which produces 10% fewer greenhouse gas emissions than the conventional coal-fired plants. The power station also uses air-cooled condenser technology. This system condense the steam from the turbine exhaust resulting in reduced water usage of about 90% compared to the conventional plants. The power plant uses Sewage water from Toowoomba which is treated by the latest water treatment technology to make it suitable for power generation.

Millmerran power station is an advanced modern power station which has operations that involves real time monitoring and running of the power plant processes. These modern control systems play an important role in the plant performance. Millmerran power station control systems provide the necessary tools to enable the operators to monitor the plant’s operation which results in a continuous and efficient production of electricity. The power station uses super-heated steam which can result in diverse power plant disorders such as corrosion, boiler tube failures, and rise in temperatures, sediments accumulation and fatigue.

In this project, Millmerran power station oxygenated treatment control problems for dissolved oxygen is investigated. The oxygenated treatment (OT) control is good at steady load but would be great if it could control on load changes. The oxygen dispenser consists of the advanced PID controller (function code FC156) which becomes unstable when the power plant experiences load changes. An open and closed loop response tests are carried out by DCS engineers to determine the dead-time and process lags of the system.

1.1. Project Methodology

This section of the project includes the requirements for the execution of a major technical task. The project methodology comprises of the project program, project objectives, assessment of consequential effects, and risk assessment.

1.2. Project Program

This part of the research project gives a wider understanding of the control systems theory application and its importance in feed water chemistry control and monitoring. It provides an appreciation of power plant control systems strategies and future modifications. The following aspects need to be achieved in this project.

- Study the operation of Millmerran power plant chemistry feed scheme
- Research on the control strategy of the oxygen dispenser
- Conduct a literature search of similar problems in other coal fueled power stations.
- Provide control simulation models of Millmerran power station process performance using matlab or simulink.
- Report results, analysis and conclusions.

1.3. Project Objectives

The objective of the project is to investigate on the functions of the oxygenated treatment control, and the problems associated with its operation. The control system of the process involves the PID controller performance. Various system tuning methods are considered like the Ziegler/ Nichols and the internal model control (IMC) method to work out the robustness of the controller for oxygen injection process. The change in load at Millmerran power plant causes the oxygen injection process to become unstable due to some dead-time and process lags. Processes with large dead times present some challenges to any controller. The controller must wait until the dead time has passed before it gets any feedback from the process. This research is focusing mainly on how to bring about a better control system which can withstand load changes and remain stable.

1.4. Assessment of consequential effects

The project work involves a consideration of the outcomes. A sustainable attempt has to be put in place to provide the best outcomes for the human and natural environment for now and the future. This project provides a control strategy on how to utilize recycled waste water for power production. A good corrosion control of the boiler tubes can minimize costs of replacing a boiler and power plant shutdown. The project plays an important role in reducing air pollution by the use of super-heated steam which is produced from less coal hence less emissions.

The oxygenated treatment strategy prevents scaling in the boiler tubes which reduces heat transfer efficiency in the boiler tubes. As a result of this oxygen injection program, less coal is utilized hence emissions are also cut down. The reason for this research project work is to provide possible utilization of waste water in power stations leading to availability of clean water for human consumption. The power plant operates at high temperatures, voltages and pressures so human intervention with the power plant is reduced by the use of plant automation. This reduces the risk to power plant operators.

1.5. Risk Assessment

This aspect is very important in every engineering research projects because it addresses the hazards and dangers involved during the work. Power station has a higher level of hazard due to high voltages, high temperatures and excessive noise from machines. Risk management has to be practiced. Risk management is a logical and systematic approach to the uncertainty of hazards identified in the workplace.

In this research project, the control of dissolved oxygen in the feed water is very important and if the system fails to meet the required specifications, a major damage can result in power plant such as explosions and shutdown.

Basic steps of risk management are as follows:

1. Identify the hazard
2. Assess the risk
3. Control the risk
4. Review and monitor

Risk assessment in a power station can be extended to the use of emergency switches and alarms. In a power station, if there is part of the plant that is not working a warning signal can be seen on the screen. The engineers will have to attend to the faulty section of the plant by identifying the hazard, assessing the risk, controlling the risk and reviewing and monitoring. According to this research, care should be taken when in the power plant premises. Some electronic devices like mobile phones need to be switched off especially at the generator section since electricity production involves magnetic fluxes that might be extending to some areas in the power plant. Exposure of these devices may cause electric shocks due to interference of the signals. No smoking in the power plant environment because there are some flammable gases such as oxygen that can result in fire. Use of pathways is important to reduce contact of body parts with hot surfaces and high voltage cables.

Chapter 2 Coal Fired Power Station

2.1. How Millmerran Power Station Works

Millmerran power plant consists of a variety of complex systems. It is therefore necessary to study the power plant's operations before concentrating on a specific section of the plant. This section of the report comprises of the major areas of the coal fired power plant electricity production process. A deep study on feed water treatment and chemistry is also carried out in this chapter. The following describes some major parts of Figure 2-1 below.

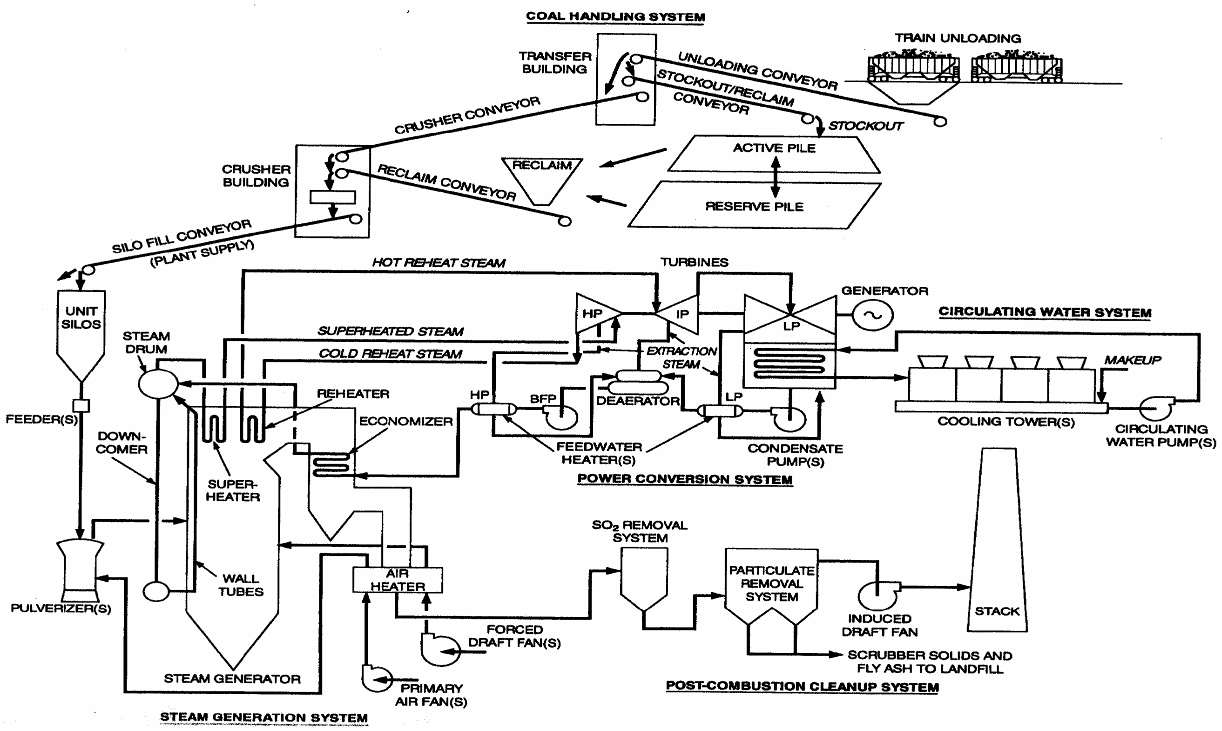


Figure 2-1: Modern pulverized coal fueled electrical generating unit

Figure 2-2: Coal Bunkers

Figure 2-3 Coal transfer unit

2.1.1. Coal Handling System

Millmerran power station uses coal from the adjacent open cut coal mine. Raw coal is taken to the transfer building (Figure 2-3) through unloading conveyer belt. In the transfer building some of the coal goes to the crusher while some is stockpiled. In the crusher, raw coal is reduced in size. From the crusher it is transported to the power plant through conveyers where it is pilled up in the storage units (silos or bunkers Figure 2-2) to become ready for use in the electricity production. Coal bunkers can hold 600 tonnes of coal each and when full can run coal for 10 to 12 hours before emptying with coal feeder speeds at 50 to 60 tonne per hour. Before coal enters the boiler unit, it is crushed further in the pulverizer to about 5cm in size. A mixture of crushed coal and air is blown into the furnace with the help of forced draft fans (FD fans), this mixture of air and coal is burnt to heat up the water in the boiler tubes.

2.1.2. Steam Generation System

Burning coal-air mixture heats the water in the boiler tubes to a temperature of about 540 degrees Celsius. The water is pre-compressed to 24 mega Pascal or 240 atmospheres from a series of heaters (low pressure and high pressure heaters) and about 350kg of water is turned into steam in a second. Millmerran power plant uses a once-through boiler which does not involve a stem drum. Super heated steam drives the turbines which are connected to the generator by a shaft and electricity is produced.

2.1.3. Power Conversion System

Feed water is pre-heated in the low pressure (LP), intermediate pressure (IP) and high pressure (HP) heaters before it reaches the super heater. These heaters are powered by extraction steam from the turbine exhaust as can be seen in Figure 2-1[1]. So energy conversion takes place from heated steam to the feed water that has low temperatures. The steam is then condensed through a series of air cooled condensers.

2.1.4. Circulating Water System

Figure 2-4 Millmerran power plant air-cooled condensers

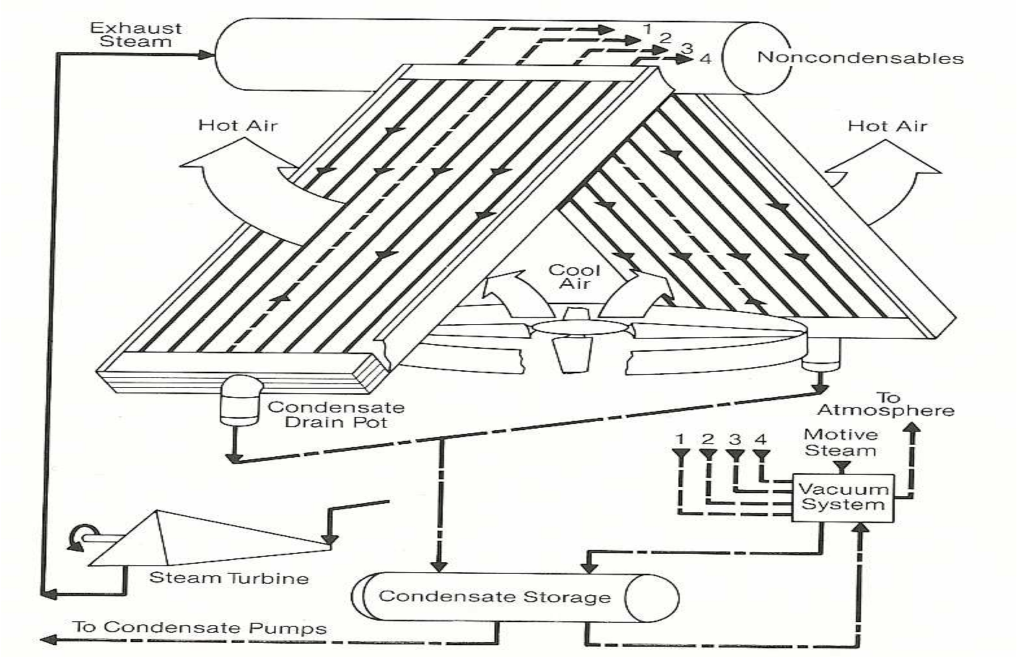


Figure 2-5 Air-cooled steam condenser system schematic

The steam from the turbine exhaust is re-used by going through the air cooled condensers (cooling towers) which turn it back into water and it is called condensate. This condensate goes through the cycle and it is used in the electricity production process. Make up water from the pre-treatment plant is used to top up water that is lost through leakages in the circulating water system. Figure 2-4 shows the cooling towers at Millmerran power plant. These cooling towers consist of 36 individual fans and gearboxes. Cool air is blown by the fan (Figure 2-5) through the condenser fins hence lowering the temperature of the steam pipes and resulting in condensation.

Figure 2-6 Bag house

2.1.5. Post-Combustion Cleanup System

Burning coal produces sulfur dioxide gas, carbon dioxide gas and nitrogen oxides. These combustion gases require additional treatment for removal of fly ash particulates, sulfur dioxide, and nitrogen oxides by the plant pollution control systems before the gases are released through the plant exhaust stack. The bag-house (Figure 2-6) extracts dust particles from the boiler flue gases. The gases are drawn from the boiler by the induced draft fans (ID fans) and forced out through the stack into the atmosphere.

2.2. Millmerran Power Station feed water Treatment Cycle

This section of the report is the main area of concern in this research project. Feed water quality is very essential for supercritical boilers. At higher operating pressures and temperatures of the modern steam power plants, the effects of dissolved and suspended constituents in the feed water makes the boiler tubes more susceptible to damage. Boiler tube corrosion problems are a major concern in power plants, so feed water chemistry control has to be practiced precisely to reduce the corrosion impact on boiler tubes. In this project, it is crucial to consider ways of managing the feed water quality. Millmerran power plant feed water purification and treatment will be studied in more details.

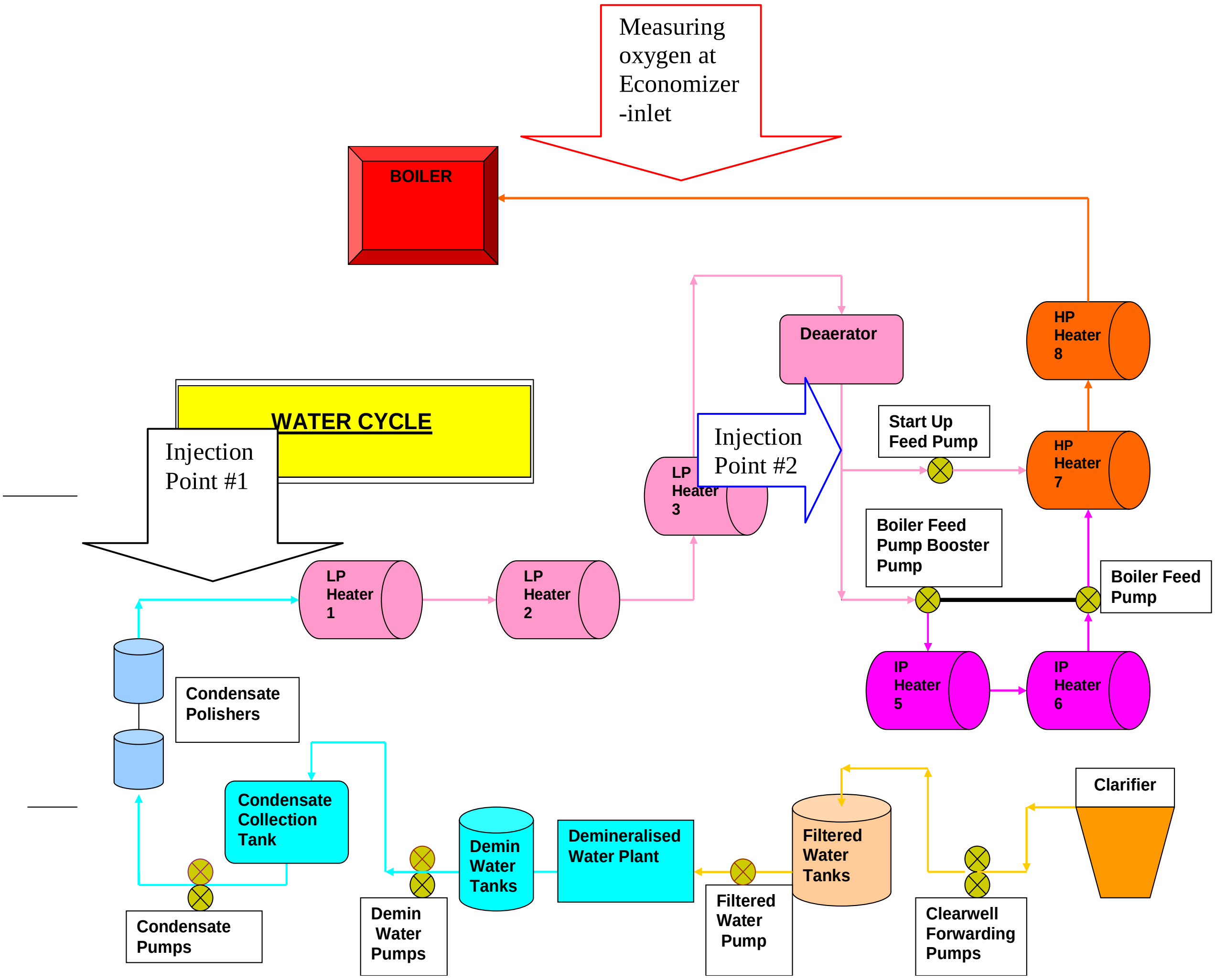


Figure 2-7 Millmerran Feed water Treatment Cycle

2.2.1. Boiler water pre-treatment plant

Sewage water is recycled and used in the power production. This raw water contains some dissolved substances which can cause corrosion to the power plant boiler tubes. It is therefore necessary to treat the water before entering the feed water cycle. In once-through boilers, high purity of the feed water needs to be maintained. Raw water is separated from mud and other dense particles in the clarifier. Mud settles at the bottom of the clarifier and clear water is pumped by the clear-well forwarding pump through a filtering tank which further removes suspended particles from the water. From this point, water goes to the demineraliser where ion exchange and reverse osmosis processes take place.

2.2.2. Theory of Osmosis and reverse osmosis

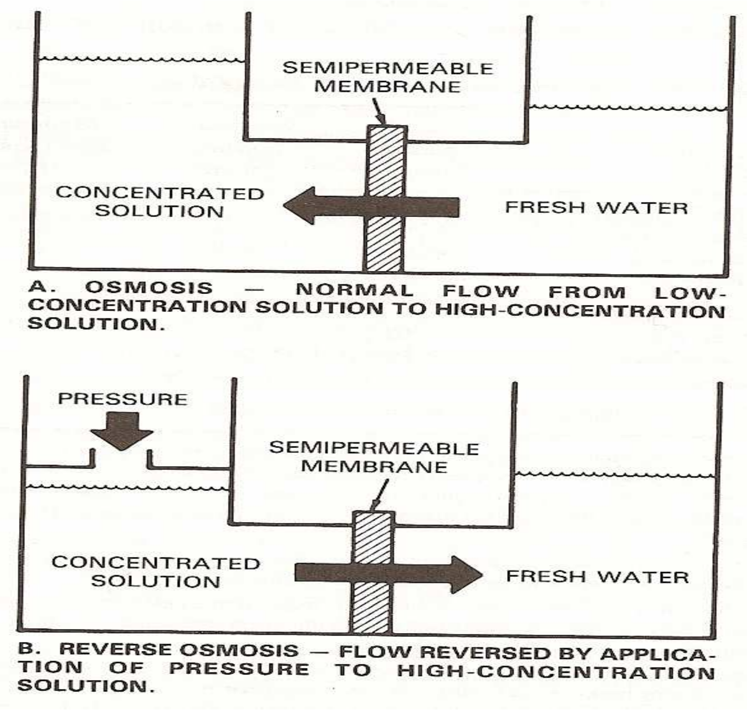


Figure 2-8 Reverse osmosis process

Raw water has a lot of dissolved substances which have different ionic concentrations. Osmosis is a process whereby a solution of different ionic concentration is separated by a permeable membrane. The membrane only allows water molecules to cross from the lower concentration to the higher concentration side (Figure 2-8A) until equilibrium is achieved. Reverse osmosis in the other hand is a process where the solution is pressurized from a higher concentration to a lower concentration. The semi permeable membrane is prevented from fouling by carrying out the reverse osmosis process. Millmerran power plant feed water pretreatment system has the reverse osmosis process as shown in Figure 2-10.

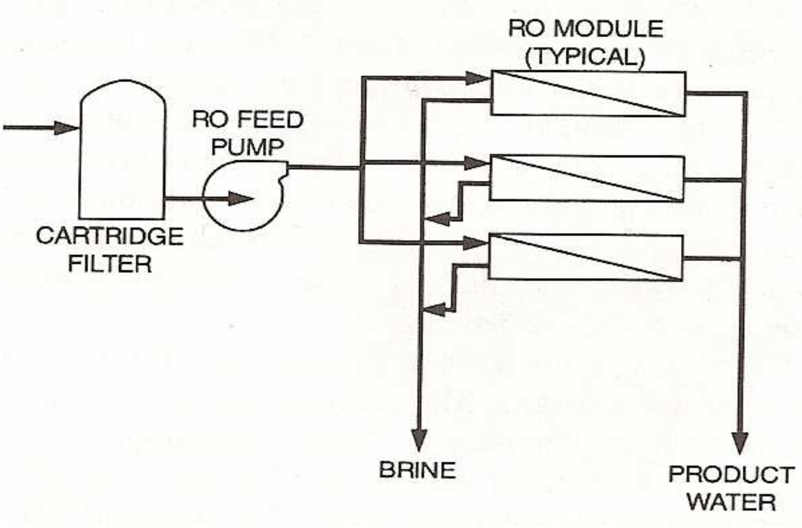


Figure 2-9 A simplified reverse osmosis system diagram

Figure 2-10 Millmerran power plant reverse osmosis water treatment unit

2.2.3. Demineralization by reverse osmosis

Figure 2-9 shows a simplified diagram of the reverse osmosis system configuration. Raw water is pumped in to the RO modules by the RO feed pump from the cartridge filter which uses filter elements mounted in a pressure vessel. This pump creates a pressure which reverses the flow of water molecules from a lower concentration point. A continuous reverse osmosis process results in an improved water quality that undergoes other levels of purification.

The demineralization train converts raw water containing between 100 and 1500ppm dissolved solids in to water that contains no more than 10 to 20 ppb dissolved solids. These treatment processes includes filtering and reverse osmosis (RO), softening, chlorine removal, degasification and ion exchange. Reverse osmosis usually requires pretreatment which include removing of solid suspended contaminants to prevent fouling the membrane surfaces [7]. The types of fouling that can be prevented or reduced by pretreatment include the following:

- Membrane scaling,
- Metal oxide fouling,
- Plugging,
- Biological fouling.

If fouling occurs, the membrane must be cleaned. Various cleaning solutions that can be used are mentioned in the following **Error! Reference source not found.**. If cleaning is carried out properly most foulants will be removed [1].

	Chemical				
Foulant	Acid	$NaOH$	NH_4OH	Phosphate Detergents	Sodium Bisulfite
CaCO3	X	-	X	-	-
SO4 Scales	X	X	X	-	-
Silica	-	X	-	X	-
Metal oxides	X	-	X	-	-
Inorganic colloids	X	X	X	X	-
Biological	-	-	-	X	X
Organics	X	-	-	X	-

Table 2-1 Typical chemical cleaning solutions

X = denote yes

- = denote not

2.2.4. Demineralization by ion-exchange

Demineralization is basically the removal of dissolved ionic impurities that are present in the water. Demineralization can consist of the ion exchange, membrane desalination and thermal desalination. Ion exchange is one of the most effective processes for the production of high purity water that is required in supercritical boilers. The process involves an exchange of ions with the resin. Cation resins have a fixed negatively (OH-) charged sides and exchanges with a positively charged ion in the solution. In the other hand we have an anion resin which has a fixed positively (H+) charged sites that will react with any negatively charged ion in the water.

In the process of ion exchange, the hydrogen ion (H+) is displaced from the cation resin and this hydrogen ion (H+), will react with the hydroxide ion that is displaced from the anion resin. The whole idea of this process is to remove the dissolved ions from the water and replace them by pure water. The reaction of the resins with dissolved water impurities can be represented as follows [1]:

Cation resin: $R^-H^+ + C^+ \Leftrightarrow R^-C^+ + H^+$

$$2R^-H^+ + C^{2+} \Leftrightarrow R_2^-C^{2+} + 2H^+$$

Anion resin: $R^+OH^- + A^- \Leftrightarrow R^+A^- + OH^-$

$$2R^+OH^- + A^{2-} \Leftrightarrow R_2^+A^{2-} + 2OH^-$$

R = resin matrix and fixed charge site;

C = cation such as Ca^{2+}, Mg^{2+} and Na^+; and

A = anions such as HCO_3^-, Cl^-, and SO_4^{-2}.

The process of ion exchange is cyclic; therefore the resins can get exhausted or cannot remove other impurities without releasing impurities into the water. In this situation, the resin is enriched or regenerated with a solution of sulfuric acid which is a recommended regenerant for cation resins. The same regeneration process has to be done to anion resin this time with the sodium hydroxide solution. Similarly the reactions are shown below for the regeneration of the resins.

Cation resin regeneration: $2R^-C^+ + H_2SO_4 \Leftrightarrow 2R^-H + C_2^+SO_4^{2-}$

$$R_2^-C^{2+} + H_2SO_4 \Leftrightarrow 2R^-H^+ + C^{2+}SO_4^{2-}$$

Anion resin regeneration: $R^+A^- + NaOH \Leftrightarrow R^+OH^- + Na^+A^-$

$$R_2^+A^{2-} + 2NaOH \Leftrightarrow 2R^+OH^- + Na_2^+A^{2-}$$

2.2.5. Degasification Process

In these chemical reactions, gases can be released such as oxygen and carbon dioxide. Presence of these gases above certain amounts can result in other problems such as corrosion downstream of the feed water cycle. Presence of ingress gases can lead to inappropriate performance of the oxygenated treatment process. A treatment process called degasification is involved to help in removing these gases from the water. Oxygen can be removed by vacuum degasification while carbon dioxide can be removed by either vacuum degasification or forced draft degasification. Figure 2-12 below shows a vacuum degasification system layout.

Millmerran power plant uses vacuum degasification process to remove gases in the feed water. In a vacuum degasifier, water is sprayed and the gases are removed by maintaining a vacuum in the tower.

Figure 2-11 shows how the system works. A vacuum is maintained with the help of degasifier vacuum pumps [1]. For the oxygenated treatment to work efficiently, all the gases must be removed from the feed water. The vacuum degasifier prepares the make-up water that will be used later in topping up the condensate waters.

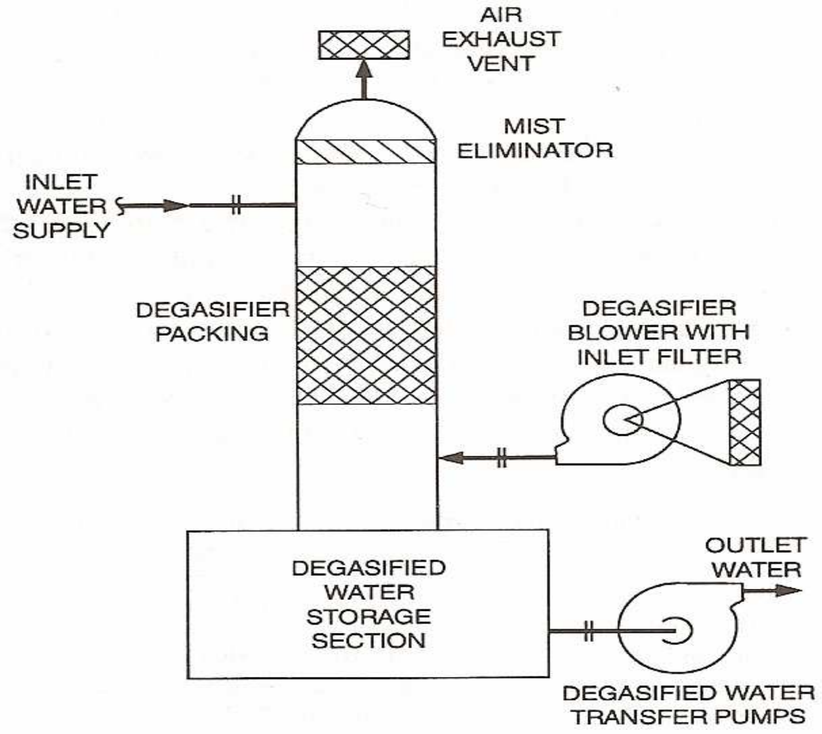


Figure 2-11 Schematic of a typical forced draft degasifier

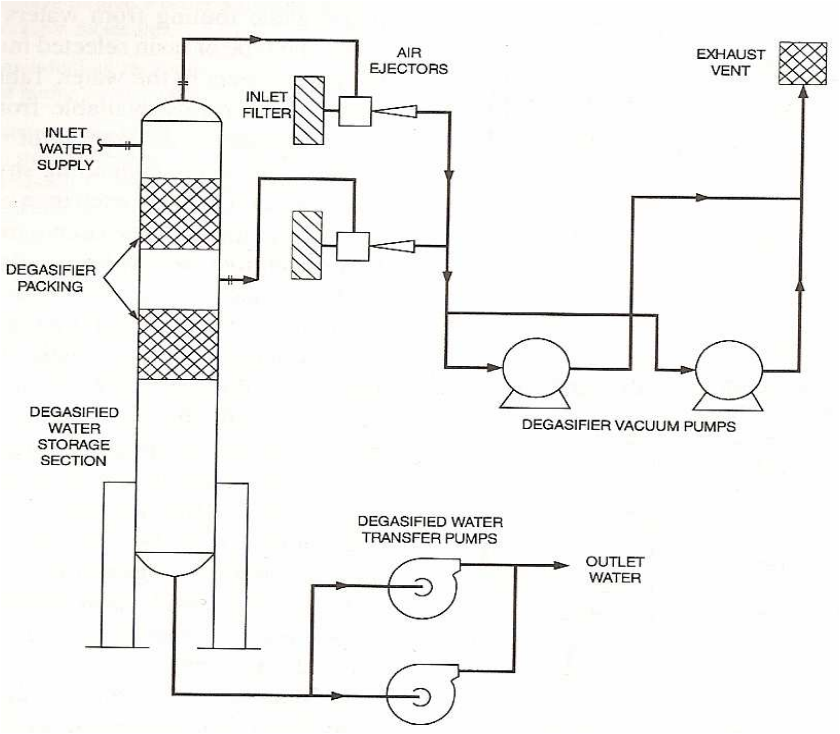


Figure 2-12 two-stage vacuum degasifier

2.3. Corrosion in boiler tubes

Corrosion is the deterioration of the boiler tube surfaces when they are exposed to chemical reactions. Most metals form an oxide or hydroxide layer when exposed to water. The oxide layer acts as a protective coating from further chemical attack. The formed oxide layer may collapse and become carry over. As the oxide layer exfoliates, more and more chemical reactions takes place which will result in more corrosion effects.

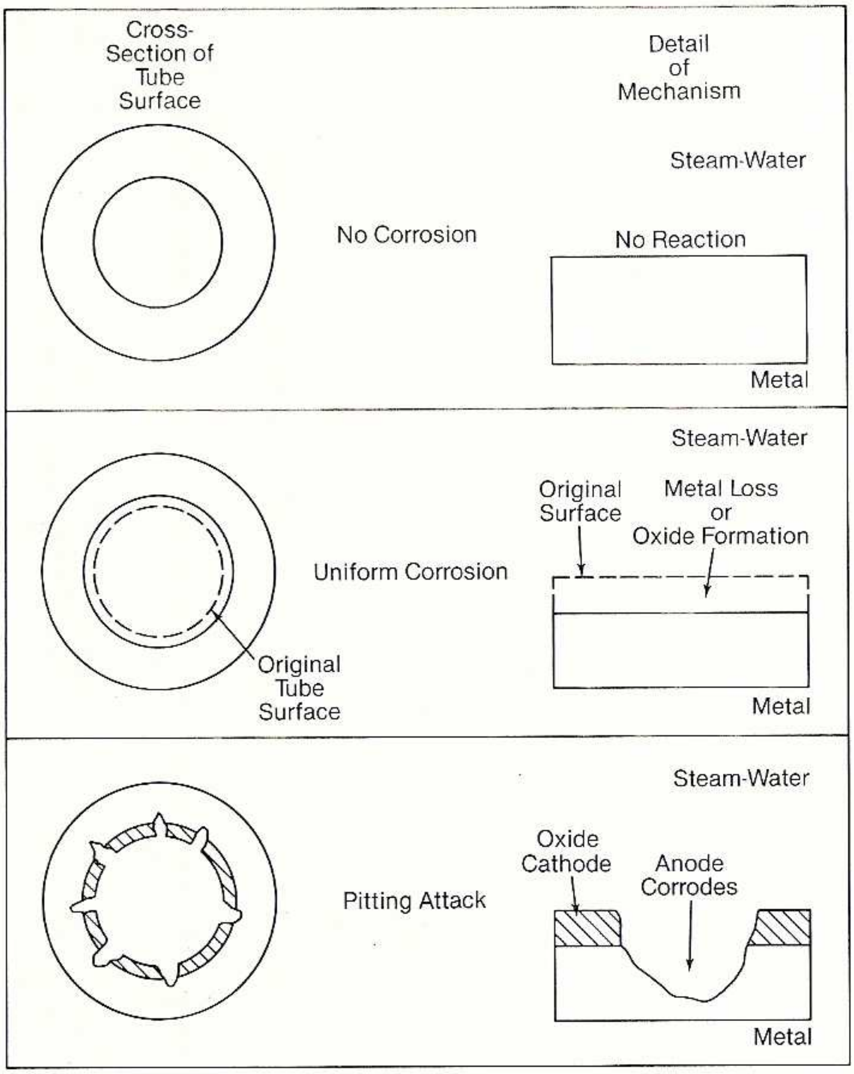


Figure 2-13 Schematic showing difference between pitting attack and uniform corrosion

2.3.1. Uniform Corrosion

This is a common form of boiler tube corrosion where by the metal surface is turned into an oxide. The formation of this oxide reduces the boiler tube thickness. A protective layer of magnetite (Fe_3O_4) reduces the corrosion rate with time to a low constant rate. A layer can be a non-protective scale which will have significantly higher corrosion rates. In once through boilers, oxygen can be injected in to the feed water to form a protective layer which will also protect metal from getting exposed to corrosion.

Figure 2-14 Pitting attack

Figure 2-15Boiler tube scaling

2.3.2. Pitting corrosion

Pitting is a localized form of corrosion where by the protective oxide film breaks down. According to Figure 2-14, once the protective layer is destroyed, an active corrosion site is created and corrosion speeds up. The oxide adjacent to the pit is a reducing site (cathode) for the corrosion reaction, and it is not corroded away. This cathode oxide will react with any impurity that has an opposite charge to give a neutral solution. At a point where there is no oxide film, the metal is entirely exposed to impurities which will actively corrode it forming a pit.

2.3.3. Scale Formation

Scale formation on the waterside of boiler heating surfaces is caused by the contact of certain impurities in the boiler water with hot surfaces [2]. Most common impurities are calcium (Ca), magnesium (Mg), and silica (Sio_2). The presence of calcium bicarbonate and heat gives out water, carbon dioxide and calcium carbonate which form the scale. Figure 2-15 shows the layer of scale inside the boiler tube.

$$Ca(HCO_3) + Heat = CO_2 + H_2O + CaCO_3(scale)$$ Equation 2-1

Scale thickness	**Increase in fuel consumption due to scale (coal usage)**
0.5 mm	2%
1.0 mm	4%
2.0 mm	6%
4.0 mm	10%
8.0 mm	20%
16.0 mm	40%
30.0 mm	80%

Table 2-2 Scale thickness and coal consumption

Scale is an insulator therefore heat transfer efficiency between the fireside and the waterside of the boiler tube is decreased. There will be an increase in coal use hence leading to energy losses and overheating of the boiler tubes. Table 2-2 shows the effect of scale thickness with an increase in coal usage. These values for Table 2-2 are mainly for drum boilers. In a once through boiler, the boiler tubes have a small inner diameter which cannot accommodate scale to this thickness.

2.3.4. Erosion-Corrosion

Erosion corrosion occurs when protective scale is removed by flowing water. Removal of this protective scale increases the corrosion of the boiler tube surface. There are various ways in which the flow of water can bring about corrosion of the protective scale. These can result from the velocity of flow and the angle of impingement. Erosion corrosion can also result from cavitation which is the formation and implosion of gas bubbles in a fluid. Erosion corrosion appears in form of grooves or pits, this usually occurs at restrictions and curving points of the water tube where fluid velocity changes. This form of corrosion is mostly common in once-through boilers which operate at high temperatures and pressures.

2.3.5. Typical Locations of water side corrosion of a boiler.

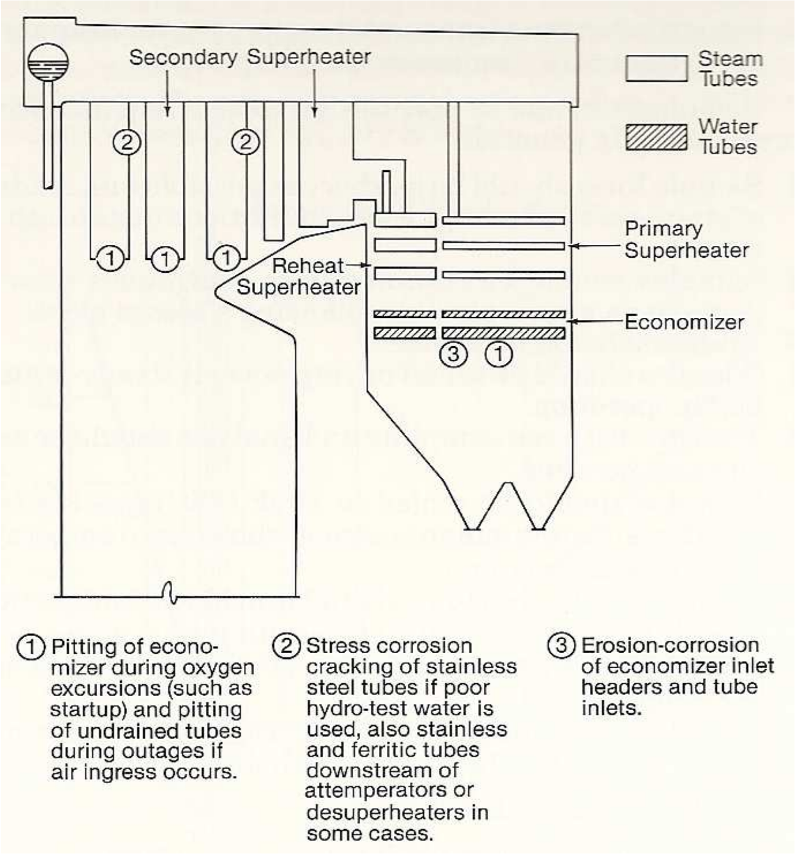


Figure 2-16 Boiler locations for various types of water-side corrosion

Source (adapted from reference [5])

Figure 2-16 shows vulnerable sections of the boiler and economizer for pitting corrosion, stress corrosion and erosion corrosion. These corrosions are mostly common at high pressure and temperature sections of the boiler. A good water treatment process will prevent these from occurring.

2.4. Feed water measurement techniques

This section of the report outlines various ways of sampling the boiler water for both formed deposits and corrosion products. These are manual and on-line measurements which are used to control water treatment. These techniques help in determining contaminants, investigating failure mechanisms and assist in chemical cleaning.

2.4.1. Manual measurement techniques

Manual sampling involves collection of the sample and analysis which should occur in a short time frame to minimize absorption of atmospheric gases [5]. The American Society for Testing Materials (ASTM) in New York provided the detailed methods for sampling of the boiler water. Some of the useful techniques are atomic absorption and ion chromatography. Atomic absorption involves measurements of elemental concentration in sample solution. The solution is forced into a flame where the elements are atomized therefore these atomized elements become capable of absorbing light at a specific wavelength. Passing a monochromatic light through the sample, the ability of the elements to absorb this light is measured and compared with absorbencies of known standards.

Ion chromatography is another useful manual sampling method that involves measuring of the amount of ions contained in the sample solution. The method involves the following steps [5]:

- Isolating each ion by passing the solution through a polarized column.
- Measuring the peak area generated by each ion as the solution travels through a conductance detector and comparing them with those generated by known standards.

In ion chromatography, several ions are determined in a single analysis. This process requires low volume samples of about 20ml and this can occur every 30 minutes. This technique can be used mainly for determining the anions and cations that are present in the feed water cycle. *Table 2-3* below shows guidelines and techniques for measurements in power plant systems.

Guidelines for Measurements on Manual Sampling

Measurement	Technique(s)	Comments(notes 1&2)
pH	Electrometric	ASTM D 1293 Method A
Conductivity	Dip or flow type Conductivity cells Energized with alternating Current at a constant frequency	ASTM D 1125 Methods A or B
Dissolved oxygen	Colorimetric or Titrimetric	ASTM D 888 methods A,B,C
Suspended ion-Oxide	Membrane comparison charts.	ASME PTC 31 Ion-exchange Equipment

Notes:
1. ASME PTC refers to Performance Test Codes of the American Society of Mechanical Engineers, New York, New York.
2. ASTM refers to testing procedures of the American Society for Testing and Materials, Philadelphia, Pennsylvania.

Table 2-3: Guidelines on manual sampling

2.4.2. On- line measurement techniques

On line measurement is a monitored process of sampling the boiler feed water. This is a continuous process and provides adequate information on the water quality. Millmerran power plant uses this technique in monitoring the pH and dissolved oxygen in the boiler water. On-line monitoring utilizes a computer which is interfaced with dissolved oxygen and pH detecting devices.

Chapter 3 Coal-Fired Power Station Control Systems

3.1. Coal-Fired Power plant control

In modern power plants, the control actions required to operate the processes are automated. The reason was to reduce human error in plant operation and thus providing safety for plant personnel. Secondly, automation reduces the number of operations required to run the plant, which reduces labor costs. The control functions used in operating a power plant can be classified in many ways. For the purpose of this report, the functions of the plant control system are classified by the type of control action used. There is on-off control known as digital control and modulating control which is sometimes called closed loop control [1]

3.2. Millmerran power plant Basic Control Functions

3.2.1. On-Off Control Function

This control action produces a control that varies in discrete states. On-off control involves two states which are either start or stop command and no intermediate states exist between the running and stopping states. The on-off control operation is applicable to motor-driven rotating equipment such as pumps, fans, compressors and conveyers.

3.2.2. On-Off Control Applications

The On-Off control has an important role in the power plant operations. This control action involves protective interlocking, sequential control logic, and unit protection logic.

Protective interlocking is used for the operation of individual pieces of power-operated equipment. A motor driven boiler feed pump is a typical example. This feed pump has oil supply for lubricating the bearings, before the pump start operating, lubricating oil must be available at the pump bearing, sufficient water must be in the deaerator storage tank, water path in the suction line must be open and the pump motor must be started against a closed discharge valve. A control signal from the tank level limit, oil level limit, suction valve limit, and discharge valve limit is checked and if a correct position of all these parameters is attained, the pump motor start when the operator issues the starting command.

Sequential control logic is a composition of control logic for a group of equipment operating in a predetermined sequence. In modern pulveriser coal-fueled boilers, the group equipment includes the pulveriser, feeders, primary air fans, and air dampers around the pulveriser. All these equipments must be controlled in a proper order and in correct proportions.

The unit protection logic is simply the protective interlocks associated with the operation of the boiler, the turbines, and the generator. This control function actually ensures maximum safety to plant personnel and to guard against serious damage to the power plant equipment. If an abnormal operating condition arises, the boiler, turbines, and generator are tripped individually. The boiler, turbines and generator are closely coupled; the boiler supplies steam to the turbine and the turbines drives the generator. If an unusual condition happens to any of these equipments, the whole system will be disabled. This will provide protection to the equipment and safety to the plant operators.

3.3.Dissolved oxygen closed loop control functions

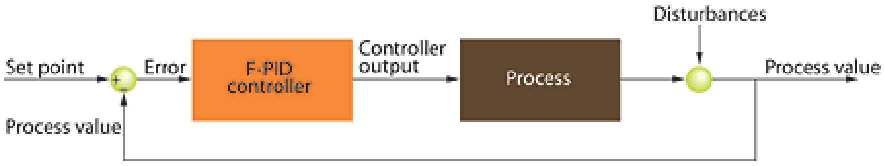


Figure 3-1 Feedback control loop

The figure shows the dissolved oxygen control loop. The dissolved oxygen is controlled at a desired value (set point) by automatically and continuously modulating the control valve supplying the oxygen to the deaerator outlet [1]. The basic elements of the loop are as follows:

- Controlled variable – Process parameter (dissolved oxygen level in the feed water) that is controlled by the control loop to a desired value(set point)
- Controller – Element that compares the value of the controlled variable to the set point value and produces a control action to correct the setpoint deviation (error) to zero.
- Manipulated Variable or controller output – Parameter (oxygen injection rate) that is varied as a result of the control action of the PID controller so as to change the value of the controlled variable towards the set point value
- Final control element – Device that changes the value of the manipulated variable (control valve) to correct the set point deviation according to the control action of the controller.
- Disturbances – Some unknown actions that changes the process value or the output.

The injected oxygen flow to the feed water deaerator outlet is the manipulated variable. If the dissolved oxygen drops below the oxygen set point, the controller applies a control action to the oxygen deviation (error) and produces a control signal to increase the opening of the control valve. This increases the oxygen flow into the feed water thus bringing the dissolved oxygen level back to the set point value. The control loop is said to be closed in that the controlled variable is measured and the measured value is used to verify the result of the control action.

The PID (proportional, integral and derivative) parameters are related to the relationship between the set point error and the controller output to the final element. In proportional control, the magnitude of the controller output is proportional to the magnitude of the set point error. A relationship between the input, error and output exists:

$P = (kp)\ E$ Equation 3-1

Where

P = output

E = error (set point deviation)

Kp = proportional gain

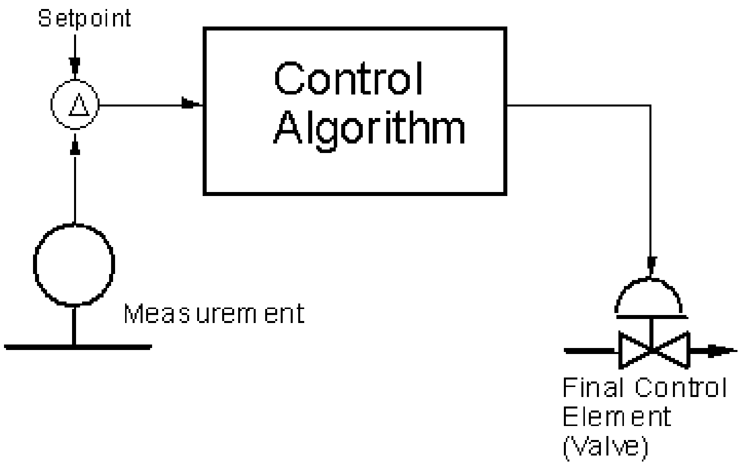


Figure 3-2 A simplified control system layout

The proportional gain is a measure of the sensitivity of the controller and it is an adjustable parameter of the controller. For example, in the control loop shown in Figure 3-2, given dissolved oxygen level deviation from the set point (error) produces a control signal that drives the control valve to a corresponding position depending on the proportional gain. This relationship keeps the dissolved oxygen level at the desired set point as long as the feed water flow, pressure and temperature supply remain constant. If any of these conditions changes, the controller must make necessary corrections to maintain the exit oxygen flow at the set point. These changes are called load changes. When a load change is large, the controller will not be able to produce an output to bring the oxygen injection back precisely to the set point

The PID controller has another parameter called the integral control which is also known as the reset control. With the integral control, the output of the integral controller changes whenever there is a set point error. The integral action produces an output that changes at a rate proportional to the magnitude of the error.

$dp/dt = (1/Ti)\,E$ Equation 3-2

Where

Ti = integral (or reset) time.

The equation can be written as

$p = (1/Ti) \int E\, dt$ Equation 3-3

An integral controller according to Equation 3-4 produces an output that keeps changing for as long as there is an error in the process. The output stops changing once the error is reduced to zero. From Figure 3-2, when a dissolved oxygen level error exists in the feed water, the integral action of the controller keeps moving the control valve as long as the exit oxygen is not at the set point. The valve will keep moving until the oxygen is returned to the set point.

Lastly there is a derivative control parameter which is known as the rate control. The controller produces an output whenever there is a set point error and the magnitude of the output is proportional to the rate of change of the error.

The output becomes:

$$P = (Td)\, dE/dt \qquad \text{Equation 3-5}$$

Where

Td = rate (derivative) time

With the derivative control, the faster the error changes, the greater the controller output. In a feedback control configuration, the controller produces a control action only when it detects an error in the controlled variable. It applies corrective action only after the error has occurred. So to improve system response to process changes, a technique known as feed forward control is sometimes added to the feedback controller. The feed forward control represents a load change in the process, and a signal is passed forward as a corrective action. The purpose of this signal is to provide a control action before a set point deviation occurs and thus to minimize any disturbance in the controlled variable caused by a change. So the PID transfer function becomes;

$$U = KpE + Ki \int Edt + Kd * dE / dt$$

Where U = controller output

Kp = Proportional gain

Ki = Integral gain

Kd = derivative gain

E = error signal

t = process time

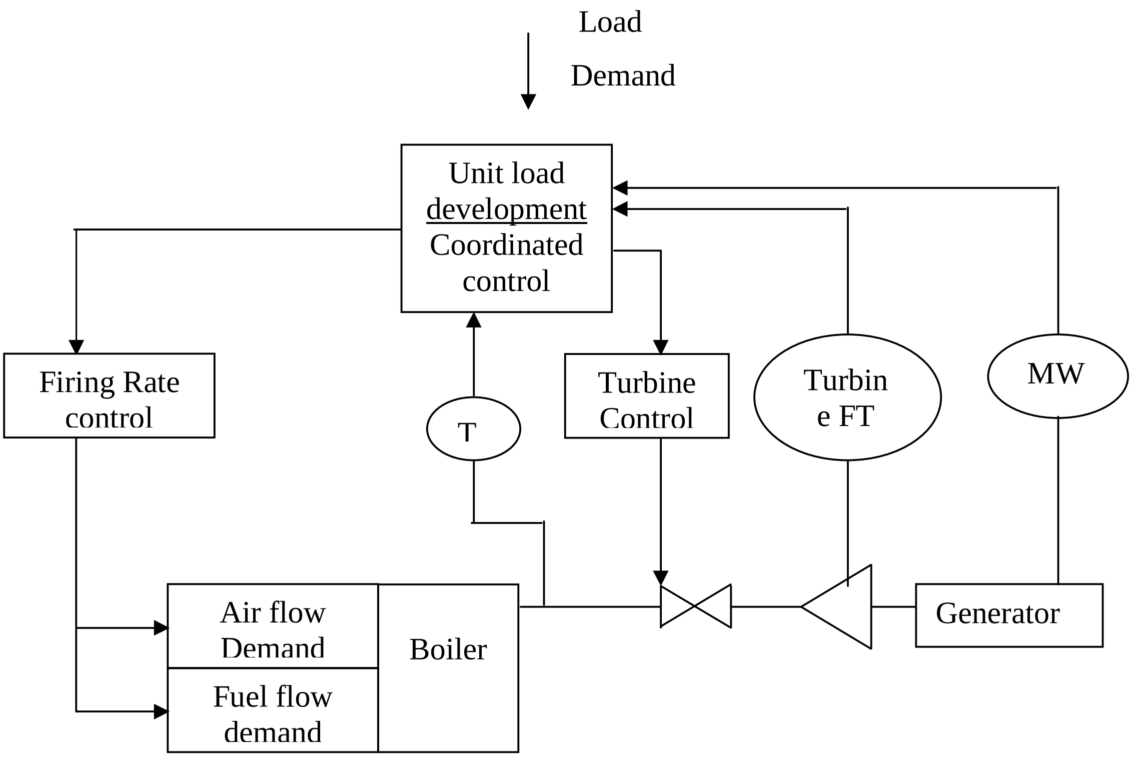


Figure 3-3 Coordinated control system layout

3.4. Load Demand Control

The load demand control of the boiler control system uses the load demand signal from the load dispatcher and converts the signal into demand signal for fuel flow, air flow and feed water flow as well as the oxygen injection rate demand. The coordinated control scheme was designed to accommodate the once-through boilers [2]. The basic principle of the coordinated control scheme is that load demand is provided as a feed forward signal to both the boiler, and turbine control systems in parallel. Coordinated control ensures a simultaneous change of processes when a load demand signal is available. A simple coordinated control scheme is shown in Figure 3-3.

According to Figure 3-3, the turbine and the boiler receive the load demand signal in parallel, but the turbine valve is used to control the pressure, and the firing rate is used to control megawatts error. This kind of control is an integrated control therefore there is no simultaneous action to a load signal within a short time frame. Having this kind of systems will result in large dead-time and system delays.

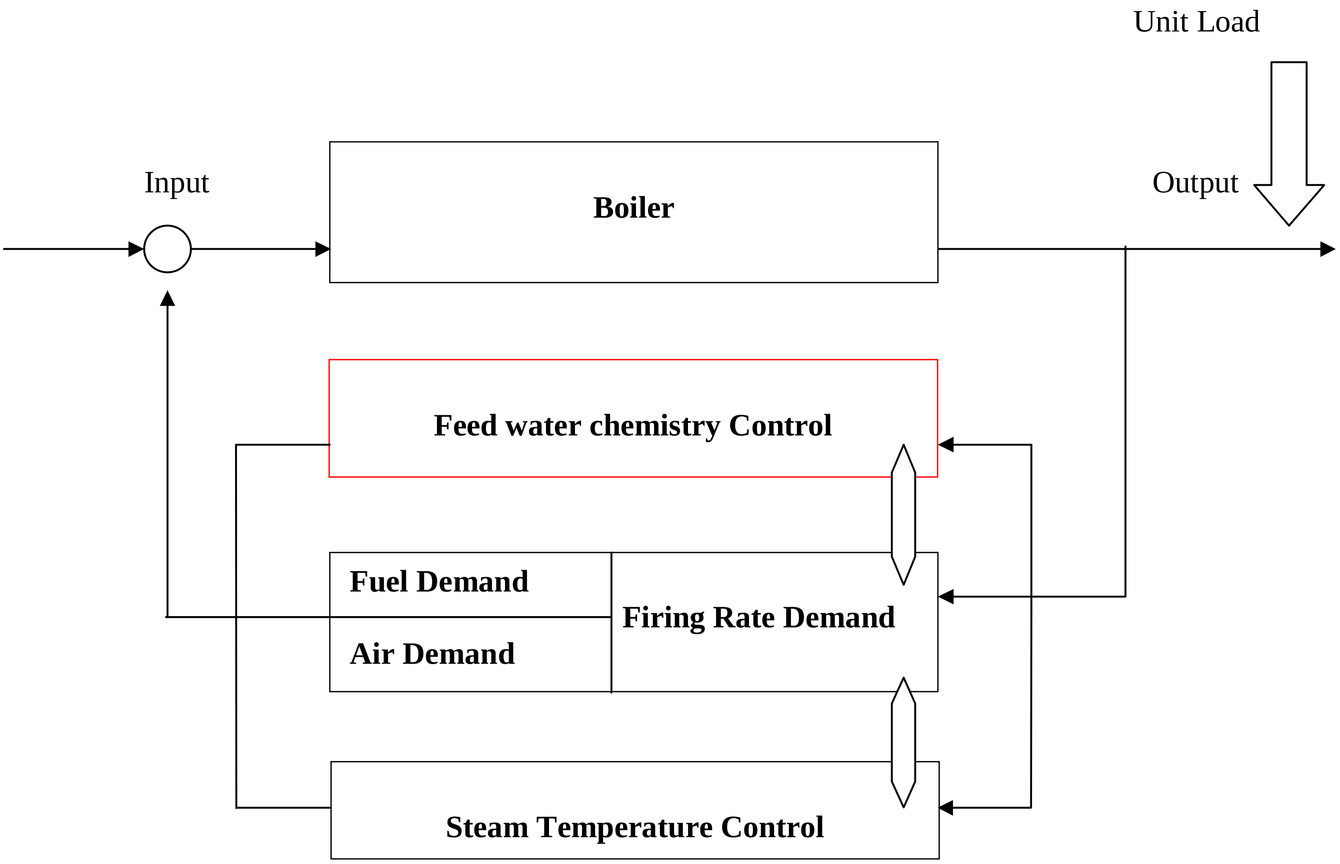


Figure 3-4 Boiler control system

The boiler control system is a process in which the energy and mass balances of the boiler are managed. Figure 3-4 shows a coordinated control system of various controls that build a single boiler control [4]. To obtain a desired output condition, the feed water chemistry control, fuel demand, air demand, firing rate demand and steam temperature control must be regulated depending on the unit load changes. When the load increases, firing rate will also increase creating demands for the mass of fuel and combustion air. Feed water control is a process control that involves water flow rate and storage tank level controls as well as feed water chemistry control. Feed water control involves the boiler water chemistry control to prevent boiler tube scale formation. Boiler feed water can cause damages to the boiler tubes if not treated precisely. The common boiler tube problems caused by poorly treated feed water were discussed in the previous chapter.

3.5. Millmerran power plant oxygen injection structure

Oxygen gas is supplied to the boiler water at the deaerator outlet. The gas gets dissolved in the water and the chemical reactions at high temperatures and pressures provide a formation of a thin film that prevents formation of scale or adherence of any suspended particles in the feed water. Oxygen supply is monitored through a process control that involves a PID controller. A closed loop system is formed with a loop feedback signal measured from the condensate flow transmitter. The condensate flow transmitter is located after a series of heaters and thus provides a longer time delay for a sensor to pick up the dissolved oxygen level signal.

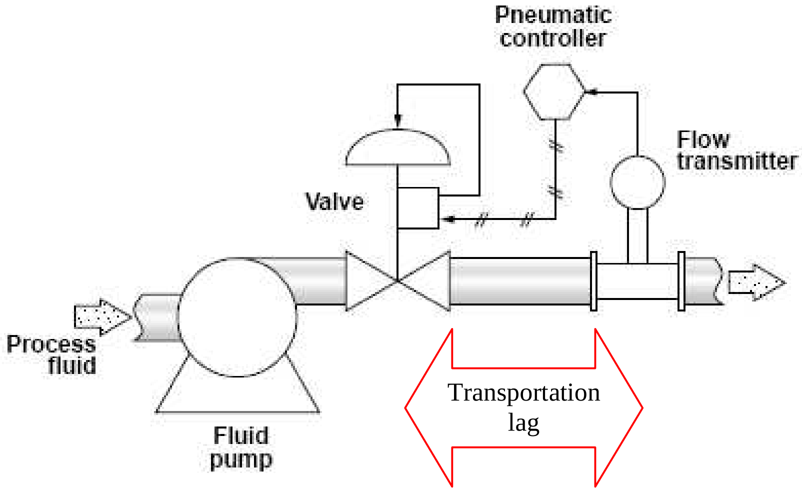


Figure 3-5 Typical system for oxygen injection point and detection point

Figure 3-5 shows a typical structure of the connections between a valve and a sensor. In every controller based process, the location of a sensor from the injection point matters a lot. Locating a sensor close to the injection point will help in reducing the dead-time. Dead-time can be caused by the following:

- Transportation delay/lag due to difference in the piping diameter
- Locating a probe or sensor far from the injection point
- Flow rate can also contribute to some process dead-time

3.6. Computer Management System

Computers are a backbone of every industrial process. Large and sophisticated systems of modern coal fired power stations which have a wide range of activities that need to be timely controlled, requires a computer to do the monitoring of the entire plant. This section of the project includes various ways of managing the control systems applications of a power plant.

3.6.1. Communication Network

Communication is very important in a power plant. For components to perform effectively as an integrated unit, they need to exchange information and share resources (inputs, outputs, or process data) by communicating with one another. This process of data exchange occurs through a communication line (sometimes known as the data highway) that connects the components to form a network. The communications network handles data in binary form. A communications network handles a large volume of data at a very high speed and saves a tremendous amount of field wiring [1]. A common network for a power station is a local area network (LAN) that is commonly employed to facilitate data transmission between computers in office buildings.

In a communications network, components are connected to the network by nodes, and these components are often referred to as a drop. The pattern in which the drops are connected to one another within the network is referred to as the network topology. There are three basic types of network topology, these are: star topology, bus topology and ring topology (Figure 3-6). In a star network topology, components in the system are connected to a central computer by a point to point line. In this network topology information between various components is routed through the central computer. The network is very much dependent on the integrity of the central computer to keep the communications lines open.

The bus network topology involves a single cable for transporting information between devices that are connected to the highway (Figure 3-6). Communication of devices in a bus topology requires a method for all components on the bus to share the use of transmission line. Millmerran power plant uses this network strategy to link various components of the power plant to a transmission line.

The ring network topology links system components in a continuous loop. Information is passed around the continuous loop until it reaches its destination. Information transmission on a ring network topology is usually unidirectional. A bidirectional route can be established by involving sophisticated software and special control devices. Figure 3-7 shows typical connections for a bus topology and ring topology. The diagram consists of two main transmission highways which links all the computers in the power plant. The oxygenated treatment control systems can be controlled through sharing connections with other systems in the network such as the data link server, historian logger where information for this project was obtained.

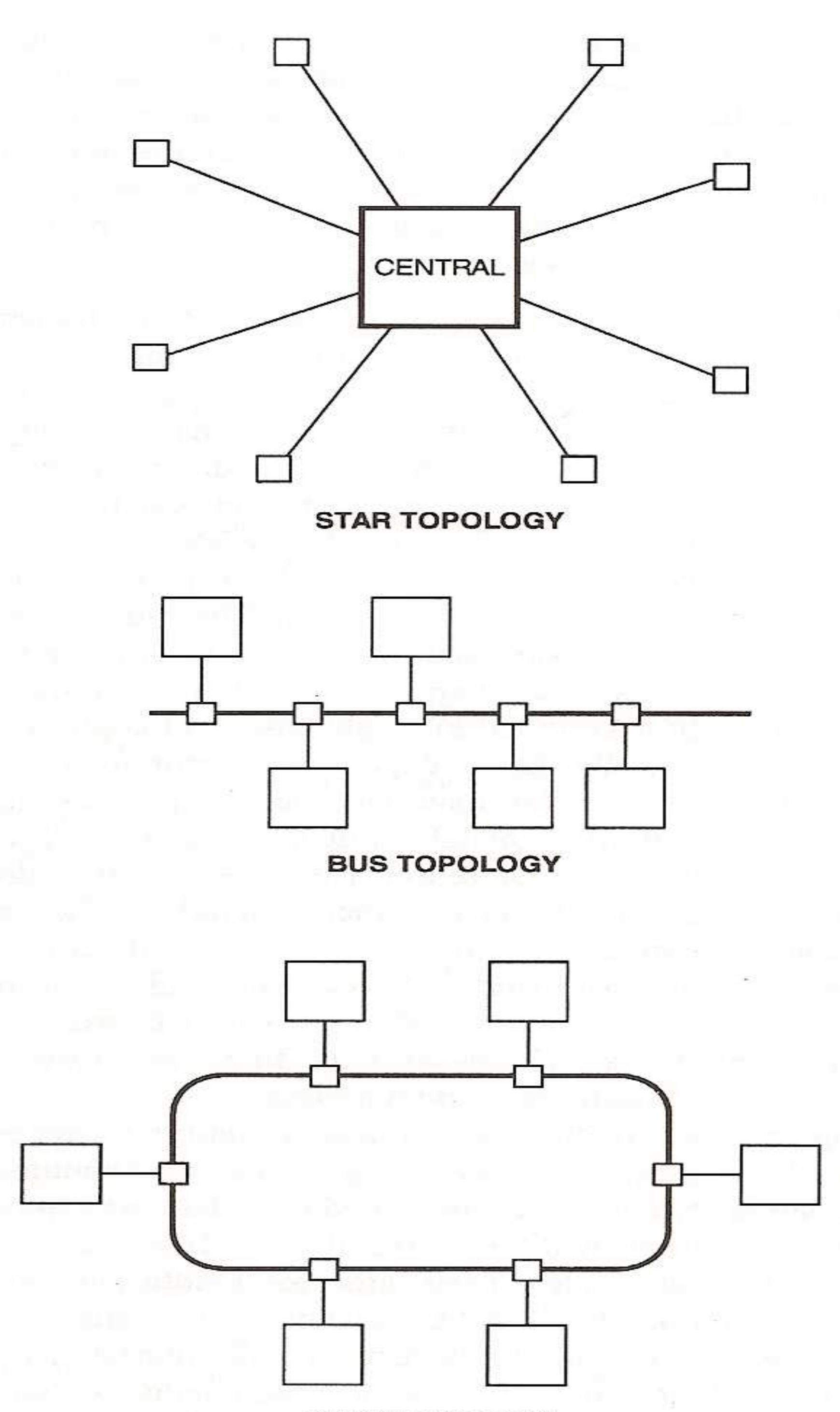


Figure 3-6 Network topology

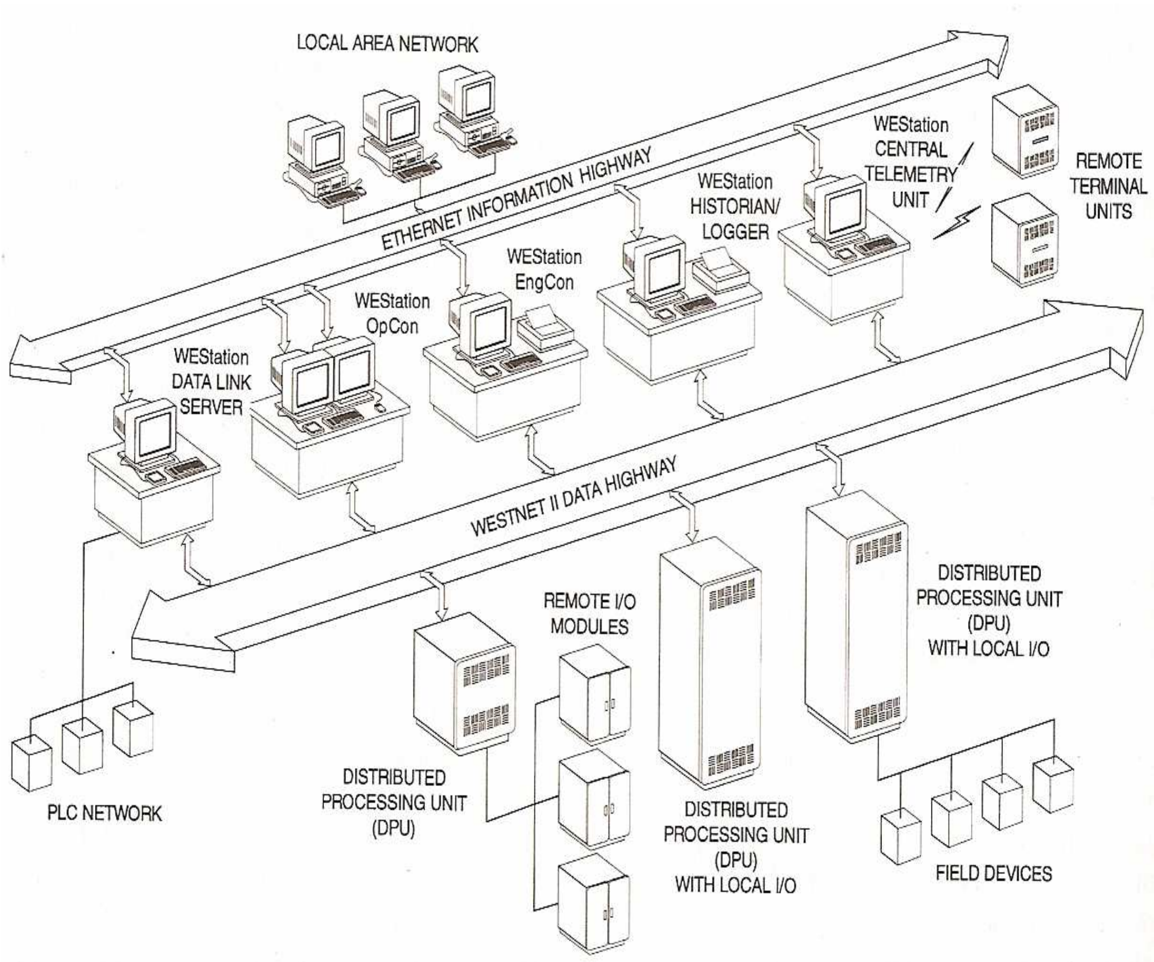


Figure 3-7 Network Structure

3.6.2. Programmable Logic Controller

A power station uses computer languages that are used to control the power plant pumps, motors and other controllers needed in the power plant. The programmable logic controller (PLC) was a digital control computer developed in 1969 for the automobile industry replacing the relay control logic. The PLC has special characteristics that made it different from other control computers:

- The PLC was used to control the on-off control functions like protective interlocking, sequential control logic, and unit protection logic.
- The software was made easy to use by the plant operators.

Programmable logic controllers can be divided into two categories: PLC's used in balance of plant equipment and the stand alone processes. Stand alone processes refers to the packaged designs that are supplied by the manufacturer as a complete system with all the control equipments included [1]. The oxygenated treatment control package is a typical example of the stand alone process that is compatible with the PLC; other applications include coal handling systems, steam temperature handling systems and burner control systems.

The PLC can also install equipments that are used for the balance of plant such as boiler draft equipments like induced draft fans, forced draft fans and feed water equipment such as condensate pumps, boiler feed pumps and shutoff valves. PLC application with respect to balance of plant systems is mainly in the area of on-off or start/stop operations.

3.6.3. Distributed Control System

The distributed control systems (DCS), was first known to be a control system for the boiler control and data acquisition functions of the power plant. DCS has replaced the centralized computer systems. The DCS programming format involves the use of function blocks. This is like a subroutine consisting of a set of algorithms designed to execute a specific control or data manipulating functions such as a PID control function [1]. DCS applications in a power plant typically cover the following:

- Recording functions
- Boiler controls, like firing rate, feed water control loops, steam temperature controls.
- Burner control and pulveriser control.
- Periodic reports and event logs.

- Historical data storage.

Figure 3-8 Millmerran power plant control room (DCS) configuration

Figure 3-8 shows a distributed control system (DCS) room of Millmerran power plant. The oxygenated treatment process is controlled and monitored by the distributed control system plant operators through observing the computer graphics and warning indicators in the control room. Distributed control system has the ability to generate logs and reports. Any information about what happened in the past can be obtained and used for investigations. To study the behavior of the oxygenated treatment process, some of the information was obtained from the DCS.

Chapter 4 Boiler water chemistry control and evaluation

4.1 Boiler steam-water flow circuitry

The steam-water flow of a coal fired power station has the following roles:

- It generates high purity superheated steam from cooled inlet feed water at a specified pressure, temperature and flow rate.
- It protects metal components from getting excessive temperature which might result in boiler tube failure.

4.1.1 Boiler circulation methods

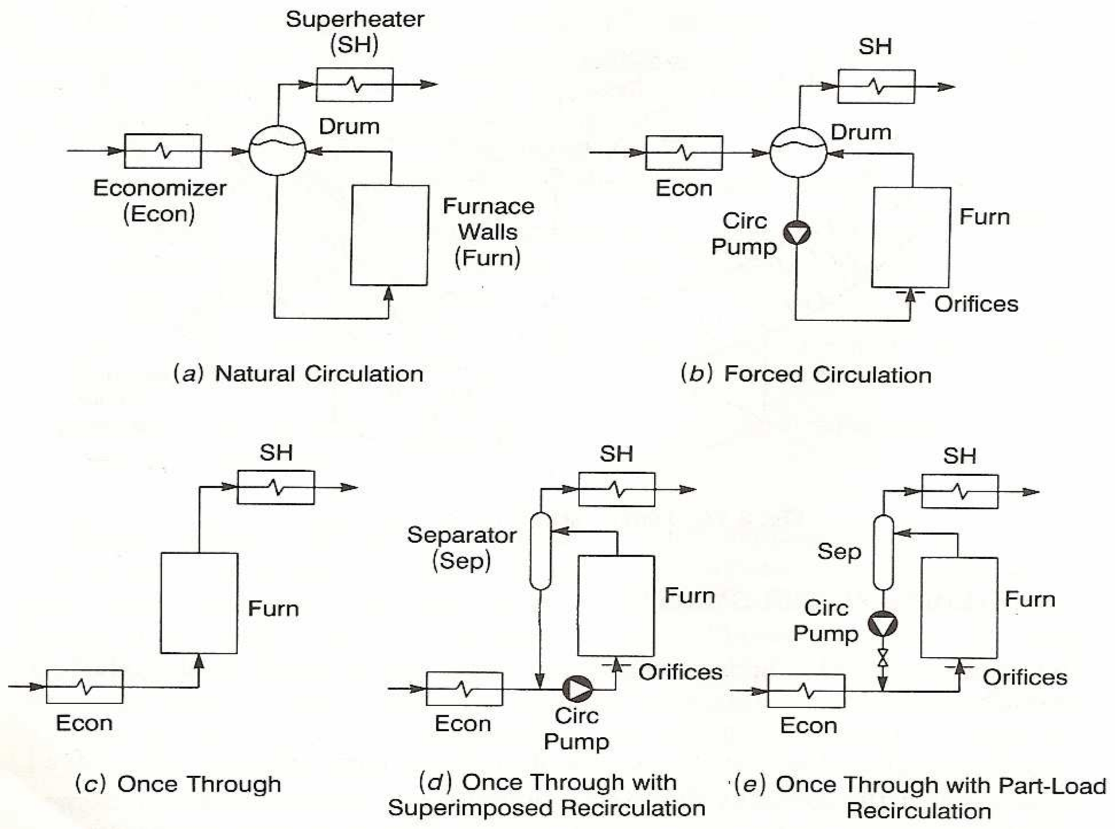


Figure 4-1 Boiler Circulation Systems

There is a wide range of circulation systems that is used in coal fired power stations. The commonly used systems are shown in the diagram above (Figure 4-1). These circulation systems may be classified as either once-through or recirculation types. In the recirculation system, water is partially converted in to steam at all load levels. The remaining water is then recirculated back to the evaporator for further heating.

4.1.2 Millmerran power plant boiler circulation system

Millmerran power plant uses a once-through boiler circulation method with part-load recirculation (Figure 4-1 e). In a pure once-through circulation, water in the boiler tubes is continuously evaporated to dryness. Availability of a part-load recirculation overcomes low-load and start-up limitations of pure once-through design.

4.2 Millmerran power station boiler water chemistry control

433 MW Load	Specific conductivity	Cation Conductivity	Dissolved oxygen	pH	Silica
Main steam (HP)	14.52 uS/CM	0.10 uS/CM			
Reheat Steam		0.14 uS/CM			
Polisher inlet		0.14 uS/CM		9.64 pH	0.00 ppb
Polisher #1		0.10 uS/CM			0.00 ppb
Polisher #2		0.09 uS/CM			0.00 ppb
Polisher outlet	13.37 uS/CM		103.32 ppb	9.55 pH	
Deaerator outlet		0.10 uS/CM	168.43 ppb		
Boiler Feed water Economizer Inlet	14.71 uS/CM	0.11 uS/CM 0.12 uS/CM 0.11 uS/CM	200.14 ppb	9.62 pH	

Table 4-1 Millmerran unit #1 steam and water sampling data

Error! Reference source not found. above shows different results for dissolved oxygen level in parts per billion for polisher outlet, deaerator outlet and the boiler feed water economizer inlet. The measurement for pH level and silica level were also taken for the power station unit #1 steam cycle. All these results were obtained through on-line sampling. Any offset in the results can be viewed on a computer screen and proper observation can be made by the plant operators. Offset can be due to ingress gases entering the feed water cycle through leaks or during make-up. Figure 4-2 shows the steam cycle, so the results of **Error! Reference source not found.** were taken from some sections of the steam cycle mentioned in **Error! Reference source not found.**.

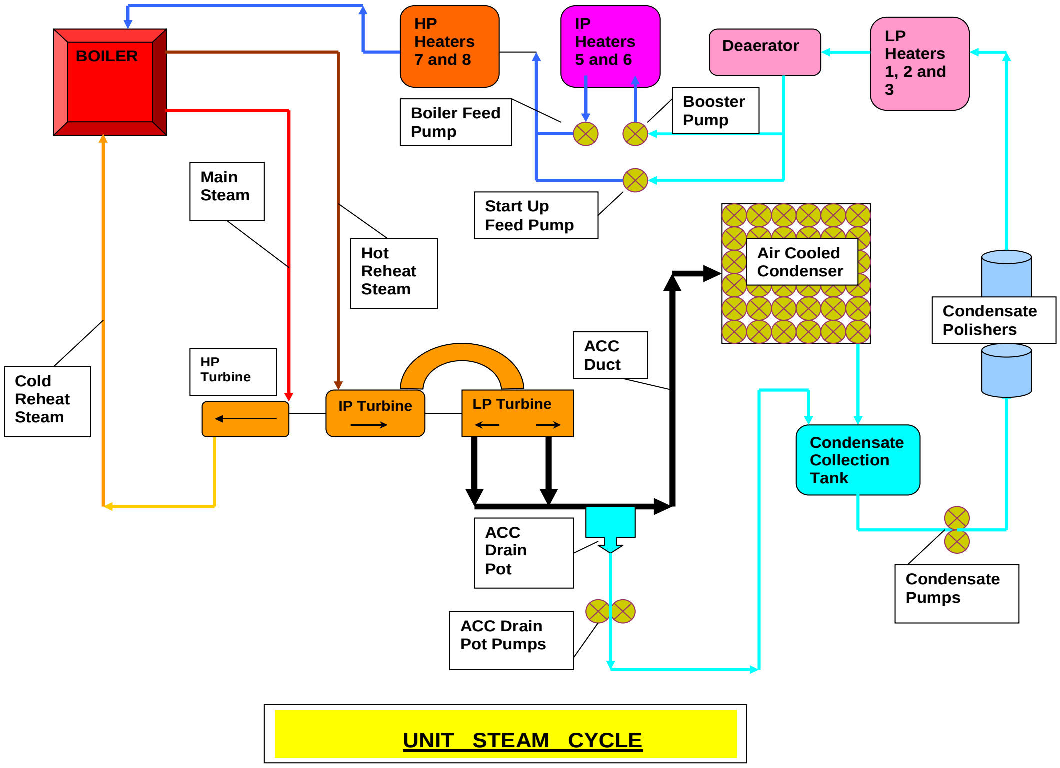


Figure 4-2 Millmerran power plant steam cycle

4.2.1 Steam cycle for supercritical boilers

In a supercritical boiler, water is directly turned into steam. So any impurities from the pre-treatment plant passes through the economizer will either:

- Be deposited on the walls of the boiler tubes at the transition zone.
- Dissolve in the steam and later deposit on the turbine blades

- Be carried forward in suspension in the steam and deposited at the valve opening hence leading to valve failures due to sticking.

In a supercritical boiler the following parameters are recommended for the feed water:

Total dissolved solids	75-150 p.p.b
Conductivity	10-5 mmho
Conductivity after cation column	0.3-0.5 mmho
Dissolved oxygen	2-5 p.p.b
pH	8.7-9.7
H2	5 p.p.b
Fe	5 p.p.b
Cu	5 p.p.b
Si	5-20 p.p.b

Table 4-2: Boiler chemistry requirement

4.2.2 Oxygenated treatment control background information

Figure 4-3 Oxygenated Treatment Skid

Source :(Millmerran power plant, 2007)

Oxygenated treatment was developed in Germany in the early 1970s for treatment of once-through steam generators [1]. The basis of the treatment is the feed of oxygen or other oxidizers to all-steel cycle for cycle conditioning. In a purely oxidizing environment, a different protective layer is formed over the steel materials. This protective corrosion layer of ferric hydrate oxide covers a base layer of magnetite. Reports from Germany and the former Soviet Union indicate that plants using this type of treatments have operated for significantly longer periods of time without plant shutdown to replace a damaged boiler due to corrosion.

4.2.3 Oxygen & Ammonium Hydroxide (AVT) Feed

There are two different boiler water treatment regimes in use at Milmerran power plant. These are the traditional all-volatile treatment (AVT) and the modern oxygenated treatment (Figure 4-3). The AVT regime involves the injection of ammonia hydroxide into the condensate system to monitor the water pH within the range of 9.2 – 9.6. The AVT regime of Millmerran power plant for ammonia dosing has not worked since the pH has been upped to offset corrosion in the air cooled condensers (ACC). Other power stations have switched to conductivity to control dosing. The AVT work together with OT and it utilizes condensate de-aeration to maintain low dissolved oxygen levels, typically < 10 parts per billion (ppb). The OT regime injects oxygen in a controlled manner. The aim of this oxygen injection is to control the condensate dissolved oxygen level to a range of 50 – 200 ppb. Millmeran plant condensate water pH level is controlled within the range of 8.0 – 8.5. To prevent removal of gaseous oxygen by de-aeration all feed heater vents and the de-aerator vent to condenser must remain closed during normal operation. The AVT is used immediately after boiler start-up and prior to boiler shutdown. This maintains low dissolved oxygen and pH levels in case of a prolonged plant shutdown hence reducing the solubility of the formed oxide layer.

The oxygen injection varies with the power plant conditions. During a load change in the power plant, the dissolved oxygen varies anywhere from 50 ppb to 300ppb. The oxygen control logic is fairly slow and takes some time for changes to be picked up. A recent information of the OT performance from Millmerran power plant showed that for an output of 420MW which lasted 8 hours, oxygen started at 205ppb and dropped back to 180ppb by the end of the 8 hour session. Load dropped 380 MW and oxygen came back to 160ppb. For load changes below 300 MW, oxygenated treatment reverts to AVT and oxygen injection stops. At this stage a manual operation takes place to maintain the normal condition of the formed oxide layer.

4.2.4 Oxygen Feed System arrangement

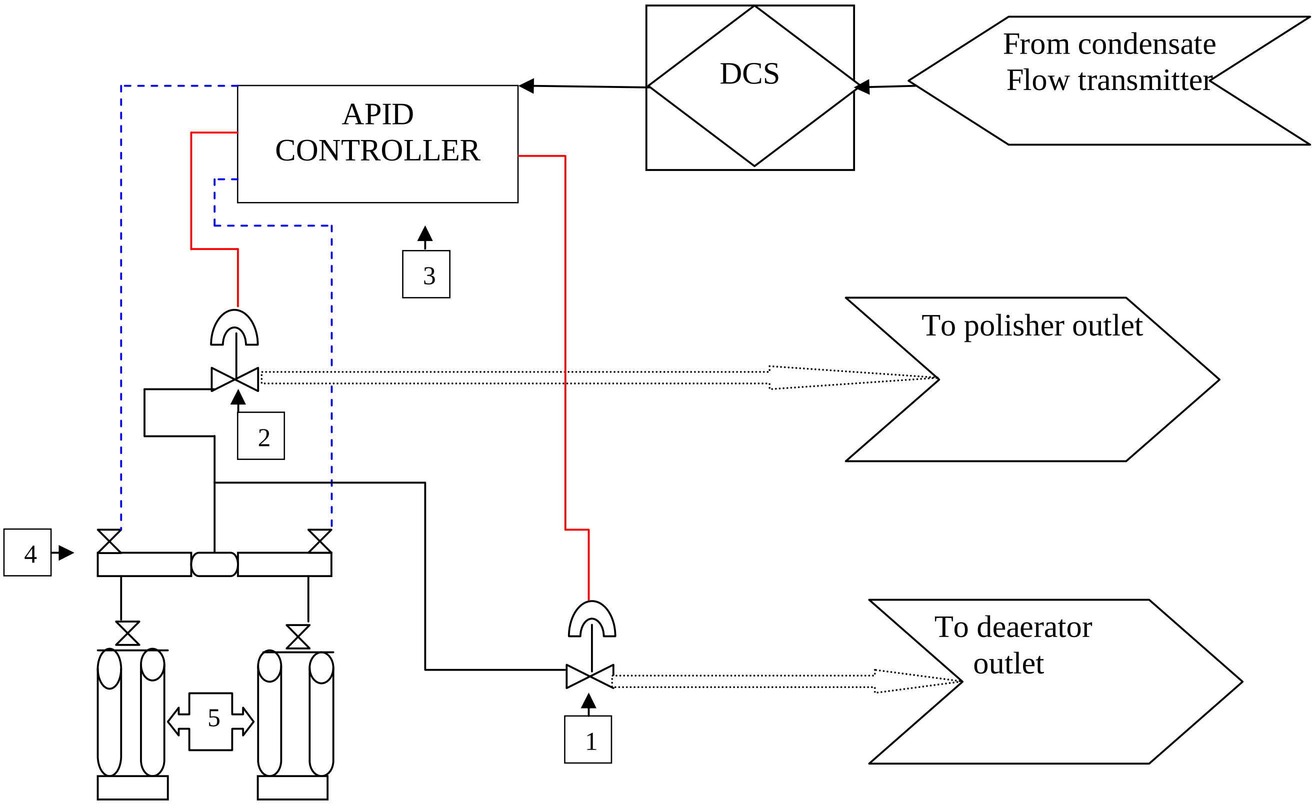


Figure 4-4 Millmerran power plant oxygen injection controller structure

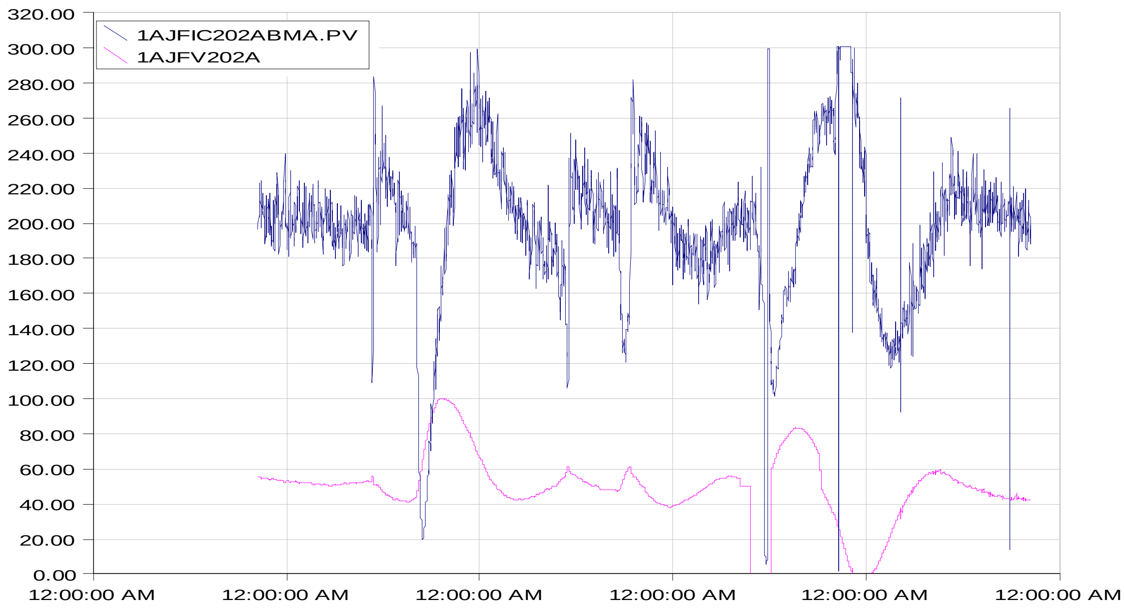
Figure 4-4 above shows the dissolved oxygen injection structure that is used at Millmerran power plant. The system consists of an advanced PID (proportional, integral and derivative) controller (3) which has an error detector function. This function measures the error between the primary variable and the set point. Numbers (1) and (2) shows the control valves which are controlled by the PID controller to vary the amount of oxygen injection in the deaerator outlet and the polisher outlet. When the controller is turned on, the valves are opened at the oxygen sources (5). A controller receives a control signal from the condensate flow transmitter through the control room and the DCS. At the control room, the power plant operators can see the process control variability. The system can be manually controlled and auto-controlled depending on the power plant conditions. Manual control involves tuning of the controller parameters during start-up to obtain a better response.

4.2.5 Historian data of oxygenated treatment process

Time	PV	Load	Valve demand
12:00:00 AM	189.95	432.15	53.21
12:01:00 AM	188.36	432.21	53.27
12:02:00 AM	187.54	431.35	53.34
12:03:00 AM	188.83	428.74	53.40
12:04:00 AM	185.09	426.16	53.47
12:05:00 AM	185.73	427.09	53.53
12:06:00 AM	190.40	428.87	53.49
12:07:00 AM	189.61	429.67	53.43
12:08:00 AM	193.97	429.31	53.37
12:09:00 AM	200.60	428.94	53.31
	(ABMA.PV)	(MW)	(1AJFV202A)

Table 4-3 Historian data of Millmerran power plant

Figure 4-5 Millmerran dissolved oxygen control response (5 days sampling)



Data in Table 4-3 was obtained from the oxygenated treatment control process. The signal for the valve (1AJFV202A) was produced from the controller output due to a demand from the process variable and the set point. The set point for the dissolved oxygen was set at 200ppb. The response for the process variable shows some variation which were above and below the set point. This system behavior shows that the dissolved oxygen is alternating above and below the set-point. This will result in more than the required amount of dissolved oxygen injection in the feed water. The lower graph shows the response of the control valve due to variations in the level of dissolved oxygen in the boiler water.

4.3 Oxygenated treatment control system process modeling

The oxygen injection process of Millmerran power plant uses an advanced proportional, integral and derivative controller (A-PID). This controller is different from the normal PID controller because of the following:

- It has a direct use of the feed forward signal into a PID controller
- It has improved algorithms for derivative action calculation
- The controller has bumpless manual to auto transfer
- It has a quick saturation recovery option

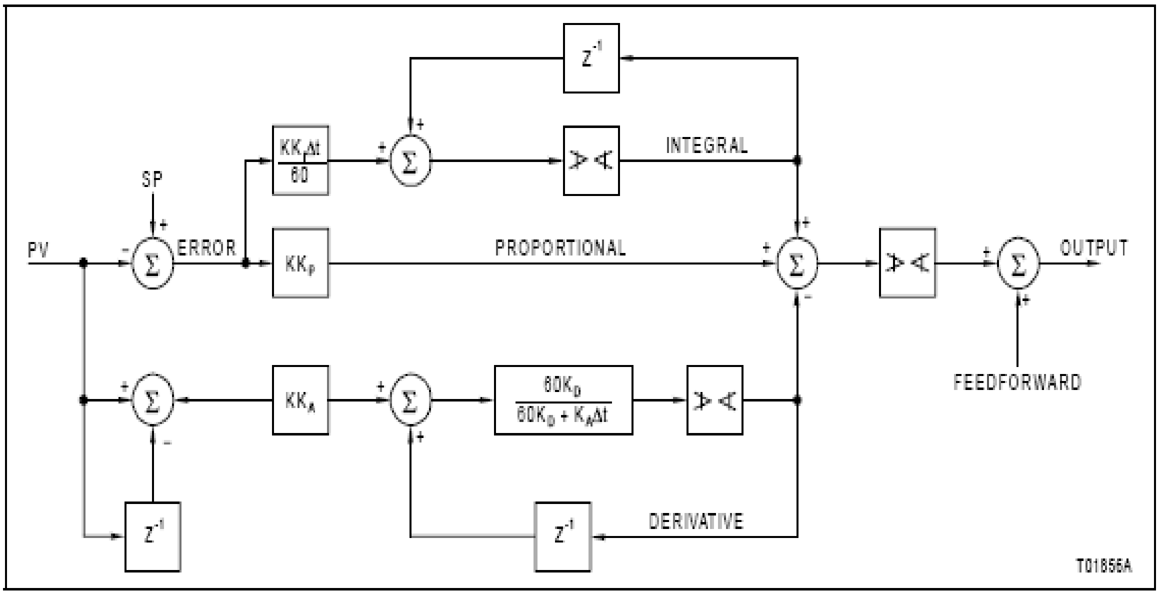


Figure 4-6 Advanced PID controller

Figure 4-6 shows the schematic diagram of the advanced PID controller used for oxygen injection process at Millmerran power plant. This controller has proportional part, integral part and derivative part. The controller monitors and controls the amount of dissolved oxygen in the feedwater by sending electric signals to a servo valve which either increases or decreases the amount of oxygen gas injection into the feed water.

The figure above shows the internal structure of the controller. A simplified control loop for the oxygen injection consists of the controller part, the plant or controlled device which is a servo valve and a block which represent the delay or transportation lag. The delay or dead time is simply the duration of the fluid flow through a conduit. The next Figure 4-7 illustrates the transportation delay of the oxygen injection process.

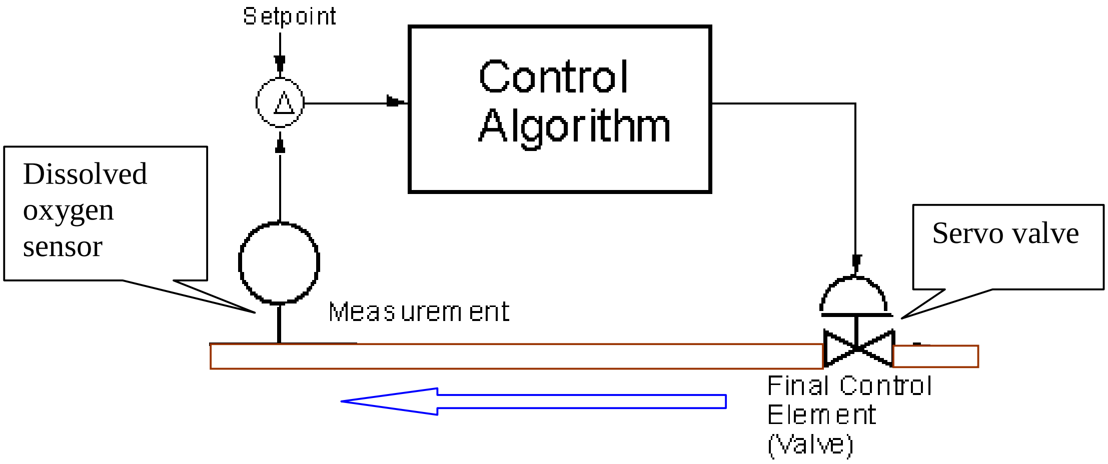


Figure 4-7 Dead-time due to fluid transport delay

In this diagram, the arrow shows direction of fluid flow. The servo valve injects oxygen gas in to the feed water stream. The amount of time it takes the solution to reach the dissolved oxygen sensor is called dead time. Dead time can increase due to the size of pipes which transport the solution. For a narrow pipe the fluid can take less time to travel through the entire length hence reducing the delay in fluid transportation. In a power plant, there are small and large fluid passage ways such as low pressure heaters, high pressure heaters and the boiler which are all in different sizes. This results in a non uniform flow of the feed water. If we consider a uniform pipe in Figure 4-8, there is a uniform area and a small volume of liquid passing through the pipe. The liquid will take less time to travel through the pipe than for a large volume liquid pipe.

Figure 4-8 Narrow fluid passage

Millmerran power plant's advanced PID controller faces some challenges in trying to control the oxygen gas injection process which has a large dead time of about 12 to 15 minutes. The controller is over working in trying to control the dissolved oxygen to a required level. To model the behavior of the oxygenated treatment process, matlab and simulink software were used. In the simulation, a servo valve was used as the model for the oxygen injection system.

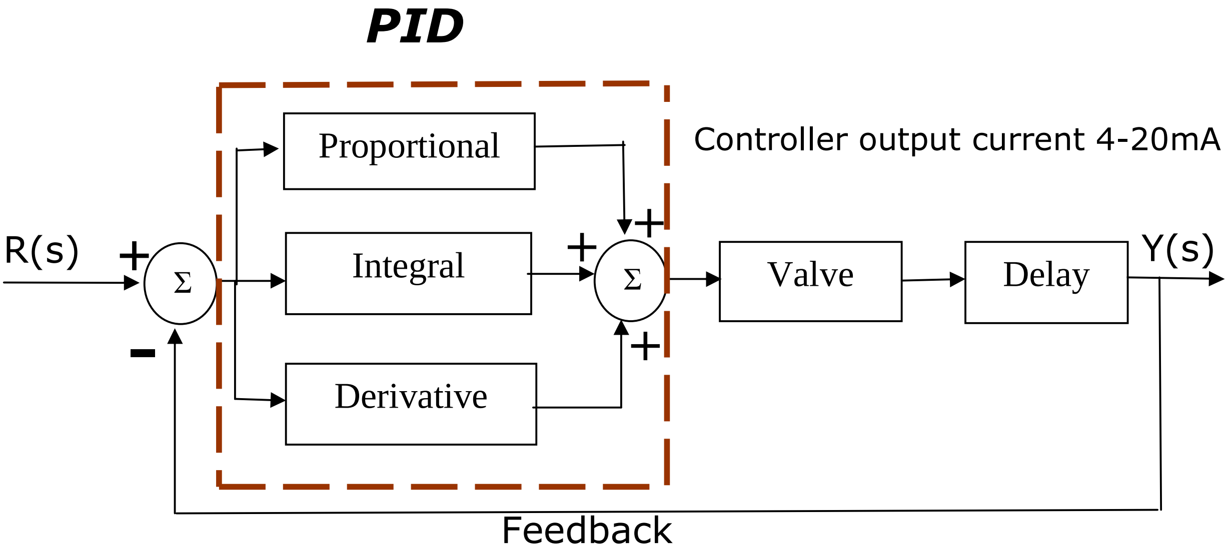


Figure 4-9 Simplified structure of oxygenated treatment process control

4.3.1 Servo valve modeling

This section of the project is looking into introducing a plant model that will be used in the demonstration of oxygenated treatment controller behavior. This is a controlled device that has an integrator and a time constant and it is designed for position control applications. The valve hosts a DC motor which is driven by an electric current from the controller. The current from the controller is in the range 4-20 mA. The valve opens and closes depending on the amount of current which the controller outputs. In this case the valve will be fully open when a current of 20 mA is supplied and fully closed when a current of 4 mA is supplied from the controller output. In between these current ranges, the valve opening and closing can be controlled depending on the amount of oxygen required. Figure 4-10 and Figure 4-11 below shows the connections between the oxygen sources and the valves at Millmerran power plant.

An electro hydraulic servo valve transforms an electric signal into hydraulic power. This involves mechanical motion by means of an electromagnetic torque motor which is used to stroke the mechanical control element of the valve. The torque motor drives the hydraulic amplifier which in turn strokes the power spool. Figure 4-9 shows the connections of the valve to the advanced PID controller for the simulink simulation modeling.

Figure 4-10 Oxygenated treatment control valve panel

Figure 4-11 Servo valve

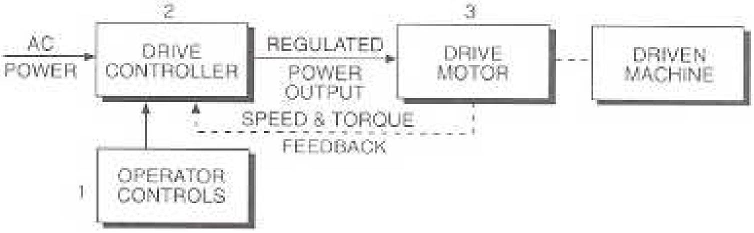
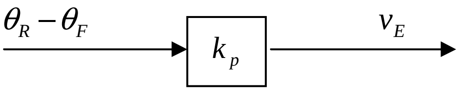


Figure 4-12 Servomotor and controller inputs and outputs

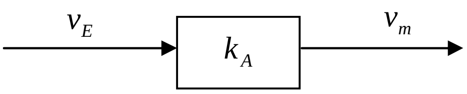
Mathematical model of the DC motor for the servo valve can be expressed by the time constant (relating armature voltage and speed) followed by an integration (relating speed and output shaft position). The dc motor is the heart of a dc servo system. In the dc servo system, the input is usually considered to be the desired angle and the output is the actual angle which produces torque and speed (Figure 4-12). The block diagram representation of a typical dc servo system was modeled as follows:

Considering the d.c servo system with the input usually considered being the desired angle and the output as the actual angle. The block diagram representation of a typical servo system involves the input angle θ_R which is compared with the feedback angle θ_F and the error angle θ_E converted into a voltage v_E by means of a rotary potentiometer with a gain k_p.



$$v_E = k_p(\theta_R - \theta_F)$$

The error voltage v_E is amplified to produce the drive voltage v_m for the motor.



$$v_m = k_A v_E$$

k_A = amplifier gain

The motor rotates and produce an output speed ω_m depending on the voltage applied.

k_m = motor gain

T_m = motor time constant

The resulting block diagram shows the servo system transfer function used in the modeling of the oxygen injection response. For simplicity, this transfer function was used to model the response of an advanced PID controller for this project. The real system consists of more complex blocks that are connected between the controller and the servo valve or the injection valve. Using the system transfer function in the block below, the effect of system delay can be modeled for different times ranging from small dead time to large dead time.

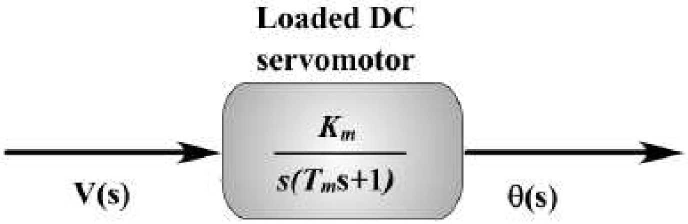


Figure 4-13 Servo valve transfer function

4.3.2 Advanced PID Controller Tuning

The advanced PID controller has 5 tuning parameters which are as follows:

k_p = Proportional gain

k_i = Integral reset (reset per minute)

k_d = Derivative rate action (minutes)

k_a = Derivative lag constant (typically equal ten)

k = Gain multiplier

Modeling the response for the servo valve, the common method for tuning the PID controller was proposed by Callender et al. (1936). Callender proposed a design for widely used PID controller by specifying satisfactory values for the controller settings based on the estimates of the plant parameters that an operating engineer could make from experiments on the process itself [9]. The approach was developed by Ziegler and Nichols (1942,1943), who recognized that the step responses of a large number of process control systems exhibit a process reaction curve as shown in Figure 4-14 below. The parameters for tuning the PID controller were obtained by using the Ziegler and Nichols open loop method. The procedure involves the following steps:

Step 1: Make an open loop plant test (e.g. a step test)
Step 2: Determine the process parameters: Process gain, deadtime, time constant (measure L and T as shown)
Step 3: Calculate the parameters according to the following formulas in Table 4-4

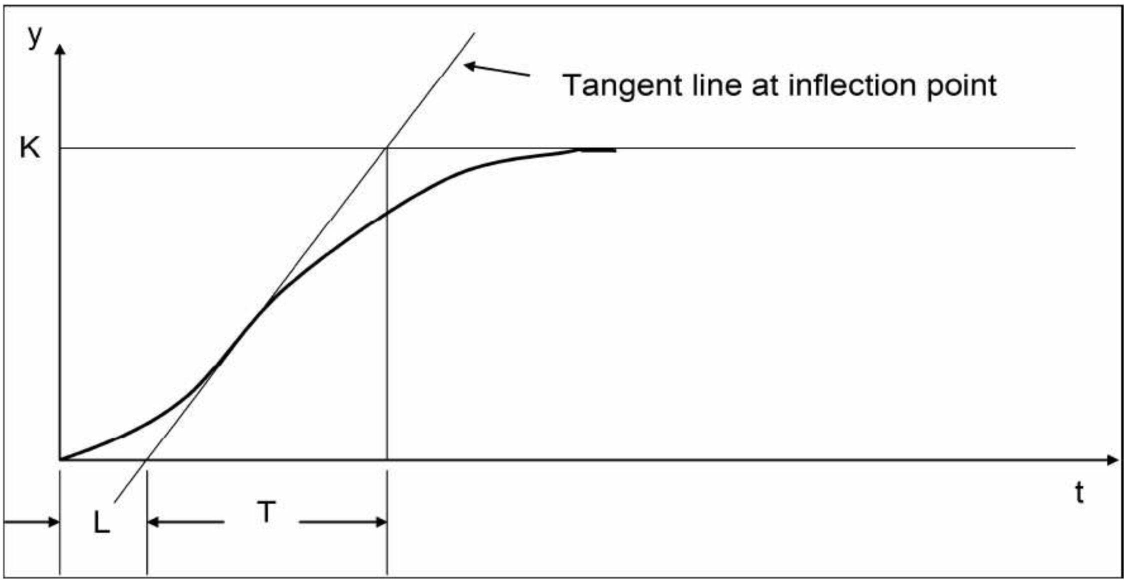
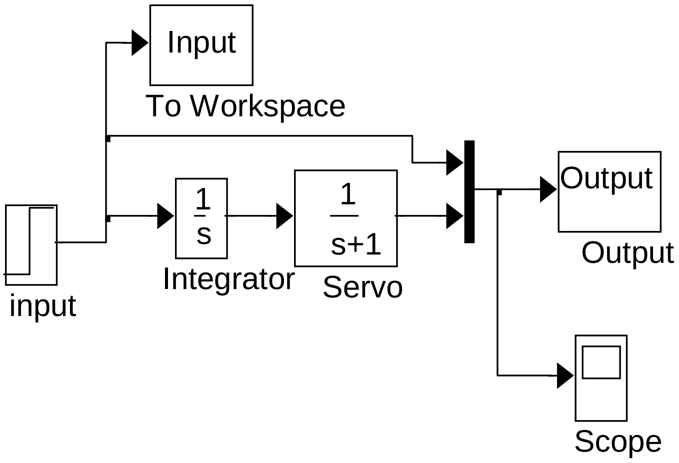


Figure 4-14 S shaped open loop response of a system

Controller	Proportional Kp	Integral K_i	Derivative K_d
PID	$0.5\frac{T}{L}$	$0.6\frac{T}{L^2}$	$0.6T$

Table 4-4 Parameters for tuning PID controller



Model 4.1

To obtain the tuning parameters for the advanced PID controller, an open loop step response model for the servo valve transfer function was carried out. It is estimated that by setting these parameters, a response with an overshoot of 25% and good settling time should be obtained [9]. In ZN method, tuning is based on the period and the critical gains which are determined by adjusting the proportional gain until the stability limit is reached. The parameters L and T were approximated from the open loop response as follows:

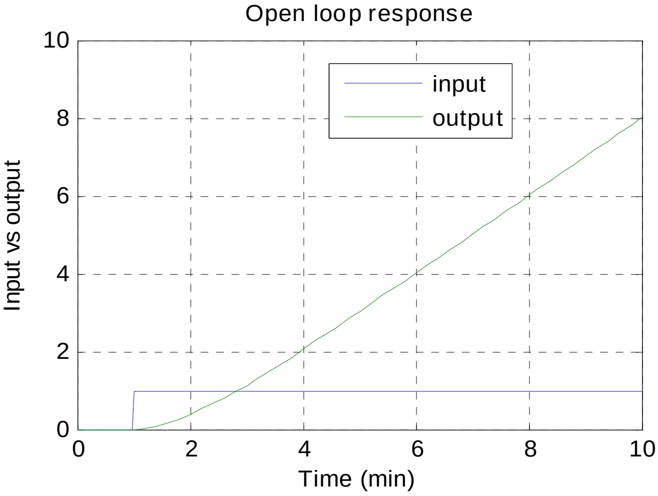


Figure 4-15 Ziegler Nichols first trial

The values of the parameters L and T from Figure 4-14 were estimated as follows:

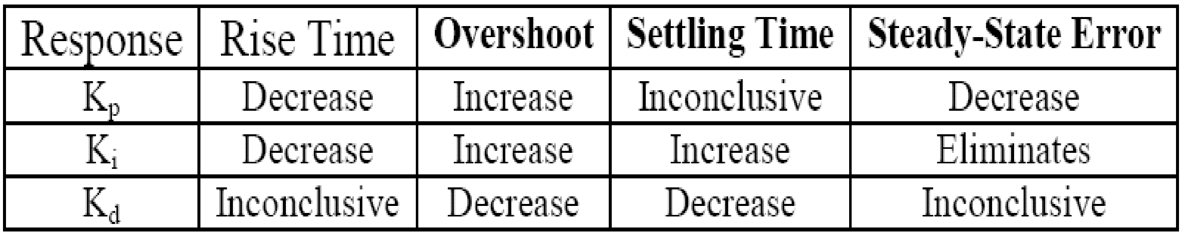
L = 1.5

T = 9.8

By substituting the values for L and T in Table 4-4, the resulting table consists of Ziegler Nichols first trial PID tuning parameters.

CONTROLLER	PROPORTIONAL (KP)	DERIVATIVE (KD)	INTEGRAL (KI)
APID	3.27	2.61	5.9

Table 4-5: Tuning parameters



Response	Rise Time	Overshoot	Settling Time	Steady-State Error
K_p	Decrease	Increase	Inconclusive	Decrease
K_i	Decrease	Increase	Increase	Eliminates
K_d	Inconclusive	Decrease	Decrease	Inconclusive

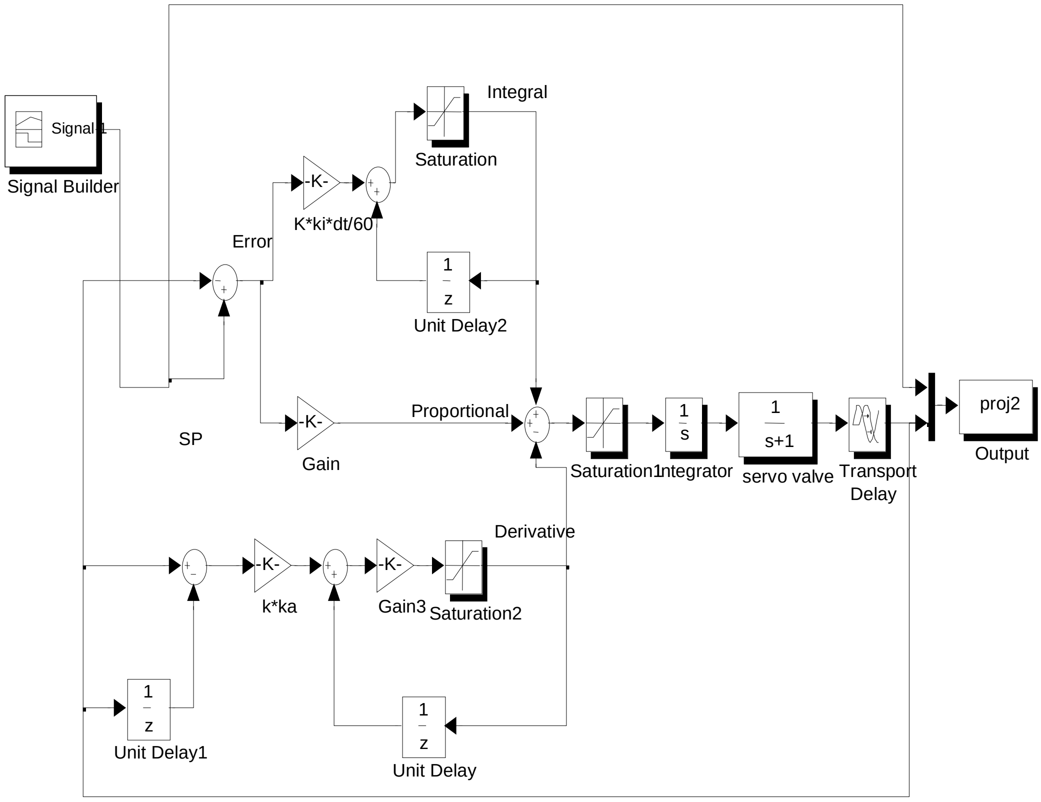
Table 4-6: controller parameter tuning guidance

Tuning the advanced PID controller was mostly done by trial and error approach. By tuning the parameters separately with the help of table 4-4, 4-5 and 4-6, the response was able to follow the set point. This simulation mainly demonstrates the effect of dead time on stability of a system. The controller can be automatically tuned during oxygen injection operation. The controller tuning for this OT process is continuous due to variations in load.

Chapter 5 New Control System Proposals

5. Introduction

The block diagram below shows the complete model for the advanced PID controller which is used for the oxygen injection process at Millmerran power plant. The process set point for the dissolved oxygen in the feed water was set to 200 ppb and 180 ppb. To show the behavior of the controller, the model tests were carried out for different dead times. This was done by changing the time value in the transport delay block.



Advanced PID used to drive a servo-control valve driven by a DC motor

Figure 5-1 A system model of a servo valve and advanced PID controller

5.1.System Analysis

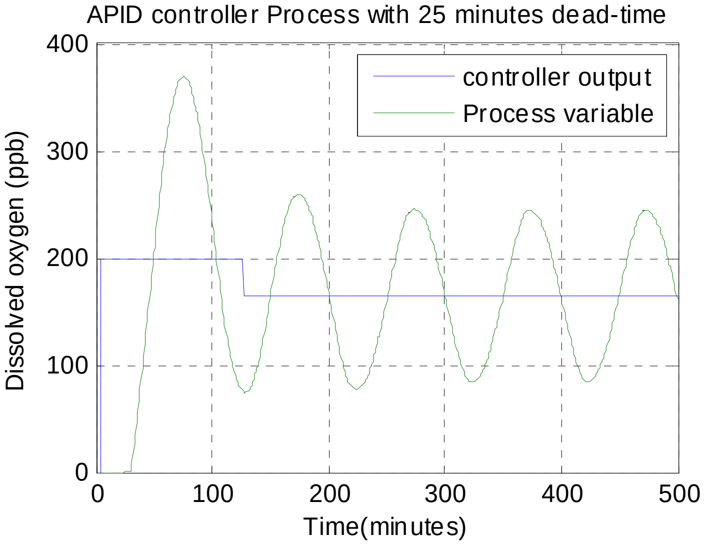


Figure 5-2: Unstable Response

The system response in Figure 5-2 above was obtained by inserting a dead time of 25 minutes in the delay block of . It can be seen that the process variable developed some overshoot and the system losses stability. With reference to Figure 4-5, the process response showed upsets and the dissolved oxygen response fluctuated above and below the set point.

A further reduction in the time delay of 20 minutes led to an unstable system which takes some time to settle (Figure 5-3). Oxygen injection process of Millmerran power plant is dynamic and has a large dead time therefore the controller cannot find enough time to drive the process variable towards the set point during sudden load changes. For a stable load, the controller performance at Millmerran power plant developed a better response in the process variable which has small overshoots.

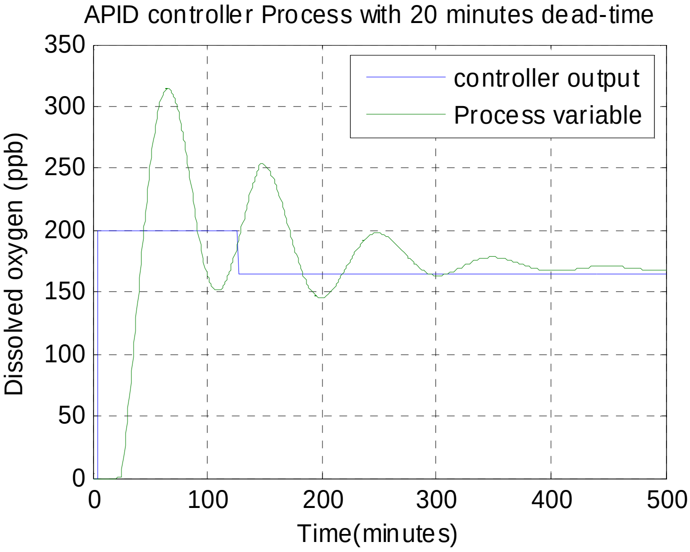


Figure 5-3: Unstable Response

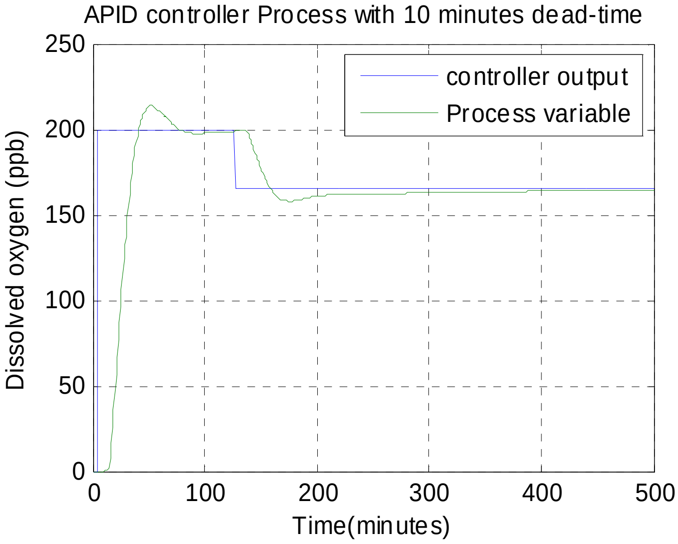


Figure 5-4: Stable System

The dissolved oxygen response can become stable by reducing the dead time. Figure 5-4 illustrates a response which was generated for 10 minutes dead time. The response shows a better set point tracking. It can be seen that for a reduction in the dead time, the response becomes more and more stable. The best way to control a system with large dead time is to reduce the dead time. Figure 5-5 shows a perfect response generated for a small dead time of 5 minutes.

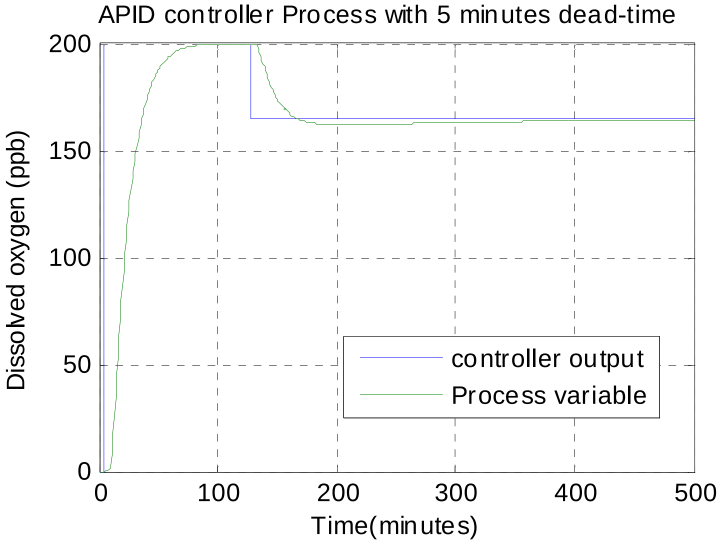


Figure 5-5: A stable system with reduced dead time

5.2. Chapter Summary

New control system proposals for the oxygenated treatment control process are as follows:

- Reducing the dead time of the OT process by moving the injection point closer to the dissolved oxygen sensor.
- Eliminate ingress gases during make up

Moving the injection point closer to the sensor location reduces the delay in the solution transportation. A proper dissolved oxygen control prevents boiler tube failures which can result in plant shut down and huge amount of capital losses. Therefore relocating the injection point is a better option for controlling the OT process of Millmerran power plant. Power plant shut down results in massive capital losses; it is therefore important to put more emphases on preventing corrosion of the boiler tubes. Once through boiler operates efficiently under highly treated feed water. For the boiler to operate for a long time, it is important to maintain the required levels of dissolved oxygen and pH.

Chapter 6 Instrumentation for Boiler water Quality

6. Introduction

This chapter covers various instruments that are used for determining the boiler water quality parameters. Instruments that are used in a power plant for boiler water quality have to be properly selected, installed and maintained to improve the overall plant performance. The improvement in performance can be in the treatment process such as more efficient chemical and energy use, increased security, or more consistent water quality. Instruments also provide more timely and accurate process information to power plant operators and managers.

In a supercritical boiler, water quality assurance testing plays an important role in the life of a power plant. The objectives of quality assurance testing are as follows [10]:

- To determine the long term maintenance requirements
- To provide a calibration reference point
- To obtain instruments that are accurate, reliable, and stable and which do not require excessive maintenance.

6.1. Dissolved Oxygen Measuring Instrument

Dissolved oxygen reference values are best determined with a reference probe. This reference probe is calibrated in air and against laboratory prepared solutions of known dissolved oxygen concentration. The dissolved oxygen in the feed water is measured in parts per billion (ppb). Figure 6-1 shows the dissolved oxygen sensor. This is a luminescent dissolved oxygen (LDO) sensor which is the first luminescent sensor to provide trace oxygen monitoring in pure water processes where ppb level monitoring is needed.

Figure 6-1Dissolved oxygen sensor

6.2. pH Measuring Instrument

Chemical monitoring in the feed water consists of measuring ammonia, pH, conductivity, and cation conductivity for either AVT or OT. Ammonia can be measured directly or indirectly from pH and conductivity. Ammonia reacts in water to produce hydroxide ion (OH-) therefore indirect measuring method is often used. Both conductivity, which is a measure of the ions in solution, and pH, which is an indirect measurement of OH- can be combined to yield the ammonia concentration. Figure 6-1 below shows a measuring instrument that can be used.

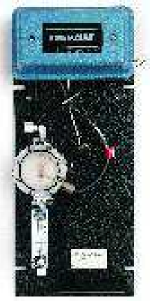


Figure 6-2High purity pH sensor (model 320Hp)

Chapter 7 Conclusion and Future Work

This project investigated the boiler water dissolved oxygen control system of the modern supercritical boiler at Millmerran power plant. Boiler water quality plays an important role in reducing corrosion of the boiler tubes and increasing the efficiency as well as life of the power plant. Millmerran power plant has a modern oxygen injection process which helped in maintaining optimum conditions for its supercritical once through boiler performance. The operation of the oxygen dispenser experienced some stability problems due to dead time. The controller can perform better if the oxygen injection point can be moved from the polisher outlet to the high pressure heaters inlet. From the high pressure heaters, extreme temperatures and pressures start to build up to the superheater, so the boiler tubes need to be supplied with a required level of dissolved oxygen for protection and efficiency.

The advanced PID controller can give a better performance with reduced dead time. Any process with a large dead time present special challenges to a controller, the controller has to wait until the dead time has passed for it to get feedback from the process. This new system recommendation will benefit the power plant in managing a good dissolved oxygen concentration. Enough oxygen gas will be supplied at a required time hence maintaining the formed oxide film and reducing the chances of a power plant shut down due to boiler tube failures.

Future work in this study may relate to involvement of other controllers like the smith predictor and other model based controllers. These controllers are believed to work well in dead time processes. From a control system point of view, moving injection point would only give a better controller action. This may have other effects in the power plant which need to be considered in future.

References

[1] Power Plant Engineering 1996, Plant Control System, Augustine H. Chen, New York.

[2] Steam Boilers 1981, Water Tube Boilers, Harry M. Spring, Jr, Anthony Lawrence Kohan, USA.

[3] Richard C. Dorf, Robert H. Bishop 2000, Modern Control Systems, New Jersey 07458

[4] Control of Boilers 1991, improving boiler efficiency, Duke low, Sam G. – 2nd Ed. Kansas State University, USA.

[5] Steven C. Stultz and John B. Kitto, 1992, Babcock & Wilcox, Barberton, Ohio, U.S.A.

[6] Sadik Kakac, Boilers, Evaporators, and Condensers 1991, University of Miami Coral Gables, Florida. U.S.A.

[7] David H.F.Liu, Bela G. Liptak, Waste Water Treatment, Boca Raton London, New York, Washington, D.C.

[8] http://www.me.umn.edu/courses/me4231/labs/Lab6.pdf

[9] Gene F. Franklin, David Powell, Abbas Emami-Naeini, 1986, Feedback Control Of Dynamic Systems, Upper Saddle River, New Jersey 07458

[10] Skrentner, Robert G. 1988, Instrumentation handbook for water and wastewater Treatment plants, United States of America.

Appendix A

University of Southern Queensland
Faculty of Engineering and Surveying
ENG 4111/4112 RESEARCH PROJECT
Project Specification

For: Mmitsi Lefhoko
Topic: Power Station Operations (Millmerran)
Supervisor: Robert Fulcher
Industrial Advisor: Michael Smith (DCS engineer Millmerran)
Sponsors: Botswana government (Ministry of education) and Foes, USQ and Millmerran power station

Project Aims: This project aims to investigate operational engineering problems at Millmerran power station. The project mainly focuses on the control system problems that are faced by the power station and solutions to these problems.

Program: **Issue A, 14th March 2007**

1. Describe the Millmerran power station and operations with specific details of Millmerran power plant control system.
2. Review and analyse the control system problems that are faced by the Millmerran power station.
3. Conduct a literature review of similar problems in other coal fired power stations, solutions to these problems and the theory of control associated with such problems.
4. Develop solutions to solve the Millmerran power station specific problem
5. Define the cost-benefit of these solutions

6. Provide Millmerran with a report of the findings and recommendations.
7. Write dissertation of the project work.
8. If time permits, report on the implementation of any of the recommendations, if accepted.

Agreed: ________________ (student)_____________(supervisor) Date ____/___/___

Appendix B

Matlab code

Matlab code for the controller gains:

```
%This code consists of parameters for the controller tuning
%These gain parameters can be changed to tune the PID controller.
k=0.1;
%integral gain
ki=2;
dt=0.01;
%proportional gain
kp=0.5;
ka=0.2;
%derivative gain
kd=3;
```

Matlab code for plotting the response curves

```
%This code plots the response curves
plot(tout,proj2);title('PID controller with dead-time');
ylabel('Dissolved oxygen (ppb)');
xlabel('Time');grid;
legend('Controller output’,’ Process variable')
```