Otahuhu B Power Station Condenser In-Leakage Analysis and Condensate Monitoring System

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ABSTRACT

Considerable ongoing risk of condenser in-leakage exists at Otahuhu B (OTB) Power Station. The condenser cooling water used at OTB station is corrosive brackish water with exceedingly high sodium and chloride concentrations. Significant signs of corrosion inside the condenser have been found recently. In the event of condenser in-leakage, the salt contaminants in the cooling water will directly enter the Heat Recovery Steam Generator (HRSG) with the potential for significant and costly damage resulting in a long plant outage.

A dynamic mathematical model was developed in the thesis to analyse the consequences of condenser in-leakage at OTB station. The analysis results show that the tolerance of the condenser to any leakage of cooling water is almost zero. Because the existing condensate monitoring system is not designed to detect contamination in this time frame, a new fast response system is required to detect condenser in-leakage immediately.

A new dedicated fast response condensate monitoring system has been engineered and installed at OTB station as a part of the project scope. The new system dramatically reduces the response time to condenser in-leakage events. Critical instruments utilise multiple redundancy schemes to enhance the availability and reliability of the system. In addition, action level voting, timing, and alarming has been automated to assist operators in making correct decisions.

The new condensate monitoring system is presently fully functional. The project has successfully achieved the objective of controlling the risk of condenser in-leakage events and minimising damage and negative effects on the plant.

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LIST OF ABBREVIATIONS

AI	Analogue Input
AO	Analogue Output
AP	Automation Processor
APF	Automation Processor Fail-Safe
APT	Automation Processor Turbine
AS	Automation System
AVT	All Volatile Treatment
barA	bar Absolute
CB	Circuit Breaker
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
DCS	Distributed Control System
DI	Digital Input
DN	Diameter Nominal
DO	Digital Output
DP	Differential Pressure
DS	Diagnostic System
DT	Diagnostic Terminal
EOH	Equivalent Operation Hour
EPRI	Electric Power Research Institute
EPROM	Erasable Programmable Read-Only Memory
ES	Engineering System
ET	Engineering Terminal
FAC	Flow Accelerated Corrosion
HMI	Human Machine Interface
HP	High Pressure
HRSG	Heat Recovery Steam Generator
ID	Inside Diameter
IP	Intermediate Pressure
LP	Low Pressure
MCB	Miniature Circuit Breaker
MCC	Motor Control Centre
OD	Outside Diameter
OM	Operation and Monitoring System
OT	Operation Terminal
OTB	Otahuhu B Power station

PI	Plant Information
ppb	parts per billion
ppm	parts per million
TSV	Thermal Shutoff Valve

CHAPTER 1

INTRODUCTION

1.1 Introduction to OTB Condenser System

Otahuhu B (OTB) Power Station commissioned in 1999 is the second biggest single modern combined cycle gas turbine power station in New Zealand. Figure 1.1 shows a simplified layout of OTB station, which mainly consists of a V94.3A Siemens gas turbine, a triple pressure Heat Recovery Steam Generator (HRSG), a triple pressure Siemens steam turbine, and condenser system. The HRSG consists of a Low Pressure (LP) drum, an Intermediate Pressure (IP) drum and a High Pressure (HP) drum. The HRSG is a heat exchanger using hot exhaust from the gas turbine to generate steam. The steam in turn drives the steam turbine. This combination is more efficient than using either a gas turbine or a steam turbine alone.

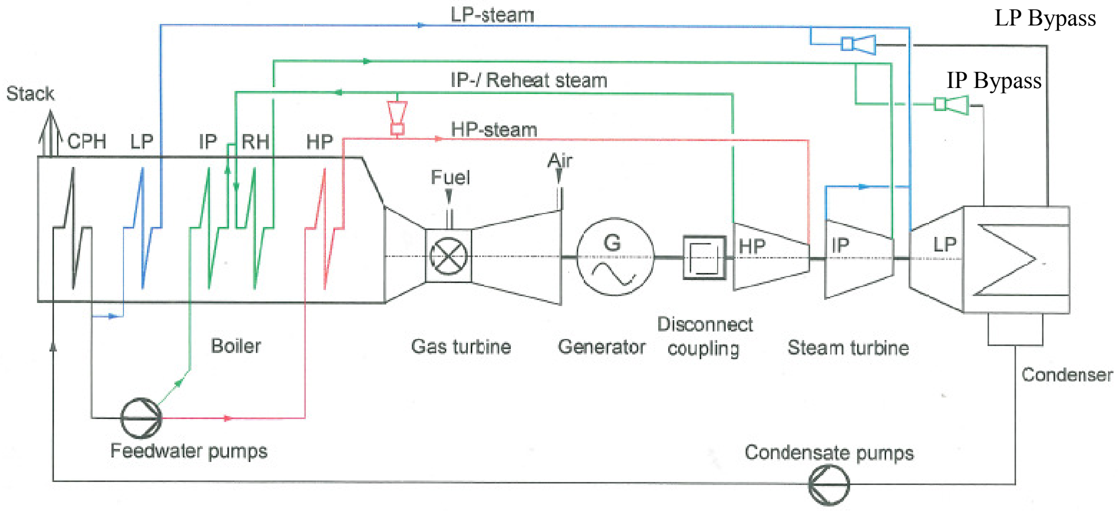


Figure 1.1 Simplified layout of OTB station [1]

The condenser system is used for steam condensation and condensate recirculation. Figure 1.2 shows a schematic diagram of the condenser system. Main equipment of this system consists of a condenser, two cooling water pumps, and two condensate extraction pumps. The condenser has the function of condensing the steam exhausted from the LP turbine, and producing a vacuum that improves steam turbine thermal efficiency. The exhausted steam must be condensed to maintain circulation in the system.

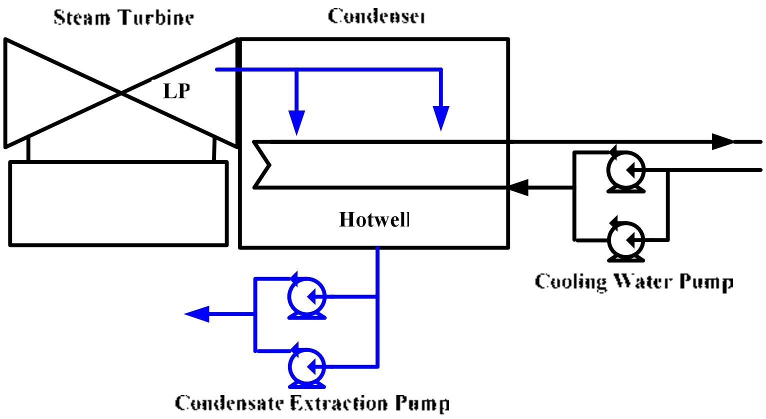
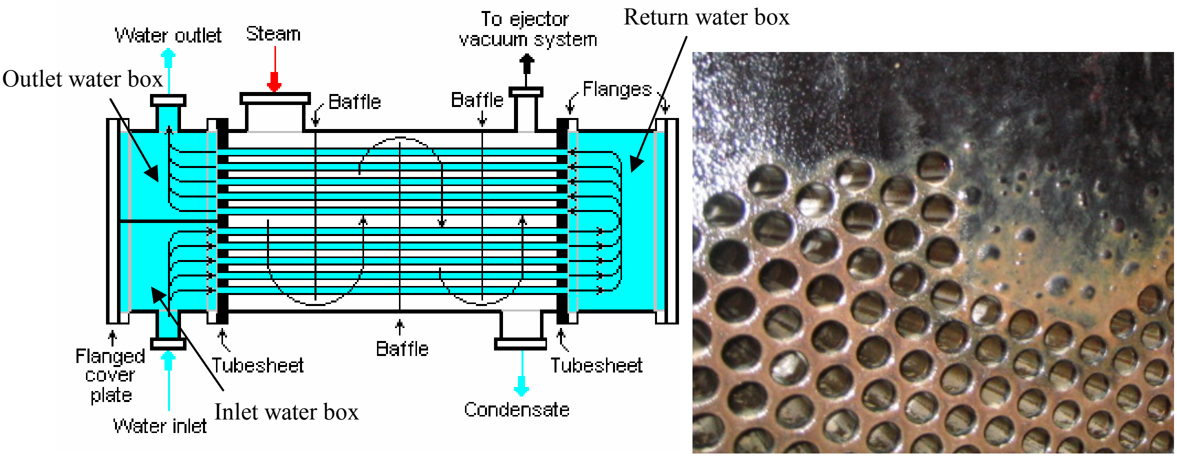


Figure 1.2 Schematic diagram of OTB condenser system



(a) Typical diagram of condenser [2]

(b) Condenser tube sheet

Figure 1.3 Internal structure of a condenser

Figure 1.3 shows internal structure of a condenser, which comprises a large number of tubes supported by the tube sheets. The tubes are inserted into holes in the tube sheets and the ends are rolled to produce a watertight seal. The condenser steam side and cooling water side are completely isolated from one another. On the cooling water side, the cooling water firstly enters the inlet water box, and then flows through the bottom half of the condenser tubes toward the return water box. In the return water box, the flow is fed into the top half of the tube bundle and is directed toward the outlet water box. Finally, the cooling water leaves the outlet water box and returns back to the circulating water system. At OTB station, turbine exhaust steam flows horizontally into the condenser and is condensed to water as passing over the tubes vertically. Finally, the condensate is collected in the condenser hotwell before being extracted by the condensate extraction pumps.

The condenser at OTB station is a titanium-tubed condenser with following general specification:

- Tube diameter: 19 mm
- Tube wall thickness: 0.7 mm
- Tube number: 22,000
- Tube material: Titanium
- Tube sheet material: CuAl10Ni5Fe
- Tube water velocity: 2.02 m/s

Titanium-tubed condensers are known to exhibit superior corrosion resistance and erosion resistance performance when compared to almost all alloy types. The weakness of titanium as a construction material for condenser tubes however is its low thermal conductivity. To ensure cost-efficient heat transfer, titanium tubes must be manufactured to a thin wall thickness, e.g. 0.7 mm. The thinness of the tube wall makes it susceptible to failure if there is a sufficiently large stress applied.

The pressure on the cooling water side at OTB station is approximately 2.3 barA (Absolute), whereas the pressure on the steam side in the condenser is only approximately 0.1 barA. A high vacuum on the steam side increases the thermal efficiency of the steam turbine. However, the cooling water will pass to the steam side because of the differential pressure of 2.2 bar in the event of a condenser tube leak. The consequence of this leakage may be catastrophic if the leakage is not detected immediately.

1.2 Risk of Condenser Tube Failure

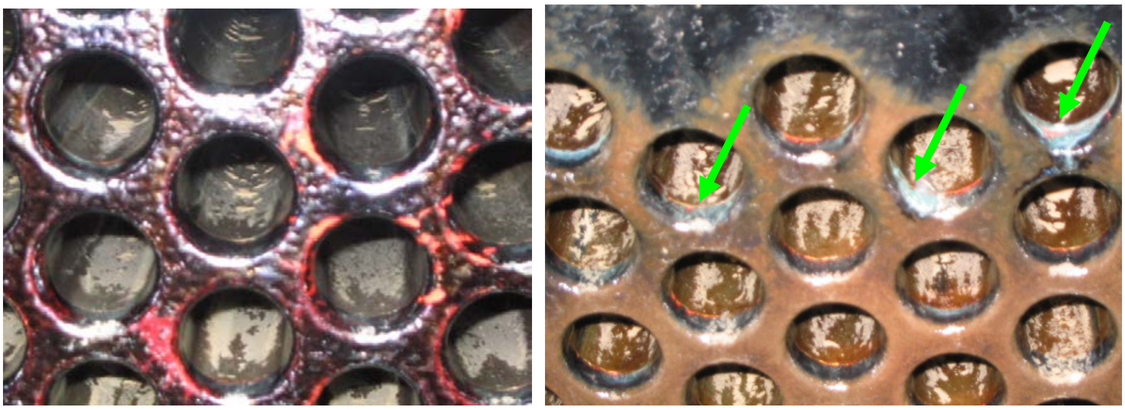
Leakage caused by a condenser tube failure is usually termed a condenser leak or condenser in-leakage. Condenser tube failures include steam side failures or cooling water side failures. A steam side failure did occur during plant commissioning due to mechanical fatigue caused by vibration. Although the condenser was subsequently modified after the event, the risk of a reoccurrence still exists.

Compared to steam side failures, cooling water side failures are much more likely to occur at OTB station because the station uses salty water for cooling. OTB station takes water from the Tamaki Estuary for use in its cooling system. Analysis shows that this cooling water is corrosive brackish seawater with a high sodium and chloride concentration (e.g. Na^+=13000 ppm, Cl^-= 23000 ppm), high suspended solids loading, and a high population of macro-organisms.

Condenser tube failure mechanisms from cooling water side include tube penetration or rupture due to the stress imparted by growing macro-organisms in the tube, such as mussels or shells. This is certainly possible at OTB station, as there is a great diversity and population of macro-organisms in the Tamaki Estuary and these can be readily entrained to the cooling water system. Should macro-organisms take hold in either the tube or tube sheet areas of the condenser, consequence would be serious when such organisms become mature. The hard-shelled crustaceans in particular can penetrate or completely rupture the small-diameter, thin-walled titanium condenser tubes. It is also very important to note that cooling water chemistry at OTB station, like all environmentally sensible chemistries, is not designed to kill macro-organisms. Because of this fact, macro-organism induced tube failures are always a threat to OTB station.

Failure in condenser tube sheets, including pinhole or crevice penetrations in the tube sheets, are also likely to occur at OTB station where bronze tube sheets are used. Bronze does not exhibit as good corrosion resistance as titanium does. The abrasive nature of the suspended solids loading in the cooling water, the corrosive nature of salts in the water and the oxidising biocides dosed to the water, can prove to be a ruinous combination for the material integrity of the bronze tube sheet.

During the condenser inspection at the last major outage in late 2005, it was noted that there were significant signs of corrosion developing where the titanium condenser tubes are expanded into the bronze tube sheets. These joints are a possible cause of a condenser leak. Figure 1.4 shows the distinctive difference between the clean tube sheet and the corroded tube sheet (photo taken in 2005).



(a) Clean tube sheet (b) Corroded tube sheet

Figure 1.4 Clean tube sheet and corroded tube sheet

As a result, there is considerable ongoing risk of condenser in-leakage at OTB station. The risk of such a leak occurring is increasing with time as the equipment ages and its condition deteriorates. Based on industry experience including experience at New Plymouth Power Station (Contact Energy), which is also seawater cooled, a condenser leak could be expected to occur within the next 5 years of operation.

1.3 Effects and Cost of Condenser In-Leakage

1.3.1 Effect on Water and Steam Cycle Chemistry

The main purpose of water and steam cycle chemistry is to maintain adequate pH so that the water and steam cycle can run in an alkaline environment to minimise acidic corrosion on metal alloys. OTB station runs a modern but very simplified water and steam cycle chemistry based on ultrapure water supplied from a deionisation plant. The water and steam cycle chemistry consists of aqueous ammonia dosing in order to maintain an adequate pH value no less than 9.6 in the water and steam cycle, and discrete sodium hydroxide (NaOH) dosing to the LP drum for preventing Flow Accelerate Corrosion (FAC) in low pressure evaporator circuits. Although this chemistry program meets normal operation requirements, it is not designed to manage condenser in-leakage events.

The simplicity is an outstanding advantage of this chemistry program but it does not provide adequate protection against corrosion due to the ingress of acidic salts from the cooling water. Because aqueous ammonia is volatile, a large proportion carries over from the boiler drums into the steam phase, which makes the local drum water pH lower than the applied feedwater pH. The pH of the cooling water is usually between 7 and 7.5, which is much lower than the controlled value of 9.6. If acidic salts from the cooling water contaminate the drum systems, aqueous ammonia can provide very little alkaline buffering capacity against severe pH suppression. Severe pH suppression can greatly increase the direct attack of acidic salts on the HRSG tube metal and the risk of HRSG tube failures.

Dosing caustic soda (NaOH) to the HRSG can mitigate negative effects of condenser in-leakage, which neutralises acidic salts and maintains water pH. Caustic soda is non-volatile so it is present in the water phase where it is required for protection during acidic salts ingress. However, it must be noted that caustic corrosion from overdosing is a high risk and carryover of sodium or free hydroxide into the steam phase must be avoided at any time.

At OTB station, a caustic dosing system is available to inject caustic into the water phase of each boiler drum. Caustic is manually dosed to the LP drum on a routine basis to prevent flow accelerate corrosion only. Because the IP and HP drums have not required any caustic dosing function since the station was commissioned, the associated caustic dosing equipment remains off all the time. From the perspective of water and steam cycle chemistry, it is unknown whether or not caustic should be dosed to the IP and HP drums in the event of condenser in-leakage and how much caustic should be dosed. In this case, the longer the station runs after a condenser leak occurs, the more severe the damage to the plant.

1.3.2 Effect on Plant Performance

If a condenser leak can not be detected immediately, the leak may result in an emergency plant trip after it has expanded. From operational experience with titanium-tubed condensers, a complete rupture of one of the thin-walled tubes is possible. If a condenser leak occurs, it is likely to worsen very quickly and contamination of the condensate with acidic salts may reach the maximum limit within a very short time. However, emergency trip is not desirable from a commercial availability or a plant life assessment point of view as it will dramatically impair the plant life.

Shutting down the plant in a controlled manner would take between 20 to 30 minutes depending on the load. By this time, contamination levels may have risen to the point where significant irreversible damage would be occurring to condensate and feedwater systems in the HRSG. If contamination level in the drums rises high enough then carryover of contaminants into the steam phase will occur, placing the steam piping and steam turbine at risk.

The tube leak must be found and repaired after a plant trip. The contaminated water must be drained and the water and steam cycle system must be washed and cleaned before reinstating the plant. Plant availability and performance is affected by any condenser in-leakage event; and the consequences of the event depend on the degree of leakage.

1.3.3 Effect on National Grid

Condenser in-leakage is likely to occur at full load because OTB station runs at full load more than half the time. If the plant is tripped from full load (average 380 MW) due to a condenser leak, the frequency of the national grid will likely drop to 49 Hz or even worse. This frequency excursion will affect the stability of the national grid especially if other power stations are not capable of responding to the frequency drop immediately, or when reserve capacity is very limited in dry years. Because OTB station is located in Auckland, the largest city in New Zealand, the consequences of losing electricity in the city should be considered seriously.

1.3.4 Cost of Condenser In-Leakage

Any condenser leak could cause significant damage to the equipment and incur expensive costs. It is difficult to determine what the cost may be, but at the very least, there would be the cost associated with:

- Under frequency penalty charges if plant trips from full load ($400k).
- EOH penalty (200 EOH/trip) ($200k).
- Business interruption costs.
- Labour costs associated with plant investigation, reinstatement and startup.
- Plant replacement costs.

It is expected that total costs would be in excess of $2 million per event.

As a comparison, a condenser tube leak occurred on Unit 3 at New Plymouth Power Station (Contact Energy) on 1 March 2007. This event is very similar to the scenario of concern at OTB station. An inspection on the LP steam turbine rotor was still being carried out several months later and the total direct cost of the event was expected to exceed $2 million. Chapter 3 will give investigation of this event in detail.

1.4 Current Issues of Managing Condenser In-Leakage

OTB station is currently confronted with the following issues with respect to managing condenser in-leakage events:

- Unknown tolerance of the system to ingress of cooling water

  It is unsure how quickly condenser in-leakage will affect the water and steam cycle although the risk of condenser in-leakage at OTB station is increasing with time as equipment ages and its condition deteriorates. Carryover of sodium or chloride contaminants into the steam cycle from the drums should be avoided under all circumstances. Therefore, it is important to know how long it will take for contaminated water to arrive at the three drums after condenser in-leakage occurs. This will give operators a guideline as to taking proper action to prevent the catastrophic consequences happening.

  In addition, the tolerance of the water and steam cycle to contamination caused by condenser in-leakage is unknown. It is important to know how quickly the contamination in the condensate system will reach the level requiring an immediate plant shutdown, as this will allow the operators to work out an approximate shutdown time. Without knowing these factors, it will be difficult for the operators to proactively take action to minimise damage to the plant.

- Low reliable instruments configuration for condensate chemistry

Any abnormality in condensate chemistry requires an operator's further verification on the local monitoring system because the configuration of instruments is unreliable. Due to the simplicity of the chemistry program, the existing on-line instruments for condensate chemistry only consist of one sodium analyser and one cation conductivity analyser. These instruments can be relied on to detect a condenser leak only when both instruments are fully functional. However, it is possible that one of the two analysers may be unavailable or not responding, in which case the operator would be completely reliant on single instrument. It is too risky to count on any single analyser to determine the instance and severity of a condenser leak, and all subsequent actions, including a possible emergency trip. Therefore, an operator's further verification is always required for any abnormality. It could take 30 minutes to verify the data from the time the first alarm is received, during which time excessive transport of acidic salts around the HRSG circuit may have occurred.

In addition, the existing analysers can not rapidly detect a condenser leak. The analysers installed on the condensate pipeline are approximately 60 metres away from the condenser, which means there is a considerable lag between the time of leak and the time of detection. A long sample lag time results in a long time to respond to the leak, thereby it causes more severe contamination of the system. Therefore, a new fast response condensate monitoring system is required for rapid detection of condenser in-leakage.

- Inadequate monitoring information for the operator

OTB station has a detailed document with respect to managing condenser in-leakage events. The document details not only the values of different parameters at different contamination levels, but also the time that the plant is allowed to run at each contamination level and the actions that should be taken at each contamination level. Once condenser in-leakage occurs, the duty shift operator has to read this document, look up the contamination level table to decide which contamination level has reached, and manually record the time at each level; meanwhile, the operator also has to operate the plant. In such an emergency situation, it is possible for the operator to inadvertently make a mistake resulting in severe damage to the plant.

In light of the above analysis, OTB station is not well designed to manage condenser in-leakage events. Therefore, it is imperative that management of a condenser in-leakage event rely on a highly reliable automatic monitoring and control system.

1.5 Study Purpose and Project Scope

The main purposes of this study are to examine the major current issues involved in managing a condenser in-leakage event at OTB station, to analyse impacts of condenser in-leakage on the water and steam cycle, to improve the capability of detecting a condenser leak and to reduce the chance of wrong decision making during these events. Methodologies applied to this study consist of literature review, site event investigation, mathematical analysis, chemical experimentation and engineering practice.

Based on the issues that OTB station currently has, the scope of the project includes:

- Analyse impacts of condenser in-leakage on the water and steam cycle system and demonstrate the most likely consequences in the event of a condenser leak by using mathematical modelling methods.

- Engineer a reliable and fast-response condensate monitoring system to improve the capability of detecting a condenser leak.

- Design an automatic contamination level voting and timing program in the distributed control system to directly aid the operator in making the right decisions and taking the correct actions.

1.6 Structure of the Thesis

This thesis consists of seven chapters. The structure of the thesis is as following:

Chapter 2 reviews literatures on chemical treatments of the water and steam cycle and elaborates chemical parameters for monitoring condenser in-leakage.

Chapter 3 describes a condenser tube leak event occurred at New Plymouth Power Station and gives event investigation in detail.

Chapter 4 presents a dynamic mathematical model for analysing condenser in-leakage at Otahuhu B station. Study cases in the model demonstrate the consequences of different leakage situations.

Chapter 5 demonstrates experimental results regarding responses of different chemical parameters to a condenser leak. Functions of the major parts of the new condensate monitoring system are elaborated, which includes mechanical, electrical and instrumentation areas.

Chapter 6 briefly introduces Teleperm XP distributed control system and details how field signals are processed in Teleperm XP. The functions of the logic program for the condensate monitoring system is elaborately explained using schematic function block diagrams, which helps readers follow the logic programs in Teleperm XP.

Chapter 7 summarises the results and conclusions of the project and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Condenser In-Leakage

Condenser in-leakage, resulting in cooling water entering into the condensate system, can create major problems, particularly in seawater-cooled power stations. In a thermal power station, the condenser plays a critical role in water and steam cycle by condensing steam from the steam turbine or the bypass system. Acidic salts from cooling water can cause serious damage to water and steam cycle facilities, which may result in forced plant shutdowns and costly repairs to vital plant operating equipment.

The overall objective of water and steam cycle chemistry is to maintain a high level of purity and prevent corrosion in the boiler, steam and feedwater systems. All volatile treatment is being widely applied in power stations because of its simplicity. However, it hardly protects the water and steam cycle against corrosion due to the ingress of corrosive salts. Caustic treatment can be used in case of seawater cooling condenser leaks to neutralise the ingress of the acidic salts.

Critical on-line instruments should be installed at different stages of water and steam cycle to monitor the quality of the steam and water continuously. If any monitored parameters reach target values of different action levels due to condenser in-leakage, corresponding actions should be taken to minimise damages.

2.2 Chemical Treatment

All volatile treatment and caustic treatment are two popular chemical treatments in thermal power stations and are used to maintain a pH of 9.6 in order to minimise corrosion of water and steam cycle facilities [3]. An acidic pH caused by the ingress of salty water or an alkaline pH caused by the overdosing of caustic will result in corrosion of water and steam cycle facilities.

2.2.1 All Volatile Treatment

The basis of the All Volatile Treatment (AVT) is an elevated pH in all cycle streams to protect the feedwater heaters, boiler, superheater, reheater and steam turbine against corrosion without further chemical additions [3]. Volatile reagent ammonia is widely used in modern power stations for the control of pH. The popularity of AVT is attributable to its simplicity. AVT can be used for HRSG drum-type boilers, provided high purity feedwater is available and the build-up of impurities in the boiler water is strictly controlled [4].

The main disadvantage of AVT is that constant vigilance is required to prevent the ingress of contaminants, such as from condenser in-leakage. Ammonia is a poor alkalizing agent and does not provide adequate protection against corrosion caused by the ingress of corrosive salts. Furthermore, because ammonia is volatile, a large proportion carries over from boiler drums into steam phase so the local drum water pH is lower than the applied feedwater pH. Should acidic salts contaminate drum circuits, there is very little alkaline buffering capacity to guard against severe pH decrease. This can greatly increase the risk of boiler tube failures. Therefore, continuous monitoring of water and steam cycle chemistry is particularly important for HRSG drum units on AVT.

2.2.2 Caustic Treatment

Caustic treatment is an effective emergency measure to neutralise the ingress of acidic contaminants from cooling water. Sodium hydroxide (NaOH) is the principal boiler water conditioning chemical in caustic treatment. In a caustic treatment program, boiler water pH is maintained within a range of 9.4 to 9.6 by the addition of caustic [5]. Caustic treatment of HRSG boiler water significantly increases the amount of chloride that can be tolerated without corrosion. This is important for dealing with seawater-cooled condenser leaks. In addition, caustic treatment has been used in HRSGs for controlling flow accelerated corrosion in low pressure circuits, where all volatile treatment has proved ineffective.

With caustic treatment, the concentration of sodium hydroxide in the boiler water has to be continuously monitored and carefully controlled to reduce the risk of carryover into the steam. Carryover of sodium hydroxide has been noted to result in stress corrosion cracking damage of steam turbines at HRSG facilities [6]. Determination of carryover is usually accomplished by the measurement of sodium in the saturated steam exiting the boiler drum.

On the one hand, it is important to ensure that there is sufficient sodium hydroxide present to prevent acidic conditions in the event of condenser in-leakage, but on the other hand, it is also important to limit the amount of sodium hydroxide in order to prevent excessive carryover into the steam phase.

2.3 Chemical Parameter Monitoring for Condenser In-Leakage

On-line monitoring of chemical parameters provides real-time data for the quality control of water and steam and plays an important role in operating power stations. Any excursion of chemical parameters indicates existence of an abnormal situation. Therefore, on-line monitoring must be reliable and sensitive. Five chemical parameters that are usually used for the detection of a condenser leak are reviewed in the following sections. They are specific conductivity, cation conductivity, pH, sodium and chloride.

2.3.1 Specific Conductivity

Conductivity is the ability of water to conduct electric current. Conductivity of water changes substantially as its temperature changes. Conductivity is an indirect measure of the presence of ionic (dissolved) constituents. The basic unit of conductivity is the siemens (S). Since measurement cell geometry affects conductivity values, the standardised measurement is expressed in specific conductivity units (S/cm) to compensate for variations in electrode dimensions. Specific conductivity (C) is simply the product of measured conductivity (G) and the electrode cell constant (L/A), where L is the length of the column of liquid between the electrodes and A is the area of the electrodes as shown in Figure 2.1 [7].

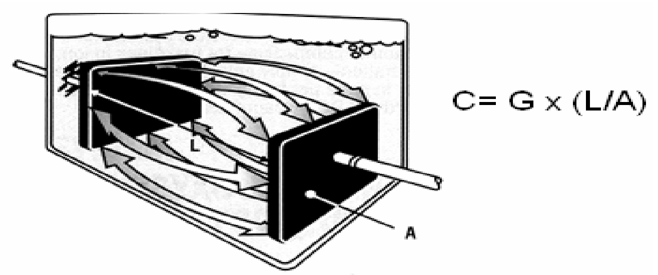


Figure 2.1 Measurement of specific conductivity [7]

Specific conductivity is an inexpensive and reliable method for monitoring the overall level of contamination and treatment chemicals. For example, water with a high sodium and chloride ion (Na^+ , Cl^-) concentration can conduct electricity due to ionisation. In general, the greater the concentration of ions in water, the higher the conductivity. Specific conductivity is also a temperature corrected value since temperature affects conductance. Usually, the actual conductivity of a solution would be at 25°C.

While measuring the conductivity of very pure water such as condensate, it is essential to prevent the water sample from being exposed to air. The water sample can rapidly take up carbon dioxide from the air, giving an erroneous result. Thus, when measuring condensate, the electrodes are usually placed in the main pipe work or an enclosed cell connected to the sampling line.

2.3.2 Cation Conductivity

Cation conductivity monitoring is a basic surveillance tool for detecting the ingress of contaminants into the cycle [8]. The cation conductivity of condensate, feedwater, boiler water, and steam in fossil fired plant cycles is the most important surveillance parameter [9]. However, it has been recognised that very poor accuracy of specific and cation conductivity temperature compensation is a major issue with most conductivity instruments. To resolve this, either the sample must be controlled at very close to 25°C or the instrumentation must have specialised temperature compensation algorithms proven to be accurate for these sample types [10].

In practice, cation conductivity is measured after the sample is passed through a column of cation exchange resin in the hydrogen form (cation). The effect of this procedure is to convert all cations in the sample into hydrogen ions (H+). Hydrogen ion has a higher equivalent conductance than all other cations. Thus the cation exchange column can be considered as a “conductivity amplifier” for acid contaminants, increasing the sensitivity of the conductivity analyser to low levels of contamination.

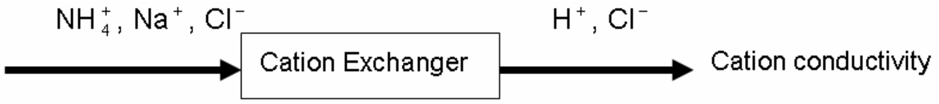


Figure 2.2 Principle of cation exchanger

After a sample containing sodium chloride goes through a cation exchanger, sodium chloride (NaCl) is converted into hydrochloric acid as shown in Figure 2.2. The sensitivity of the conductivity measurement by using cation conductivity is greatly improved because the acid has a much higher conductivity than the corresponding salts.

Cation conductivity of the condensate and HRSG boiler water should be monitored as a reliable and primary method of determining the onset of contaminant ingress. If cation conductivity of the condensate and boiler water is excessive, then there is a clear need to determine what is causing it, and whether it could be harmful.

2.3.3 Power of Hydrogen

Power of Hydrogen (pH) measures the acidity or alkalinity of a solution. The process variable pH is the negative logarithm of the hydrogen ion activity [11], which is nonlinear.

The principal aim of water treatment is to minimise the corrosion in the system. This can be achieved by adjusting the pH value of the water to give the lowest corrosion rate. The corrosion rate of carbon steel reaches a minimal value over the pH range of 9.2 to 9.6 [4]. Ingress of acidic salts caused by condenser in-leakage can result in a low boiler water pH. Immediate shutdown of plants is recommended if the boiler water pH is less than 8 or greater than 10 [4].

In practice, conductivity measurement is typically more reliable than direct pH measurement. There are two reasons for the higher reliability of conductivity [10]:

- Conductivity is linear with concentration whereas pH is logarithmic. pH therefore has lower resolution. For example, a change of only 0.3 pH represents a two-fold (100 %) change in both concentration and conductivity in cycle chemistry ranges.

- pH reference electrode junction potential is notoriously unstable in low conductivity samples and this instability is frequently greater than ±0.1 pH, depending on the electrode system used. Inherent in the simple correlation above is the assumption that there is nothing present but ammonia and water.

Calculated or inferred pH is valid whenever the specific conductivity is due primarily to ammonia and contaminants have low concentrations. The pH must be within a range of 7.5-10.5 and specific conductivity must be significantly greater than cation conductivity [12]. When a sample composition complies with the above conditions, the inferred pH is very accurate. However, it is also important to be aware of the errors that can be produced when operating outside of normal conditions. In this case, operators must rely on an electrode pH measurement for accurate measurement.

2.3.4 Sodium and Chloride

Sodium analysers measure sodium (Na+) ion concentration in a solution, which is expressed in parts per billion (ppb) or parts per million (ppm). Monitoring of sodium is essential in water and steam cycle chemistry. Sodium chloride (NaCl) can be brought into condensate and feedwater systems by the ingress of salty cooling water. In addition, sodium hydroxide (NaOH) can be dosed into the low pressure drum in caustic treatment. Both sodium hydroxide and sodium chloride are in a corrosive form in the steam and are two major corrodents in turbines and superheater tubes [4]. A strict limit for sodium in steam is required to reduce the risk of caustic gouging and stress corrosion in steam turbines.

Lower sodium levels should be maintained in HRSG boiler water and steam. There is no definitive experimental data for sodium hydroxide concentration versus deposition; and the limit of 3 ppb sodium is a best-judgement number based on experience, but does not guarantee the absence of sodium hydroxide deposition in the LP turbine [4]. Higher sodium levels are permitted during excursions but are limited in duration because higher sodium levels only give more alkaline buffering capacity in boiler water but will not deter the carryover of sodium into steam phase after sodium concentration reaches its saturation level. Determination of carryover is usually accomplished by measurement of sodium in the saturated steam exiting the boiler drum.

On-line chloride monitoring is necessary at seawater-cooled power stations. Chloride is the most effective contaminant causing a marked pH decrease, which contributes to corrosion in boilers and turbines. The main contributing factor to chloride contamination of boiler water is the ingress of salty cooling water caused by condenser in-leakage. If a leak occurs, the rate of chloride build-up will be dependent on the type of cooling water used, and can be extremely rapid in the case of estuarine seawater.

Based on the solubility of sodium and chloride in super heated steam, a limit of 3 ppb is used for units with reheaters [4]. Compliance with these limits should result in avoidance of damage to the boiler and turbine. Therefore, sodium and chloride in the condensate should remain less than 3 ppb to achieve the recommended steam purity under normal operation without relying on blowdown, and to allow the full blowdown capability to be kept available for the control of abnormal conditions such as condenser tube leakage.

2.3.5 Parameter Selection and Monitoring Point

Monitoring water quality throughout water cycle is of importance in power stations. Proper monitoring points can provide reliable samples and reduce the response time to any change in water quality. Recommended monitoring points are developed based on the optimal cycle chemistry requirements. Table 2.1 provides a list of cycle chemistry monitoring parameters and monitoring points. The core monitoring parameters are considered the minimum level of surveillance that is needed for all HRSG units. The suggested additional monitoring parameters represent those chemistry surveillance measures most likely to be included in customised chemistry programs for specific plants.

In general, the use of on-line analysers for continuous analysis of chemistry is preferred. The monitoring approach suggested in Table 2.1 considers limitations on manpower at many HRSG plants and the fact that some analysers require significant maintenance and attention to perform reliably i.e. chloride analysers. Therefore, chloride measurement only requires daily grab sample analysis.

Table 2.1 HRSG cycle chemistry monitoring parameters [4]

Core Monitoring Parameters (Minimum Surveillance for Most Units)	
Parameter / Monitoring Approach	Monitoring Points
Cation Conductivity Continuous by On-Line Analyser	• Condensate Pump Discharge • Feedwater(Economiser Inlet) • Saturated Steam, and Main or Hot Reheat Steam
Specific Conductivity Continuous by On-Line Analyser	• Treated Makeup Water
pH Continuous by On-Line Analyser	• Blowdown or Downcomer(Drum Units)
Sodium Continuous by On-Line Analyser	• HP Main or Hot Reheat Steam
Suggested Additional Monitoring Parameters	
Specific Conductivity Continuous by On-Line Analyser	• Feedwater(Economiser Inlet)
pH Continuous by On-Line Analyser	• Feedwater(Economiser Inlet)
Chloride Grab Sample Analysis Daily	• Blowdown or Downcomer(CT)
Sodium Continuous by On-Line Analyser	• Condensate Pump Discharge • Saturated Steam

According to Table 2.1, cation conductivity and specific conductivity are core parameters that must be continuously monitored at the condensate system. Considering the fact that the cooling water used at OTB station is brackish water with high sodium and chloride concentrations, on-line monitoring of sodium and pH are indispensable as suggested in Table 2.1.

As can been seen from Table 2.1, the best monitoring point for detecting condenser in-leakage is the discharge side of the condensate extraction pump. The condensate extraction pump is usually located close to the condenser, which considerably reduces the sample lag time.

2.3.6 Target Value of Parameters

The Electric Power Research Institute (EPRI) is a non-profit organisation that provides expert guidance on the relative need for corrective action in the event of cycle chemistry excursions. EPRI developed the target values and action levels of each monitoring parameter at the critical monitoring points. Contact Energy Ltd is a member of EPRI and has adopted EPRI's guidelines as the standard on site. According to the requirements for OTB station and EPRI's guidelines, Table 2.2 summarises target values and action levels of each parameter for condensate contamination in the event of a condenser leak. This includes four action levels (contamination levels) for each of the monitored parameters.

Table 2.2 Action level conditions for condensate contamination [4]

Parameter	Units	Normal Value	Action Level 1	Action Level 2	Action Level 3	Action Level 4
Cation Conductivity at 25ºC	µS/cm	< 0.2	≥ 0.2 < 0.35	≥ 0.35 < 0.5	≥ 0.5	≥ 1
Specific Conductivity at 25 ºC	µS/cm	< 20	≥ 20 < 25	≥ 25 < 30	≥30	≥ 50
PH at 25 ºC		>9.6	≤ 9.6 > 9.3	≤ 9.3 > 9	≤ 9	≤ 8
Sodium (Na)	ppb	< 3	≥ 3 < 6	≥ 6 < 12	≥ 12	≥ 500
Chloride (Cl)	ppb	< 3	≥ 3 < 6	≥ 6 < 12	≥ 12	≥ 500
Period of time per event during which the turbine may remain in operation with the respective values	hour	Unlimited	≤ 100	≤ 24	≤ 4	0
Cumulative hour per year	h/a	Unlimited	≤2000	≤500	≤80	0

All of the above parameters need to be continuously monitored by on-line analytical instruments. Normal values are consistent with long-term system stability. Four action levels are established based on the following criteria [3]:

- Action Level 1

  There is a potential for the accumulation of contaminants and corrosion. The plant can keep running at base load but the total running time must be less than 100 hours.

If values do not indicate a downward trend, decrease the plant load and shut down according to normal operating procedures.

- Action Level 2

  The accumulation of contaminants and corrosion will occur. The plant can keep running at base load at the beginning of this level and the values must show a noticeable downward trend during the next couple of hours. Decrease the plant load. Running time at minimum combined cycle load must be less than 24 hours. If values do not indicate a downward trend, the plant needs to be shut down according to normal operating procedures.

- Action Level 3

  Rapid corrosion could occur. Decrease the plant load immediately and run at minimum combined cycle load. Running time must be less than 4 hours. If values do not indicate a noticeable downward trend, the plant needs to be shut down according to the normal operating procedures.

- Action Level 4

  Immediate plant shutdown is required because steam quality will be substantially impaired, and this will result in damage to equipment.

2.4 Chapter Summary

Condenser in-leakage can seriously affect the operation of power stations. It can impair the productivity and availability of the plant and damage water and steam cycle facilities. The consequence of the condenser in-leakage is even more destructive at seawater-cooled plants because seawater is more corrosive than river water.

Although all volatile treatment is an effective approach to maintaining pH in order to minimise corrosion during normal operation, it can not effectively protect water and steam cycle against the ingress of acidic salts. Caustic treatment of HRSG boiler water can increase the tolerance to acidic salts contamination but the concentration of sodium hydroxide in the boiler water and steam has to be closely monitored to avoid excessive carryover due to over dosing caustic into the boiler water. The concentration factor is usually plant specific. However, the relevant data is not clear at OTB station.

Reliable on-line analysers must be installed to monitor the quality of HRSG boiler water and steam. According to EPRI's guideline, the best monitoring point for detecting condenser in-leakage is the discharge side of the condensate extraction pump because it offers the shortest sample lag time. Because of the special situation of OTB station, specific conductivity, cation conductivity, pH and sodium have to be continuously monitored for the detection of condenser in-leakage. Target values and action levels of each parameter developed by EPRI provide general guidance for the management of condenser in-leakage events at OTB station.

CHAPTER 3

NEW PLYMOUTH POWER STATION

UNIT 3 CONDENSER TUBE LEAK EVENT STUDY

3.1 Introduction

New Plymouth (NPL) Power Station is a gas-fired thermal power station, which consists of five 110MW units. The station uses seawater as for condenser cooling water, which is the same as OTB station. A condenser tube leak occurred on Unit 3 on 1 March 2007. During Unit 3 startup, the failure of a rivet on the LP turbine row 6 blade arched cover band resulted in rupturing a condenser tube. However, Unit 3 kept running for almost two hours after the leak occurred because of both instrumentation and operational reasons.

Figure 3.1 Inspection on LP steam turbine rotor

The consequences of the event were catastrophic. Severe chloride and sodium contamination damaged the boiler tubes and the steam turbine. As shown in Figure 3.1, the LP turbine rotor had been pulled out for inspection. The unit down time was over six months and the direct cost of the event was estimated at over $2 million.

3.2 Condensate Monitoring System

The condensate sample point at NPL station is right after the Condensate Extraction Pump (CEP) but before the discharge valve as shown in Figure 3.2. The pipe length from the condenser to the CEP is around eight metres. The length of the sampling tube from the sample point to analysers is approximately four metres. This arrangement considerably reduces the sample lag time by shortening the distance from the condenser to the analysers.

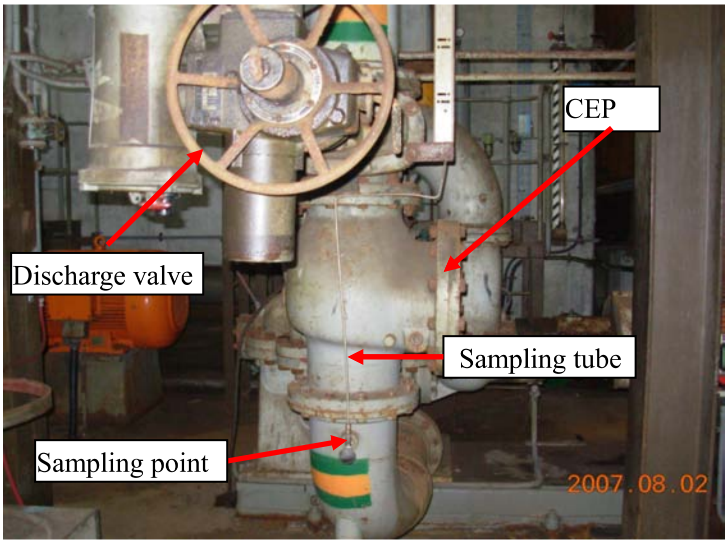


Figure 3.2 Condensate sample point

The condensate monitoring system at NPL station consists of one sodium analyser, one cation conductivity (KH+) analyser and one specific conductivity (Ko) analyser as shown in Figure 3.3. Measurement ranges of the analysers can only be manually switched over on the field devices due to obsolete technology.

Figure 3.3 KH+ analyser and Ko analyser

3.3 Condenser Tube Leak Event Study

This study is based on the condenser tube leak event that occurred on Unit 3 NPL on 1 March 2007. All data used in this study is from the Plant Information (PI) database at NPL station

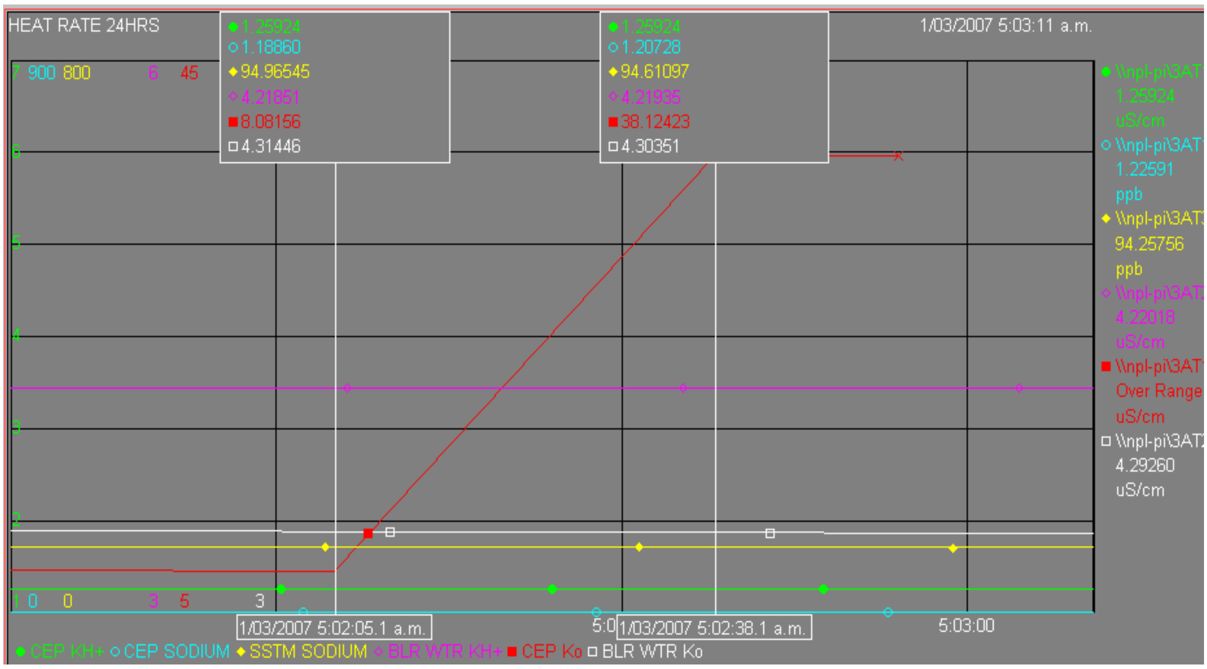


Figure 3.4 Condensate specific conductivity (CEP Ko) trend

This event occurred during the unit startup. Figure 3.4 shows the condensate specific conductivity (CEP Ko) trend in red. As can be seen from the trend diagram, the specific conductivity analyser detected the condenser tube leak at 05:02:05. The specific conductivity (CEP Ko) increased from 8 µS/cm to 38 µS/cm within 33 seconds and then over-ranged because the specific conductivity analyser was set in the range of 0 – 40 µS/cm. The maximum specific conductivity value during normal operation at NPL station should be less than 2.9 µS/cm but the value can be higher than this during startup.

According to EPRI's guideline, if the specific conductivity is greater than 50 µS/cm, then the plant should be immediately shut down. Although the diagram can not show a value above 40 µS/cm due to the limit of the measurement range, it can be deduced from the trend that it would not take more than one minute for the specific conductivity to rise to 50 µS/cm. This means that the plant should be immediately shut down one minute after the condenser tube leak occurred.

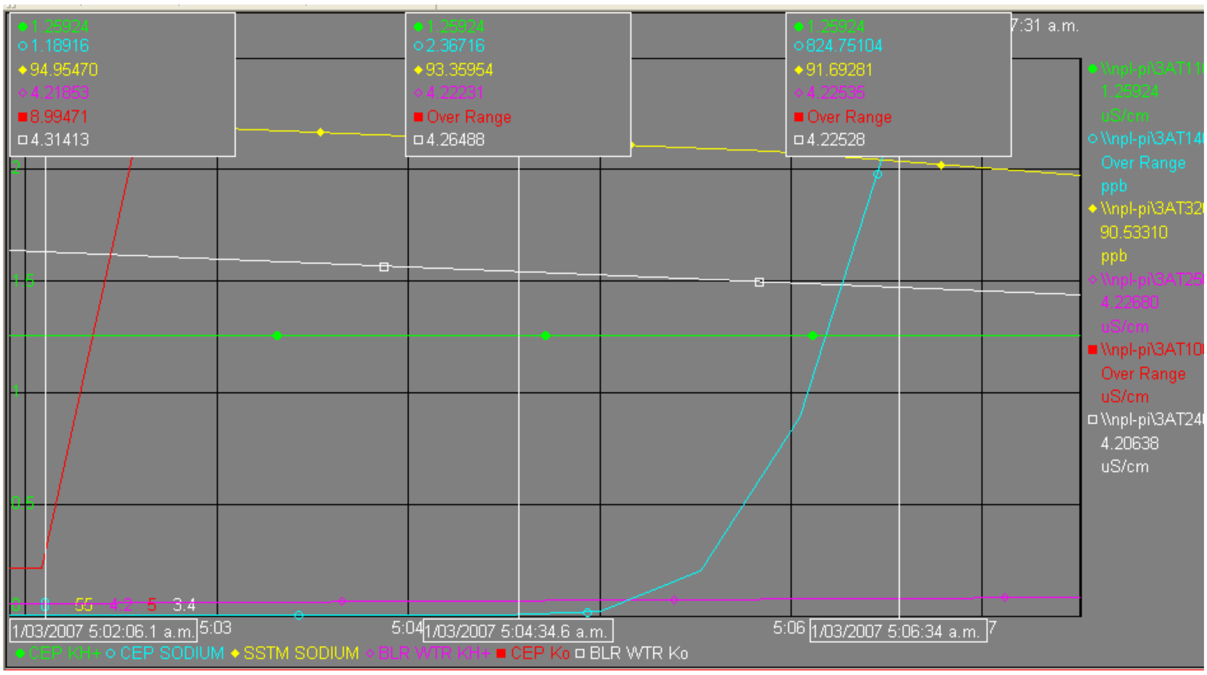


Figure 3.5 Condensate sodium (CEP SODIUM) trend

According to EPRI's guideline, if sodium concentration in the condensate exceeds 500 ppb, then the plant should be immediately shut down. As can be seen from Figure 3.5, sodium concentration (CEP SODIUM) in the condensate shown in blue started increasing at 05:04:34 and rose to 824 ppb within two minutes. Although the sodium analyser responded two minutes later than the specific conductivity (CEP Ko) analyser did, both analysers showed that Unit 3 should be shut down approximately one minute after the leak was detected.

NPL station does not feed condensate to the boiler from the condenser, but feeds water from a surge tank during the startup until the cation conductivity (KH+) of the condensate returned to normal range. As shown in Figure 3.6, sodium concentration (yellow curve) in the boiler drum remained steady for almost one hour after the leak occurred because the contaminated condensate in the condenser was not fed into the boiler drum during this period.

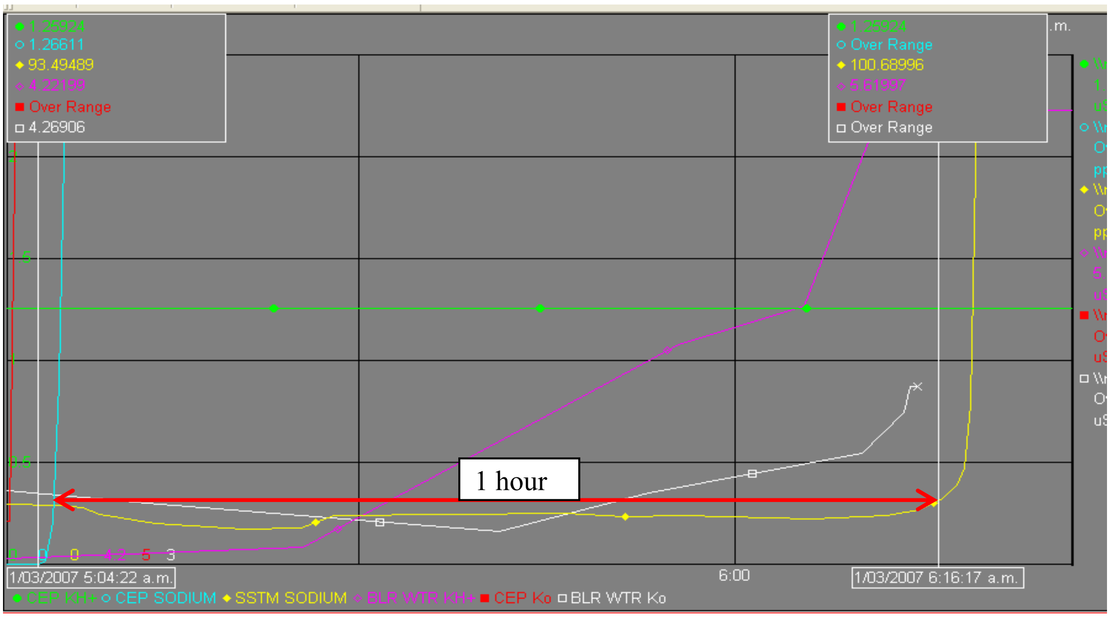


Figure 3.6 Time delay for sodium concentration in the boiler drum

As can be seen from Figure 3.7, once the contaminated condensate was fed to the boiler drum, the sodium concentration in yellow started rising and only took three minutes to increase from 100 ppb to 716 ppb. The contamination in the drum was accelerated because contaminates accumulated in the drum and was not carried over into the steam phase until their saturation level was reached. In addition, sodium concentration in the condensate (CEP SODIUM) was already over-ranged, and was greater than 900 ppb. The unit load at that time was only 55 MW.

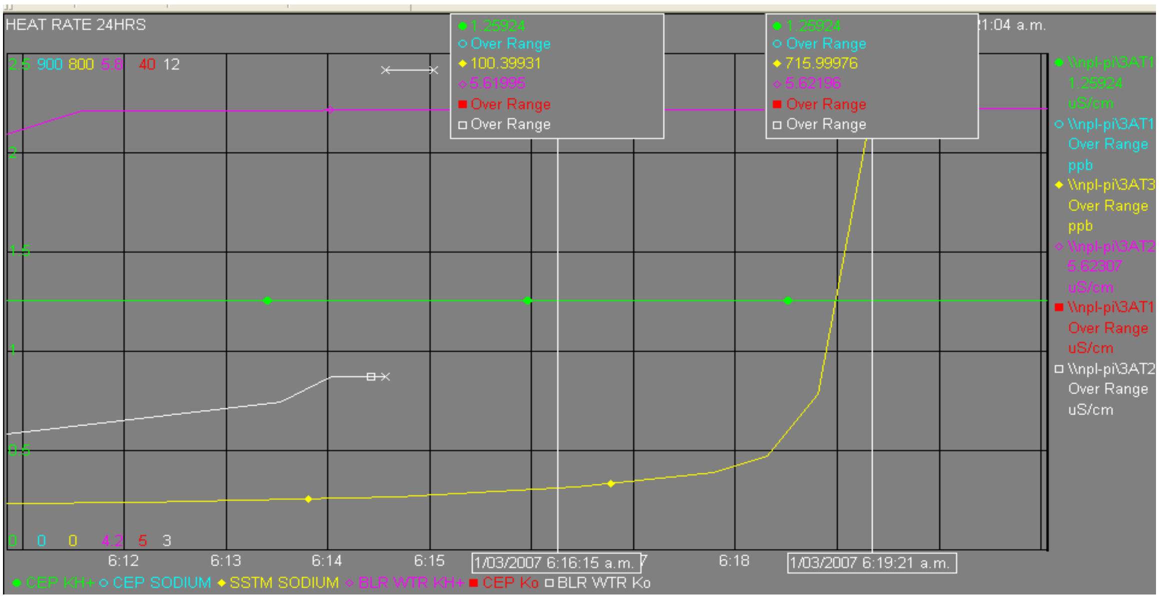
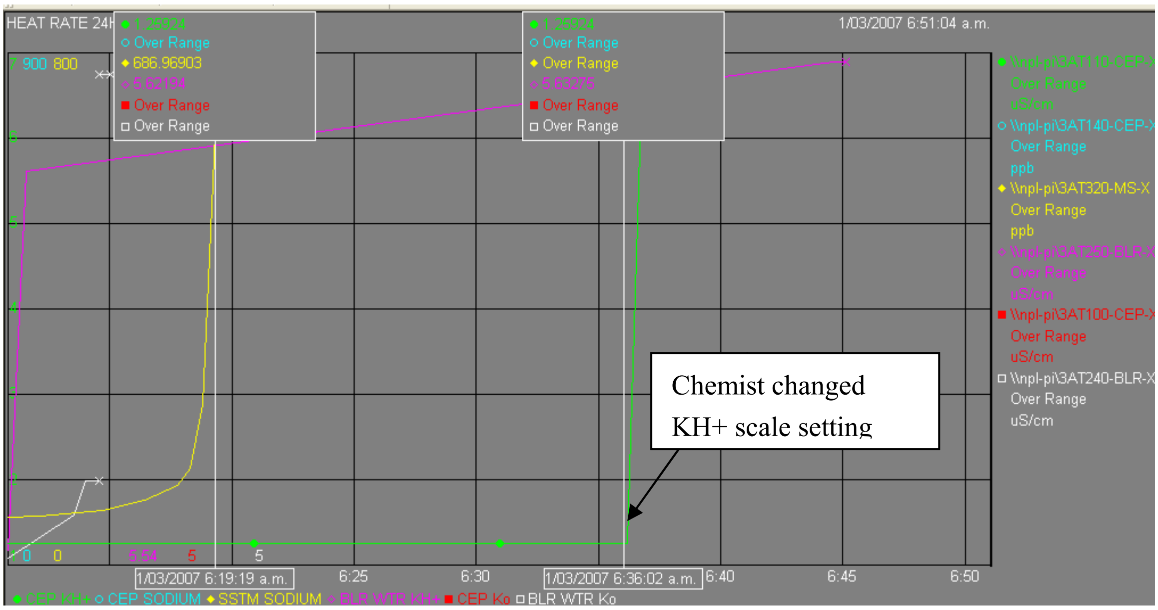


Figure 3.7 Sodium concentration in the boiler drum

According to sodium concentration values in the condensate and the boiler drum, the unit should have been shut down immediately, however the duty shift operator did not shut down the unit. One of the reasons was that changes of cation conductivity (CEP KH+) in the condensate could not be seen. As can be seen from Figures 3.4 to 3.7, CEP KH+ (green colour) had remained steady at 1.25 µS/cm all the time since the tube leak occurred. This value was still below the maximum limit, 1.5 µS/cm, during startup at NPL station. This was a main reason why the operator did not shut down the plant.

After analysis and investigation, it was found that 1.25 µS/cm did not represent the actual cation conductivity. The cation conductivity analyser has three scales, which are 0 – 1 µS/cm, 0 – 10 µS/cm and 0 – 50 µS/cm. The scale was selected to 0 – 1 µS/cm at that time, however the scale was not able to automatically change when the measured value was over-ranged. 1.25 µS/cm is the maximum measured value at 0 – 1 µS/cm scale. Therefore, even though the actual value had already exceeded 1.25 µS/cm, the reading on the operator console displayed 1.25 µS/cm. The scale was changed to 0 – 10µS/cm at 06:36:02 when the chemist found that the wrong scale had been used, which was about one and a half hours after the leak occurred. As can be seen from Figure 3.8, the condensate cation conductivity (CEP KH+) in green went out of the range again immediately after the Chemist changed the scale setting to 0 - 10 µS/cm.



Chemist changed KH+ scale setting

Figure 3.8 Cation conductivity (CEP KH+) in the condensate

The Chemist conducted a laboratory experiment at 06:40. According to the experimental results, contamination in the boiler and the steam turbine caused by the leak was astonishing. The results showed that the sodium concentration in the condensate was 822263 ppb and the sodium concentration in the drum was 2691300 ppb. However, the unit should have been tripped after the sodium concentration exceeded 500 ppb. Unit 3 was finally shut down at 06:50, which was approximately 100 minutes after the leak occurred. It was found during the inspection that severe chloride and sodium contamination damaged the boiler tubes and the steam turbine.

Although the cation conductivity analyser has its inherent flaw, human error was an main factor that resulted in devastating consequences. The event shows that lack of formal training in unit chemistry and its management resulted in poor decision-making. For instance, during the unit startup, the duty shift operator was unaware of the need to change the cation conductivity analyser scale. Because condenser in-leakage seldom occurs, most of operators have not been involved in an incident, and would not have been very familiar with the signs.

In order to assist operators in making right decisions, the on-line analysers must be able to provide sufficient reliable real-time data. When the instruments indicate an abnormal situation, operators usually question instrumentation first. Hence, they usually can not make correct decisions within the required time frame without sufficient data. In addition, multiple redundancy on the critical analysers are essential to improve the reliability of the measurement. It is also important to provide adequate information on the operator console, which will help minimise the probability of human error.

3.4 Chapter Summary

Based on the experience at NPL station, severe contamination of condensate caused by condenser in-leakage can happen very quickly, although this depends on the degree of leakage. An immediate plant shutdown is likely to be required within minutes, not hours, after a condenser tube leak occurs. The consequence may be catastrophic if proper actions can not be taken immediately after a leak occurs, particularly for seawater cooled plants.

Compared to OTB station, the condensate monitoring point at NPL station is much closer to the condenser, which considerably reduces the sample lag time. Sodium, cation conductivity and specific conductivity analysers are used to detect condenser in-leakage. The analysers must be able to provide reliable real-time data so operators can count on these data to make correct decisions. In addition, training in unit chemistry and its management is also important to avoid human errors.

CHAPTER 4

MATHEMATICAL MODELLING AND ANALYSIS ON CONDENSER IN-LEAKAGE

4.1 Introduction to Condenser In-Leakage

OTB station uses a titanium-tubed condenser. Figure 4.1 shows the simplified inner structure of the condenser. Cooling water flows in and out of the condenser through the inside of the titanium tubes. Exhaust steam from the LP steam turbine condenses into condensate as it passes over the tubes. The condensate extraction pump then extracts the condensate out of the condenser hotwell where the condensate is stored.

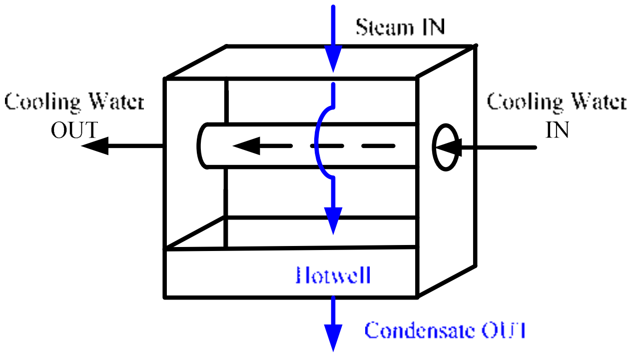


Figure 4.1 Simplified inner structure of the condenser

Under normal conditions, the pressure on the cooling water side is 2.3 barA (Absolute); the pressure on the condensate side is approximately 0.1 barA. The Differential Pressure (DP) between the cooling water side and the condensate side is approximately 2.2 bar. Figure 4.2 shows a leak point in a condenser tube. Should any pinhole or crack appear in the tube or tube sheet, salty cooling water will enter into the condensate side straightway, which will contaminate the condensate in the condenser hotwell.

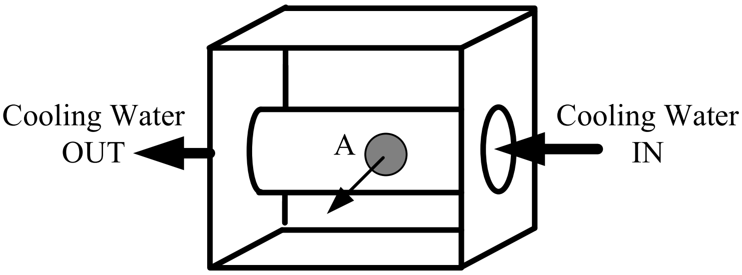


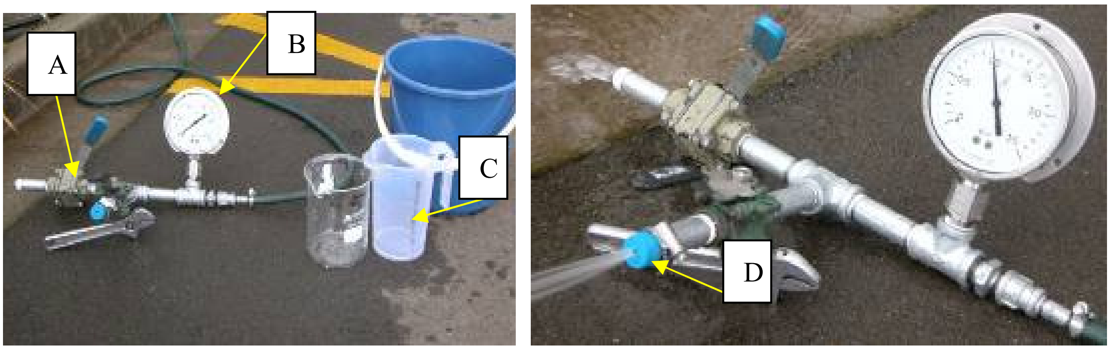
Figure 4.2 A leak point in a condenser tube

4.2 Orifice Leak

Both experimental and calculation approaches are performed on the basis of the leakage rate through an orifice in a condenser tube. Any pinhole or crack in condenser tubes or tube sheets is assumed as an equivalent “ideal” circular orifice in order to simplify the calculation and experiment.

4.2.1 Experiment on Orifice Leak

An experiment, simulating a condenser tube leak, was performed to measure the leakage rate through an orifice in a metal tube. Figure 4.3 shows the setup of the experiment. Valve **A** was used to adjust the differential pressure between the inside and outside of the tube, which was equivalent to the differential pressure between the cooling water side and the condensate side of the condenser. The pressure gauge **B** was used to display the differential pressure. The measuring vessel **C** was used to measure the volume of water leaking from the orifice. The orifice **D** was used to simulate a pinhole leak in the condenser tube. The orifice had a diameter of 2 mm (r =1 mm).



(a) Experiment devices (b) Leakage with a differential pressure of 1 bar

Figure 4.3 Experiment simulating a condenser tube leak

The volume of water leaking through the orifice **D** was measured for one minute and then same measurement was repeated for the next differential pressure. The differential pressure was increased 0.2 bar each time from 0.4 to 2.4 bar. Figure 4.3 (b) shows the leakage through the orifice with a differential pressure of 1 bar. Figure 4.4 shows the results of the experiment, the leakage rate increases as the differential pressure rises. The leakage rate through this orifice is 2.6 litres per minute when the differential pressure is 2.2 bar. Table A.1 in Appendix A shows detailed data.

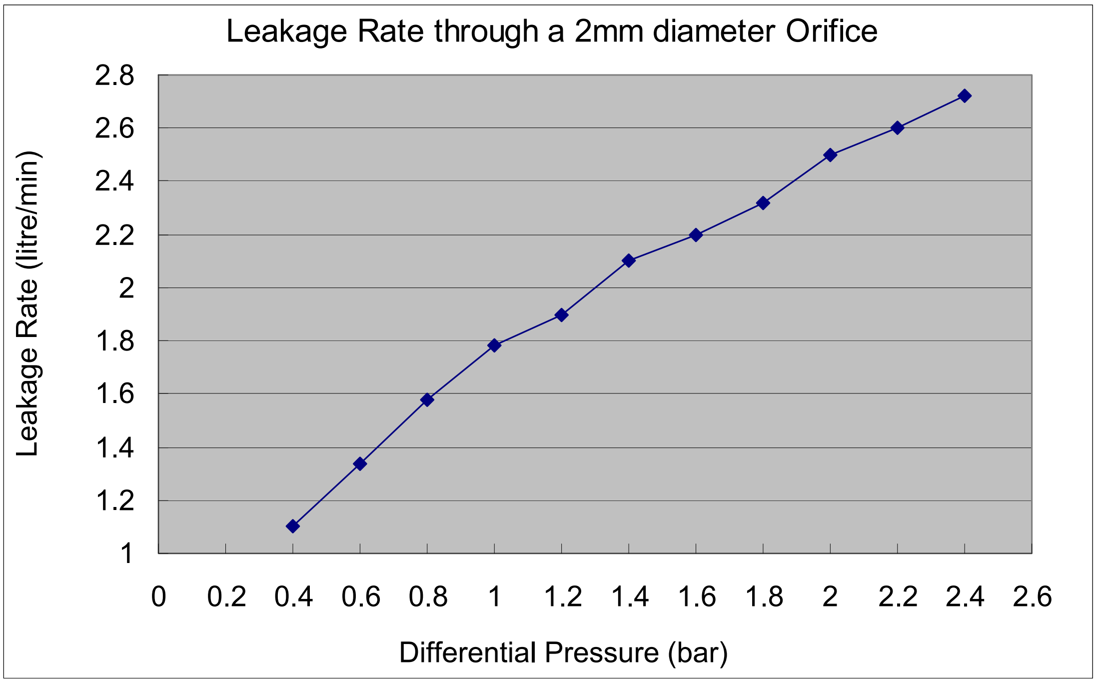


Figure 4.4 Leakage rate through a 2 mm diameter orifice

4.2.2 Orifice Flow Calculations

The leakage rate through an orifice can be calculated using the orifice flow formula. Two orifice mass flow formulas are used to verify the results of the experiment.

$$Q_m = C * A * \sqrt{2 * \rho * (P_1 - P_2)} * 60 \qquad [13] \qquad (4.1)$$

Where:

Q_m = mass flow rate (kg/min)

C = discharge coefficient (0.62 for thin walled orifice)

A = orifice cross-sectional area (m^2)

ρ = liquid density (water: 1000 kg/m^3)

P_1 = absolute cooling water pressure (pa)

P_2 = absolute ambient pressure (pa)

$$Q_m = C * A * \sqrt{2 * g * d * (P_1 - P_2)} * 60 \qquad [14] \qquad (4.2)$$

Where:

Q_m = mass flow rate (lb/min)

C = discharge coefficient (0.62 for thin walled orifice)

A = orifice cross-sectional area (ft^2)

g = gravitational constant (32.17 ft/s^2)

d = liquid density (water: 62.43 lb/ft^3)

P_1 = absolute cooling water pressure (lb/ft^2)

P_2 = absolute ambient pressure (lb/ft^2)

Example:

Assume that there is a pinhole leak in a condenser tube. The pinhole has a diameter of 2 mm (r =1 mm). Cooling water side pressure (P_1) is 2.3 barA; condensate side pressure (P_2) is 0.1 barA.

Experiment result:

According to the experimental results, the volumetric flow rate through this 2 mm diameter orifice is 2.6 litres per minute (Q_v = 2.6 litre/min) with a differential pressure of 2.2 bar.

Equation 4.1 result:

(1 mm = 0.001 m, 1 bar = 100,000 pa, ρ = 1 kg/litre or 1000 kg/m^3)

The mass flow rate (Q_m) through this orifice is given by:

$$Q_m = C*A*\sqrt{2*\rho*(P_1 - P_2)}*60$$

$$= 0.62 * 3.14 * 0.001^2 * \sqrt{2*1000*(2.3-0.1)*100000} * 60$$

$$= 2.45 \text{ kg/min}$$

The volumetric flow rate (Q_v) through this orifice then is:

$$Q_v = Q_m / \rho = 2.45 / 1 = 2.45 \text{ litre/min}$$

Equation 4.2 result:

(1 mm = 0.003281 ft, 1 bar = 2088.543 lb/ft^2, 1 lb = 0.454 kg, ρ = 1 kg/litre)

The mass flow rate (Q_m) through this orifice is:

$$Q_m = C*A*\sqrt{2*g*d*(P_1 - P_2)}*60$$

$$= 0.62 * 3.14 * 0.003281^2 * \sqrt{2*32.17*62.43*(2.3-0.1)*2088.543} * 60$$

$$= 5.402 \text{ lb/min}$$

Convert lb/min to kg/min, then Q_m is:

$$Q_m = 5.402 * 0.454 = 2.45 \text{ kg/min}$$

The volumetric flow rate (Q_v) through this orifice is:

$$Q_v = Q_m / \rho = 2.45 / 1 = 2.45 \text{ litre/min}$$

Both formulas show the same result; the volumetric flow rate through this orifice is 2.45 litre/min. The experimental result was 2.6 litre/min. The error between calculation and experiment is 0.15 litre/min, which is less than 6 per cent of the flow rate. As can be seen from Figure 4.5, both the calculated and experimental results show a similar trend that the leakage rate is proportional to the differential pressure. Although there is an error between the experimental and calculated results, this error is acceptable in practice because the non-standard orifice used in the experiment and other measurement errors are likely to result in this error. The calculated result therefore matches the experimental result, which means that Equations 4.1 and 4.2 can be used to calculate the leakage rate through an orifice in a condenser tube in the event of condenser in-leakage. Table A.1 in Appendix A lists detailed data in Figure 4.5.

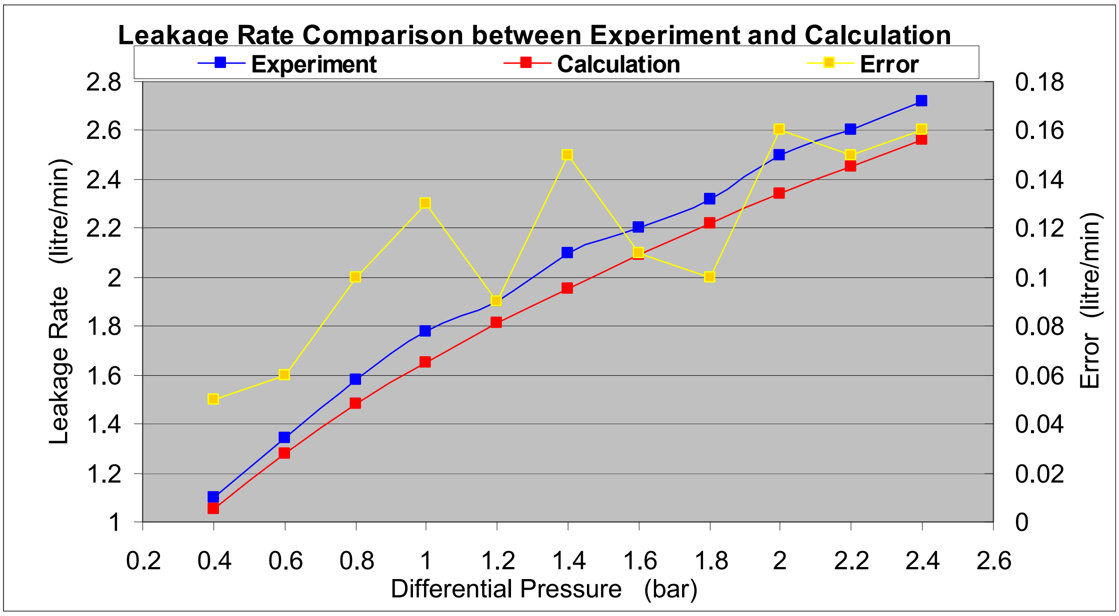


Figure 4.5 Leakage rate comparison between calculated and experimental results

In order to simplify calculations, change the engineering unit of the orifice cross-sectional area in Equation 4.1 from **m^2 to mm^2** (1 mm^2 = 0.000001 m^2), pressure from **pa** to **bar** (1 bar = 100,000 pa) and water density from **kg/m^3** to **kg/litre** (1 kg/litre = 1000 kg/m^3)**.** The mass leakage rate Q_m (kg/min) is given by:

$$Q_m = C*A*0.000001*\sqrt{2*(P_1 - P_2)*100000*1000}*60$$

$$= C*A*\sqrt{2*(P_1 - P_2)}*0.6$$

The volumetric leakage rate Q_v (litre/min) equals the mass leakage rate Q_m (kg/min) divided by water density ($\rho = 1$ kg/litre), which is given by:

$$Q_v = C*A*\sqrt{2*(P_1 - P_2)}*0.6 / \rho$$

$$= C*A*\sqrt{2*(P_1 - P_2)}*0.6$$

Substitute ΔP for $(P_1 - P_2)$, the volumetric leakage rate Q_v is:

$$Q_v = C*A*\sqrt{2*\Delta P}*0.6 \qquad (4.3)$$

Where:

Q_v = volumetric leakage rate from an orifice (litre/min)
C = discharge coefficient (0.62 for thin walled orifice)
A = orifice cross-sectional area (mm^2)
ΔP = differential pressure between the cooling water side and the condensate side (bar)

The volumetric leakage rates through different radius orifices (from 0.5 to 4 mm) with various differential pressures (from 0.4 to 2.4 bar) are calculated using Equation 4.3 and plotted in Figure 4.6. Table A.2 in Appendix A includes detailed data. As can be seen from the diagram, with a differential pressure of 2.2 bar, the volumetric leakage rate through the orifice increases 16 times from 2.45 litre/min to 39.2 litre/min while the orifice radius increases 4 times from 1 mm to 4 mm. This means that the leakage rate through an orifice is proportional to the square of the radius of the orifice.

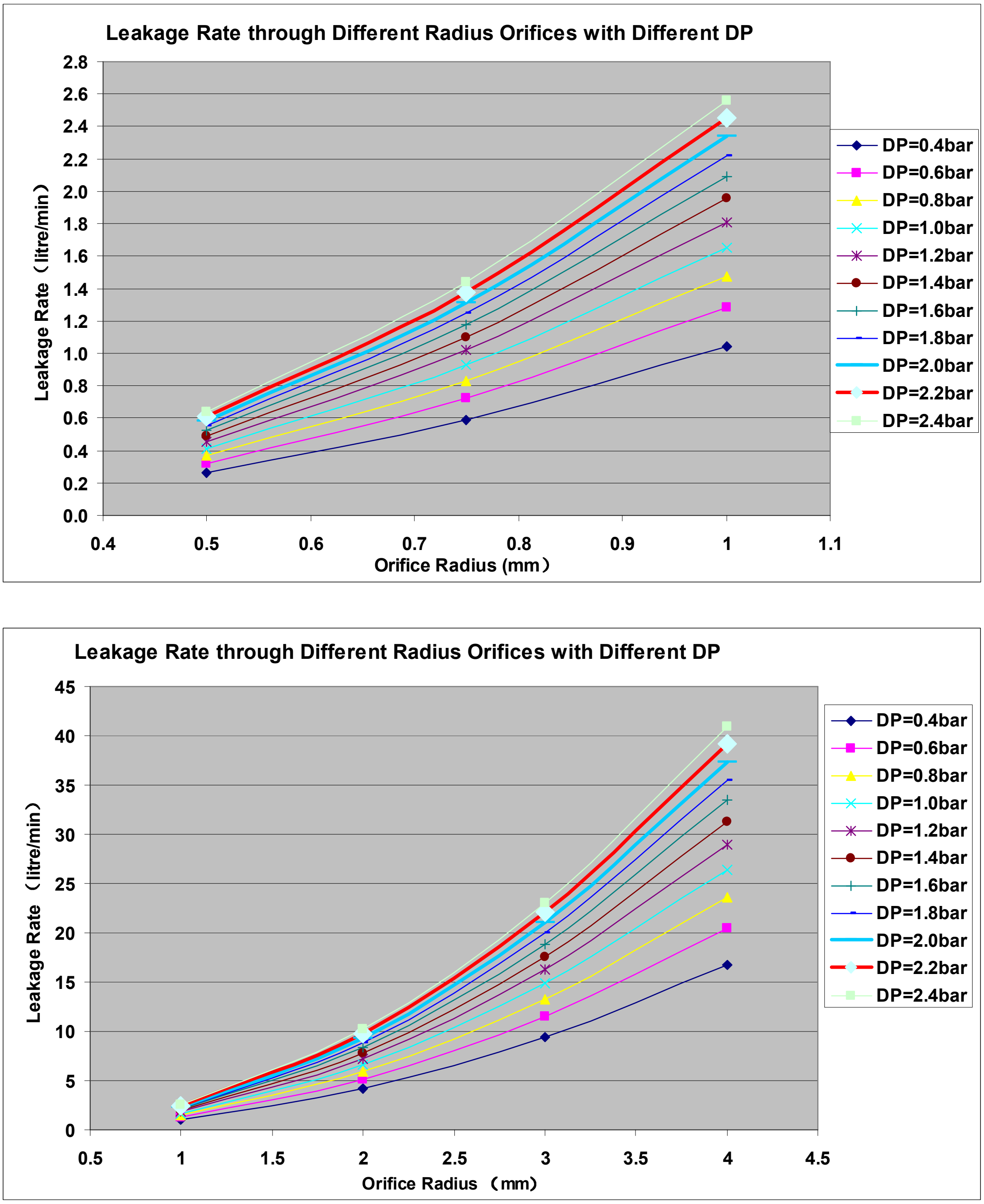


Figure 4.6 Leakage rate through different orifices with different differential pressures

4.3 Mathematical Model of Condenser In-Leakage

A mathematical model is an abstract model that uses mathematical language to describe the behaviour of a system. This approach has been being widely used in process engineering for the dynamic analysis of a system. The condenser in-leakage model is developed based on a theoretically ideal situation in which all minor factors have been ignored. For example, the original condensate in the condenser hotwell is considered as pure water without any contaminants. The steam from the steam turbine condensed in the condenser hotwell is considered as pure steam. This model only analyses the scenario where no chloride and sodium are carried over to the steam because, in reality, chloride and sodium may take a few hours to reach saturation level in the drums. The leak orifice in a condenser tube or tube sheet is considered as an equivalent ideal circular orifice. The total volume of the condensate in the condenser hotwell always remains constant. Only chloride (Cl) and sodium (Na) in the salty cooling water are considered as contaminants.

4.3.1 Condenser Hotwell Model

Figure 4.7 shows the condenser hotwell model. The original condensate volume in the condenser hotwell is **v** litres. Cooling water leaks into the condensate side through an orifice at a rate of **w** litre/min. Sodium (Na) concentration in the cooling water is **c** mg/litre**.** The volume of the condensate flowing in and out of the condenser hotwell remains at the same rate of **q** litre/min ($\mathbf{q_{in}} = \mathbf{q_{out}}$) because the water level in the condenser hotwell must remain constant while the plant is in service.

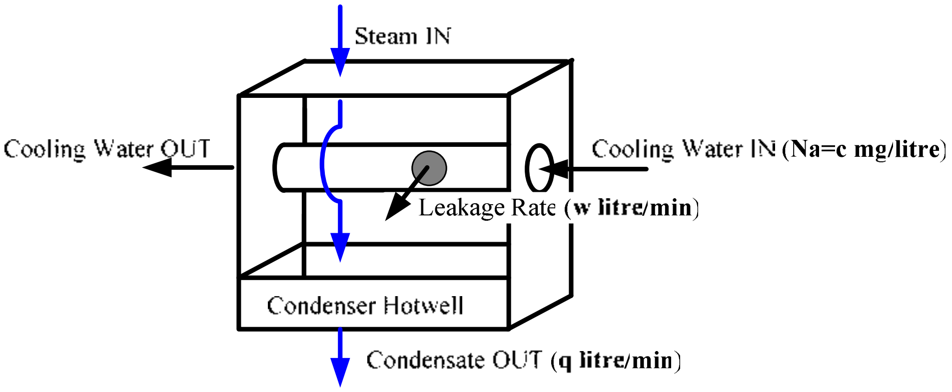


Figure 4.7 Condenser model

In order to simplify the analysis of the sodium (Na) dispersing process in the condensate, an assumption must be made that the Na concentration in the condensate becomes evenly mixed in a very short time so that the sodium dispersion time in the condensate can be ignored.

Let the total sodium (Na) solute in the condenser hotwell equal **X(t)** mg at time **t**, and then consider the Na variation ***dx*** in the condenser hotwell from **t** to **t** + ***dt*** (***dt*** **→ 0)**. Na variation ***dx*** in the condenser hotwell during ***dt*** is:

$$dx = X_{in} - X_{out}$$

Xin is the total Na solute (mg) leaking into the condensate side from the cooling water side during a period time of ***dt*** , which is given by:

$$X_{in} = c * w * dt$$

Where:

c = Na concentration in the cooling water (mg/litre)

w = leakage rate through an orifice in a condenser tube (litre/min)

dt = time duration

Xout is the total Na solute (mg) flowing out of the condenser hotwell during a period time of ***dt***. The total volume of water in the condenser hotwell at anytime **t** is a constant value **v** (litres) because the water level in the condenser hotwell remains constant. Therefore, Na concentration in the condenser hotwell at time **t** is $\frac{x(t)}{v}$**.** As ***dt*** is a very short period of time (***dt*** **→ 0**), the Na concentration in the condenser hotwell can be considered a constant; therefore, **Xout** is:

$$X_{out} = \frac{q * x * dt}{v}$$

Where:

q = flow rate of condensate flowing out of the condenser (litre/min)

x = total sodium (Na) solute in the condenser hotwell (mg)

v = total volume of condensate in the condenser hotwell (litre)

dt = time duration

Then Na variation ***dx*** in the condenser hotwell during ***dt*** is:

$$\begin{aligned} dx &= \mathrm{X}_{\mathbf{in}} - \mathrm{X}_{\mathbf{out}} \\ &= \mathrm{c} * \mathrm{w} * dt - \frac{\mathrm{q} * \mathrm{x} * dt}{\mathrm{v}} \\ &= \left(\mathrm{c} * \mathrm{w} - \frac{\mathrm{q} * \mathrm{x}}{\mathrm{v}} \right) * dt \end{aligned}$$

Move ***dt*** to the left side of the equation:

$$\frac{dx}{dt} = \mathrm{c} * \mathrm{w} - \frac{\mathrm{q} * \mathrm{x}}{\mathrm{v}}$$

$$\frac{dx}{dt} + \frac{\mathrm{q} * \mathrm{x}}{\mathrm{v}} = \mathrm{c} * \mathrm{w} \qquad (4.4)$$

Equation 4.4 is therefore a first-order linear differential equation.

An assumption is made that the condensate in the condenser hotwell is pure water without any sodium (Na) before a condenser leak occurs, thus when time equals zero (**t = 0**), Na solute **x(0)** in the condensate is zero. Therefore, the mathematical model for the condenser hotwell in the event of condenser in-leakage is:

$$\left\{ \begin{matrix} \dfrac{dx}{dt} + \dfrac{\mathrm{q} * \mathrm{x}}{\mathrm{v}} = \mathrm{c} * \mathrm{w} \\ \mathrm{x}(0) = 0 \end{matrix} \right\} \qquad (4.5)$$

Where:

dt = time duration

dx= Na variation in the condenser hotwell during *dt*

q = flow rate of condensate flowing out of the condenser (litre/min)

x = total Na solute in the condenser hotwell (mg)

v = total volume of condensate in the condenser hotwell (litre)

c = Na concentration in the cooling water (mg/litre)

w = leakage rate through an orifice in a condenser tube (litre/min)

A general solution for Equation 4.5 is:

$$\frac{dx}{dt} + \frac{q * x}{v} = c * w$$

$$\frac{dx}{dt} = \frac{c * w * v - q * x}{v}$$

$$\frac{dx}{c * w * v - q * x} = \frac{dt}{v}$$

Integrate the both sides of the equation,

$$\int \frac{dx}{c * w * v - q * x} = \int \frac{dt}{v} + C$$

$$-\frac{1}{q} * \int \frac{d(-qx)}{c * w * v - q * x} = \int \frac{dt}{v} + C$$

$$-\frac{1}{q} * \ln(c * w * v - q * x) = \frac{t}{v} + C \qquad (4.6)$$

Assume that the condensate is pure water without any sodium contamination before a tube leak occurs, thus when time **t** equals zero the total Na solute **x(0)** in the condensate is zero (**x(0)=0**). Therefore, the constant, **C**, in Equation 4.6 is given by:

$$-\frac{1}{q} * \ln(c * w * v - q * 0) = \frac{0}{v} + C$$

$$C = -\frac{1}{q} * \ln(c * w * v) \qquad (4.7)$$

Substitute Equation 4.7 into Equation 4.6,

$$-\frac{1}{q} * \ln(c * w * v - q * x) = \frac{t}{v} - \frac{1}{q} * \ln(c * w * v)$$

$$\ln(c * w * v - q * x) = \ln(c * w * v) - \frac{q * t}{v}$$

$$c*w*v-q*x = e^{\left(\ln(c*w*v) - \frac{q*t}{v}\right)}$$

$$q*x = c*w*v - \left(\frac{c*w*v}{e^{\left(\frac{q*t}{v}\right)}} \right)$$

The total Na solute **x(t)** mg in the condenser hotwell at anytime **t** is therefore:

$$x = \frac{c*w*v}{q} * \left(1 - e^{\left(\frac{-q*t}{v}\right)} \right) \qquad (4.8)$$

The Na concentration **y(t)** ppb (parts per billion) in the condenser hotwell at anytime **t** is equal to the total Na solute **x(t)** mg in the condenser hotwell divided by the volume of the condensate water **v** litres in the condenser hotwell. Therefore, the Na concentration **y(t)** is:

$$y = \frac{x}{v} = \frac{c*w}{q} * \left(1 - e^{\left(\frac{-q*t}{v}\right)} \right) * 1000 \qquad (4.9)$$

Where:

y = Na concentration in the hotwell (ppb, 1 mg/litre = 1000 ppb)
c = Na concentration in the cooling water (mg/litre)
w = leakage rate through an orifice in a condenser tube (litre/min)
q = flow rate of condensate flowing out of the condenser (litre/min)
v = total volume of condensate in the condenser hotwell (litre)
t = duration of leakage (minute)

Based on the assumption that the Na dispersion time in the condenser hotwell can be ignored, the Na concentration in the condensate that is extracted out of the condenser hotwell can be considered to be the same as the Na concentration in the condenser hotwell.

4.3.2 Case Study on Condenser Hotwell Model

Four cases are studied under different situations including different unit loads, different tube leaks and different cooling water samples. The data used in the following cases are obtained from the OTB station database.

The length of the condenser hotwell (**L**) is 6 metres; the depth of condenser hotwell (**D**) is 4.5 metres. The condensate level in the condenser hotwell (**H**) is automatically maintained at 0.8 metres so it is considered as constant at all times to simplify the analysis. Therefore, the total volume of the condensate (**v**) in the condenser hotwell is given by:

$$v = L * W * H = 6 * 4.5 * 0.8 * 1000 = 21600 \text{ litres} \qquad (4.10)$$

4.3.2.1 Case Study 1: Full Load Analysis

Assume that a condenser leak occurs at full load (380 MW). The condensate flow rate to the HRSG is 6000 litre/min (100 kg/s) at full load. The radius of the leak orifice (r) in the condenser tube is 1 mm. Take Na and Cl as analysis parameters.

c_1= 13000 mg/litre (Na concentration in cooling water sampled on 09/03/2007)

c_2 = 23000 mg/litre (Cl concentration in cooling water sampled on 09/03/2007)

q = 6000 litre/min (Condensate flow rate at full load)

ΔP = 2.2 bar (Differential pressure between condensate side and cooling water side)

The leakage rate through the orifice can be calculated using Equation 4.3. Therefore, the leakage rate through an orifice of 1 mm radius with a differential pressure of 2.2 bar is:

$$\begin{aligned} w &= C * A * \sqrt{2 * \Delta P} \; *0.6 \\ &= 0.62 * 3.14 * 1^2 * \sqrt{2 * 2.2} \; *0.6 \\ &= 2.45 \text{ litre/min} \end{aligned}$$

Sodium (Na) concentration in the condenser hotwell is calculated using Equation 4.9 as follows:

$$y_{Na} = \frac{c_1 * w}{q} * \left(1 - e^{(\frac{-q*t}{v})}\right) * 1000$$

$$= \frac{13000 * 2.45}{6000} * \left(1 - e^{(\frac{-6000*t}{21600})}\right) * 1000$$

Then,

$$y_{Na} = 5308 * \left(1 - e^{(-0.2778 * t)}\right) \qquad (4.11)$$

Chloride (Cl) concentration in the condenser hotwell can also be calculated using Equation 4.9 as follows:

$$y_{Cl} = \frac{c_2 * w}{q} * \left(1 - e^{(\frac{-q*t}{v})}\right) * 1000$$

$$= \frac{23000 * 2.45}{6000} * \left(1 - e^{(\frac{-6000*t}{21600})}\right) * 1000$$

Then,

$$y_{Cl} = 9392 * \left(1 - e^{(-0.2778 * t)}\right) \qquad (4.12)$$

Figure 4.8 shows Na and Cl concentration trends in the condensate, which are plotted using Equations 4.11 and 4.12. As can been seen from the diagram, Na and Cl concentrations increase very quickly as time elapses. Na and Cl concentrations reach 500 ppb within 22 and 12 seconds respectively after the condenser leak occurs. As recommended in Table 2.2 (page 22), an immediate plant shutdown is required if Na or Cl concentration in the condensate reaches 500 ppb, which is action level 4. This means that, theoretically, Na and Cl concentrations will reach action level 4 within 30 seconds with this leakage rate and the plant must be immediately shut down according to EPRI's guidelines. This conclusion is based on the assumption that the dispersion time of Na and Cl in the condensate is ignored. Table A.3 in Appendix A lists detailed data in Figure 4.8.

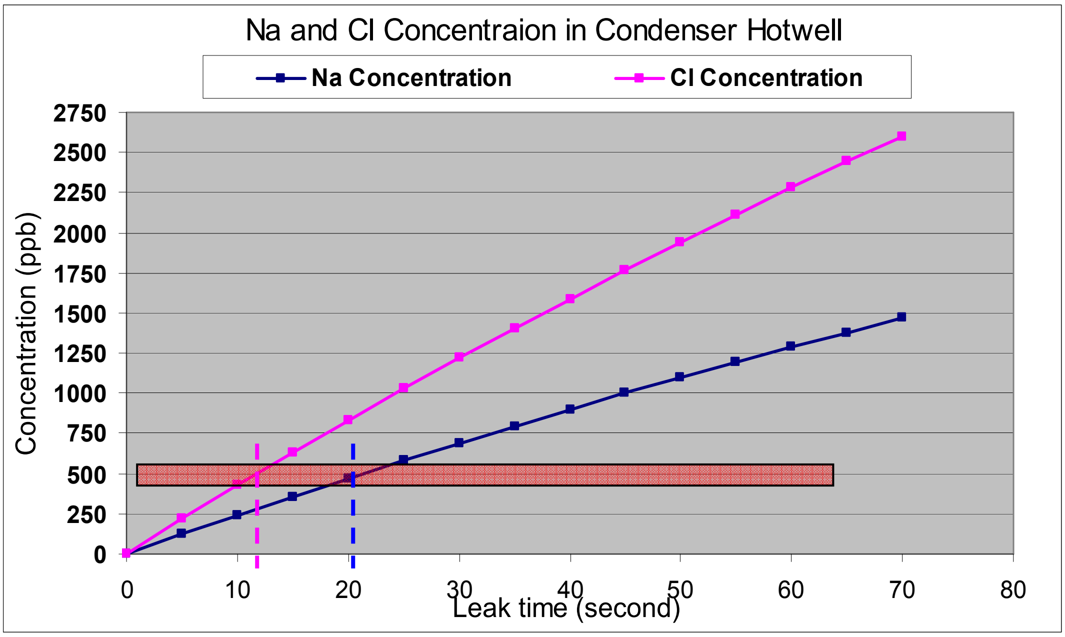


Figure 4.8 Na and Cl concentrations in condenser hotwell (1)

According to experience, the dispersion time might take 30 seconds to one minute depending on where the leak is. Therefore, it is realistic that the plant must be immediately shut down approximately one minute after the tube leak takes place in this case. This is a very short period of time and requires the operator to respond instantly. In addition, it is certain from above analysis that the tolerance of the condenser to the contamination caused by even a tiny tube leak (e.g. a 2 mm diameter orifice leak), is almost zero at OTB station.

As shown in Figure 4.9, the speed of increase of both Na and Cl concentrations slows down as leakage duration increases. According to Equations 4.11 and 4.12, as time $t \rightarrow + \infty$, Na and Cl concentrations in the condensate will reach a maximum value of 5308 ppb and 9392 ppb respectively. The maximum value is the Na and Cl concentrations in the mixture of the incoming condensate condensed from the steam and the cooling water leaking into the condenser hotwell. This maximum value is based on the assumption that no Cl and Na are carried over to the steam. In reality, Cl and Na may take a few hours to reach saturation level in the drums and then be carried over to the steam. This is too long to be considered because the plant should have been shut down (within minutes) already with this leakage rate before any Cl and Na are carried over to the steam. As illustrated in Figure 4.9, Na and Cl concentrations will reach the maximum value around 19 minutes after the leak occurs in this case. However, the plant must be immediately shut down approximately one minute after the tube leak takes place. In addition, because Cl concentration in the cooling water is much higher than Na concentration, the final Cl concentration in the condensate is higher than Na concentration. Table A.3 in Appendix A lists detailed data in Figure 4.9.

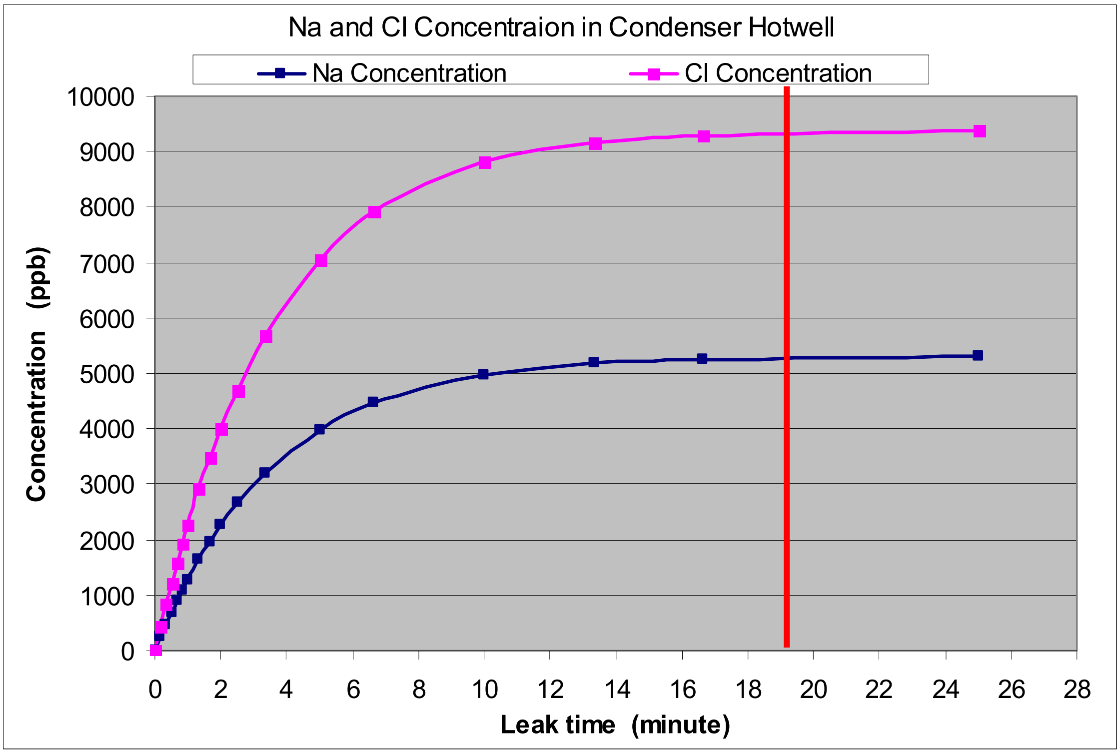


Figure 4.9 Na and Cl concentrations in the condenser hotwell (2)

4.3.2.2 Case Study 2: Minimum Combined Cycle Load Analysis

Assume that a condenser tube leak occurs at 240 MW when the condensate flow to the HRSG is 4500 litre/min (75 kg/s). 240 MW is the minimum combined cycle load with reserve and the most likely low load when the plant runs in combined cycle mode. The radius of the orifice (r) in the condenser tube is 1 mm. Na and Cl are taken as analysis parameters.

c_1= 13000 mg/litre (Na concentration in cooling water sampled on 09/03/2007)
c_2 = 23000 mg/litre (Cl concentration in cooling water sampled on 09/03/2007)
q = 4500 litre/min = 75 kg/s (Condensate flow at 240MW)
ΔP = 2.2 bar (Differential pressure between condensate side and cooling water side)

According to Equation 4.10, the total volume of the condensate (**v**) in the condenser hotwell is 21600 litres.

The leakage rate through the orifice can be calculated using Equation 4.3. Therefore, the leakage rate through the 1 mm radius orifice with a differential pressure of 2.2 bar is:

$$w = C*A*\sqrt{2*\Delta P}\ *0.6$$

$$= 0.62 * 3.14 * 1^2 * \sqrt{2*2.2}\ *0.6$$

$$= 2.45 \text{ litre/min}$$

Na concentration in the hotwell is calculated using Equation 4.9 as follows:

$$y_{Na} = \frac{c_1 * w}{q} * \left(1 - e^{\left(\frac{-q*t}{v}\right)}\right) *1000$$

$$= \frac{13000*2.45}{4500} * \left(1 - e^{\left(\frac{-4500*t}{21600}\right)}\right) *1000$$

Then,

$$y_{Na} = 7077 * \left(1 - e^{(-0.20833*t)}\right) \qquad (4.13)$$

Cl concentration in the condenser hotwell can also be calculated using Equation 4.9 as follows:

$$y_{Cl} = \frac{c_2 * w}{q} * \left(1 - e^{(\frac{-q*t}{v})}\right) * 1000$$

$$= \frac{23000 * 2.45}{4500} * \left(1 - e^{(\frac{-4500*t}{21600})}\right) * 1000$$

Then,

$$y_{Cl} = 12522 * \left(1 - e^{(-0.20833*t)}\right) \qquad (4.14)$$

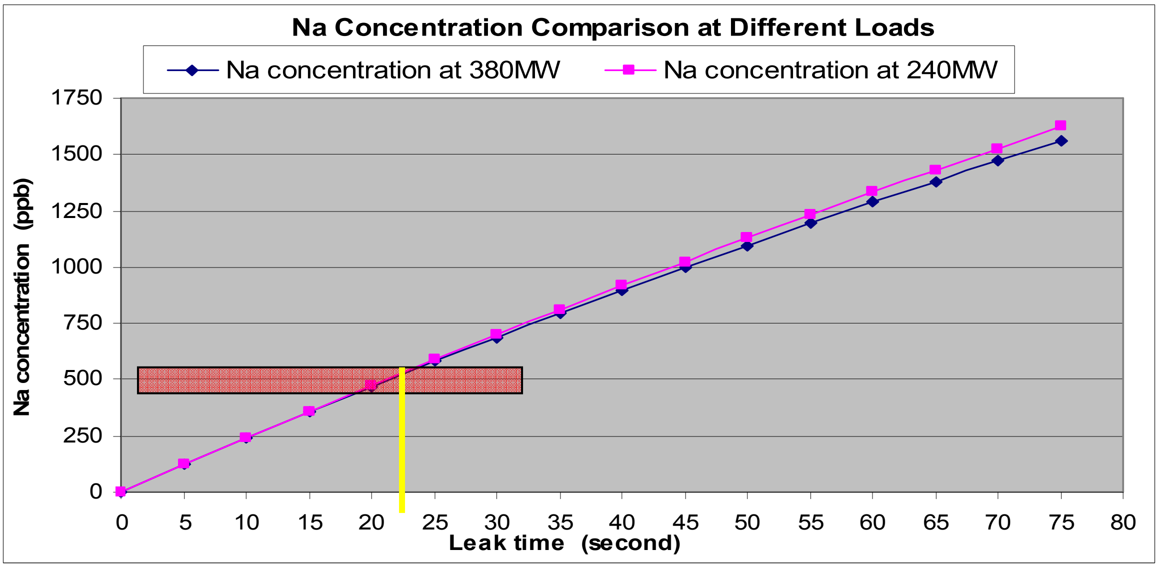


Figure 4.10 Na concentration comparison at 380MW and 240MW (1)

Figure 4.10 compares Na concentration in the condensate at 240 MW and 380 MW using Equations 4.11 and 4.13. Na concentration rises as time elapses and both Na concentrations reach 500 ppb at almost the same time, which is approximately 22 seconds after the condenser leak occurs. This means that even at the minimum combined cycle load (240MW), Na concentration can reach action level 4 within 30 seconds, and the plant must be immediately shut down based on EPRI's guidelines. Table A.4 in Appendix A shows detailed data. This result does not take Na dispersion time into account. However, as can been seen from the above analysis, it is certain that as long as the plant runs in combined cycle mode, the plant requires an immediate shutdown even with a very small amount of leakage.

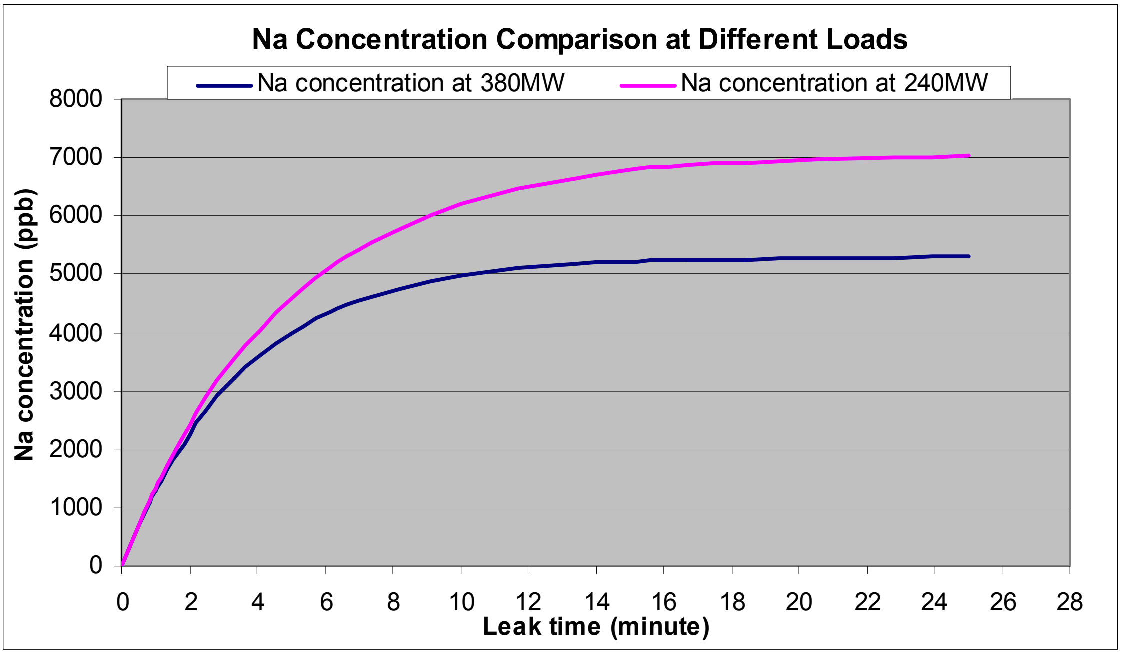


Figure 4.11 Na concentration comparison at 380MW and 240MW (2)

As shown in Figure 4.11, the speed of increase of both Na concentrations in the condenser hotwell slows down as time increases; and as time $t \rightarrow +\infty$, Na concentrations reach a maximum value of 5308 ppb and 7077 ppb respectively. Na concentration in the condenser hotwell at high load is lower than at a low load even though the tendency is not apparent initially. This is because the condensate flowing from the condenser hotwell to the HRSG at high load is much more than at low load; so compared to low load, more sodium is transported from the condenser hotwell to the HRSG at high load, and hence less sodium remains in the condenser hotwell. Therefore, the higher the load, the more severe the contamination of the HRSG. Table A.4 in Appendix A includes detailed data.

4.3.2.3 Case Study 3: Different Leakages Analysis

Assume that a condenser tube leak occurs at full load (380 MW) when the condensate flow to the HRSG is 6000 litre/min (100 kg/s). The radius of the orifice (r) in the condenser tube changes from 1 mm to 0.5 mm in this case.

c_1= 13000 mg/litre (Na concentration in cooling water sampled on 09/03/2007)
c_2 = 23000 mg/litre (Cl concentration in cooling water sampled on 09/03/2007)
q = 6000 litre/min (Condensate flow rate at full load)
ΔP = 2.2 bar (Differential pressure between condensate side and cooling water side)

According to Equation 4.10, the total volume of the condensate (**v**) in the condenser hotwell is 21600 litres.

The leakage rate through the orifice can be calculated using Equation 4.3. Therefore, the leakage rate through a 0.5 mm radius orifice with a differential pressure of 2.2 bar is:

$$\begin{aligned} w &= C*A*\sqrt{2*\Delta P}\ *0.6 \\ &= 0.62*3.14*(0.5)^2*\sqrt{2*2.2}\ *0.6 \\ &= 0.613 \text{ litre/min} \end{aligned}$$

Na concentration in the condenser hotwell is calculated using Equation 4.9 as follows:

$$y_{Na} = \frac{c_1*w}{q}*\left(1-e^{(\frac{-q*t}{v})}\right)*1000$$

$$= \frac{13000*0.613}{6000}*\left(1-e^{(\frac{-6000*t}{21600})}\right)*1000$$

Then,

$$y_{Na} = 1328*\left(1-e^{(-0.2778*t)}\right) \qquad (4.15)$$

Cl concentration in the condenser hotwell is calculated using Equation 4.9 as follows:

$$y_{Cl} = \frac{c_2 * w}{q} * \left(1 - e^{\left(\frac{-q*t}{v}\right)} \right) * 1000$$

$$= \frac{23000 * 0.613}{6000} * \left(1 - e^{\left(\frac{-6000*t}{21600}\right)} \right) * 1000$$

Then,

$$y_{Cl} = 2350 * \left(1 - e^{(-0.2778*t)} \right) \qquad (4.16)$$

According to Equations 4.15 and 4.16, as time *t* → + ∞, Na and Cl concentrations will reach a maximum value of 1328 ppb and 2350 ppb respectively. Compared to the first study case, it is concluded that the final Na and Cl concentrations in the condensate will increase 4 times when the radius of the orifice in the condenser tube doubles. This is because the cross sectional area of the orifice is proportional to the square of the radius of the orifice.

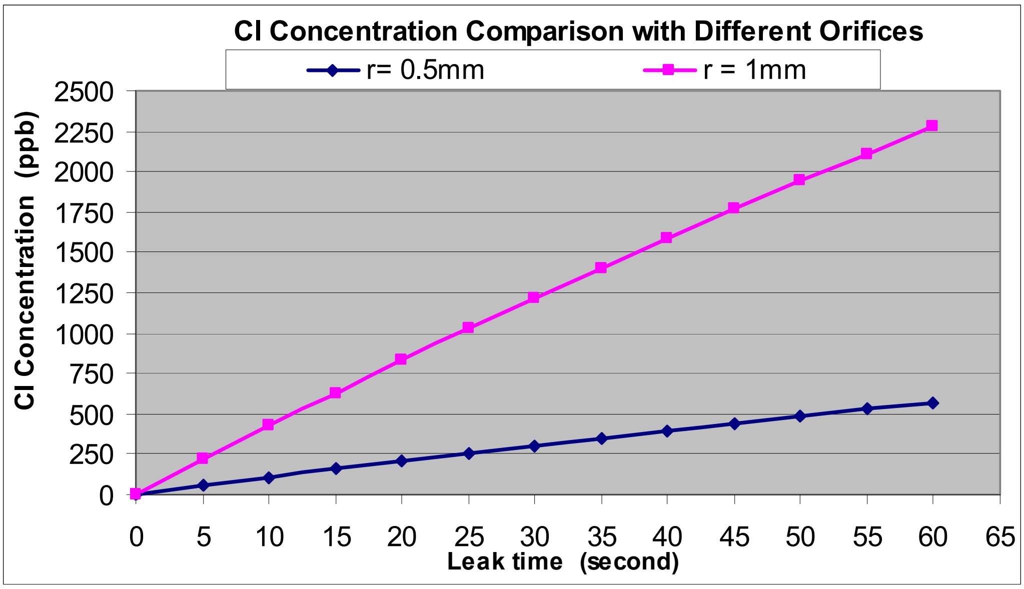


Figure 4.12 Cl concentration variation with different radius orifices.

Figure 4.12 shows Cl concentrations in the condensate under two different leak situations. The radiuses of the orifices are 0.5 mm and 1 mm respectively. As illustrated in this diagram, Cl concentration takes 53 seconds to reach 500 ppb when the radius of the orifice (r) is 0.5 mm. However, the same value is reached within 12 seconds when the radius becomes 1mm. The time taken to reach the same contamination level will reduce by a factor of 4 when the radius of the leak orifice doubles. Therefore, the bigger the leak, the more devastating the consequences of the condenser in-leakage. Table A.5 in Appendix A shows detail data.

4.3.2.4 Case Study 4: Different Cooling Water Samples Analysis

Assume that a condenser tube leak occurs at full load (380MW). The condensate flow rate to the HRSG is 6000 litre/min (100kg/s) at full load. The radius of the orifice (r) in the condenser tube is 1 mm.

c_1 = 4500 mg/litre (Na concentration in cooling water sampled on 09/07/2004)
c_2 = 8000 mg/litre (Cl concentration in cooling water sampled on 09/07/2004)
q = 6000 litre/min (Condensate flow at full load)
ΔP = 2.2 bar (Differential pressure between condensate side and cooling water side)

	09/07/2004	09/03/2007
Na (mg/litre)	4500	13000
Cl (mg/litre)	8000	23000

The Na and Cl concentrations in the cooling water sampled on 09/03/2007, used in the first study case, are the highest concentrations within last 4 years, whereas the value obtained from the sample on 09/07/2004 is the lowest concentrations within last 4 years. Compared to the cooling water sample in the first study case, this sample contains much less Na and Cl. The tide and rainfall result in variations of Na and Cl concentrations in the cooling water. Thus, any variation of Na and Cl in the cooling water should be taken into account when analysing the consequences of a condenser leak.

The leak rate through a 1 mm radius orifice with a 2.2 bar differential pressure is 2.45

litre/min, which was calculated in Case Study 1.

Na concentration in the condenser hotwell is calculated using Equation 4.9 as follows:

$$y_{Na} = \frac{c_1 * w}{q} * \left(1 - e^{(\frac{-q*t}{v})} \right) *1000$$

$$= \frac{4500 * 2.45}{6000} * \left(1 - e^{(\frac{-6000*t}{21600})} \right) *1000$$

Then,

$$y_{Na} = 1838* \left(1 - e^{(-0.2778*t)} \right) \qquad (4.17)$$

Cl concentration in the condenser hotwell is calculated using Equation 4.9 as follows:

$$y_{Cl} = \frac{c_2 * w}{q} * \left(1 - e^{(\frac{-q*t}{v})} \right) *1000$$

$$= \frac{8000 * 2.45}{6000} * \left(1 - e^{(\frac{-6000*t}{21600})} \right) *1000$$

Then,

$$y_{Cl} = 3267* \left(1 - e^{(-0.2778*t)} \right) \qquad (4.18)$$

According to Equations 4.17 and 4.18, as time $t \rightarrow +\infty$, Na and Cl concentrations will reach a maximum value of 1838 ppb and 3267 ppb respectively. As can be seen from Figure 4.13, based on the sample taken on 09/07/2004, Na and Cl concentrations in the condensate will reach 500 ppb within 70 and 36 seconds respectively after the condenser leak occurs. Table A.6 in Appendix A includes detailed data.

Comparing Case 4 to Case 1, although the final Na and Cl contamination levels in the condensate reduce as Na and Cl concentrations in the cooling water decrease, the contamination of the condensate caused by the lowest concentration cooling water can still reach action level 4 (500 ppb) approximately 1 minute after the condenser leak occurs.

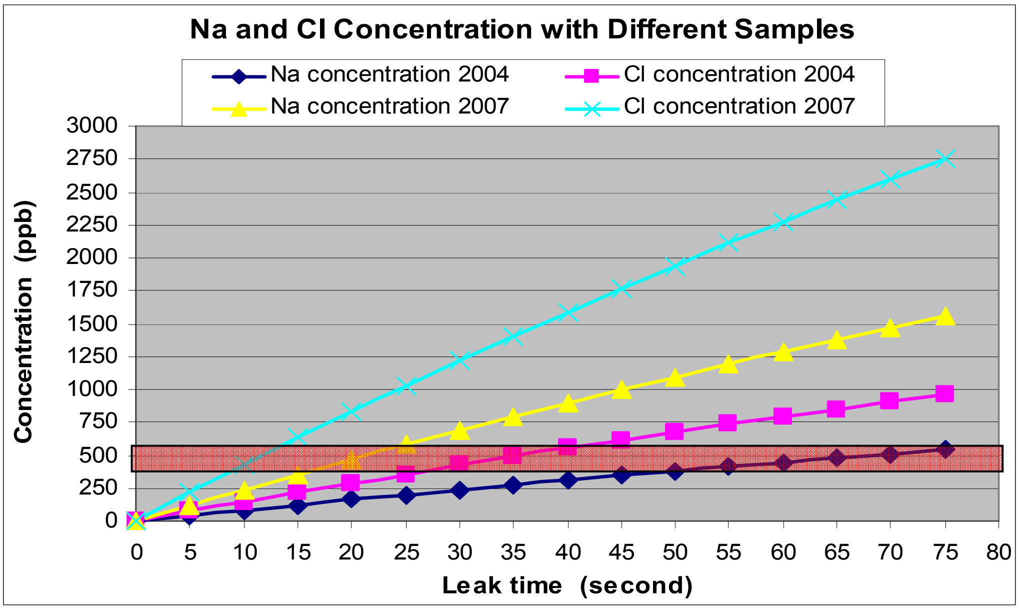


Figure 4.13 Cl and Na concentrations in the condenser hotwell with different samples

4.3.3 Summary of Condenser Hotwell Model

The condenser hotwell model is a mathematical model based on the dynamic process, which is much more accurate than a static model. The model substantially represents the actual process even though some assumptions have been made to ignore minor factors.

In general, the results of the analysis show that even a very small amount of ingress of salty cooling water will cause serious contamination in the condensate within a very short time. Therefore, online analysers must be able to accurately measure any leakage immediately and inform the duty shift operator. Otherwise, the consequence can be catastrophic. Four cases were analysed based on mathematical models and the following conclusions have been reached:

- With a 1 mm radius orifice in the condenser tube, the leakage rate of the cooling water under normal conditions at OTB station is 2.45 litres per minute. When the plant is running at full load, this leakage rate will theoretically raise Na and Cl concentrations in the condenser hotwell to 500 ppb (Action Level 4) within 22 and 12 seconds respectively after the leak occurs. This means that a plant shutdown is required immediately after the leak is detected. This result is based on the cooling water sampled on 09/03/2007 when Na and Cl concentrations were the highest in the last four years.

- Cl contamination of the condensate occurs faster than Na contamination as the Cl concentration in the cooling water is much higher than the Na concentration. Take Case 1 for example, Cl concentration reaches 500 ppb 12 seconds after a tube leak occurs whereas Na takes 22 seconds to reach the same level.

- Cl and Na concentrations in the cooling water is affected by environmental factors such as rainfall and tide. Although the final Na and Cl contamination levels in the condensate reduce as Na and Cl concentrations in the cooling water decrease, a rapid response to condenser leakage is required at low Na and Cl concentrations.

- Na and Cl concentrations in the condenser hotwell at high load are lower and rise more slowly than at low load even though this tendency is not apparent initially. This is because more condensate flows out from the condenser to the HRSG at high load than at low load so less Na and Cl remain in the condenser hotwell at high load. The higher the load, the less contamination in the condenser but the more severe the contamination in the HRSG.

From the above analysis, it is concluded that the tolerance of the condenser to contamination caused by any condenser in-leakage is almost zero. Even a very small condenser tube leak will require an immediate plant shutdown to avoid catastrophic consequences because the contamination in the condenser hotwell takes place very quickly and reaches the plant shutdown level (Action Level 4) within one minute in all of the four case studies.

In addition, practically, any tube leak is likely to become worse very quickly after a leak starts as the leak orifice will enlarge as cooling water flows through the orifice. The response time to any tube leak therefore becomes a critical issue, and requires that any online analysers must be able to accurately detect any leakage immediately rather than relying on human intervention and confirmation.

4.3.4 HRSG Drum System Model

Major parts of the HRSG at OTB station comprise reheater, evaporators, drums, superheaters, and economisers. The HRSG is a triple pressure HRSG that consists of three systems: a Low Pressure (LP) system, an Intermediate Pressure (IP) system, and a High Pressure (HP) system. Each system consists of a steam drum and an evaporator where water is converted to steam. The steam then passes through superheaters to raise the temperature in order to meet the requirements of the steam turbine.

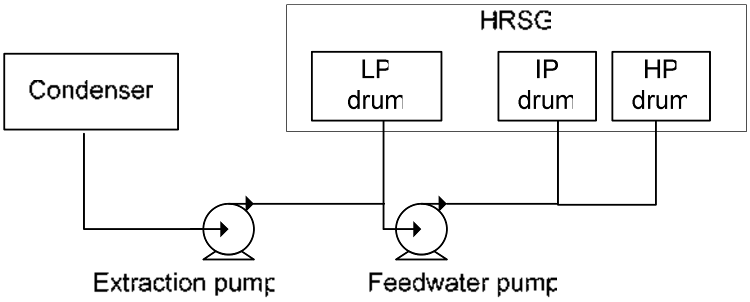


Figure 4.14 Simplified water cycle system

Figure 4.14 shows a simplified water cycle system diagram including only the major parts of the system. As can be seen from the diagram, condensate is extracted from the condenser hotwell by the condensate extraction pump and is pumped into the feedwater system. After that, the feedwater pump feeds the water into the three drum systems. The feedwater then is evaporated to steam in the evaporator. Figures A.1 and A.2 in Appendix A show a detailed water and steam cycle and HRSG process diagram.

The HRSG drum model is developed based on an assumed ideal situation in which some minor factors have been ignored. For example, the original boiler water in the HRSG is assumed to be pure water without any contaminants. Feedwater flow rate is equal to condensate flow rate. All feedwater from the condensate system is assumed to flow into the three drums so no boiler blowdown or leakage loss occurs; and no desuperheating spray water is taken from the feedwater pipeline. The steam evaporation rate from the drums is assumed to be strictly equal to the water feed rate into the drums **(IN=OUT)** because the water level in the drums is constant under normal operating conditions**.**

Chloride (Cl) and sodium (Na) remain in the drum and will not be carried over to the steam cycle until the saturation level has been reached. The time taken for the Cl and Na concentrations to reach their saturation level depends on the unit load, drum pressure and the severity of the condenser tube leak. Carryover test has never been implemented at OTB station because there are no sodium analysers installed for monitoring the saturated steam quality. It may take a few hours to reach saturation level in the drum, which is a much longer time compared to the quick response required on the condenser hotwell side. Therefore, in this model, it is assumed that all Na and Cl remains in the water cycle and none is carried over to the steam cycle.

In this model, chloride (Cl) is the subject of analysis because Cl concentration in the condensate caused by the ingress of cooling water is much higher than that of Na as illustrated in the condenser hotwell model.

Let the original volume of boiler water in HP, IP, and LP systems be $\mathbf{h}_{HP}$**,** $\mathbf{h}_{IP}$**,** and $\mathbf{h}_{LP}$ litres respectively. Based on the condenser hotwell model, it is already known that the Cl concentration in the condensate (**y** mg/litre) is a function of time **t**, and this equals the Cl concentration in feedwater. The feedwater flows into the HRSG at a rate of **q** litre/min as shown in Figure 4.15**.** The amount of steam evaporating from the drums at any time is equal to the amount of feedwater flowing into the drums because the water levels in three drums remain constant (***In*** = ***Out***) during normal operation. In order to simplify the analysis of the dispersion process, the following assumptions are made:

- Chloride contaminant in the boiler water system will not be carried over to the steam system until the contamination reaches the saturation level.

- Water levels in three drums remain constant all the time. Only water phase in three drum systems are considered. Concentrations of the feedwater and the condensate are equal. Steam concentrations in the drums do not require to be considered.

- Chloride concentration in the drum becomes evenly mixed in a very short time so that the dispersion time can be ignored. In reality, the Cl concentration in the drum is higher than the evaporation tubes because the feedwater is directly fed into the drum.

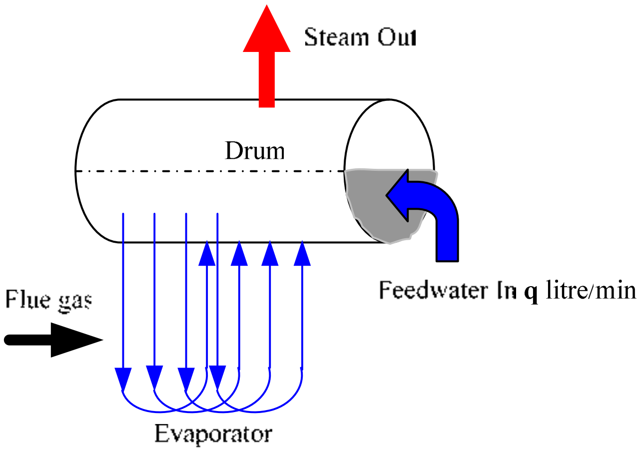


Figure 4.15 Drum model diagram

Let the total chloride (Cl) solute in the three drums equal **x(t)** mg at time **t**; and then consider the Cl variation ***dx*** in the drum systems from **t** to **t** + ***dt*** (***dt*** → ***0***). Cl variation ***dx*** in the drum systems during ***dt*** is

$$dx = x_{in} - x_{out}$$

x_{in} is the total Cl solute flowing into the drum systems at time **t**, which is:

$$x_{in} = y * q * dt$$

Where:

y = Cl concentration in the feedwater (mg/litre)
q = feedwater flow rate (litre/min)
dt = time duration (dt→0)

As feedwater flow rate is equal to condensate flow rate, and Cl concentration in the feedwater is equal to Cl concentration in the condensate, Cl concentration in the feedwater can be expressed using Equation 4.9:

$$y = \frac{c*w}{q} * \left(1 - e^{(\frac{-q*t}{v})}\right)$$

Then,

$$x_{in} = y*q*dt$$

$$x_{in} = \frac{c*w}{q} * \left(1 - e^{(\frac{-q*t}{v})}\right) * q * dt$$

$$x_{in} = c*w*\left(1 - e^{(\frac{-q*t}{v})}\right) * dt \qquad (4.19)$$

Where:

c = Cl concentration in the cooling water (mg/litre)
w = leakage rate through the orifice in the condenser tube (litre/min)
q = feedwater flow rate (litre/min)
v = total volume of water in the condenser hotwell (litre)
t = duration of leakage (minute)

Xout is the total Cl solute that is carried over from the drums to the steam cycle at any time (**t**). Based on the assumption that Cl in the boiler water cycle will not be carried over to the steam cycle until Cl reaches the saturation level in the drums, so **Xout** equals **zero**. Although this model only analyses the scenario where no Cl is carried over to the steam cycle, this analysis covers a sufficient leak time because, in reality, Cl may take a few hours to reach saturation level in the drum. Therefore, Cl variation ***dx*** in the drum systems during ***dt*** is given by:

$$dx = \mathrm{Xin} - \mathrm{Xout}$$

$$= \mathrm{c} * \mathrm{w} * \left(1 - e^{\left(\frac{-q*t}{v}\right)} \right) * dt - 0$$

Then,

$$\frac{dx}{dt} = \mathrm{c} * \mathrm{w} * \left(1 - e^{\left(\frac{-q*t}{v}\right)} \right) \qquad (4.20)$$

Move ***dt*** to the right side of the equation:

$$dx = \mathrm{c} * \mathrm{w} * \left(1 - e^{\left(\frac{-q*t}{v}\right)} \right) dt \qquad (4.21)$$

An assumption is made that the boiler water is pure water without any Cl contaminant before a condenser leak occurs so the Cl solute, **x(t),** in the boiler water is 0 mg when **t** equals 0 (**x(0) = 0**). Therefore, the accumulated Cl in the drum systems at time **t** is:

$$\int_0^x dx = \int_0^t c*w*\left(1-e^{(\frac{-q*t}{v})}\right)dt$$

$$x = c*w*(\int_0^t dt - \int_0^t e^{(\frac{-q*t}{v})} dt)$$

$$= c*w*(t - \left(\frac{-v}{q}\right)\int_0^t e^{(\frac{-q*t}{v})} d\left(\frac{-q}{v}\right)t)$$

$$= c*w*(t + \frac{v}{q}*e^{(\frac{-q*t}{v})}\Big|_0^t)$$

$$= c*w*(t + \frac{v}{q}*(e^{(\frac{-q*t}{v})} - 1))$$

Therefore, the total accumulated Cl, **x(t)** mg, in the three drum systems at time **t** is given by:

$$x = \ c*w*t + \frac{c*w*v}{q}*(e^{(\frac{-q*t}{v})} - 1) \qquad (4.22)$$

Where:

c = Cl concentration in the cooling water (mg/litre)

w = leakage rate through the orifice in the condenser tube (litre/min)

q = feedwater flow rate (litre/min)

v = total volume of water in the condenser hotwell (litre)

t = duration of leakage (minute)

The accumulated Cl in each individual drum system at time **t** is equal to the product of total accumulated Cl in the drum systems and the ratio of the feedwater flow rate to each individual drum to the total feedwater flow rate. Take the HP system for example, the accumulated Cl in the HP drum system, x_{HP}, is:

$$x_{HP} = x * \frac{q_{HP}}{q} = \left(c * w * t + \frac{c * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{HP}}{q} \quad (4.23)$$

Where:

x_{HP} = accumulated Cl in the HP drum system (mg)

q_{HP} = feedwater to the HP drum flow rate (litre/min)

q = total feedwater flow rate (litre/min)

According to Equation 4.23, the accumulated Cl in the IP drum system, x_{IP}, is:

$$x_{IP} = x * \frac{q_{IP}}{q} = \left(c * w * t + \frac{c * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{IP}}{q} \quad (4.24)$$

Where:

x_{IP} = accumulated Cl in the IP drum system (mg)

q_{IP} = feedwater to the IP drum flow rate (litre/min)

q = total feedwater flow rate (litre/min)

The accumulated Cl in the LP drum system, x_{LP}, is:

$$x_{LP} = x * \frac{q_{LP}}{q} = \left(c * w * t + \frac{c * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{LP}}{q} \quad (4.25)$$

Where:

x_{LP} = accumulated Cl in the LP drum system (mg)

q_{LP} = feedwater to the LP drum flow rate (litre/min)

q = total feedwater flow rate (litre/min)

The Cl concentration **z(t)** in each individual drum system is equal to the accumulated Cl ***x*(t)** in each drum system divided by the volume of water of each individual drum system **h**. Take the HP system for example, Cl concentration in the HP drum system, z_{HP} , is given by:

$$z_{HP} = \frac{x_{HP}}{h_{HP}} * 1000 = \left(c * w * t + \frac{c * w * v}{q} * \left(e^{\left(\frac{-q*t}{v}\right)} - 1\right) \right) * \frac{q_{HP}}{q} * 1000 / h_{HP} \quad (4.26)$$

Where:

z_{HP} = Cl concentration in the HP drum system (ppb, 1 mg/litre = 1000 ppb)

x_{HP} = accumulated Cl in the HP drum system (mg)

h_{HP} = volume of boiler water in the HP drum system (litre)

c = Cl concentration in the cooling water (mg/litre)

w = leakage rate through the orifice in the condenser tube (litre/min)

t = duration of leakage (minute)

q = total feedwater flow rate (litre/min)

v = total volume of water in the condenser hotwell (litre)

q_{HP} = feedwater to HP drum flow rate (litre/min)

According to Equation 4.26, Cl concentration in the IP drum system, z_{IP}, is given by:

$$z_{IP} = \frac{x_{IP}}{h_{IP}} * 1000 = \left(c * w * t + \frac{c * w * v}{q} * \left(e^{\left(\frac{-q*t}{v}\right)} - 1\right) \right) * \frac{q_{IP}}{q} * 1000 / h_{IP} \quad (4.27)$$

Where:

z_{IP} = Cl concentration in the IP drum system (ppb, 1 mg/litre = 1000 ppb)

x_{IP} = accumulated Cl in the IP drum system (mg)

h_{IP} = volume of boiler water in the IP drum system (litre)

q_{IP} = feedwater to IP drum flow rate (litre/min)

Cl concentration in the LP drum system, z_{LP}, is given by:

$$z_{LP} = \frac{x_{LP}}{h_{LP}} * 1000 = \left(c * w * t + \frac{c * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{LP}}{q} * 1000 / h_{LP} \quad (4.28)$$

Where:

z_{LP} = Cl concentration in the LP drum system (ppb, 1 mg/litre = 1000 ppb)

x_{LP} = accumulated Cl in the LP drum system (mg)

h_{LP} = volume of boiler water in the LP drum system (litre)

q_{LP} = feedwater to LP drum flow rate (litre/min)

4.3.5 Case Study on HRSG Drum System Model

As analysed in the condenser hotwell model, the feedwater flow rate increases as the unit load rises so more Na and Cl is transported from the condenser hotwell to the HRSG at high load. The higher the load, the more severe the contamination of the HRSG. Since the most serious contamination of the HRSG takes place at full load, contamination at full load (380 MW) has been used in the following example. The feedwater flow rate to the HRSG is 6000 litre/min (100 kg/s) at 380MW. Assume that the radius of the leak orifice (r) in the condenser tube is 1 mm. Na and Cl are taken as analysis parameters.

c_1 = 23000 mg/litre (Cl concentration in cooling water sampled on 09/03/2007)

c_2= 13000 mg/litre (Na concentration in cooling water sampled on 09/03/2007)

q = 6000 litre/min (Condensate flow at full load 380MW)

ΔP = 2.2 bar (Differential pressure between the condensate side and the cooling water side)

According to Equation 4.10, the total volume of the condensate (**v**) in the condenser hotwell is 21600 litres.

Leakage rate (w) through the 1 mm radius orifice with a 2.2 bar differential pressure can be calculated using Equation 4.3:

$$w = C*A*\sqrt{2*\Delta P}\ *0.6$$

$$= 0.62*3.14*1^2*\sqrt{2*2.2}\ *0.6$$

$$= 2.45 \text{ litre/min}$$

A drum system consists of a drum and an evaporator. As the HRSG consists of three drums, the feedwater is divided into three separate streams, one to each individual drum system. Table 4.1 shows the volume of water in each pressure section and the flow rate to each drum system at 380MW. Each drum system needs to be analysed individually as they have different volumes and flow rates.

Table 4.1 Feedwater flow rate to each drum system

HRSG Drum System	Volume (litre)		Flow Rate		Percent of Total Feedwater
	Evaporator	Drum	kg/s	litre/min	
HP drum system	144000	37700	73	4380	0.73
IP drum system	40890	16140	15	900	0.15
LP drum system	76810	17530	12	720	0.12
Feedwater flow rate is 100 kg/s (6000 litre/min) at 380MW.					

- **HP Drum System**

As the HP drum system consists of a HP evaporator and a HP drum, and the drum is half full of water, the total volume of water in the HP drum system, h_{HP}, is:

$$h_{HP} = 144000 + 37700/2 = 162850 \text{ litres}$$

The flow rate of the feedwater into the HP drum, q_{HP}, is 4380 litre/min as shown in

Table 4.1. According to Equation 4.26, Cl concentration in the HP drum system, z_{HPCl}, is given by:

$$z_{HPCl} = \left(c_1 * w * t + \frac{c_1 * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{HP}}{q} * 1000 / h_{HP}$$

$$= \left(23000 * 2.45 * t + \frac{23000 * 2.45 * 21600}{6000} * (e^{(\frac{-6000*t}{21600})} - 1) \right) * \frac{4380}{6000} * 1000 / 162850$$

Then,

$$z_{HPCl} = 252.6 * t + 909.35 * (e^{(-0.2778*t)} - 1) \qquad (4.29)$$

According to Equation 4.26, Na concentration in the HP drum system, z_{HPNa}, is:

$$z_{HPNa} = \left(c_2 * w * t + \frac{c_2 * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{HP}}{q} * 1000 / h_{HP}$$

$$= \left(13000 * 2.45 * t + \frac{13000 * 2.45 * 21600}{6000} * (e^{(\frac{-6000*t}{21600})} - 1) \right) * \frac{4380}{6000} * 1000 / 162850$$

Then,

$$z_{HPNa} = 142.77 * t + 513.98 * (e^{(-0.2778*t)} - 1) \qquad (4.30)$$

- **IP Drum System**

As the IP drum system consists of an IP evaporator and an IP drum, and the drum is half full of water, the total volume of water in the IP drum system, h_{IP}, is:

h_{IP} = 40890 + 16140/2 = 48960 litres

The flow rate of the feedwater into the IP drum, q_{IP}, is 900 litre/min as shown in Table 4.1. According to Equation 4.27, Cl concentration in the IP drum system, z_{IPCl}, is:

$$z_{IPCl} = \left(c_1 * w * t + \frac{c_1 * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{IP}}{q} * 1000 / h_{IP}$$

$$= \left(23000 * 2.45 * t + \frac{23000 * 2.45 * 21600}{6000} * (e^{(\frac{-6000*t}{21600})} - 1) \right) * \frac{900}{6000} * 1000 / 48960$$

Then,

$$z_{IPCl} = 172.64 * t + 621.51 * (e^{(-0.2778*t)} - 1) \qquad (4.31)$$

According to Equation 4.27, Na concentration in the IP drum system, z_{IPNa}, is:

$$z_{IPNa} = \left(c_2 * w * t + \frac{c_2 * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{IP}}{q} * 1000 / h_{IP}$$

$$= \left(13000 * 2.45 * t + \frac{13000 * 2.45 * 21600}{6000} * (e^{(\frac{-6000*t}{21600})} - 1) \right) * \frac{900}{6000} * 1000 / 48960$$

Then,

$$z_{IPNa} = 97.58 * t + 351.29 * (e^{(-0.2778*t)} - 1) \qquad (4.32)$$

- **LP Drum**

As the LP drum system consists of a LP evaporator and a LP drum, and the drum is half full of water, the total volume of water in the LP drum system, h_{LP}, is:

$$h_{LP} = 76810 + 17530/2 = 85575 \text{ litres}$$

The flow rate of the feedwater into the LP drum, q_{LP}, is 720 litre/min as shown in Table 4.1. According to Equation 4.28, Cl concentration in the LP drum system, z_{LPCl}, is:

$$z_{LPCl} = \left(c_1 * w * t + \frac{c_1 * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{LP}}{q} * 1000 / h_{LP}$$

$$= \left(23000 * 2.45 * t + \frac{23000 * 2.45 * 21600}{6000} * (e^{(\frac{-6000*t}{21600})} - 1) \right) * \frac{720}{6000} * 1000 / 85575$$

Then,

$$z_{LPCl} = 79.02 * t + 284.47 * (e^{(-0.2778*t)} - 1) \qquad (4.33)$$

According to Equation 4.28, Na concentration in the LP drum system, z_{LPNa}, is:

$$z_{LPNa} = \left(c_2 * w * t + \frac{c_2 * w * v}{q} * (e^{(\frac{-q*t}{v})} - 1) \right) * \frac{q_{LP}}{q} * 1000 / h_{LP}$$

$$= \left(13000 * 2.45 * t + \frac{13000 * 2.45 * 21600}{6000} * (e^{(\frac{-6000*t}{21600})} - 1) \right) * \frac{720}{6000} * 1000 / 85575$$

Then,

$$z_{LPNa} = 44.66 * t + 160.79 * (e^{(-0.2778*t)} - 1) \qquad (4.34)$$

Figure 4.16, plotted using Equations 4.29 and 4.30, shows the Cl and Na concentrations in the HP drum. The concentration curves are exponential curves, which means that Na and Cl concentrations in the HP drum increases at an accelerating rate. This is because all of the Na and Cl contaminants remain in the water cycle of the drum system until they reach saturation level at which time they will be carried over into the steam cycle of the HRSG. Even when the contaminants reach their saturation level, only a very small amount of contaminant will be carried over to the steam cycle compared to the total amount of contaminants flowing into the drum system.

As shown in Figure 4.16, Cl and Na concentrations in the HP drum system will reach 500 ppb (Action level 4) 4.6 and 6.6 minutes respectively after the contaminated feedwater flows into the drum. Cl concentration rises faster because the Cl concentration in the cooling water is higher than that of Na. Table A.7 in Appendix A lists detailed data.

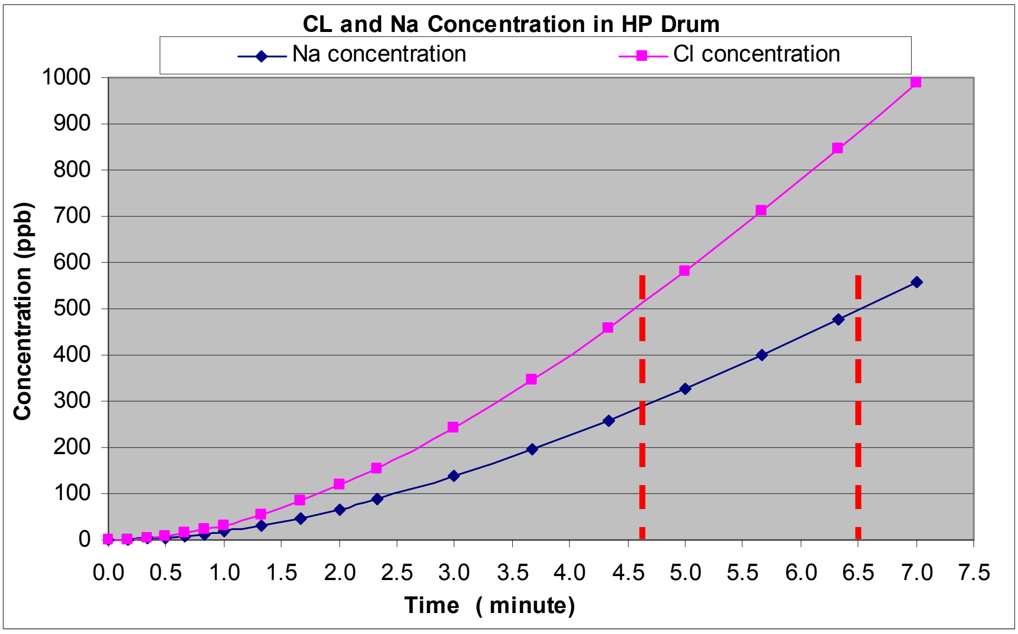


Figure 4.16 Cl and Na concentrations in HP drum system

Figure 4.17, plotted using Equations 4.29, 4.31, and 4.33, shows Cl concentrations in the HP, IP and LP drum systems. All three concentration curves increase at an accelerating rate. Cl concentration in the HP drum increases fastest, which means that the HP system will suffer the most serious contamination in the event of condenser in-leakage. This is because 73 percentage of the contaminated feedwater flows into the HP drum system.

The contamination level in the LP drum system will be much lower than that in the IP drum system because even though the volume of contaminated feedwater flowing into the IP and LP drum systems is similar, the volume of water in the LP drum system is twice the volume of water in the IP drum system (as shown in Table 4.1). Table A.8 in Appendix A lists detailed data.

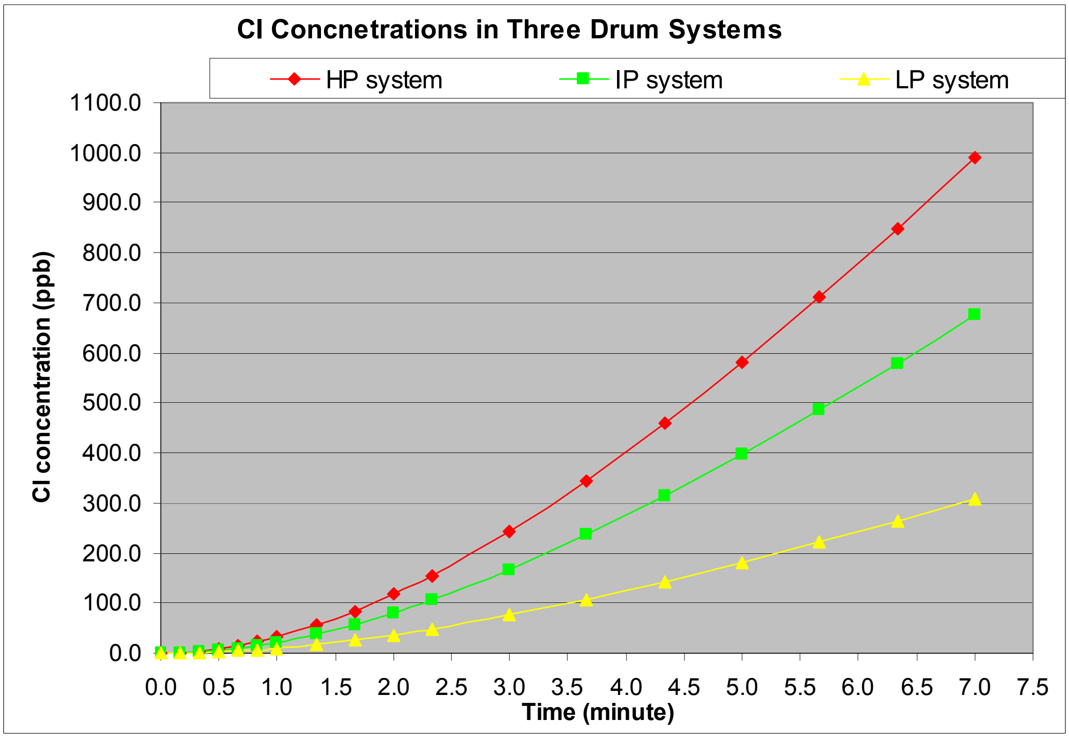


Figure 4.17 Cl concentrations in the three drum systems

4.3.6 Summary of HRSG Drum System Model

The HRSG drum system model is a mathematical model based on the dynamic process. The model substantially represents the actual process even though some assumptions have been made to ignore minor factors.

The results of the analysis show that Cl and Na concentrations in three drums display the same tendency and will accumulate in the drums at an accelerating rate. Contamination in the HP drum increases fastest among the three drums because 73 percent of the contaminated feedwater flows into the HP drum system. Therefore, the HP drum system will suffer the most serious contamination among the three drums if contaminated feedwater flows into all three drums at the same time.

According to the analysis, the theoretical time for the Cl concentration to reach 500 ppb (Action Level 4) in the HP drum is approximately 4.6 minutes as shown in Figure 4.16, whereas it will only take 12 seconds to reach the same value in the condenser hotwell. Compared to the HP drum system, it only takes a very short time for Na and Cl in the condenser to reach action level 4. Therefore, the condenser is still the most vulnerable place to be considered in the event of condenser in-leakage. However, contamination of the drum systems also requires close monitoring because once Na and Cl concentrations reach their saturation level, they will be carried over to the steam cycle, and to the steam turbine. Even though a very small amount of Na and Cl is carried over to the steam cycle, the damage to the steam cycle facilities and the steam turbine will be very serious.

4.3.7 General Water Cycle Model

The major facilities in the water cycle of the plant consist of the condenser, condensate preheater, economisers and drums. The preheater and economisers are heat exchangers located in the HRSG, which heat the water flowing through them and improve the HRSG efficiency by extracting heat from the gas turbine exhaust gases.

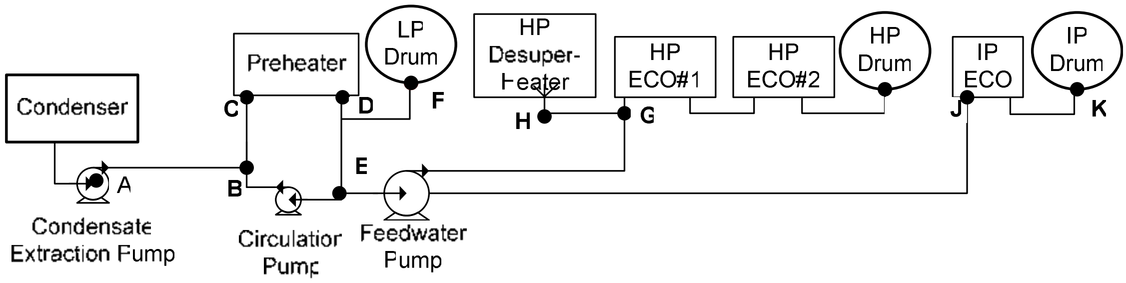


Figure 4.18 Simplified water cycle flow diagram

Figure 4.18 shows the simplified water cycle flow diagram. The condensate is extracted from the condenser by the condensate extraction pump, and after flowing through the condensate preheater it is separated into three individual streams. The first stream goes to the LP drum directly (*D* – *F*); the second stream goes back to the inlet of the preheater through the circulation pump (*E* – *B* – *C*); the third stream goes to the feedwater pump.

From the feedwater pump discharge side, the feedwater is divided into two streams. The first stream passes through two HP economisers (HP ECO#1 and HP ECO#2) then to the HP drum (*E* – *G* – *I*). The second stream goes to the IP drum via the IP economiser (IP ECO) (*E* – *J* – *K*). The HP desuperheater (*G* – *H*) is only used during startup or shutdown, so there is no flow during normal operation.

The feedwater travel time is a critical parameter when analysing the impact of condenser in-leakage on the drum systems. As shown in Figure 4.18, the physical distances from the condenser to the three drums are different. In addition, the physical size of the various water pipes and economisers are different. All these factors have a significant impact on the feedwater travel time from the condenser to different drums. A shorter travel time requires the quicker response. The water travel time in the pipelines and economisers are individually analysed in the following model. Finally, the contamination situation from the condenser to the different drums in the water cycle of the HRSG will be analysed in an integrated model.

4.3.7.1 Water Travel Time through Pipelines

The fluid velocity in the pipe equals the flow rate divided by the inside cross-sectional area of the pipe and is given by:

$$v = q/A \qquad (4.35)$$

Where:

v = fluid velocity (dm/min)
q = flow rate (litre/min)
A= inside cross-sectional area of the pipe (dm^2)

The travel time between two points in the pipe is equal to the length of pipe between two points divided by the fluid velocity and is given by:

$$t = \lambda / v \qquad (4.36)$$

Where:

t = travel time (minute)

λ= pipe length (metre)

v = fluid velocity (m/min)

4.3.7.2 Water Travel Time through Preheater

The preheater is the first heat exchanger in the HRSG through which the condensate passes. As shown in Figure 4.18, the condensate travel time through the preheater is the time taken from point ***C*** to point ***D***. Table 4.2 shows the technical data for the condensate preheater.

Table 4.2 Technical data for condensate preheater

Tube Outside Diameter (OD)	50.8	mm
Tube wall thickness	2.667	mm
Tube Inside Diameter (ID)	45.5	mm
Tube radius (r)	22.73	mm
Tube inside cross-sectional area	1622.7	mm^2
Tube length	17.678	m
No. of rows	11	
No. transverse sections	140	
No. of flow circuits	70	

According to the manual provided by the manufacturer, the main technical terms are explained as follows:

- **Rows** of tubes perpendicular to the gas flow, and are numbered in the direction of the gas flow in the HRSG. Row #1 of a particular bundle would be the hottest row of tubes.

- **Transverse Sections** refers to the number of tubes per row.
- **Flow circuits** refers to the number of parallel flow paths into which the flow is equally divided.
- **Coil** refers to a specific group of tubes, such as in the HP Superheater.

As can be see from Table 4.2, the preheater is half-circuit flow because the number of flow circuits is half the number of transverse sections. Figure 4.19 shows a schematic diagram of how water flows through the preheater. As shown in the diagram, the half-circuit means that there are half as many circuits as there are transverse sections in a given coil such that half of the flow is travelling downward and half of the flow is travelling upward in any given row of the coil.

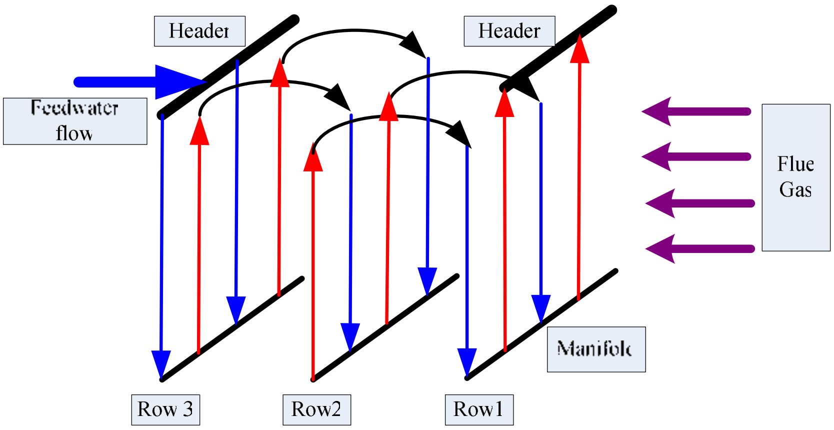


Figure 4.19 Diagram of water flowing through the preheater

The flow rate through each flow circuit in the preheater, $\mathbf{q}_{ph}$, is given by:

$$q_{ph} = (q + q_r) / n_f \qquad (4.37)$$

Where:

q_{ph} = flow rate through each flow circuit in the preheater (litre/min)

q = total condensate flow rate (litre/min)

q_r = condensate recirculation flow rate (litre/min)

n_f = No. of flow circuits

According to Equation 4.35, the flow velocity in a single preheater tube, $\mathbf{v}_{ph}$, is given by:

$$v_{ph} = q_{ph} / A = (q + q_r) / (n_f * A) \qquad (4.38)$$

Where:

v_{ph} = flow velocity in a single preheater tube (dm/min)

q_{ph} = flow rate through each flow circuit in the preheater (litre/min)

A = inside cross-sectional area of the tube (dm^2)

As half of the flow is travelling downward and half of the flow is travelling upward in any given row of a coil in the preheater, the pipe length in any row doubles. The total length of tube of one entire circuit, $\mathbf{h}_{ph}$, is given by:

$$h_{ph} = n_r * \lambda * 2 \qquad (4.39)$$

Where:

h_{ph} = length of one circuit in the preheater (metre)

n_r = No. of rows

λ= length of each single tube (metre)

According to Equation 4.36, the condensate travel time through the preheater, $\mathbf{t}_{ph}$, is therefore given by:

$$t_{ph} = h_{ph} / v_{ph} = \frac{n_r * \lambda * 2}{(q + q_r)\ /\ (n_f * A)} * 10 \qquad (4.40)$$

Where:

t_{ph} = condensate travel time through the preheater (minute)

h_{ph} = length of one circuit in the preheater (metre)

v_{ph} = flow velocity in a single preheater tube (dm/min)

n_r = No. of rows

λ= length of each single tube (metre)

q = total condensate flow rate (litre/min)

q_r = condensate recirculation flow rate (litre/min)

n_f = No. of flow circuits

A = inside cross-sectional area of the tube (dm^2)

4.3.7.3 Water Travel Time through Economisers

1) Feedwater travel time through the HP economisers

As can be seen from Figure 4.18 (Page 74), the feedwater travel time through HP economisers #1 and #2 is taken from point ***G*** to point ***I***. The feedwater travel time through HP economisers #1 and #2 has been calculated separately because each has different technical data.

- **HP Economiser #1**

Table 4.3 shows the technical data for the HP economiser #1. HP economiser #1 is half-circuit flow as the number of flow circuits is half the number of transverse sections.

Table 4.3 Technical data for HP economiser #1

Tube OD	50.8	mm
Tube wall thickness	3.251	mm
Tube ID	44.3	mm
Tube radius	22.15	mm
Tube inside cross-sectional area	1540.4	mm^2
Tube length	17.678	m
No. of rows	7	
No. Transverse sections	112	
No. of flow circuits	56	

With reference to Equation 4.40, the feedwater travel time through HP economiser #1, $\mathbf{t}_{h1}$, is given by:

$$t_{h1} = h_{h1} / v_{h1} = \frac{n_r * \lambda * 2}{q_{h1} \;/ (n_f * A)} *10 \qquad (4.41)$$

Where:

t_{h1} = feedwater travel time through HP economiser #1 (minute)

h_{h1} = length of one circuit in HP economiser #1 (metre)

v_{h1} = flow velocity in a single HP economiser #1 tube (dm/min)

n_r = No. of rows

λ= length of each single tube (metre)

q_{h1} = HP feedwater flow rate (litre/min)

n_f = No. of flow circuits

A = inside cross-sectional area of the tube (dm^2)

- **HP Economiser #2**

Table 4.4 shows the technical data for the HP economiser #2. As can be see from Table 4.4, HP economiser #2 is half-circuit flow as the number of flow circuits is half the number of transverse sections.

Table 4.4 Technical data for HP economiser #2

Tube OD	50.8	mm
Tube wall thickness	3.2	mm
Tube ID	44.4	mm
Tube radius	22.2	mm
Tube inside cross-sectional area	1547.5	mm^2
Tube Length	17.678	m
No. of Rows	9	
No. Transverse Sections	140	
No. of Flow Circuits	70	

With reference to Equation 4.41, the feedwater travel time through HP economiser #2, $\mathbf{t}_{h2}$, is given by:

$$t_{h2} = \frac{n_r * \lambda * 2}{q_{h2} \ / (n_f * A)} * 10 \qquad (4.42)$$

Where:

t_{h2} = feedwater travel time through HP economiser #2 (minute)

n_r = No. of rows

λ= length of each single tube (metre)

q_{h2} = HP feedwater flow rate (litre/min)

n_f = No. of flow circuits

A = inside cross-sectional area of the tube (dm^2)

2) Feedwater travel time through IP economiser

As can be seen from Figure 4.18 (Page 74), the feedwater travel time through the IP economiser is the time taken from point ***J*** to point ***K***. Table 4.5 shows the technical data for the IP economiser. The IP economiser is half-circuit flow as the number of flow circuits is half the number of transverse sections.

Table 4.5 Technical data for IP economiser

Tube OD	50.8	mm
Tube wall thickness	2.667	mm
Tube ID	45.5	mm
Tube radius	22.73	mm
Tube inside cross-sectional area	1622.7	mm²
Tube length	17.678	m
No. of rows	7	
No. transverse sections	28	
No. of flow circuits	14	

According to Equation 4.41, the feedwater travel time through the IP economiser, $\mathbf{t}_{ip}$, is given by:

$$\mathbf{t}_{ip} = \frac{n_r * \lambda * 2}{q_{ip} \ / (n_f * A)} * 10 \qquad (4.43)$$

Where:

t_{ip} = feedwater travel time through the IP economiser (minute)

n_r = No. of rows

λ= length of each single tube (metre)

q_{ip} = IP feedwater flow rate (litre/min)

n_f = No. of flow circuits

A = inside cross-sectional area of the tube (dm^2)

4.3.8 Case Study on General Water Cycle Model

As analysed in the condenser model and the HRSG drum model, the feedwater flow rate increases as the unit load rises so more Na and Cl contaminants are transported into the HRSG at higher load. The higher the load, the faster and more severe the contamination of the HRSG. The most serious contamination of the HRSG takes place at full load. In addition, Otahuhu B station is a large base load power station and more than half the operating time is spent running at full load (380 MW). Condenser in-leakage is more likely to occur at full load, hence the full load situation is studied in this section. Table 4.6 shows condensate and feedwater flow rates at 380 MW.

Table 4.6 Condensate and feedwater flow rates through the different systems at full load

	Condensate	**Condensate Circulation**	**LP System**	**IP System**	**HP System**
Flow Rate (litre/min)	6000	1740	720	900	4380

In order to analyse the contamination situation at different points in the water cycle, the water travel time through the major pipelines, the preheater and the economisers must be calculated individually.

4.3.8.1 Water Travel Time through Major Pipelines

Table 4.7 shows the technical data for the water cycle pipelines represented in Figure 4.20. The length of the pipes was measured using a tape measure or was obtained from the plant drawings. All other data came from the plant manuals provided by the manufacture.

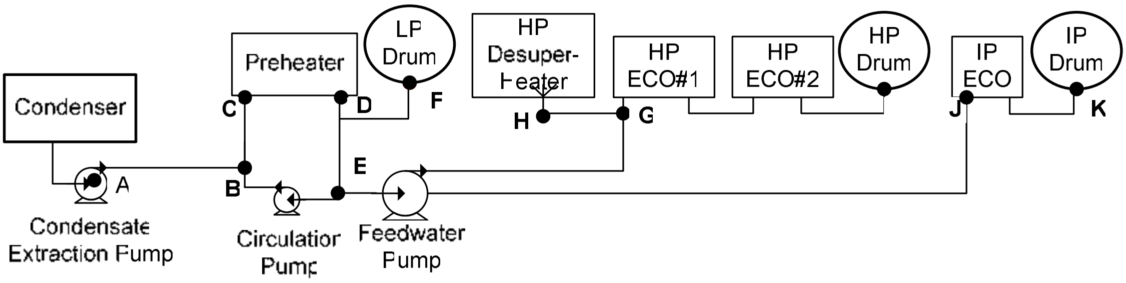


Figure 4.20 Simplified water cycle flow diagram

Table 4.7 Technical data for major pipelines [1]

Location	**Pipe size**	**OD**	**Thickness**	**ID**	**r**	**A**	**Length**
		mm	**mm**	**mm**	**mm**	**mm2**	**m**
A - B	**10"**	273.1	9.27	254.56	127.28	50869	85
B - C	**10"**	273.1	9.27	254.56	127.28	50869	35
D - E	**10"**	273.1	9.27	254.56	127.28	50869	35
D - F	**3"**	88.9	5.49	77.92	38.96	4766	15
E - G	**8"**	219.1	22.23	174.54	87.27	23914	42
E - J	**4"**	114.3	8.56	97.18	48.6	7414	45
OD=Outside Diameter; **ID**=Inside Diameter; **A** = Pipe inside cross-sectional area							

The water travel time through each pipeline shown in Table 4.7 is calculated as follows using Equations 4.35 and 4.36:

A – B: $\lambda = 85$ m; $q = 6000$ litre/min; $A = 5.0869$ dm^2

$$v = q / A = 6000 / 5.0869 = 1180 \text{ dm/min} = 118 \text{ m/min}$$

$$t = \lambda / v = 85 / 118 = 0.72 \text{ minutes}$$

B – C: λ = 35 m; q = 6000 + 1740 = 7740 litre/min; A= 5.0869 dm²

v = q / A = 7740 / 5.0869 = 1522 dm/min = 152.2 m/min

t = λ/ v = 35 / 152.2 = 0.23 minutes

D – E: λ = 35 m; q = 6000 + 1740 – 720 = 7020 litre/min; A= 5.0869 dm²

v = q / A = 7020 / 5.0869 = 1380 dm/min = 138 m/min

t = λ/ v = 35 / 138 = 0.25 minutes

D – F: λ = 15 m; q = 720 litre/min; A= 0.4766 dm²

v = q / A = 720 / 0.4766 = 1511 dm/min = 151.1 m/min

t = λ/ v = 15 / 151.1 = 0.1 minutes

E – G: λ= 42 m; q = 4380 litre/min; A= 2.391dm²

v = q / A = 4380 / 2.391 = 1832 dm/min = 183.2 m/min

t = λ/ v = 42 / 183.2 = 0.23 minutes

E – J: λ= 45 m; q = 900 litre/min; A= 0.7414 dm²

v = q / A = 900 / 0.7414 = 1214 dm/min = 121.4 m/min

t = λ/ v = 45 / 121.4= 0.37 minutes

The detailed data for the water travel time through each pipeline is summarised in Table 4.8. The HP desuperheater is not used during normal operation so the flow rate through the pipeline ***G*** – ***H*** is zero.

Table 4.8 Water travel time through pipeline

	A - B	**B - C**	**D - E**	**D - F**	**E - G**	**G - H**	**E - J**
Flow rate (litre/min)	6000	7740	7020	720	4380.0	0	900
Velocity (m/min)	118.0	152.2	138.0	151.1	182.9		121.4
Travel time (minute)	**0.72**	**0.23**	**0.25**	**0.1**	**0.23**		**0.37**

4.3.8.2 Water Travel Time through Preheater and Economisers

1) Condensate travel time through the preheater

According to Table 4.2 and Equation 4.40, the condensate travel time through the preheater, $\mathbf{t}_{ph}$, at full load (q = 6000 litre/min, q_r = 1740 litre/min) is:

$$t_{ph} = \frac{n_r * \lambda * 2}{(q + q_r)/(n_f * A)} * 10$$

$$= \frac{11 * 17.678 * 2}{(6000 + 1740)/(70 * 3.14 * (0.2273)^2)} * 10$$

= 5.71 minutes

2) Feedwater travel time through the HP economisers

- HP Economiser #1

  According to Table 4.3 and Equation 4.41, the HP feedwater travel time through HP economiser #1, $\mathbf{t}_{h1}$**,** at full load (q_{h1} = 4380 litre/min) is:

$$t_{h1} = \frac{n_r * \lambda * 2}{q_{h1} \;/(n_f * A)} * 10$$

$$= \frac{7 * 17.678 * 2}{4380 * /(56 * 3.14 * (0.2215)^2)} * 10$$

= 4.87 minutes

- HP Economiser #2

  According to Table 4.4 and Equation 4.42, the HP feedwater travel time through HP economiser #2, $\mathbf{t}_{h2}$, at full load (q_{h2} = 4380 litre/min) is:

$$t_{h2} = \frac{n_r * \lambda * 2}{q_{h2} \;/(n_f * A)} * 10$$

$$= \frac{9 * 17.678 * 2}{4380 * /(70 * 3.14 * (0.222)^2)} * 10$$

= 7.87 minutes

3) Feedwater travel time through the IP economiser

According to Table 4.5 and Equation 4.43, the IP feedwater travel time through the IP economiser, $\mathbf{t}_{ip}$, at full load (q_{ip} = 900 litre/min) is

$$t_{ip} = \frac{n_r * \lambda * 2}{q_{ip} \;\; / (n_f * A)} * 10$$

$$= \frac{7 * 17.678 * 2}{900 * / (14 * 3.14 * (0.2273)^2)} * 10$$

= 6.25 minutes

4.3.8.3 General Analysis of Water Cycle System

Figure 4.21 shows a simplified water cycle diagram of the plant. Table 4.9 summarises detailed data for the water travelling through each part of the system, which includes flow rate, velocity and travel time.

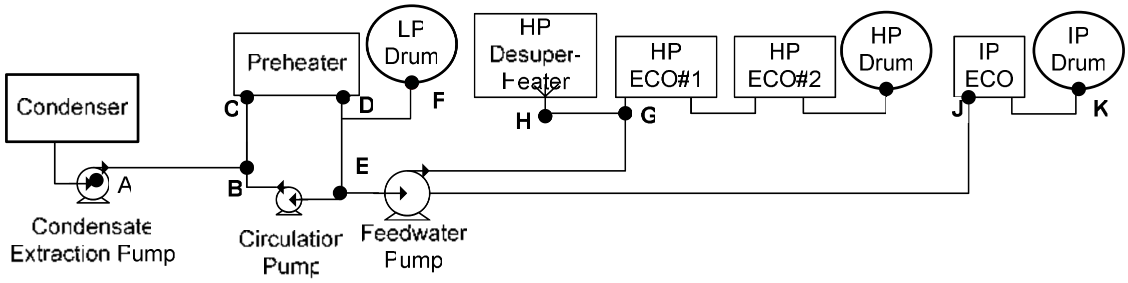


Figure 4.21 Simplified water cycle system diagram

Table 4.9 Water travel time in the water cycle system

			Preheater				**HP ECOs**			**IP ECO**
	A - B	B - C	C – D	D - E	D - F	E - G	G -I		E - J	J - K
Flow Rate (litre/min)	6000	7740	7740	7020	720	4380	4380		900	900
Velocity (m/min)	118.0	152.2	68.14	138.0	151.1	182.9	50.78 (#1)	40.43 (#2)	121.4	39.6
Travel time (minute)	0.72	0.23	5.71	0.25	0.10	0.23	4.87 (#1)	7.87 (#2)	0.37	6.25

#1 = HP economiser #1 #2 = HP economiser #2

As shown in Figure 4.21, the water travel time from the condenser to the preheater, Economisers, LP drum, IP drum and HP drum at full load can be calculated respectively as following:

- Condenser to preheater (A-B-C)

  $\mathbf{t}_{PRE} = 0.72 + 0.23 = 0.95$ minutes

  The time for the condensate to travel from the condenser to the preheater，$\mathbf{t}_{PRE}$ (A-C)，is only 0.95 minutes (57 seconds).

- Condenser to LP drum (A-B-C-D-F)

  $t_{LP} = 0.72 + 0.23 + 5.71 + 0.1 = 6.76$ minutes

  The time for the condensate to travel from the condenser to the LP drum is 6.76 minutes, which means that contamination of the LP drum will start 6.76 minutes after condenser in-leakage occurs.

- Condenser to IP economiser (A-B-C-D-E-J)

  $\mathbf{t}_{IPE} = 0.72 + 0.23 + 5.71 + 0.25 + 0.37 = 7.28$ minutes

  The time for the feedwater to travel from the condenser to the IP Economiser，$\mathbf{t}_{IPE}$ (A-J), is 7.28 minutes.

- Condenser to IP drum (A-B-C-D-E-J-K)

  $t_{IP} = 0.72 + 0.23 + 5.71 + 0.25 + 0.37 + 6.25 = 13.53$ minutes

  The time for the feedwater to travel from the condenser to the IP drum is 13.53 minutes, which means that contamination of the IP drum will start 13.53 minutes after condenser in-leakage occurs.

- Condenser to HP economiser #1(A-B-C-D-E-G)

  $t_{HPE1} = 0.72 + 0.23 + 5.71 + 0.25 + 0.23 = 7.14$ minutes

  The time for the feedwater to travel from the condenser to the HP Economiser #1，

$\mathbf{t}_{HPE1}$(A – G)，is 7.14 minutes.

- Condenser to HP drum (A-B-C-D-E-G-I)

$$t_{HP} = 0.72 + 0.23 + 5.71 + 0.25 + 0.23 + 4.87 + 7.87 = 19.88 \text{ minutes}$$

The time for the feedwater to travel from the condenser to the HP drum is 19.88 minutes, which means that contamination of the HP drum will start 19.88 minutes after condenser in-leakage occurs.

Compared to the water travel time in the preheater and economisers, the feed water travel time through the major pipelines is quite short because of high flow velocities that are between 118 m/min and 182.9 m/min. Therefore, the accuracy of major pipeline's length does not have a critical effect on the modelling result. Table 4.10 summarises the water travel time from condenser to major parts in the water cycle at full load (380 MW).

Table 4.10 Water travel time from condenser to major parts in water cycle system

	Preheater A – C	LP drum A – F	IP ECO A – J	IP drum A – K	HP ECO#1 A – G	HP drum A – I
Travel time from condenser (minute)	0.95	6.76	7.28	13.53	7.14	19.88

Now assume that a condenser leak occurs at full load (380 MW) and the radius of the leak orifice (r) in the condenser tube is 1 mm. Cl concentration in the cooling water is 23000 mg/litre (sampled on 09/03/2007). If conditions remain the same as in condenser model case study 1 (page 46) then Cl contamination at different locations in the water cycle is as follows:

- **Condenser**

According to Equation 4.12, Cl contamination in the condenser hotwell, y_{CON}, is given by:

$$y_{CON} = 9392 * \left(1 - e^{(-0.2778*t)}\right) \qquad (4.44)$$

Contamination of the condenser hotwell starts immediately when condenser in-leakage occurs. Based on the assumption that the Cl concentration in the condenser hotwell becomes evenly dispersed very quickly, Cl concentration in the condenser hotwell is always the same as the concentration in the condensate that is extracted to the feedwater system. Therefore, y_{CON} is the Cl concentration in the condensate flowing into the preheater.

- **Preheater**

As shown in Table 4.10, the contaminated condensate will reach the preheater 0.95 minutes after the condenser leak occurs, which means when the leak time is less than 0.95 minutes, Cl contamination in the preheater, y_{PRE}, is 0. Therefore, according to Equation 4.44, y_{PRE}, is:

$$\begin{cases} y_{PRE} = 0 & t \le 0.95\text{minutes} \\ y_{PRE} = 9392 * \left(1 - e^{(-0.2778*t)}\right) & t > 0.95\text{minutes} \end{cases} \qquad (4.45)$$

- **LP Drum**

The contaminated condensate will reach the LP drum 6.76 minutes after the condenser leak occurs as shown in Table 4.10. According to Equation 4.33, Cl contamination in the LP drum, y_{LP}, is given by:

$$\begin{cases} y_{LP} = 0 & t \le 6.76\text{minutes} \\ y_{LP} = 79.02 * t + 284.47 * (e^{(-0.2778*t)} - 1) & t > 6.76\text{minutes} \end{cases} \qquad (4.46)$$

- **IP Economiser**

The contaminated feedwater will reach the IP economiser 7.28 minutes after the condenser leak occurs as shown in Table 4.10. According to Equation 4.44, Cl contamination in the IP economiser, y_{IPE}, is given by:

$$\begin{cases} y_{IPE} = 0 & t \le 7.28\text{minutes} \\ y_{IPE} = 9392 * \left(1 - e^{(-0.2778*t)}\right) & t > 7.28\text{minutes} \end{cases} \qquad (4.47)$$

●IP Drum

The contaminated feedwater will reach the IP drum 13.53 minutes after the condenser leak occurs as shown in Table 4.10. According to Equation 4.31, Cl contamination in the IP drum, y_{IP}, is given by:

$$\begin{cases} y_{IP} = 0 & t \le 13.53\text{minutes} \\ y_{IP} = 172.64 * t + 621.51 * (e^{(-0.2778*t)} - 1) & t > 13.53\text{minutes} \end{cases} \qquad (4.48)$$

●HP ECO#1

The contaminated feedwater will reach the HP economiser #1 7.14 minutes after the condenser leak occurs as shown in Table 4.10. According to Equation 4.44, Cl contamination in the HP economiser #1, y_{HPE1}, is given by:

$$\begin{cases} y_{HPE1} = 0 & t \le 7.14\text{minutes} \\ y_{HPE1} = 9392 * \left(1 - e^{(-0.2778*t)}\right) & t > 7.14\text{minutes} \end{cases} \qquad (4.49)$$

●HP Drum

The contaminated feedwater will reach the HP drum 19.88 minutes after the condenser leak occurs as shown in Table 4.10. According to Equation 4.29, Cl contamination in the HP drum, y_{HP}, is given by:

$$\begin{cases} y_{HP} = 0 & t \le 19.88\text{minutes} \\ y_{HP} = 252.6 * t + 909.35 * (e^{(-0.2778*t)} - 1) & t > 19.88\text{minutes} \end{cases} \qquad (4.50)$$

Figure 4.22, plotted using Equations 4.44 through to 4.50, shows the chloride contamination situation at seven major areas in the water cycle system. (Condenser, Preheater, HP ECO#1, and IP ECO are referenced to the left-hand Y-axis; HP drum, IP drum, and LP drum are referenced to the right-hand Y-axis). Table A.9 in Appendix A includes detailed data.

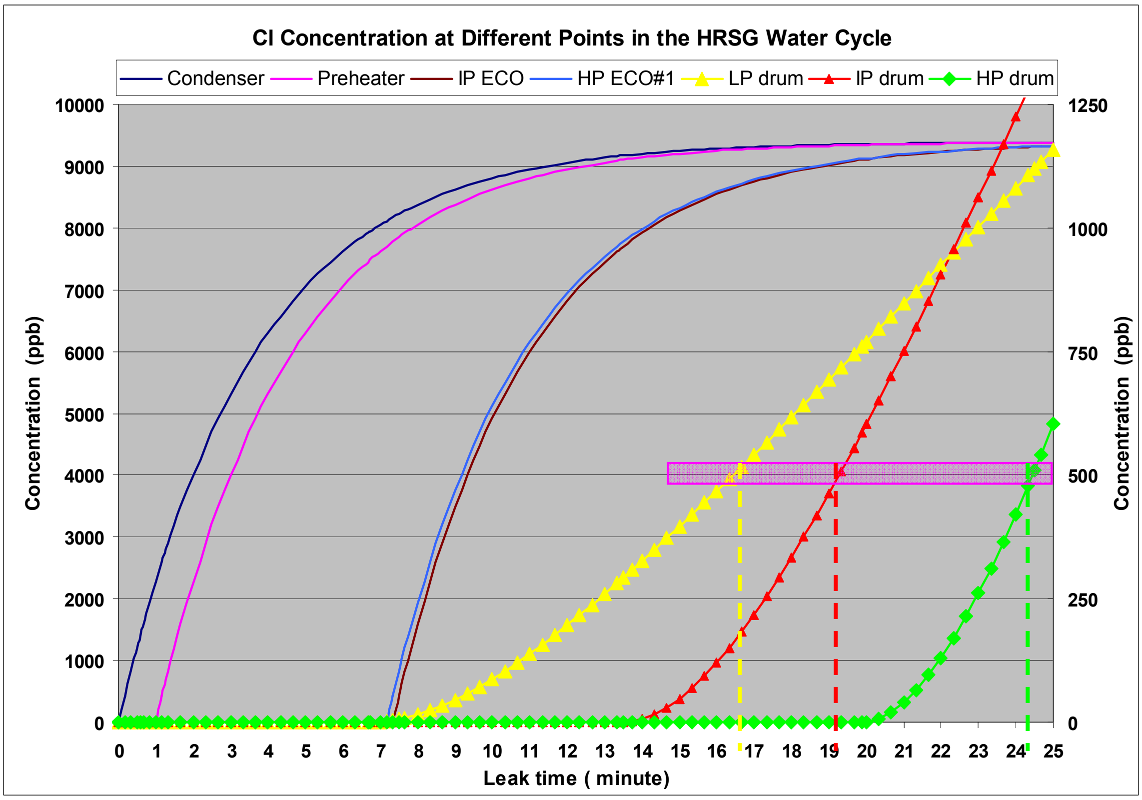


Figure 4.22 Cl concentrations at different locations in the HRSG water cycle

With reference to Figure 4.22, Table 4.11 summarises the time when the Cl contamination starts and the time when the Cl contamination reaches 500 ppb (Action Level 4) at seven locations in the water cycle system after the condenser leak occurs. Table A.9 in Appendix A includes detailed data.

Table 4.11 Cl contamination time at different locations of the water cycle system

	Condenser	Preheater	LP drum	IP ECO	IP drum	HP ECO#1	HP drum
	second	second	minute	minute	minute	minute	minute
Time when contamination starts after the tube leak occurs	0	57	6.76	7.28	13.53	7.14	19.88
Time when contamination reaches 500 ppb after the tube leak occurs	12	69	16.4	7.48	19.3	7.34	24.45

As can be seen from Figure 4.22, Table 4.11 and Table A.9, Cl concentration rises up from 0 ppb to 500 ppb in the condenser, the preheater, the IP economiser and the HP economiser #1 within a very short time (approximately 12 seconds). Contamination of the preheater takes place approximately 1 minute after the condenser leak occurs. Cl concentration in the condenser has exceeded 2600 ppb when Cl concentration in the preheater reaches 500 ppb, which is far above the plant shutdown level (Action Level 4). HP economiser #1 and the IP economiser are contaminated approximately 7 minutes after condenser in-leakage occurs. This is mainly due to the water travel time through the preheater that is approximately 6 minutes. When Cl concentration in the IP economiser reaches 500 ppb, Cl concentration in the condenser has exceeded 8222 ppb as shown in Table A.9 in Appendix A.

Among the three drums, the LP drum is the first to be contaminated, the IP drum is the second and the HP drum is the last. This is because the water travelling to the LP drum has the shortest distance to cover. Compared to the LP drum, the feedwater needs to pass through the HP and IP economisers before arriving at the HP and IP drums, which takes 12.74 minutes and 6.25 minutes respectively (Table 4.9). The Cl concentration in the LP drum starts increasing 6.76 minutes after the condenser leak occurs (Table 4.11). The Cl concentration in the LP drum reaches 500 ppb 16.4 minutes after the leak occurs, by which time the Cl concentration has only reached 150 ppb in the IP drum and is still 0 ppb in the HP drum (Table A.9).

As can be seen from Figure 4.22 (HP drum, IP drum, and LP drum are referenced to the right-hand Y-axis), once Cl contamination takes place in the HP drum, it increases quickly due to the high feedwater flow rate. Cl contamination in the HP drum starts 20 minutes after the condenser leak occurs, at which time the Cl concentrations in the LP and IP drums are already 770 ppb and 602 ppb respectively. When Cl concentration in the HP drum reaches 500 ppb, the Cl concentrations in the LP drum and IP drums are already 1120 ppb and 1307 ppb respectively (Table A.9).

Comparing the three drum systems, the LP drum system should be given the highest priority for monitoring in the event of a condenser leak. This is because the LP drum system will be contaminated first and the contamination in the LP drum is likely to reach the plant shutdown level (500 ppb) much earlier than the IP and HP drum systems (Figure 4.22).

With reference to Figure 4.21 (Page 86), the feedwater travel time from the condenser to the HP desuperheating spray system (A – H) is approximately 7 minutes. Although the HP desuperheating spray system is not used during normal operation, any passing of the control valves will carry contaminants directly into the superheated steam. The HP superheater and the steam turbine would then be contaminated. Therefore, the desuperheater valves must remain in the fully shut position in the event of condenser in-leakage. In addition, the desuperheater valves should be well maintained to prevent passing and if they are known to pass, the operator should keep in mind that rapid contamination of the superheated steam and steam turbine could occur in the event of condenser in-leakage.

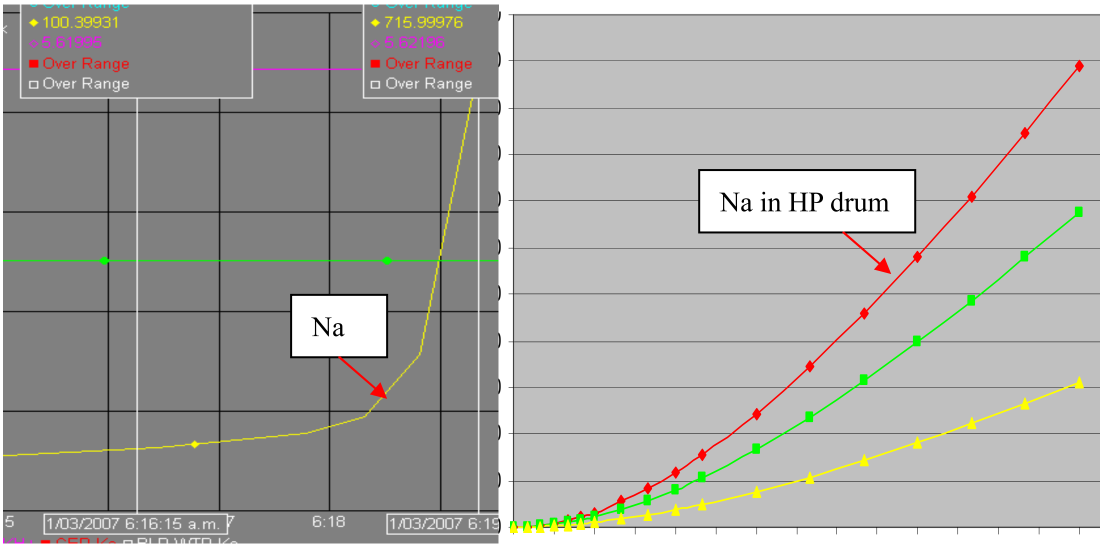
4.4 Chapter Summary

The mathematical model consists of the condenser hotwell model, HRSG drum systems model and entire water cycle model. Although the model has been developed based on theoretical ideal conditions, it substantially represents the actual process and provides convincing data for contamination situations in major components of the water cycle in the event of condenser in-leakage.

Using the condenser model, it was concluded that the tolerance of the condenser to any cooling water leakage is almost zero. The results of the analysis show that even a very small amount of ingress of salty cooling water will very quickly cause serious contamination of the condensate. For example, sodium concentration in the condensate would reach action level 4 (500 ppb) within one minute if there is a 1 mm radius orifice in a condenser tube wall. This means that a plant shutdown will be required immediately after the leak has been detected to avoid catastrophic consequences.

In addition, any tube leak may worsen very quickly after a leak starts as the leak orifice will enlarge as cooling water flows through it. The response time to any tube leak therefore becomes a critical issue. On-line analysers must be able to accurately detect any leakage immediately rather than relying on human intervention and confirmation.

Figure 4.23 (a) shows the actual Na contamination in the drum during the condenser tube leak event at NPL power station. Figure 4.23 (b) shows the modelling result of Na contamination in the HRSG drum at OTB station. Comparing the two diagrams, the Na contamination curves in both have similar tendency. The similarity of two diagrams proves the correctness of the modelling result. Therefore, this model can represent the actual contamination situation in the event of condenser in-leakage at OTB station.



(a) Actual Na contamination in drum (b) Modelled result of Na contamination in drum

Figure 4.23 Comparison between actual contamination and the modelled result

Contamination in the three drums increases at an accelerating rate. Contamination in the HP drum increases fastest among the three drums, whereas contamination in the LP drum increases the slowest. Compared to the condenser, contamination of the drums is relatively slow. However, contamination of the drum systems also requires close monitoring because once Na and Cl concentrations reach their saturation level, they will be carried over into the HRSG steam cycle and to the steam turbine, which should be always avoided.

Contamination of the drums will not take place immediately after condenser in-leakage occurs. According to the analysis results, referring to Figure 4.22, the LP drum system will be contaminated much earlier than the IP and HP drum systems and the contamination in the LP drum is likely to reach action level 4 (500 ppb) first. The LP drum system should therefore be given the highest priority with respect to monitoring in the event of a condenser leak.

According to the analysis results, it was concluded that even though contamination of the drum systems will not take place immediately after a leak occurs, contamination of the condenser from a small leak would reach the plant shutdown level very quickly. In order to minimise the consequences of condenser in-leakage, an urgent plant shutdown is required once contamination in the condenser reaches action level 4 (500ppb). However, an instantaneous trip from high load, particularly full load, will reduce the plant service life and result in a grid frequency excursion. Should the grid frequency fall below 49.25 H, a substantial fine would be incurred.

Considering the likelihood of the grid frequency falling below 49.25 Hz when the plant trips from a load in excess of 240 MW, the plant load should be reduced in a controlled manner, but as quickly as possible, after a leak has been detected. The plant should subsequently be tripped from a load that will not have a significant impact on grid frequency if the contamination in the condenser has reached action level 4. It is permissible to delay tripping the plant because contamination of the LP drum and economisers will not take place until approximately 7 minutes after the leak occurs. Therefore, the operator should make the most of the time available and take appropriate action before tripping the plant.

For example, if contamination in the condenser reaches action level 2 and shows an upward trend to action level 3, the duty shift operator should immediately proceed to minimum combined-cycle load at the maximum allowable rate. Meanwhile, the operator should report the event to Transpower, Trading, and the station chemist. Once the plant load has reduced to below 240 MW the plant can be tripped if the contamination level in the condenser has reached action level 4. In addition, it should be noted that the superheater and reheater desuperheating sprays should be isolated, otherwise contaminants will enter the superheater and reheater during deloading.

The above is only a guideline for operations staff. The final decision lies with the duty shift operator who may consult with the chemist and operations manager on the exact mode of operation to be followed during a condenser in-leakage event.

The mathematic modelling results provide a sound theoretical basis for engineering the condensate monitoring system. According to the analysis results, a highly reliable and fast response on-line monitoring system is imperative for OTB station to instantly detect condenser in-leakage.

CHAPTER 5

CONDENSATE MONITORING SYSTEM

5.1 Experiment on Different Chemical Parameters

According to EPRI's guidelines, sodium, chloride, cation conductivity, specific conductivity, and pH are the parameters commonly used for the detection of condenser in-leakage at seawater cooled power stations such as OTB station.

Using multiple parameters based on different measurement principles enhances the ability to detect condenser in-leakage, to provide reliable information to operators, and to reduce the chance of wrong decision making. The disadvantage is that if multiple parameters are not able to consistently indicate the same level of contamination during a condenser in-leakage event, it will be difficult for the operator to verify which parameter is correct. For example if sodium indicates the contamination is at action level 2 but specific conductivity indicates at action level 1 or 3, the operator can not easily make a correct decision on what the general contamination level is. In order to verify whether or not these parameters can indicate the same contamination level in the event of condenser in-leakage, an experiment was performed on these chemical parameters.

The experiment was performed by diluting the Cooling Water (CW) with the condensate taken from the condenser hotwell. This experiment only simulated static situations using a grab sample. The stock was obtained by diluting 1 ml of CW with 1000 ml of condensate. The dilution rate of the stock is 1:1000. Table 5.1 shows the final six solutions obtained by different dilution rates of the stock. Six solutions were used to simulate different contamination levels during a condenser in-leakage event, the leakage of cooling water increasing from the first to the last solution.

Table 5.1 Solutions with different dilution rates

Solution	Stock	Condensate	Final Dilution Rate	*Equivalent Leakage
1	1 ml	5 litre	1 : 5,000,000 (0.2*E-06)	4.32 ml
2	2 ml	5 litre	1 : 2,500,000 (0.4*E-06)	8.64 ml
3	5 ml	5 litre	1 : 1,000,000 (1*E-06)	21.6 ml
4	10 ml	5 litre	1 : 500,000 (2*E-06)	43.2 ml
5	20 ml	5 litre	1 : 250,000 (4*E-06)	86.4 ml
6	50 ml	5 litre	1 : 100,000 (10*E-06)	216 ml

The equivalent leakage column in Table 5.1 means the equivalent volume of the cooling water in the condenser hotwell, which is a static situation. For example, as the condensate volume in the condenser hotwell is 21600 litres, the dilution rate will be 1:5,000,000 if there is 4.32 ml of cooling water in the condenser hotwell.

5.1.1 Sodium

The sodium analyser used for the experiment was the ABB 8036 sodium analyser. Table 5.2 shows the sodium measured and calculated results for the six solutions. The second row in this table is the calculated result based on the assumption that the sodium concentration should be proportional to the leakage of cooling water.

Table 5.2 Sodium measured and calculated results

Solution	Condensate	1	2	3	4	5	6
Na Measured (ppb)	0.3	4.36	5.01	10.1	19.9	35.7	82.4
Na Calculated (ppb)	0	1.65	3.3	8.24	16.48	32.96	82.4
Contamination Level	0	1	1	2	3	3	3

In Table 5.2, the measured result of the 6th solution (82.4 ppb) is used as the calculated result of the 6th solution. The original sodium concentration in the condensate is considered to be 0 ppb. The calculated results of other solutions are obtained using 82.4

ppb divided by the ratio of the dilution rate of the 6th solution to the dilution rate of the corresponding solution in Table 5.1. For instance, the calculated result for the 5th solution is given by:

$$\frac{82.4}{(10 * E - 06 / 4 * E - 06)} = 32.96 \text{ ppb}$$

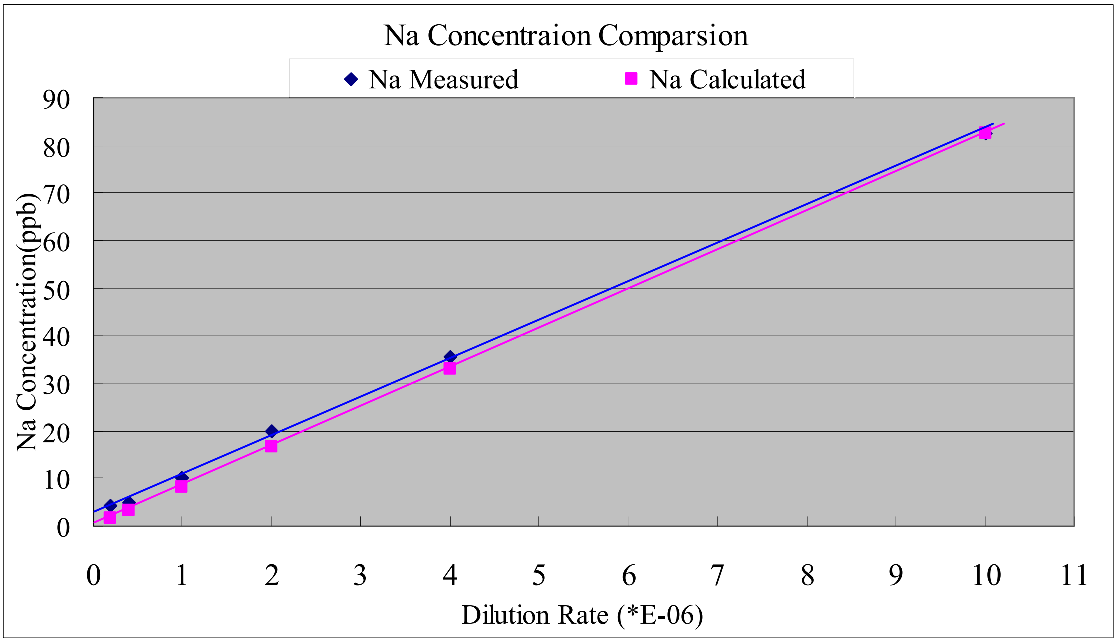


Figure 5.1 Comparison between the calculated and measured sodium (Na) results

Figure 5.1 shows the calculated and measured results of the sodium concentration for each solution. As can be seen from the diagram, the deviation between the measured and calculated results is exceedingly small. Because the calculated results are based on the assumption of proportionality, it can be concluded that the sodium concentration in the condensate is proportional to the leakage of cooling water. Hence, the measured sodium concentration can accurately represent different contamination levels in the event of a condenser leak. According to EPRI's guideline, if sodium were used to determine the contamination level, as shown in Table 5.2, the contamination in the 4th solution would reach action level 3 and the equivalent leakage into the condenser is only 43.2 ml of cooling water.

5.1.2 Cation Conductivity

The cation conductivity analyser used for the experiment was the ABB AX411 conductivity analyser. Table 5.3 shows the cation conductivity measured and calculated results for the six solutions. The second row in this table is the calculated results based on the assumption that the cation conductivity should be proportional to the leakage of cooling water. The measurement result of the 6th solution (1.844 μS/cm) is used as the calculated result of the 6th solution. The initial cation conductivity in the condensate was considered to be 0 μS/cm. The calculated results of other solutions are obtained using 1.844 μS/cm divided by the ratio of the dilution rate of the 6th solution to the dilution rate of the corresponding solution in Table 5.1. For instance, the calculated result for the 5th solution is given by:

$$\frac{1.844}{(10 * E-06 / 4 * E-06)} = 0.738\ \mu S/cm$$

Table 5.3 Cation Conductivity (KH+) measured and calculated results

Solution	Condensate	1	2	3	4	5	6
KH+ Measured (μS/cm)	0.085	0.518	0.547	0.652	0.661	0.865	1.844
KH+ Calculated (μS/cm)	0	0.037	0.074	0.185	0.37	0.738	1.844
Contamination Level	0	3	3	3	3	3	4

Figure 5.2 depicts the calculated and measured results of the cation conductivity for each solution. The calculated result is based on assumption of proportionality. As can be seen from the diagram, the measured result is not as linear as the calculated result. Although the cation conductivity is not strictly proportional to the leakage of cooling water, it is near enough. According to EPRI's guidelines, if cation conductivity were used to determine the contamination level, as shown in Table 5.3, the contamination in the last solution would reach action level 4.

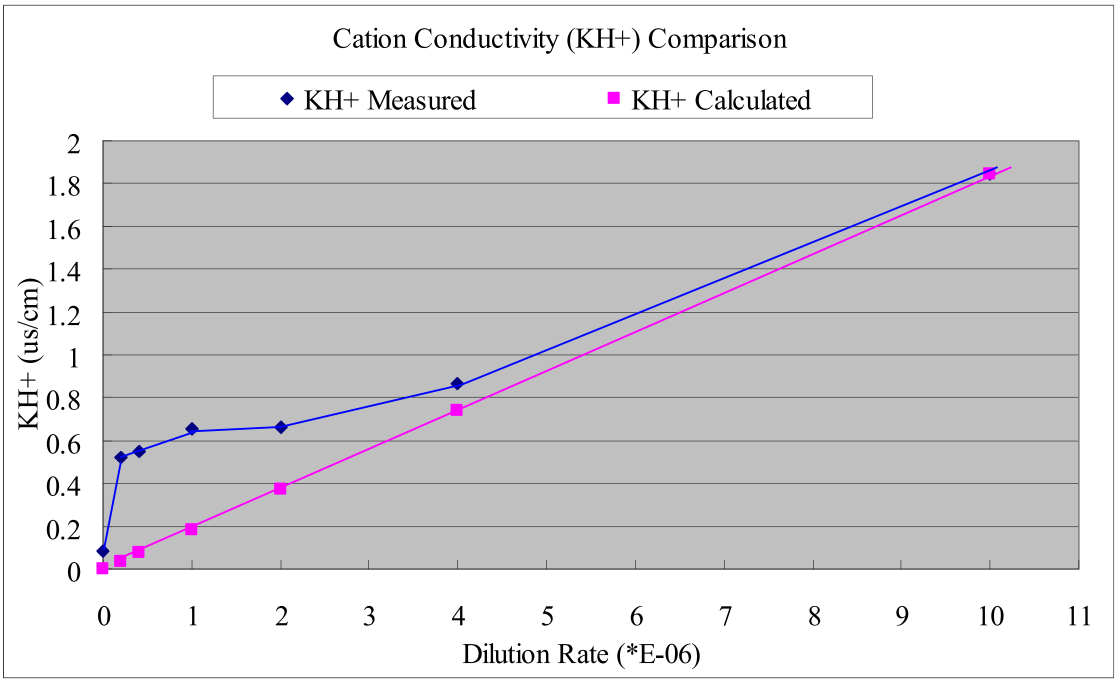


Figure 5.2 Comparison between the calculated and measured KH+ results

5.1.3 Specific Conductivity and pH

The specific conductivity analyser used for the experiment was the ABB AX411 conductivity analyser. Table 5.4 shows the specific conductivity measured results for the six solutions. As can be seen from Table 5.4 and Figure 5.3, although the specific conductivity rises as the leakage increases, the contamination level for all six solutions remains below action level 1. According to EPRI's guideline, if specific conductivity were used to determine the contamination level, all six solutions would remain at a normal level.

Table 5.4 Specific conductivity (Ko) measured results

Solution	Condensate	1	2	3	4	5	6
Ko Measured (µS/cm)	18.06	18.67	18.84	18.81	18.92	19.04	19.56
Contamination Level	0	0	0	0	0	0	0

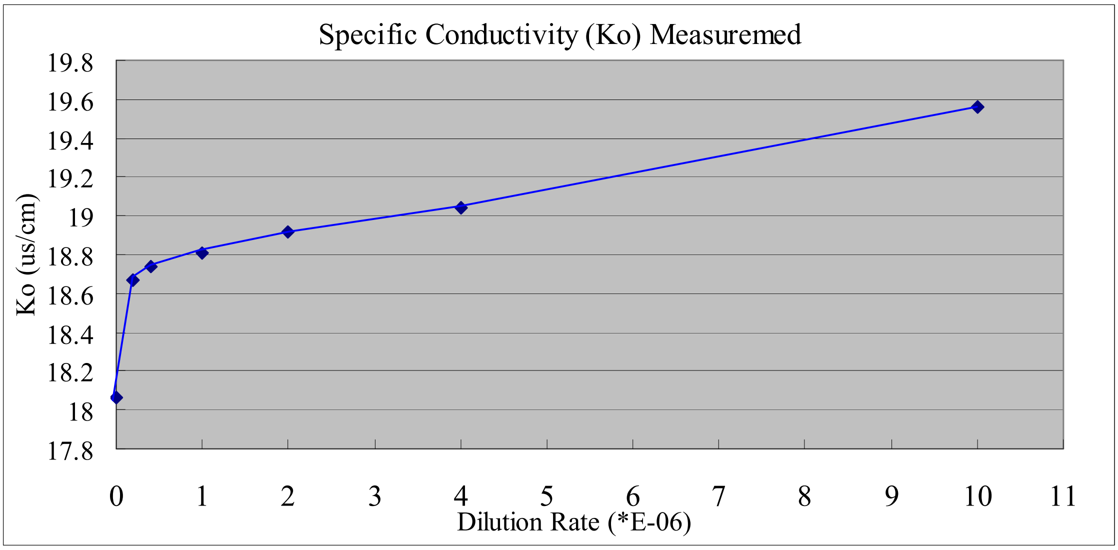


Figure 5.3 Specific conductivity measured results

As described in the literature review, pH is the negative logarithm of the hydrogen ion activity [11], which is nonlinear. In addition, pH measurement is not reliable or sensitive in low conductivity samples, which means that pH measurement can not be used to detect low level of contamination.

5.1.4 Chemical Parameters Comparison

Table 5.5 summarises the contamination levels represented by the different parameters for the six solutions shown in Table 5.1. These six solutions are used to simulate different contamination levels in the event of condenser in-leakage. The cooling water leakage increases from the first to the last solution.

Table 5.5 Contamination level comparison

Solution	1	2	3	4	5	6
Sodium (Na)	Level 1	Level 1	Level 2	Level 3	Level 3	Level 3
Cation conductivity (KH+)	Level 3	Level 3	Level 3	Level 3	Level 3	Level 4
Specific Conductivity (Ko)	Level 0	Level 0	Level 0	Level 0	Level 0	Level 0

As can be seen from Table 5.5, sodium has the best proportionality to the leakage of cooling water. The proportionality of cation conductivity is not as good as sodium; and the measured result of the cation conductivity seems to be higher than it is supposed to be, particularly at low leakage rates. Specific conductivity shows Level 0 for all six solutions, which means specific conductivity is not able to detect low level contamination in the event of condenser in-leakage.

In summary, specific conductivity and pH are not reliable measurements for the determination of the contamination level during a condenser in-leakage event, particularly at low leakage rates. Both parameters however can be used as reference information for operators. Sodium provides the most reliable information among these four parameters and has the best proportionality to the leakage rate of cooling water. Sodium is therefore the most important parameter for determining the contamination level during condenser in-leakage events. Although cation conductivity is not as linear as sodium, it can still be used as a backup for sodium for determining the contamination level. This is because it is too risky to rely on single parameter for determination of contamination level. Two parameters using different measurement principles will considerably reduce the risk of wrong decision making in the event of condenser in-leakage.

5.2 Instrumentation Selection

Based on the results of the experiment and the literature review, Table 5.6 shows the analysers initially proposed for tender, and the price of each analyser quoted by the vendors.

Table 5.6 Analyser price list

Analyser	ABB(NZ)	Swan(NZ)	Swan(Switz)
Sodium analyser	$12487	$14039	
Conductivity analyser	$3103	$9118	
pH analyser	$3984	$5345	
Chloride analyser			$44396

With respect to chloride monitoring, only Swan (Switz) quoted Orion series 8717LL chloride analyser manufactured by Thermo but both ABB (NZ) and Swan (NZ) did not recommend this chloride analyser because the reliability at low chloride concentration is unsatisfactory for this project. According to the data sheet, the measurement drift is 100 ppb per month (approximately 3 ppb per day). This means that the analyser must be calibrated everyday to ensure it is able to accurately measure values below 3 ppb. A great amount of ongoing routine maintenance work would be required if this chloride analyser were chosen. In addition, the chloride analyser is much more expensive than the other analysers. Furthermore, as shown in Table 2.1 (page 21), EPRI only recommends that chloride should be checked by grab sample on a daily basis. Therefore, the chloride analyser was not chosen for this project.

ABB (NZ), Swan (NZ&Switz) and Dr.Thiedig (Germany) were invited to tender. Dr.Thiedig provided the original chemical analysers when the OTB station was constructed. However, Dr.Thiedig was not able to provide local technical support for the commissioning analysers for this project. Based on the tender result, ABB's instruments were chosen because Swan (NZ) withdrew from the tender process due to other commitments. ABB's instruments have been widely used in other power stations owned by Contact Energy Ltd. The quality and reliability of these instruments has been recognised. In addition, the price of ABB's equipment is lower than Swan's price and all supplied equipment has a two-year warranty. Last but not least, ABB (NZ) provides local technical support for commissioning and maintaining the instruments.

When selecting instruments, the following factors were considered:

- Instrument measurement range
- Instrument accuracy
- Instrument reliability
- Instrument capital cost
- The cost of spares and their availability
- Routine maintenance requirements

Based on these six factors and discussions with the vendor, the following instruments were chosen:

- **Two sodium analysers**

  Model: 8037

  Measurement range: 0.01 ppb to 10 ppm

  Accuracy: ± 10% of concentration or ± 0.1 ppb whichever is greater

  Output signal: two isolated 4-20 mA analogue signals

  Calibration: Monthly

  Power supply: 230V AC

  It is too risky to rely on a single sodium analyser to determine the contamination level when condenser in-leakage occurs because a malfunction of the analyser will result in the loss of all sodium information. 2-out-of-3 redundancy is widely used in industry for critical parameters, however considering the high cost of the sodium analysers, a 1-out-of-2 redundancy system was finally chosen. This considerably improves the reliability of the sodium signal and is a cost-effective choice. Only one analogue output channel from each sodium analyser is used to communicate with an analogue input module in the Distributed Control System (DCS).

- **Three conductivity analysers**

  Model: AX411

  Specific conductivity sensor (AC212): 1 to 1000 μS/cm

  Accuracy: ± 1% of reading

  Cation conductivity sensor (AC221): 0.1 to 100 μS/cm

  Accuracy: ± 0.01% of span

  Inferred pH: 7 to 10

  Output signal: four isolated 4-20 mA analogue signals

  Calibration: Annually

  Power supply: 230V AC

The AX411 conductivity analyser is a multiple channel analyser, which can provide specific conductivity and cation conductivity information. In addition, the AX411 analyser can calculate an inferred pH value from the conductivity. Inferred pH is exceedingly accurate in the range of 7 to 10. Using this method, no pH electrode is required for pH measurement so the total cost of the project is reduced.

Compared to the sodium analyser, the cost of the conductivity analyser and sensors is relatively low. Therefore, three conductivity analysers were chosen in order to increase the measurement reliability by using 2-out-of-3 redundancy. As analysed in the chemical experiment section, only cation conductivity will be used to determine the contamination level. However, specific conductivity and inferred pH can be used to provide useful reference information for the operators. Three analogue output signals from each conductivity analyser are used to communicate with analogue input modules in the DCS. These three signals are cation conductivity, specific conductivity and inferred pH.

- **One pH analyser**

  Model: AX460
  Measurement range: 0 to 14 pH
  Accuracy: ±0.01pH.
  Output signal: two isolated 4-20 mA analogue signals
  Calibration: Monthly
  Power supply: 230V AC

Only one pH analyser was chosen because pH is only used for reference purposes in the event of condenser in-leakage. Although three inferred pH reading are available from conductivity analysers, the actual measured pH is useful when pH value is outside the range of 7 to 10.

In addition, the pH analyser can provide a temperature output signal, which can be used to monitor the temperature of the condensate sample. Conductivity measurement is sensitive to the sample temperature. Although the conductivity analyser has an automatic temperature compensation function, ideally the sample temperature should be controlled at 25ºC. Therefore, sample temperature should be displayed on the operator console. If the sample temperature is high, the operator should be warned by an alarm. The pH analyser provides pH and temperature output signals to the analogue input module in the DCS.

The use of two sodium analysers and three conductivity analysers will remarkably improve measurement reliability. The likelihood of incorrectly determining the contamination level in the event of condenser in-leakage is substantially reduced. The operators will no longer need to rely on a single instrument to make decisions and should be confident in taking action according to the information presented by multiple instruments.

5.3 Minimisation of Sample Lag Time

The existing condensate sampling system is part of the overall sampling wet rack system. However, the wet rack is approximately 60 metres downstream of the condensate extraction pumps. According to the calculated results in Section 4.3.8.1, the condensate velocity in the main condensate pipeline at full load is 118 m/min so the lag time from the condenser to the sample rack is approximately 30 seconds. In addition, the sample has to flow through a six metre long DN10 sample tube with an inside diameter of 12.48 mm. The sample flow rate is 0.3 litre/min and the sample velocity in the tube is:

$$\frac{0.3}{(0.1248/2)^2 * 3.14} = 24.53 \text{ dm/min} = 2.453 \text{ m/min}$$

Hence, the lag time in the sample tube is:

$$6 / 2.453 = 2.45 \text{ minutes}$$

Therefore, the total sample lag time from the condenser to the analyser is approximately three minutes, which means that three minutes would pass from the time the leak occurred to the time of detection. A three minutes delay is a short period time but in terms of responding to a condenser in-leakage event, it is a relatively long time. As analysed in Chapter 4, even a very small amount of cooling water ingress will result in serious consequences. In reality, any tube leak could expand very quickly after a leak starts because the orifice will enlarge as cooling water flows through it, the response time to any tube leak is critical. Therefore, the sample lag time must be reduced by the greatest possible degree so that condenser leaks can be detected by the analysers as soon as possible after they occur.

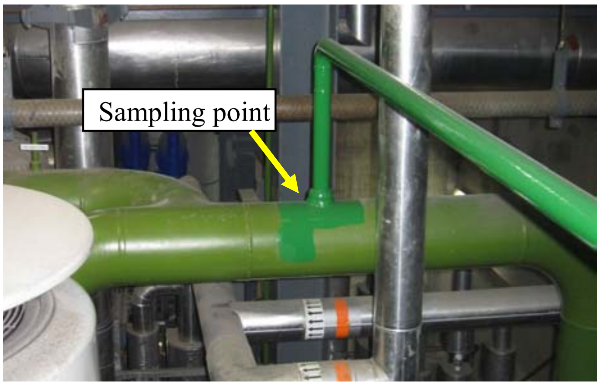


Figure 5.4 Condensate sampling point

Based on the recommendations in the literature review and the actual conditions at OTB station, as shown in Figure 5.4, the common discharge pipe immediate after the condensate extraction pumps was selected as the sample point for the new condensate monitoring system. In addition, a DN40 recirculation line was introduced between the condensate sampling point and the condenser hotwell as shown in Figure 5.5. The condensate sample is fed from the recirculation line to the analysers through a 1/4″ tube as shown in Figure 5.6. The total length of the line between the sample point and the analyser is approximately 10 metres.

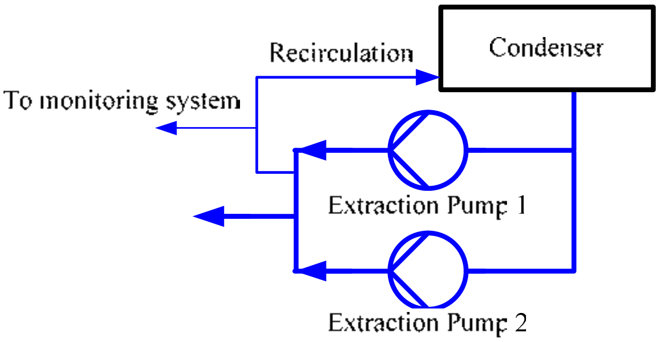


Figure 5.5 Condensate sampling pipe schematic diagram

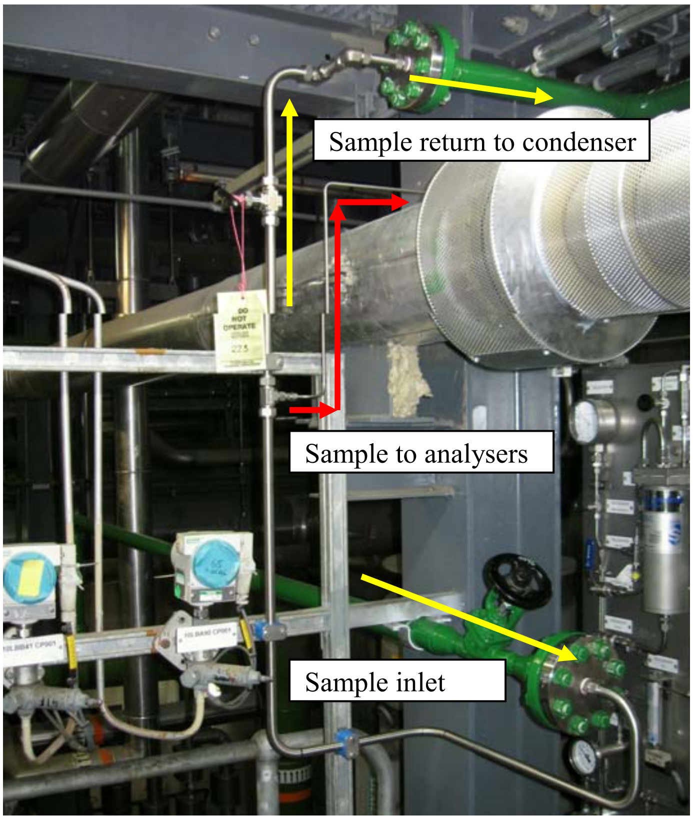


Figure 5.6 Sampling pipe layout

Over 95 per cent of the condensate sample returns back to the condenser hotwell through the recirculation line so less than 5 per cent of the sample flows through the analysers via a 1/4″tube. The recirculation line is used to keep the condensate sample flowing at a high velocity. The length of the DN40 tube is 6 metres and the inside diameter is 40.9 mm. The sample flow rate through the DN40 tube is approximately 20 litre/min. The sample velocity in the DN40 tube is:

$$\frac{20}{(0.409/2)^2 * 3.14} = 152 \text{ dm/min} = 15.2 \text{ m/min}$$

The sample lag time in the DN40 tube is therefore:

$$6 / 15.2 = 0.39 \text{ minute}$$

The length of the 1/4″ tube is only 1.5 metres and the inside diameter is 9.25 mm. The sample flow rate through the 1/4″ tube is controlled at approximately 1 litre/min based on the requirement of the six analysers. The sample velocity in the 1/4″ tube is:

$$\frac{1}{(0.0925/2)^2 * 3.14} = 149 \text{ dm/min} = 14.9 \text{ m/min}$$

The sample lag time in the 1/4″ tube is therefore:

$$1.5 / 14.9 = 0.1 \text{ minute}$$

The total lag time of the new sampling system is approximately 0.5 minutes. Compared to the sample lag time of the existing sampling system (3 minutes), the sample lag time of the new sampling system has been significantly reduced.

5.4 New Wet Analysis Rack

5.4.1 Wet Analysis Rack Arrangement

A new wet analysis rack was designed to hold all of the analytical instruments and accessories used in the new condensate monitoring system. Figure 5.7 shows the proposed location for the rack, which is close to the sample point. Because of the space limitation, the rack is a double sided design, 1780 mm high, 1800 mm wide, and 500 mm deep.

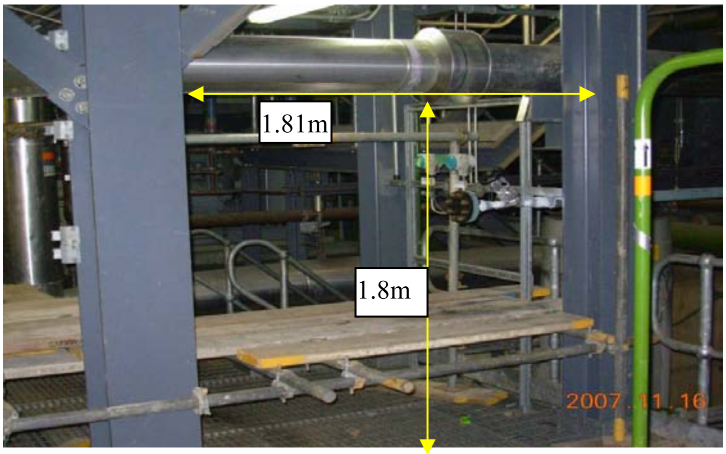


Figure 5.7 Location of the wet analysis rack

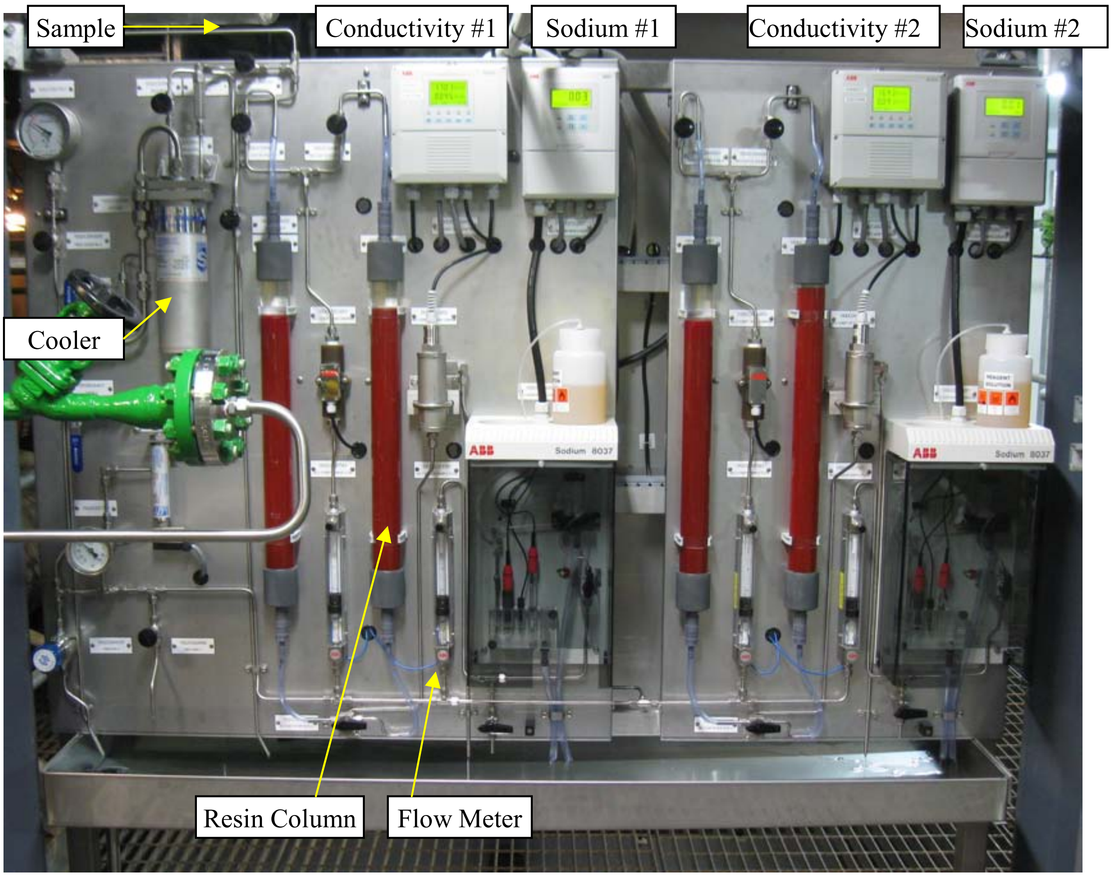


Figure 5.8 (a) Wet analysis rack front side

As shown in Figure 5.8, the front side consists of a cooler, two sodium analysers and two cation conductivity analysers. The back side consists of a third cation conductivity analyser, a pH analyser and an electrical distribution box. All measured values are displayed locally on the front panel of the analysers. Figures B.1 and B.2 in Appendix B show a full image of the wet analysis rack. The rack itself is made of the stainless steel and all of the valves and tubes are stainless steel (manufactured by Swagelok).

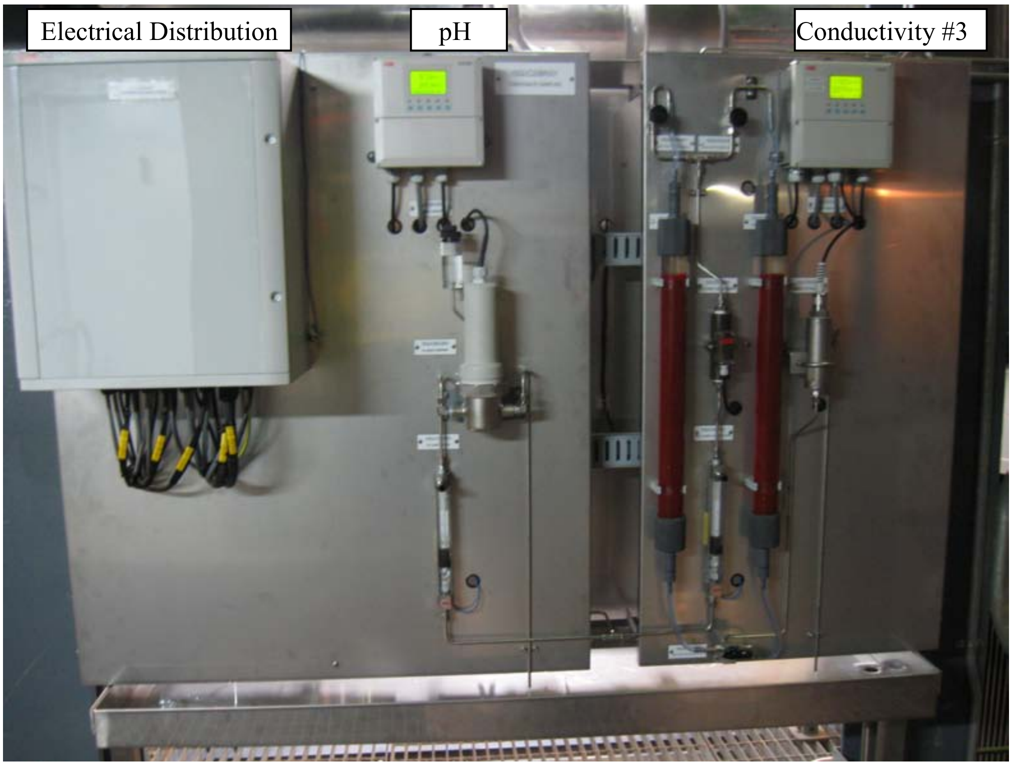
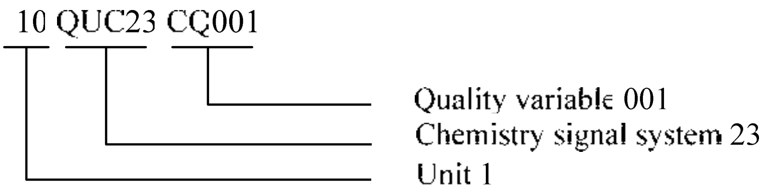


Figure 5.8 (b) Wet analysis rack back side

KKS codes are used by Siemens to identify signals and equipment in their power stations. Each item on the wet analysis rack has a unique KKS code. Table B.1 in Appendix B shows the KKS code for each item in the condensate monitoring system. Take specific conductivity analyser #1 for example, each section of the KKS code has the following meaning:



Other KKS codes in Table B.1 represent the following:

AA: Valve
CE: Electrical power supply
CF: Flow
CP: Pressure
CQ: Quality
CT: Temperature
QUC: Chemistry system
PGB: Closed cooling water system

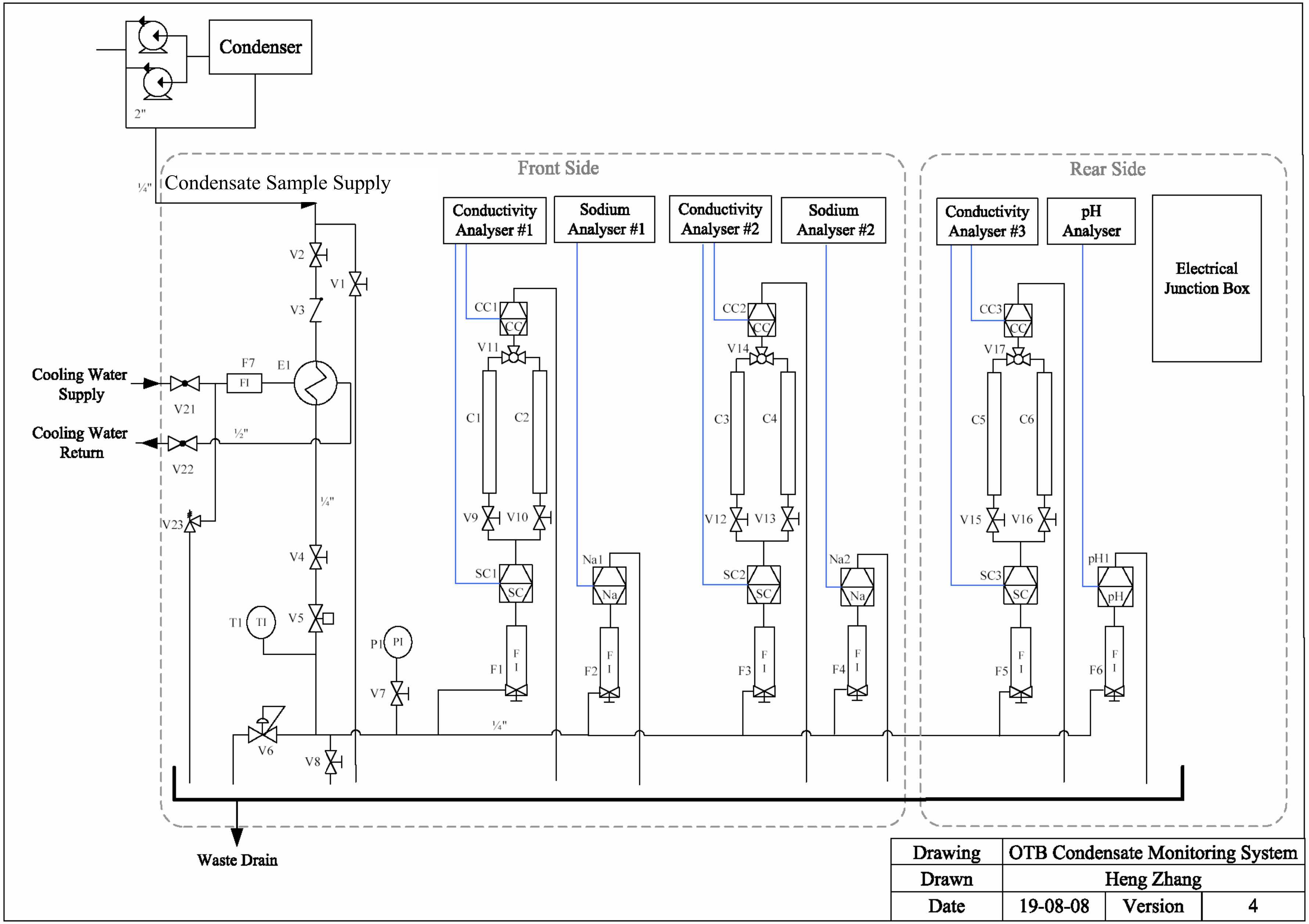


Figure 5.9 Condensate monitoring system P&ID diagram

A Piping and Instrumentation Diagram (P&ID) is a diagram showing piping, equipment and instrumentation connections within a process unit. Figure 5.9 shows the P&ID for the condensate monitoring system. The black lines represent the condensate sample tubing; the blue lines represent the electrical signal wiring.

The meaning of each symbol in the diagram is as follows:

- V: Valve
- PI: Pressure Gauge
- TI: Temperature Gauge
- FI: Flow Meter
- SC: Specific Conductivity Sensor
- CC: Cation Conductivity Sensor
- Na: Sodium Sensor
- pH: pH Sensor
- C: Resin Column

5.4.2 Function Description of Major Items

The following areas were considered and emphasized when designing the system:

- **Sample cooler**

  The sample cooler, manufactured by SENTRY, is a shell and tube heat exchanger. The shell design pressure is 31 barG and the tube design pressure is 300 barG. The cooler is used to cool the condensate sample to 25°C using the closed cooling water (a demineralisation cooling water system). The condensate temperature is usually 30 to 35°C. The best temperature for conductivity and pH measurement is 25°C, although the latest analysers have an automatic temperature compensation function.

  As can be seen from Figure 5.10, V21 and V22 are the closed cooling water isolation valves. The flow of closed cooling water can be manually controlled using

V21 to regulate the sample temperature after the cooler. The closed cooling water flow rate does not need to be adjusted regularly because the condensate temperature is quite stable. The closed cooling water flow rate is displayed by the flow indicator F7. Valve V23 is a pressure relief valve, set at 6 barG. If the cooling water pressure exceeds 6 barG the valve will open.

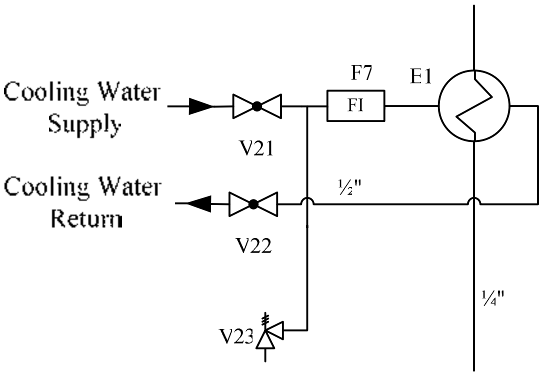


Figure 5.10 Closed cooling water loop P&ID

- **Condensate sample loop**

Figures 5.11 and 5.12 show the condensate sample loop components. When the system is put into service, blowdown valve V1 is used to flush the condensate sample line ahead of the cooler until the sample is clean. V1 remains shut during the normal operation. Isolation valve V2 is used to isolate the sample and is open during normal operation.

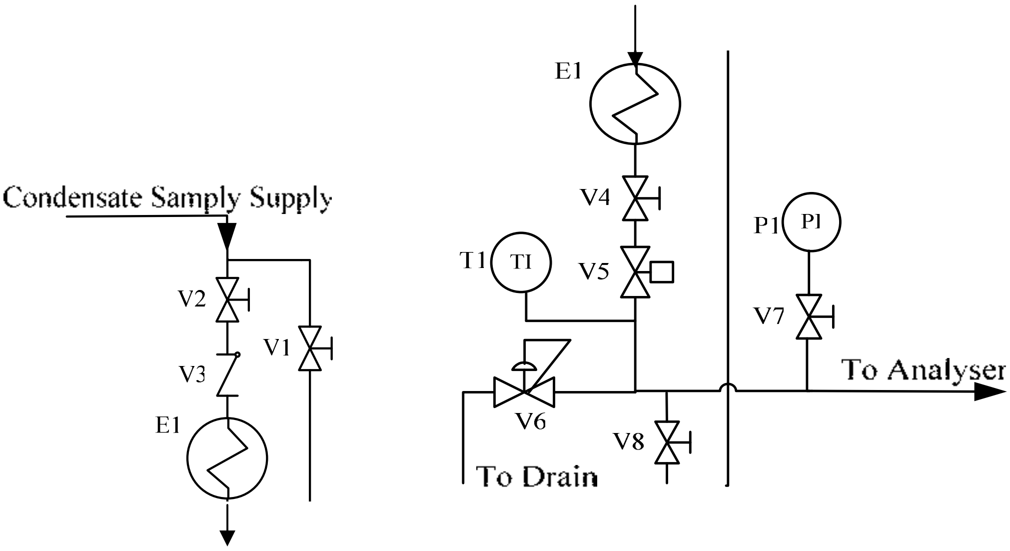


Figure 5.11 Condensate sample loop P&ID

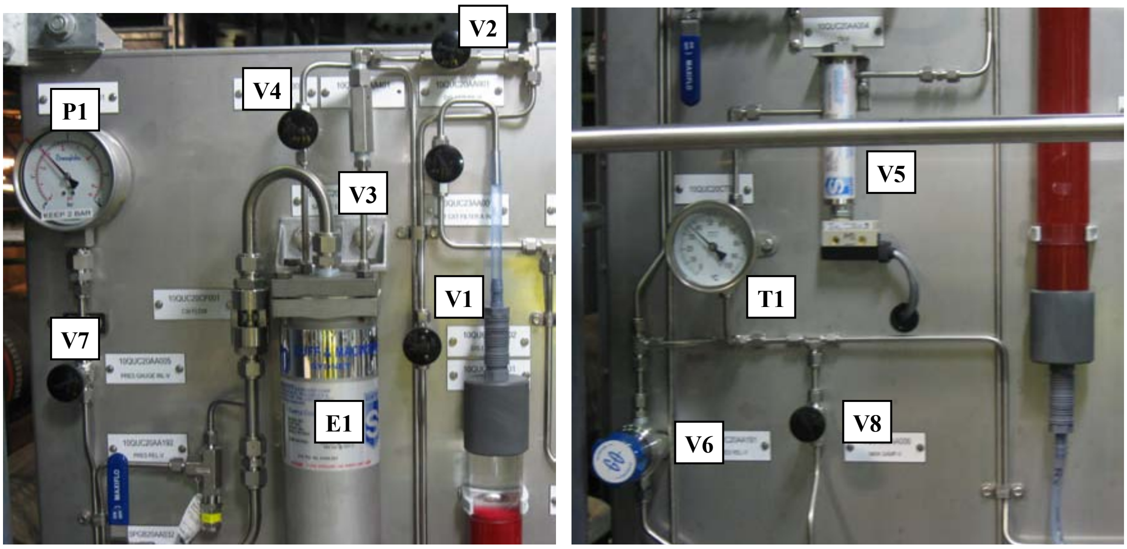


Figure 5.12 Condensate sample loop

Non-return valve V3 is used to prevent the condensate sample or air being sucked back into the condenser hotwell that is under a vacuum. This would only happen if there was not enough flow through the recirculation line. Component E1 is the cooler. Pressure-reducing valve V4 is used to reduce the sample pressure from 19 barG to 2 barG which is the nominal pressure for the analyser sensors. The sample pressure after the cooler is displayed on pressure gauge P1. Valve V8 is used to take a manual sample from the wet analysis rack. In addition, V8 can also be used to flush the sample line before the analysers when the system is put into service.

- **High pressure protection**

  The adjustable backpressure regulator V6 is used to stabilise the analyser inlet pressure. As shown in Figure 5.11, if the sample pressure exceeds 2 barG (current setpoint) the regulator V6 opens to divert the excess sample to the drain. The higher the pressure, the more the regulator opens.

- **High temperature protection**

  Thermal Shutoff Valve (TSV) V5, manufactured by SENTRY, is installed immediately after the sample cooler as shown in Figure 5.11. The TSV is a self-contained mechanical device that requires no external electrical or air supply.

The sensor/actuator is directly exposed to the sample. If the sample temperature after the cooler exceeds 49°C, the TSV will automatically shut to isolate the sample and protect the analyser sensors the from high temperature damage.

The TSV can be reopened manually after a trip by pushing the button on top of the TSV. Once the TSV is closed, the pressure in the sample line will rise, and if the pressure exceeds 2 barG, the back pressure regulator V6 will open to maintain the pressure at 2 barG by diverting the sample to drain.

As shown in Figure 5.12, the TSV(V5) also has a switch at the bottom to provide a signal for a remote alarm. This switch is wired through the electrical distribution box on the rack from where the signal is routed to the DCS. The signal is configured to be fail-safe because it is a critical signal. Once the alarm goes off, the operator needs check the valve locally. The valve will remain closed after it trips, and can only be opened again by pushing the reset button after the sample temperature falls below 49ºC.

- **Low flow detection**

Every analyser in the system must have an adequate sample continuously flowing through the analytical sensor in order to guarantee that the data sent to the DCS is accurate. Each analyser is therefore equipped with a sample flowmeter and low flow ring sensor as shown in Figure 5.13. The flowmeter ring sensor with a bistable switching action de-energies the relay in the amplifier installed in the electrical distribution box when the float falls to the trigger level. The relay remains de-energised, even if the float drops below the sensor. The relay re-energises as soon as the float crosses the trigger level in the upward direction and moves into the normal operating range.

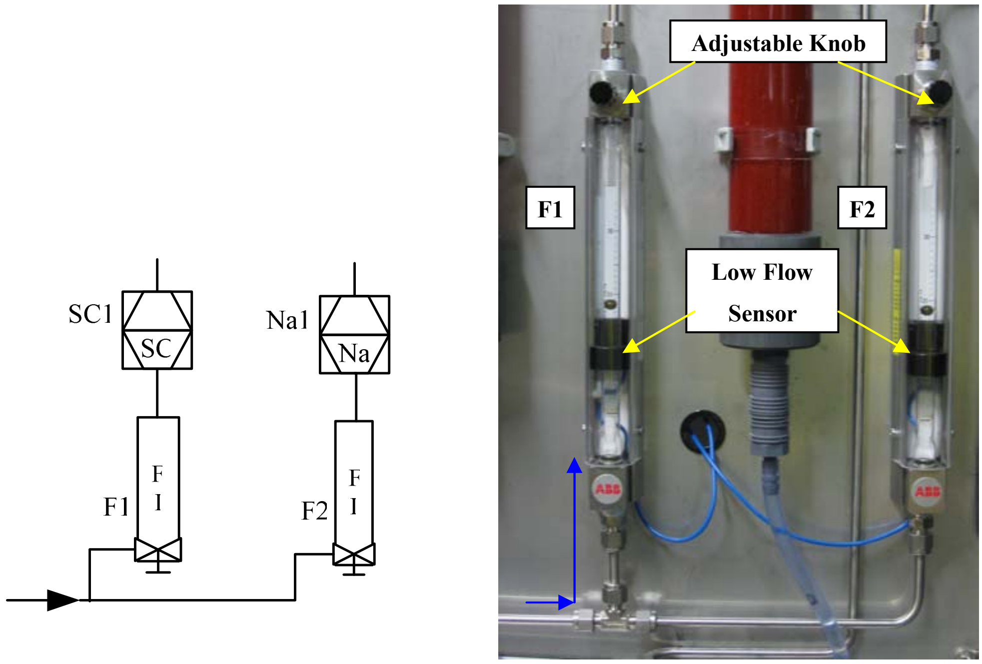


Figure 5.13 Flow meter and low flow sensor

The condensate sample flows upwards through the flowmeter. The position of the ball float indicates the sample flow rate. The sample flow can be adjusted using the knob at the top of the meter. The sample flow rate is usually kept between 150 and 200 ml/min. The trigger level of the ring sensor is 100ml/min. If the sample flow rate falls below 100 ml/min, the ball float will reach the ring sensor, de-energising the relay and generating a low sample flow alarm in the DCS.

Six low sample flow switches are connected in series and share one common alarm in the DCS. The operator must check and adjust the sample flow locally because the common alarm does not indicate which analyser has a low flow. The alarm resets only when all analysers have an adequate sample flow rate.

- **Dual cation resin columns**

The cation conductivity is measured after the condensate sample has passed through a column of cation exchange resin in the hydrogen form. The effect of this procedure is to convert all cations in the sample into hydrogen ions (H+).

The existing conductivity analysers only have one cation exchange column as shown in Figure 5.14. The cation exchange resin in the column needs to be changed every three or four days when the resin is exhausted. The measured cation conductivity is very high immediately after the resin has been changed and the new resin usually take approximately one hour to rinse down. The operator has to simulate the output value of the analyser before changing the resin to avoid generating a high cation conductivity alarm in the DCS, then remove the simulation once the measured value settles back down to normal.

Figure 5.14 Existing single cation resin column

The new condensate monitoring system uses a dual resin column configuration as shown in Figure 5.15. Valves V9 and V10 are the inlet isolation valves for each column. The three-way valve V11 is used to switch over between the two columns. One column is in service at a time. The position of the V11 shown in Figure 5.15 indicates that the left-hand column (C1) is in service.

The condensate sample flows downward through the resin column after passing through the specific conductivity sensor SC1. The sample then enters the cation conductivity sensor CC1. The re-generated resin and exhausted resin can be distinguished by colour. The re-generated resin is brown and exhausted resin is dark red.

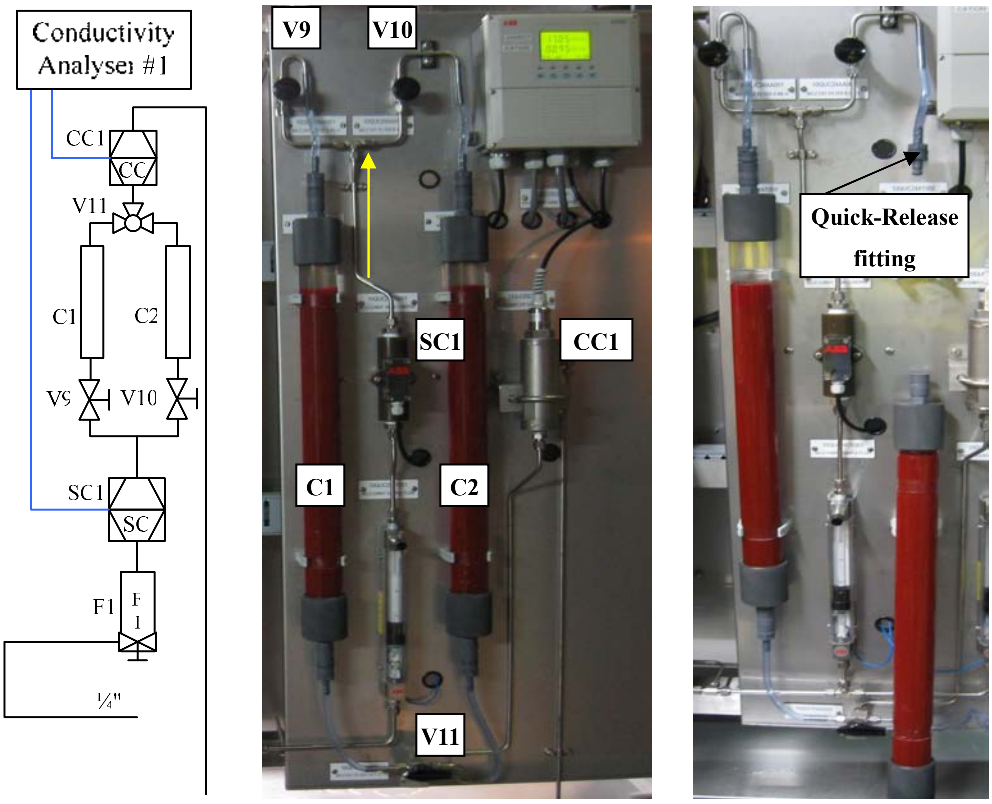


Figure 5.15 Dual cation exchange resin column diagram

The columns are easily switched over. For example, as shown in Figure 5.15, if the resin in the right-hand column (C2) is exhausted, the column can be switched over simply by changing the position of three-way valve V11. It is not necessary to operate Valves V9 and V10, and they can be left open when removing the columns for the purpose of replacing the resin because the quick-release fittings are self sealing. The exhausted resin column is easily removed by pulling the quick-release coupling at the both ends of the column. The resin column is easily reconnected after refilling with re-generated cation exchange resin.

Based on commissioning experience, re-generated resin usually takes 10 minutes to rinse down, which is much faster than the existing Siemens resin column. In addition, the operator does not need to simulate the output of the cation conductivity channel to avoid triggering a high cation conductivity alarm because the new alarm is triggered by 2-out-of-3 voting logic.

5.5 Instrumentation and Control

5.5.1 Instrumentation Power Distribution

All analysers in the new condensate monitoring system run on 230V AC. All of analysers could be powered from a common supply. This would however mean the loss of all of the signals if the common power supply fails. OTB station has three independent 230V AC buses supplied from boards 10BFG, 10BMA and 10BFE. In order to enhance the availability of the power supply, the six analysers have been divided into three groups; each group is supplied from one of the three independent buses as follows:

- 10BFG
  - Conductivity analyser #1 (10QUC23CQ)
  - Low flow alarm amplifier #1 (10QUC23CF)
  - Sodium analyser #1 (10QUC21CQ)
  - Low flow alarm amplifier #2 (10QUC21CF)

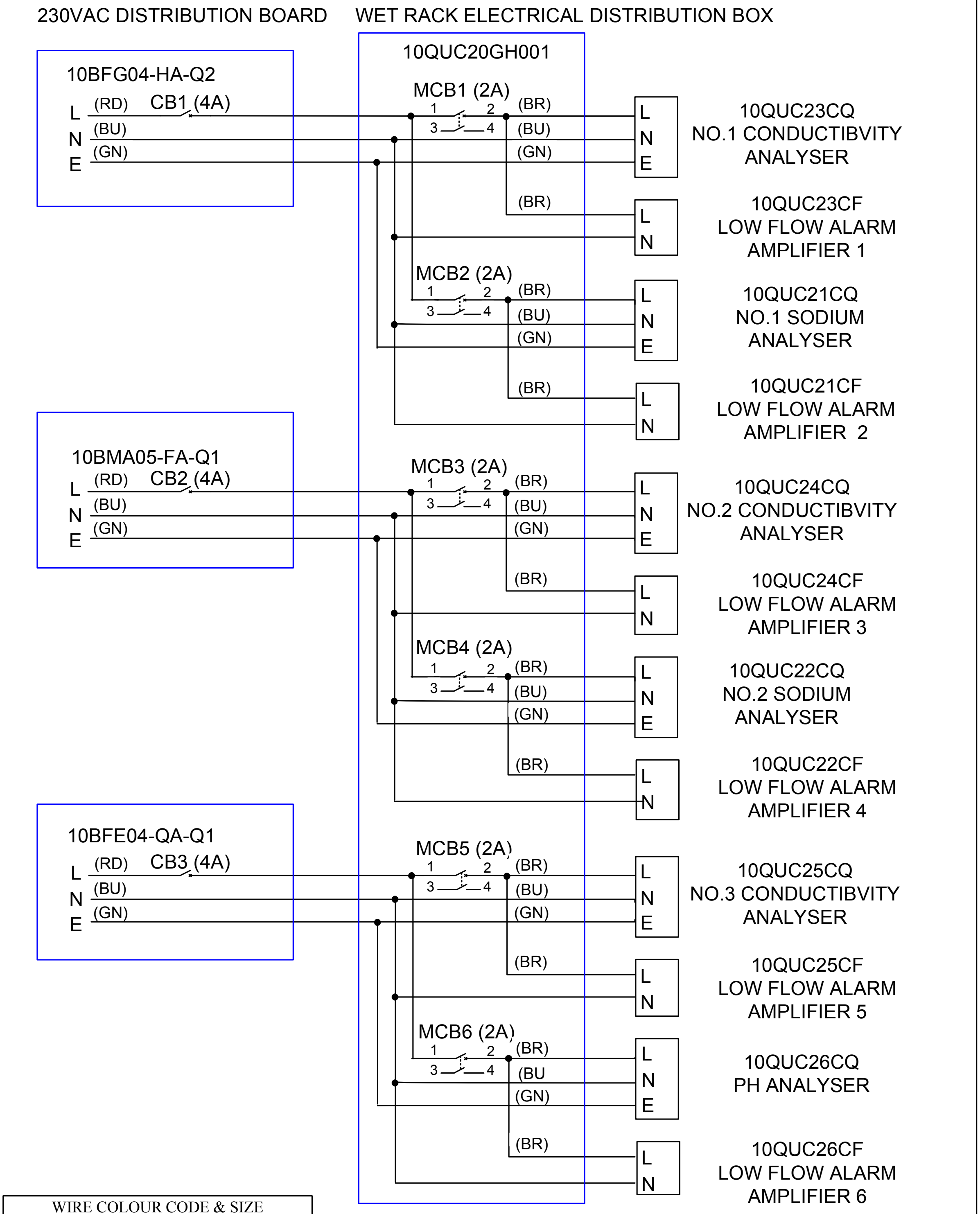
- 10BMA
  - Conductivity analyser #2 (10QUC24CQ)
  - Low flow alarm amplifier #3 (10QUC24CF)
  - Sodium analyser #2 (10QUC22CQ)
  - Low flow alarm amplifier #4 (10QUC22CF)

- 10 BFE
  - Conductivity analyser #3 (10QUC25CQ)
  - Low flow alarm amplifier #5 (10QUC25CF)
  - pH analyser (10QUC26CQ)
  - Low flow alarm amplifier #6 (10QUC26CF)

Each group has only one sodium analyser and one conductivity analyser. The advantage of this arrangement is that if any one of three power supplies fails at least one sodium analyser and two conductivity analysers are still available to the DCS system. Considering the likelihood of power failure is very low while the plant is running and in order to reduce the cabling and the digital input module cost, six analysers have been configured to share one digital channel (analyser power failure channel) in the DCS. Any analyser power failure will trigger the analyser power failure alarm but will not indicate which analyser has lost power. Therefore, any analyser power failure will disable the automatic action level voting logic as shown in Figure 6.20 (Page 164) and Figure 6.25 (Page 171). Under this situation, the operator has to rely on other on-line analysers to decide the action level if a condenser tube leak occurs.

Figure 5.16 shows the power distribution schematic wiring diagram. According to AS/NZS 3000:2007 (Australian/New Zealand Wiring Rules) [17], a four-core flexible cord cable with a 2.5 mm^2 of cross-sectional area was chosen as the 230V AC power cable. The rated current of the Circuit Breaker (CB) in 230V AC distribution boards is 4 A. The single pole Miniature Circuit Breakers (MCB) installed in the electrical distribution box located on the wet rack are used to protect the instruments from over current damage due to overloads and short circuits. The MCB model is S201C2 (ABB), which have a 2 A rating. Each analyser and corresponding low flow alarm amplifier share a common MCB. In addition, each MCB has a normally open auxiliary contact, which is used to trigger an alarm when the MCB trips.

Figure 5.17 shows the internal structure of the electrical distribution box. The Ingress Protection (IP) rating of the distribution box enclosure is IP66, which totally protects against dust and low pressure jets of water. IP66 protection complies with the requirements of OTB station. The distribution box houses three rails, the bottom rail (X03) holds the 230V AC miniature circuit breakers; the middle rail (X02) holds the low flow alarm amplifiers; the top rail (X01) holds the instrumentation wiring terminals from where the field low voltage DC signals are connected to the DCS. The advantage of this arrangement is a reduction of electrical interference because the low voltage DC signals are separated from the high voltage AC sources.



WIRE COLOUR CODE & SIZE		
COLOUR	ABBREVIATION	SIZE
BLUE	BU	2.5mm²
GREEN	GN	2.5mm²
RED	RD	2.5mm²
BROWN	BR	1.0mm²

Drawing	OTB Condensate Monitoring System Power Supply Wiring Diagram				
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Figure 5.16 Power distribution schematic wiring diagram

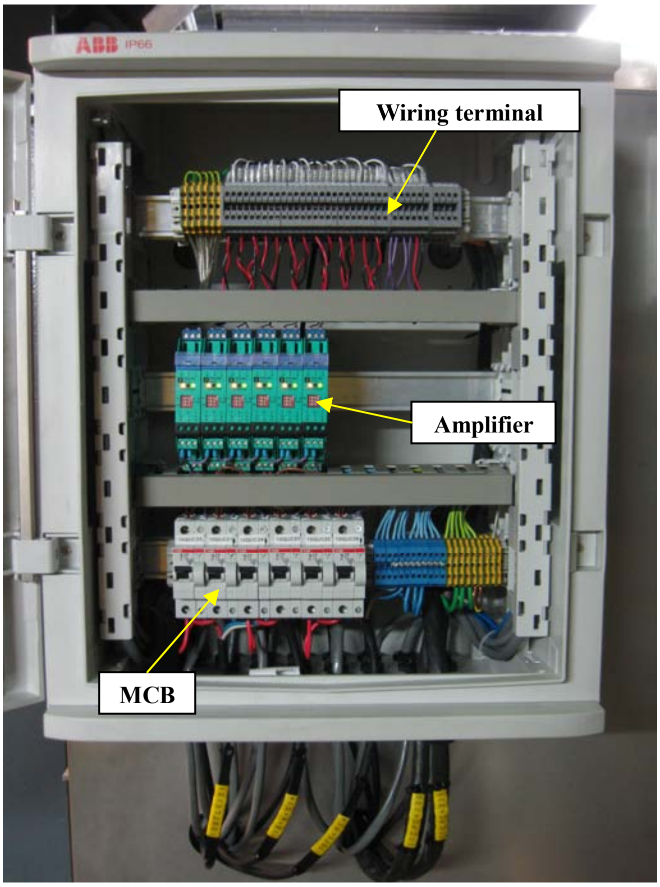


Figure 5.17 Internal structure of the electrical distribution box

5.5.2 Instrumentation Wiring

The condensate monitoring system outputs thirteen 4-20 mA DC analogue signals and three 24V DC digital signals to the DCS. The instrument cables are shielded twisted pair cable to reduce electromagnetic interference from external sources. One end of the cable is terminated at the wiring terminal block in the electrical distribution box (10QUC20GH001); the other end is terminated at the wiring terminal block in the DCS I/O module cabinet (10CPC27). Figure 5.18 shows the wiring terminal and I/O modules arrangement in the cabinet 10CPC27, which is detailed in Chapter 6.

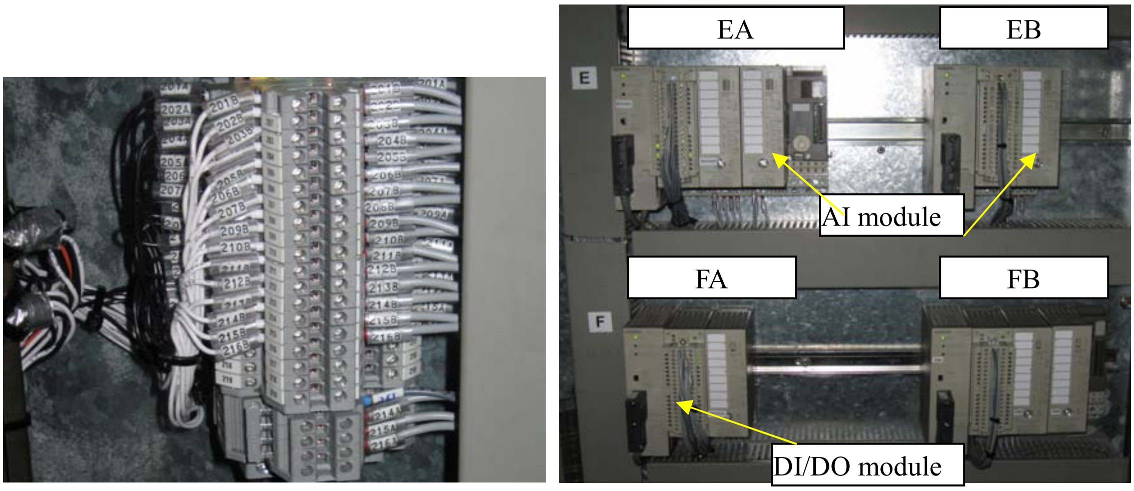
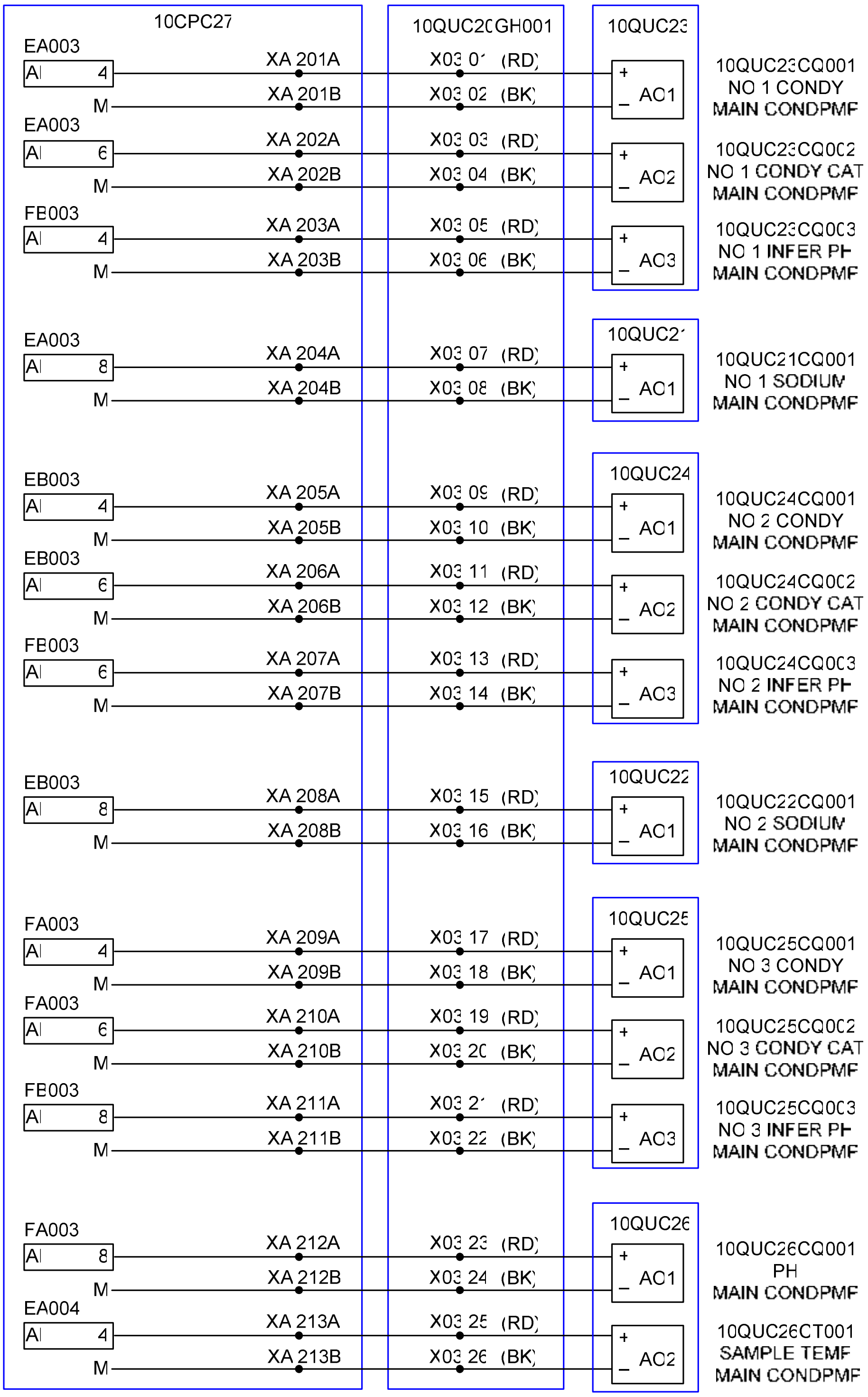


Figure 5.18 Wiring terminal and DCS I/O modules

Figure 5.19 shows the wiring diagram for all thirteen analogue signals. These 4-20 mA signals are field-powered by the analysers, not by the DCS I/O modules. The meanings of codes in the diagram are as follows:

- 10CPC27: I/O module cabinet ID
- EA003: I/O module ID. The third module on rail EA
- AI4: Analogue input terminal 4
- XA:201A, XA:201B: Wiring terminal ID. A: positive, B: negative
- 10QUC20GH001: Electrical distribution box
- AO1: Analogue output channel 1

Three digital signals are configured as fail-safe alarms. The circuit is powered by a 24V DC source located in I/O module cabinet 10CPC27. Normally, the circuit is closed and the 24V voltage is received at the DCS input module. An alarm is generated in the DCS if the voltage received at the input module is 0V. Any hard-wired alarm generated in the DCS requires the operator to carry out a local check.



WIRE COLOUR CODE & SIZE		
COLOUR	ABBREVIATION	SIZE
BLACK	BK	0.5mm²
RED	RD	0.5mm²

Drawing	OTB Condensate Monitoring System Analogue Signal Wiring Diagram				
Drawn	Heng Zhang				
Date	25-08-08	Version	5	Page	1

Figure 5.19 Analogue signal wiring diagram

Figure 5.20 shows the digital signal wiring diagram. The three digital signals are:

- **Analyser power failure (10QUC21CE001)**

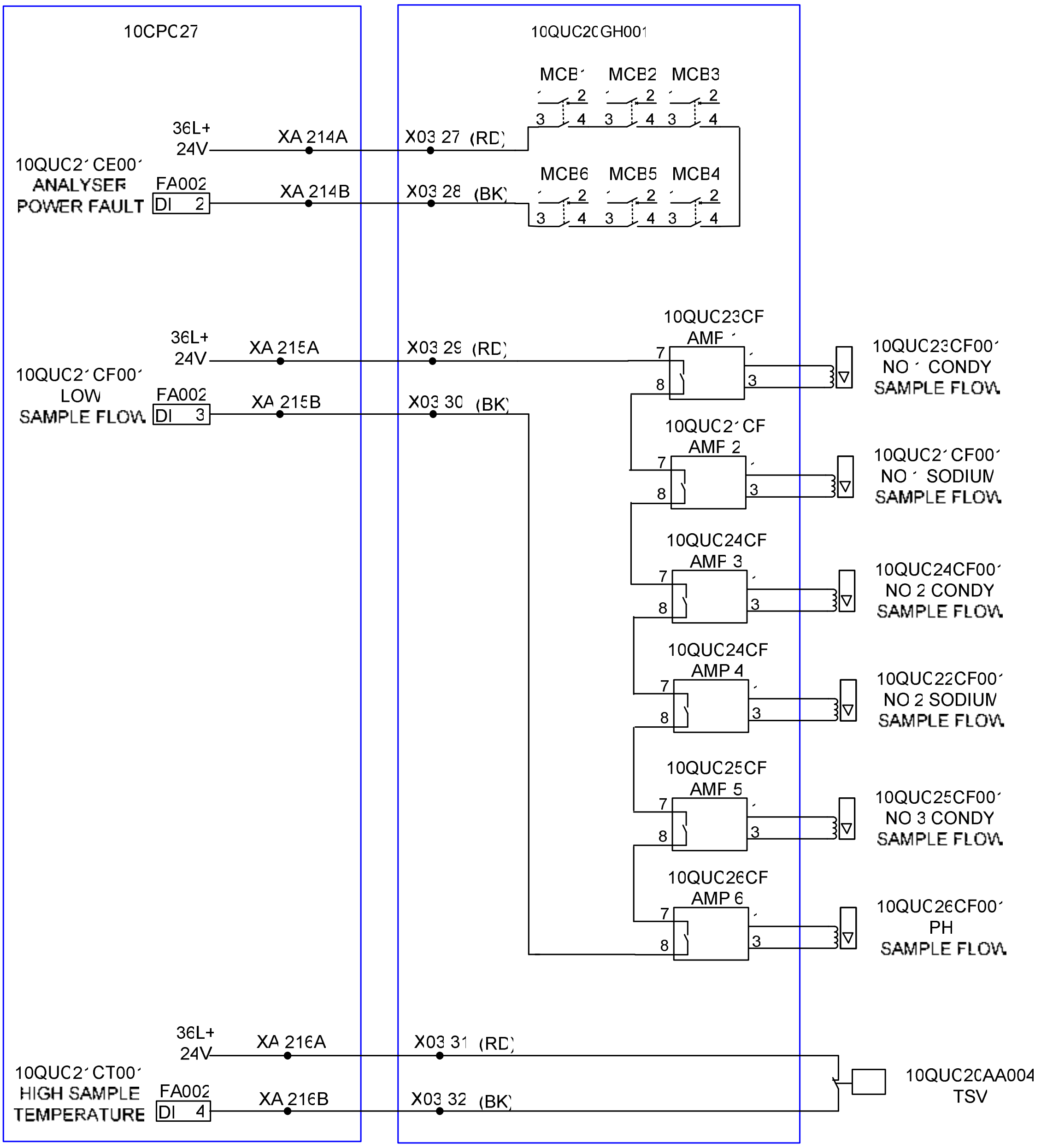
  The Normally Open (NO) contacts (3..4) in the six Miniature Circuit Breakers (MCB) are connected in series. When all six MCBs are closed, all of the NO contacts make so that a 24V voltage is received at the input module of the DCS. If any MCB trips, the associated NO contact will break the circuit and trigger the analyser power failure alarm in the DCS. The six analysers share one digital channel in the DCS, so the wiring and DI module cost is reduced.

- **Sample flow low (10QUC21CF001)**

  The low flow switch amplifiers are model KFA6-SR2 (Pepperl+Fuchs). The normally open contacts of the six amplifiers are connected in series. The ring sensor de-energies the relay in the amplifier when the float falls to the trigger level. The relay remains de-energised, even if the float drops below the sensor. Once the relay is de-energised, the NO contact will break the circuit, and trigger the sample flow low alarm in the DCS. The relay re-energises as soon as the float crosses the trigger level in the upward direction and moves into the normal operating range. The six analysers share one digital channel in the DCS, so the wiring and DI module cost is reduced.

- **Sample temperature high (10QUC21CT001)**

  The Normally Closed (NC) contact in the Thermal Shutoff Valve (TSV) is connected to a digital input channel in the DCS. If the sample temperature exceeds 49ºC, the NC contact will break the circuit, and trigger the sample temperature high alarm in the DCS.



WIRE COLOUR CODE & SIZE		
COLOUR	ABBREVIATION	SIZE
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RED	RD	0.5mm²

Drawing	OTB Condensate Monitoring System Digital Signal Wiring Diagram					
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Figure 5.20 Digital signal wiring diagram

5.6 Chapter Summary

Based on the results of the experiment and literature review, specific conductivity and pH are not reliable at low contamination levels. Therefore they are only used as reference information for operators. The contamination level in the event of condenser in-leakage is determined using only sodium and cation conductivity. Even though the proportionality of cation conductivity is not as good as sodium, two parameters using different measurement principles will considerably increase the measurement credibility and reduce the risk of wrong decision making in the event of condenser in-leakage.

Sample lag time has been dramatically reduced by sampling immediately after the condensate extraction pump. The new condensate monitoring system meets the requirement of fast response to any condenser leak. In order to enhance the availability and reliability of the system, multiple redundancy schemes have been applied to the sodium and conductivity analysers, and to the 230V AC power supplies. In addition, automatic protection devices and alarms have been included in the system to protect the analytical instruments and inform the operator of abnormal situations. Not only does the new condensate monitoring system meet the requirements of fast response and high reliability, but also the system is easy to maintain and operate.

CHAPTER 6

TELEPERM XP AND LOGIC PROGRAMMING

6.1 Introduction to Teleperm XP

OTB station uses Siemens Teleperm XP (TXP) Distributed Control System (DCS). This section will briefly introduce the structure of TXP and its major sub-systems. Automation System 620 B will be given a detailed introduction because most of the logic programs used for this project run in the AS620 B system.

6.1.1 Teleperm XP Structure

Teleperm XP (TXP) offers all of the process and control utilities required for the automation, operation, monitoring, and recording of processes. The functions of the control system are distributed between individual sub-systems, which form a complete process and control system.

As shown in Figure 6.1, the process can be controlled via monitors using Operation and Monitoring system (OM650). The open-loop and closed-loop control, and the monitoring of the plant are carried out by the automation system. The plant bus represents the communication link between the sub-system process operation and monitoring and the sub-system automation. The Engineering system is used to configure the sub-system and the communication links. With its connection to the plant bus, the Engineering System supports commissioning and maintenance and it provides documentation as far as instrumentation and control are concerned. The operating terminals required to operate the respective sub-systems are connected to the terminal bus. These operating terminals are equipped with monitors necessary for indication and operation.

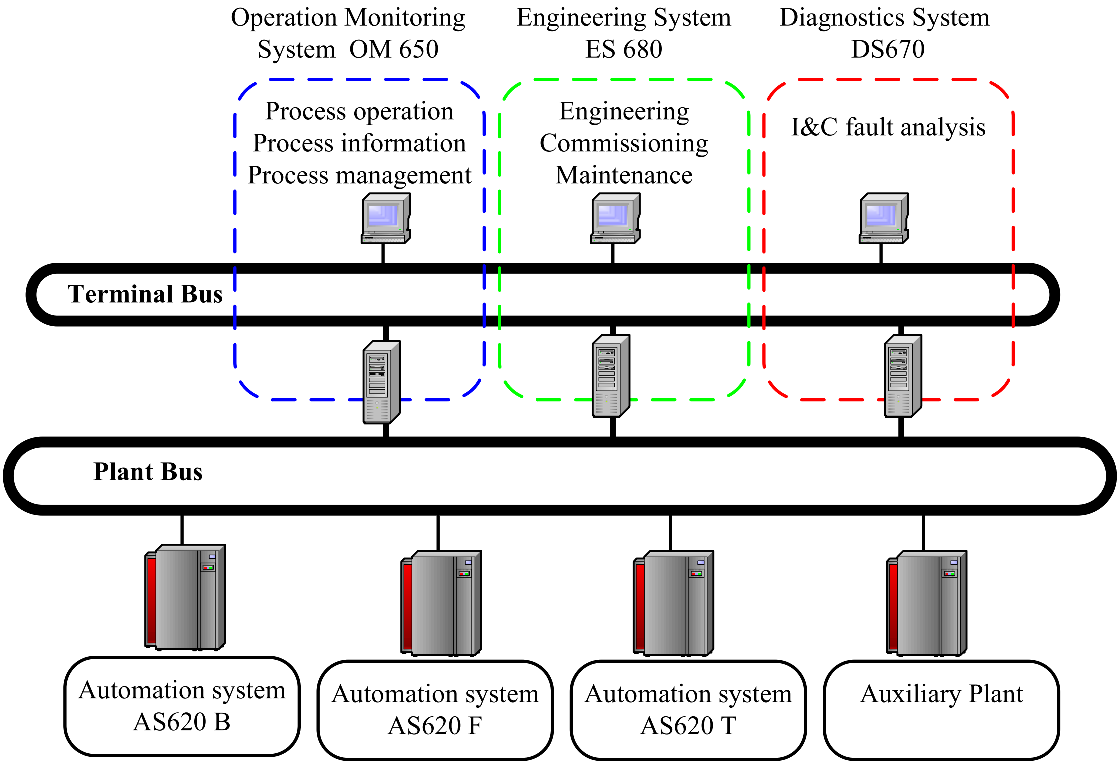


Figure 6.1 Teleperm XP distributed control system

Teleperm XP comprises of the four different sub-systems, which are connected together with industrial Ethernet at a speed of 10 MBit/s [15]. All TXP participants use the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access procedure on the bus system.

1) **Operation and Monitoring System (OM)** provides the interface between the plant and the operator in the control room. The Human Machine Interface (HMI) allows the operator to operate, observe and monitor the plant from a central point.

2) **Engineering System (ES)** is the configuration centre of Teleperm XP, and is based on the UNIX operating system. It is used to configure the Automation Systems (AS), OM, and bus system plus the required hardware. The Engineering System

administers all of the configuration data at a central point, which means that the data needs to be entered only once. The function diagrams are entered interactively into the Engineering System using the block function diagram editor.

3) **Automation System (AS)** performs the automation tasks. The automation system gathers measured values and conditions inherent in the process; it has open-loop and closed-loop control functions and transmits the resulting values or corrections and commands to the process.

There are three types of automation system in Teleperm XP. AS 620B is a basic system for general automation tasks and closed-loop control. AS 620T is the turbine control system and provides fast acting closed-loop controls for the turbo-set. AS 620F is a fail-safe system for protection and open-loop control functions.

4) **Diagnostic System (DS)** is a tool that provides monitoring of, and a detailed explanation of, any failure of the instrumentation and control components that make up Teleperm XP. When a failure occurs, the DS leads the operator to the point where the failure originated; it also indicates the cause of failure and how it can be eliminated.

Figure 6.2 shows the components that make up Teleperm XP. It also shows how they are organised into a hierarchical structure [15].

- The Individual Control Level is directly connected to the field devices. Two different modules are used to connect to the field devices: Function Module (FUM) and Signal Module (SIM).

- The Group Control Level is responsible for group automation tasks, coordination of the individual controllers and communication tasks between the Operating and Monitoring system (OM) and the field devices.

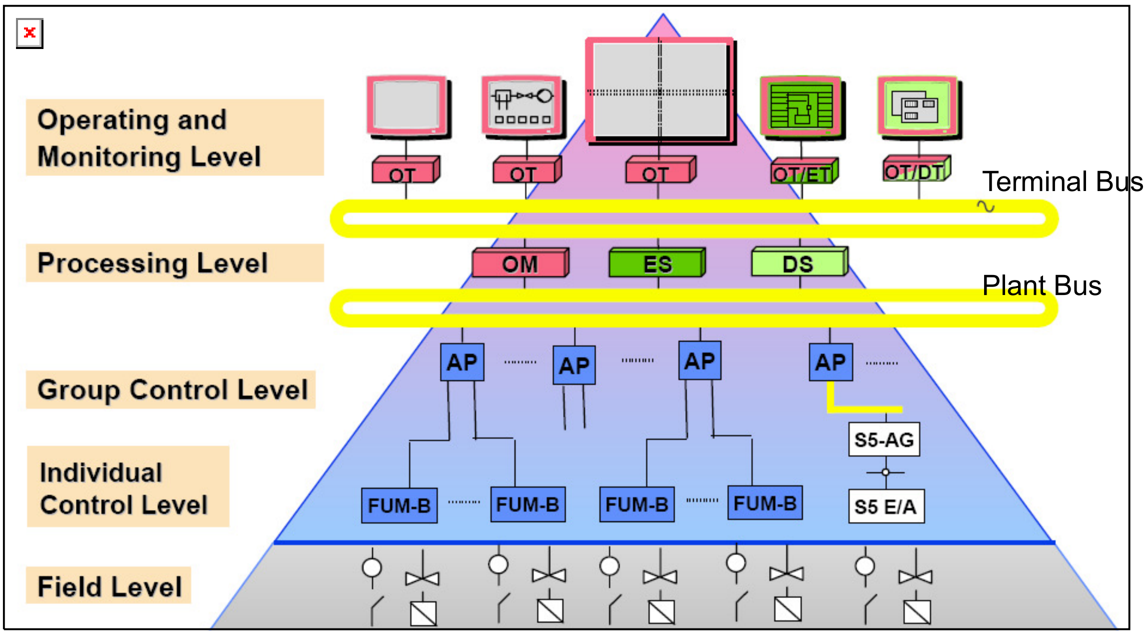


Figure 6.2 Hierarchical structure of Teleperm XP [15]

- The Processing Level processes and stores all signals from the automation system and sends operator commands to the Group Control Level.

- The Operating and Monitoring Level is the human machine interface of Teleperm XP. It displays the actual status of the plant to the operator, takes data from the processing level of the system, and interprets orders from the Operation Terminals (OT), and sends this information to the processing level.

6.1.2 Automation System

Automation System 620 (AS620) is the control centre of the plant, and performs all automation tasks. AS620 is therefore the most important subsystem in Teleperm XP. The AS620 gathers measured values from the field instruments and conditions inherent in the process. Open- and closed-loop control functions in AS620 transmit the resulting values or corrections and commands to the process. Simultaneously, the AS620 serves the other sub-systems as an interface to the processes taking place in the system: it transmits commands from the OM to the process and vice versa, it gathers information from the process. Information from the process is fed to the Operating and Monitoring

System, Engineering System or Diagnostic System.

Automation Processors (AP) are the heart of the AS620. Its design is based on the high–performance SIMATIC S5 Controller (CPU948). As shown in Figure 6.2, the APs link all of the subordinate components with the plant bus and thus with the operating and monitoring level of the process control system.

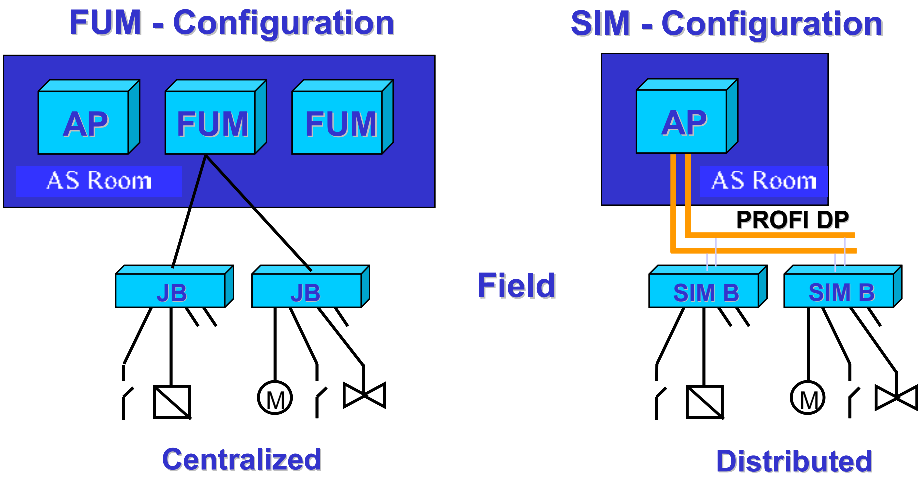


Figure 6.3 FUM and SIM configuration [15]

As shown in Figures 6.3, Siemens provide two types of Input/Output (I/O) modules. These are Function Modules (FUM) and Signal Modules (SIM). Interfacing takes place via I/O modules to which the measurement transmitters and actuators are connected. FUMs are used for central configurations and are equipped with pre-processing units with a medium to high processing performance; SIMs are used for distributed configurations and do not have pre-processing units. Otahuhu B power station currently uses the SIM configuration [15].

SIM modules are used for analogue and binary input and output signals. Their task is to digitise process signals received from field the instruments and to output digital settings as binary or analogue signals. More complex tasks such as signal processing, monitoring, and time-tagging are performed in the Automation Processors (APs).

SIM modules are from the SIMATIC S5/S7, ET200 B/ET200 M range, and allow the input and output modules to be installed locally in the process environment instead of in a central computer room[15]. The modules are combined into stations and located in distribution boxes in the immediate vicinity of the field devices.

The advantage of a distributed configuration lies in reducing the space required for the computer room, because only the cabinets for the Automation Processors (APs) are installed there. Distributed configurations also permit the APs and the input and output modules in the process environment to be located a considerable distance apart using a profibus. The Profibus used at OTB station can operate at a maximum data transmission rate of 1.5 Mbit/s and is also available in a fiber-optic version for use under adverse interference conditions or where lightning protection is required [15]. SIM modules are linked to the automation processors via Profibus. Wiring costs are dramatically reduced because only one Profibus cable is required from the SIM modules to the APs.

The AS620 comprises of three types of automation systems. These are Basic (B), Fail-safe (F), and Turbine (T) systems. AS620B is a basic system for general automation tasks and closed-loops controls. AS620T is the turbine control system providing the high-speed closed-loop controls for the turbine generator set. AS620F is a fail-safe system for protection and open-loop control functions. Figure 6.4 shows the structure of the automation systems.

- **AS620T System**

  The AS620T automation system is used for the gas and steam turbine high-speed closed-loop controls as well as for generator voltage control. Closed-loop control functions for the turbine generator set include speed, pressure, position, terminal voltage, and excitation current control. The open-loop control and protection functions associated with the turbine are implemented in the AS620B and the AS620F in fail-safe technology.

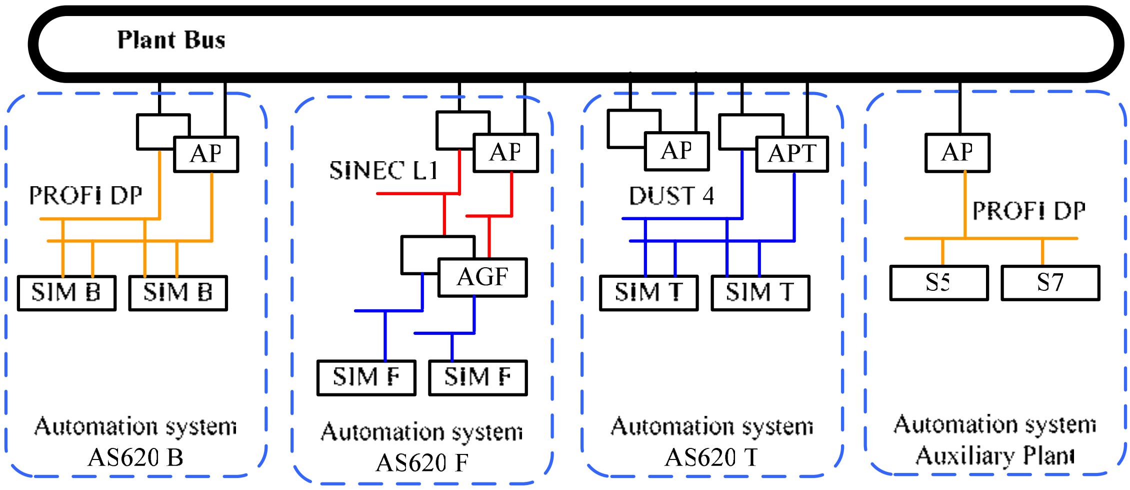


Figure 6.4 Teleperm XP Automation Systems

As shown in Figure 6.4, the AS620T consists of the Automation Processor Turbine system (APT) and the associated peripheral modules SIM T; and an associated AP that couples the APT to Teleperm XP, as the APT is unable to communicate directly with other parts of Teleperm XP. The APT is based on powerful processor modules located in the SIMADYN system and is structured redundantly [15]. Two APTs are linked to the plant bus; One APT is duty and the other is standby. In the event of a malfunction of the duty controller, the standby controller takes over via monitoring mechanisms. Signal modules (SIM T) are assigned to the APT via the DUST 4 bus [15]. In addition to high-speed control, other control tasks for the turbine generator set can be performed by the AP.

- **AS620F System**

AS620F is a fail-safe system used for open-loop control functions and for safety-related controls such as turbine and boiler protection. As shown in Figure 6.4, the AS620F consists of a SIMATIC S5-115F controller (AGF) and the associated peripheral modules SIM F. AGF is linked to the AP by a SINEC L1 bus that is a field bus developed by Siemens [15].

In order to meet the strict requirements concerning safety, the AGF fail-safe controller has a 2 out of 2 internal configuration. This means that the AGF has two processors that operate with the same program and the same clock pulse, and are monitored for bit parity by a 2 out of 2 comparator [15]. If the comparator is activated, for example due to a processor or memory fault, the AGF is immediately switched off.

- **Auxiliary Plant**

  As shown in Figure 6.4, the SIMATIC S5 and S7 controllers are linked to the plant bus by an AP. Interfacing to the SIMATIC S5 and S7 controller permits the auxiliary plant control system, which is not necessarily included in Siemens scope of supply, to be seamlessly linked to Teleperm XP.

6.1.3 Automation System 620B

The AS620B system and associated SIM I/O modules are used for general automation tasks and closed-loops controls at OTB station. There are eleven AS620B systems connected to the plant bus. As shown in Figure 6.5, the gas turbine is designated AS11 and 12; the steam turbine AS31, 32 and 33; the HRSG AS41 and 42; the water steam system AS61 and 62; the auxiliary system AS71 and 72. This topology ensures that groups of processors have a particular area to look after rather than relying on a single AS620B system; therefore, data traffic on the plant bus is dramatically reduced and the reliability of the control system is enhanced. The logic program developed for the new condensate monitoring system resides in AS61, which forms part of the water and steam control system.

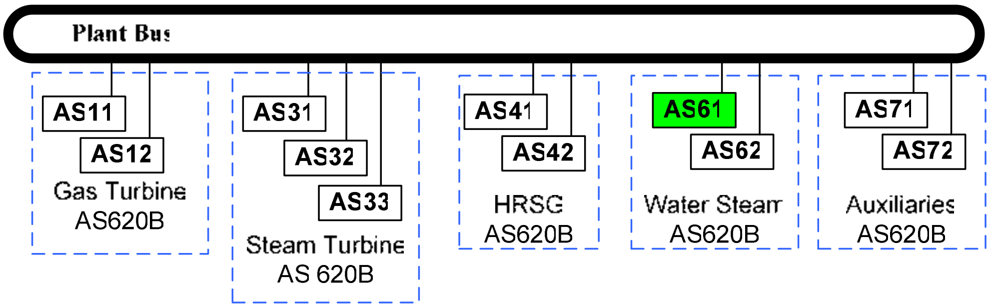


Figure 6.5 AS620B system topology

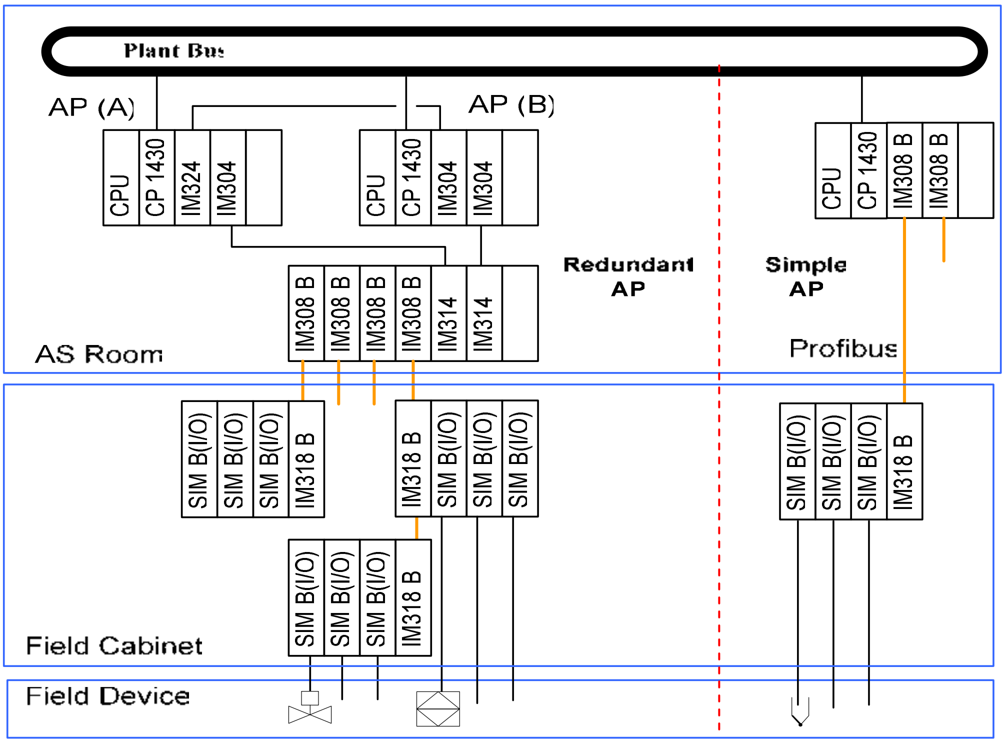


Figure 6.6 Automation system 620B structure

The AS620B system includes redundant Automation Processor (AP) structures and simple AP structures in the group control level as shown in Figure 6.6. The redundant AP structure consists of two APs, which are connected directly to the plant bus via the CP1430 connection modules and are interconnected via interconnection modules IM324 and IM304. Both APs have common connections with the individual control level through IM314 and IM304 module. One AP is on duty; the other is on standby. In the event of a malfunction of the duty AP, the standby AP takes over via monitoring mechanisms. The simple AP structure is similar to the redundant structure but only uses one AP, and is only used for low priority auxiliary systems. AS61 uses a redundant AP structure.

The peripherals in the individual control level are installed in a field cabinet close to the process equipment. The individual control level is linked to the group control level by the Profibus through interconnection modules IM308-B and IM318-B. IM318-B modules can be used as extension interfaces via Profibus by connecting more SIM-B

I/O modules as illustrated in Figure 6.6. One IM308-B may interface up to eight IM318B modules. One AP at the most can have 40 SIM-B I/O modules. SIM-B I/O modules are directly connected to field devices such as transmitters, actuators, and switches.

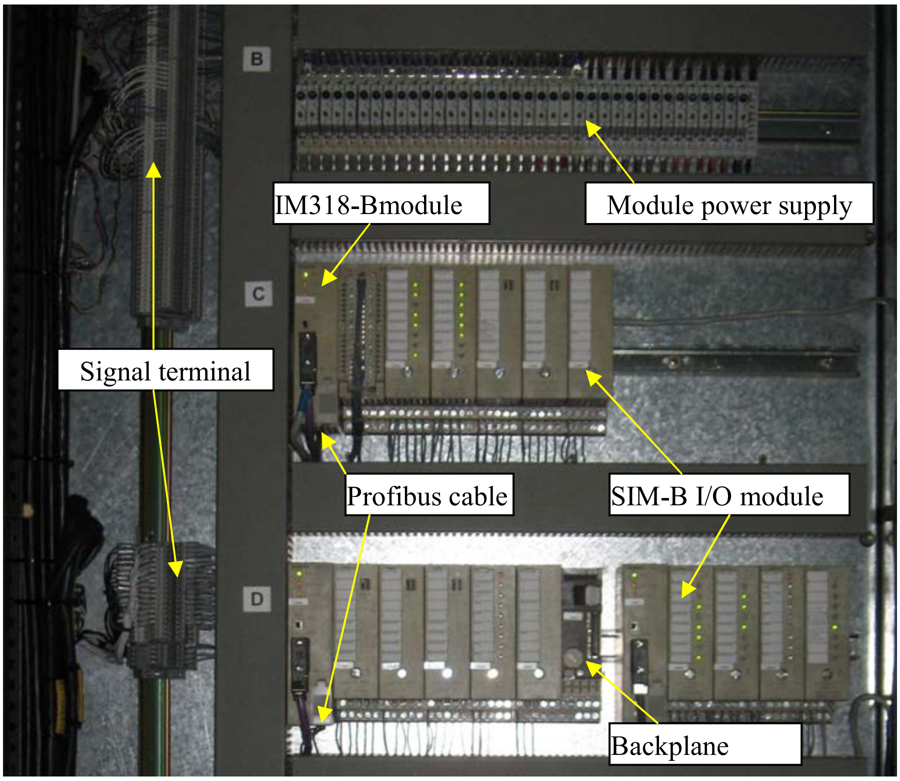


Figure 6.7 SIM module cabinet

Figure 6.7 shows the internal components of a typical SIM-B module cabinet in which the analogue and digital field signals are connected to SIM-B modules. The field signal wires are terminated at the signal terminal rack, then connected to the SIM-B module according to the signal wiring diagram. Each individual SIM-B module is connected to its associated IM318-B module via a backplane. IM318-B modules are linked together by a Profibus cable that is connected to the associated IM308-B module located in the automation system room. Every module on the Profibus has a unique address and every signal has a unique KKS code so that the automation processors in the AS620B system can determine where the signal is from and process the signal according to pre-programmed logic.

The SIM-B modules are powered by a 24V DC power supply and each module has an independent circuit breaker so that if the circuit breaker for a module trips, or a module fails, only the signals connected to the module are lost and other modules will not be affected. However, if the circuit breaker for a IM318-B module trips, or the IM318-B module fails, all of the signals associated with this IM318-B module will be lost.

6.2 Teleperm XP SIM Module Configuration

The Teleperm XP hardware configuration requires the condensate monitoring system to send 13 Analogue Input (AI) signals and 3 Digital Input (DI) signals to the water and steam AS620B system (AS61). AS61 is a redundant processor automation system. In order to process all of the signals in the DCS, the following modules were installed and configured during a plant outage in October 2007 (because it is safer to configure the hardware while the plant is shutdown):

- Four IM318-B modules. Each interconnection module is connected to its associated IM308-B module, which has been configured to allow expansion.

- Six 6ES5 464-8ME11(SIM-B) analogue input modules. Each module can process 4 channels of 4-20 mA analogue input signals.

- Four 6ES5 482-8MA13 (SIM-B) digital input/output modules. Each module can process 16 digital input and 16 digital output signals.

All of these modules have been installed in SIM-B module cabinet 10CPC27. Figure 6.8 shows the module arrangement in the cabinet. The modules are divided into four groups: EA, EB, FA and FB. Each group has a IM318-B module that is connected to its associated IM308-B module located in the automation system room. The SIM-B I/O modules can only communicate with the IM318-B module on the same backplane. In each group, the module ID is numbered from the left-hand side. For instance, the ID of the IM318-B module in group EA is EA001.

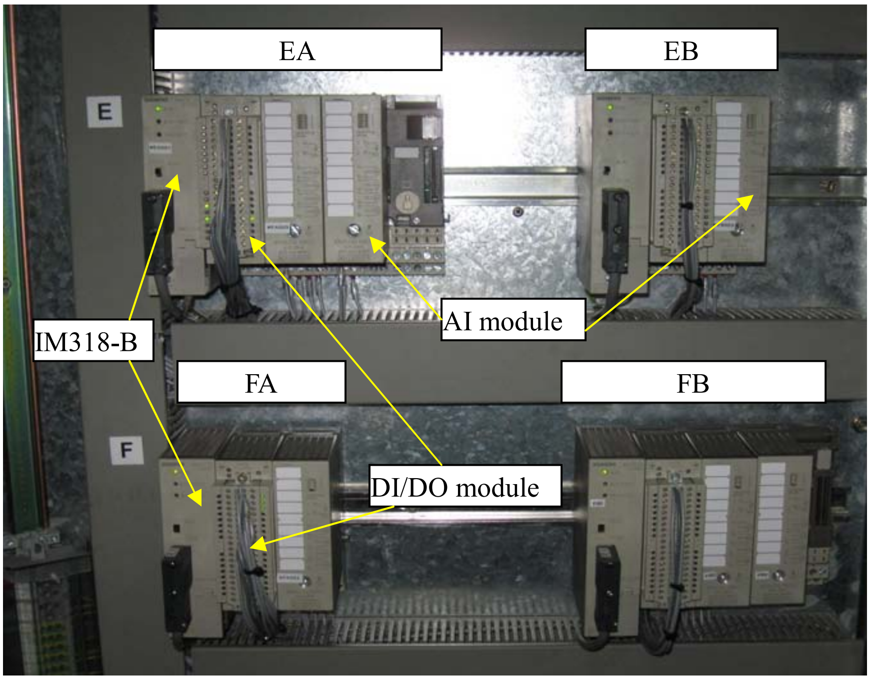


Figure 6.8 SIM-B module arrangement

The main reason for dividing the field signals into four groups is to enhance the availability of signals by using multiple redundancy configurations. As analysed in Section 5.2, sodium and cation conductivity signals are programmed to provide contamination level voting in the event of condenser in-leakage. Two sodium analysers and three conductivity analysers were chosen to strengthen the reliability of these signals. However, if all of these critical signals were connected to a single IM318-B interconnection module, all signals would be lost if the IM318-B module failed. Therefore, these signals have been separated into three different groups.

Table 6.1 shows the allocation of modules and signals. As can be seen from the table, three cation conductivity signals are allocated to EA003, EB003 and FA003 analogue input modules respectively. This ensures that if the IM318-B module or a SIM-B module in any of these three groups were to fail, the signals from the other two groups would not be affected. The DCS can still process the signal using a 2- out-of-3 voting principle. Likewise, the two sodium signals are allocated to different groups (EA003 and EB003). If one signal were lost due to malfunction of the SIM-B module, the DCS can still process the other signal using a 1-out-of-2 voting principle. Although module failures occur infrequently, the risk of losing one of these critical signals still exists. Therefore, the availability and reliability of these critical signals is substantially reinforced by allocating them to different groups.

Table 6.1 Module and signal allocation

Module ID		**Module Type**	**Signal Name**	**Signal KKS ID**
EA	001	IM318-B		
	002	6ES5 482-8MA13 (DI/DO)	For other projects	
	003	ES5 464-8ME11(AI)	Specific Conductivity 1	10QUC23CQ001_XQ01
			Cation Conductivity 1	10QUC23CQ002_XQ01
			Sodium 1	10QUC21CQ001_XQ01
	004	ES5 464-8ME11(AI)	Sample temperature	10QUC26CT001_XQ01
EB	001	IM318-B		
	002	6ES5 482-8MA13 (DI/DO)	For other projects	
	003	ES5 464-8ME11(AI)	Specific conductivity 2	10QUC24CQ001_XQ01
			Cation conductivity 2	10QUC24CQ002_XQ01
			Sodium 2	10QUC22CQ001_XQ01
FA	001	IM318-B		
	002	6ES5 482-8MA13 (DI/DO)	Analyser power fault alarm	10QUC21CE001_XB01
			Low sample flow alarm	10QUC21CF001_XB01
			High temperature alarm	10QUC21CT001_XB01
	003	ES5 464-8ME11(AI)	Specific conductivity 3	10QUC25CQ001_XQ01
			Cation conductivity 3	10QUC25CQ002_XQ01
			pH	10QUC26CQ001_XQ01
FB	001	IM318-B		
	002	6ES5 482-8MA13 (DI/DO)	For other projects	
	003	ES5 464-8ME11(AI)	Inferred pH 1	10QUC23CQ003_XQ01
			Inferred pH 2	10QUC24CQ003_XQ01
			Inferred pH 3	10QUC25CQ003_XQ01
	004	ES5 464-8ME11(AI)	Spare for others	

Each analogue input module in groups EA003, EB003, and FA003 has a spare channel that has been intentionally saved for another 2-out-of-3 redundancy signal from a future project. Because the inferred pH is only used for reference purpose, the three inferred pH signals have not been configured in three different modules and are only processed by analogue input module FB003.

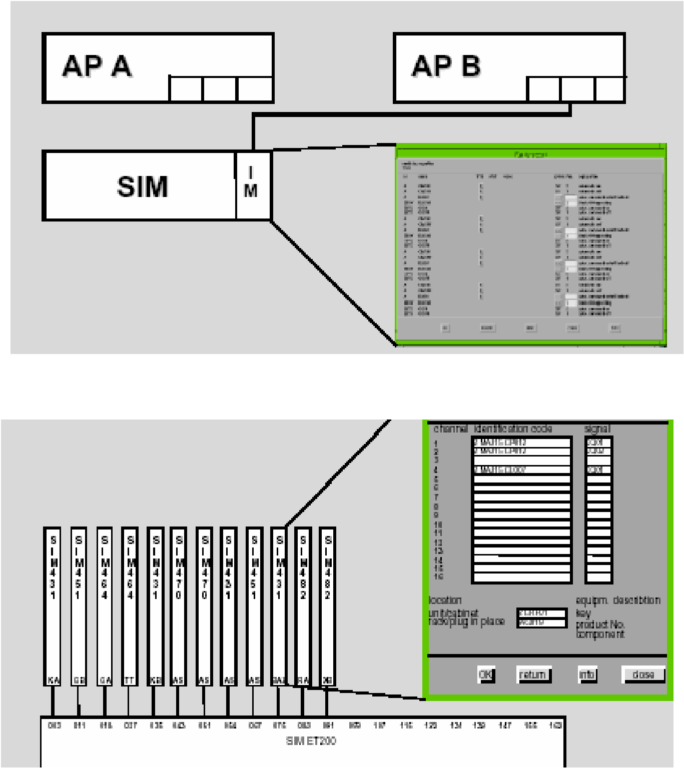


Figure 6.9 Configuration of SIM module [15]

The KKS code is used by Siemens to identify signals and equipment in their power stations. Each signal or piece of equipment in the system has a unique KKS code. The KKS code for each signal must be configured into the associated SIM-B I/O module from the engineering station as shown in Figure 6.9. After that, the configuration must be compiled and downloaded to the Erasable Programmable Read-Only Memory (EPROM) installed in the automation processor, so that the automation system can recognise these signals. For this project, the configuration of these signals has been written into the AS61 automation processors.

6.3 Condensate Monitoring System Logic Program

6.3.1 Engineering System ES680

The Engineering System (ES680) is the integrated, uniform planning and commissioning tool for Teleperm XP. It is used for all phases of project engineering from task definition and detailed engineering to commissioning and maintenance. ES680 is used for the engineering of the following subsystems of Teleperm XP :

- Operating and monitoring system OM650
- Automation system AS620
- Bus system

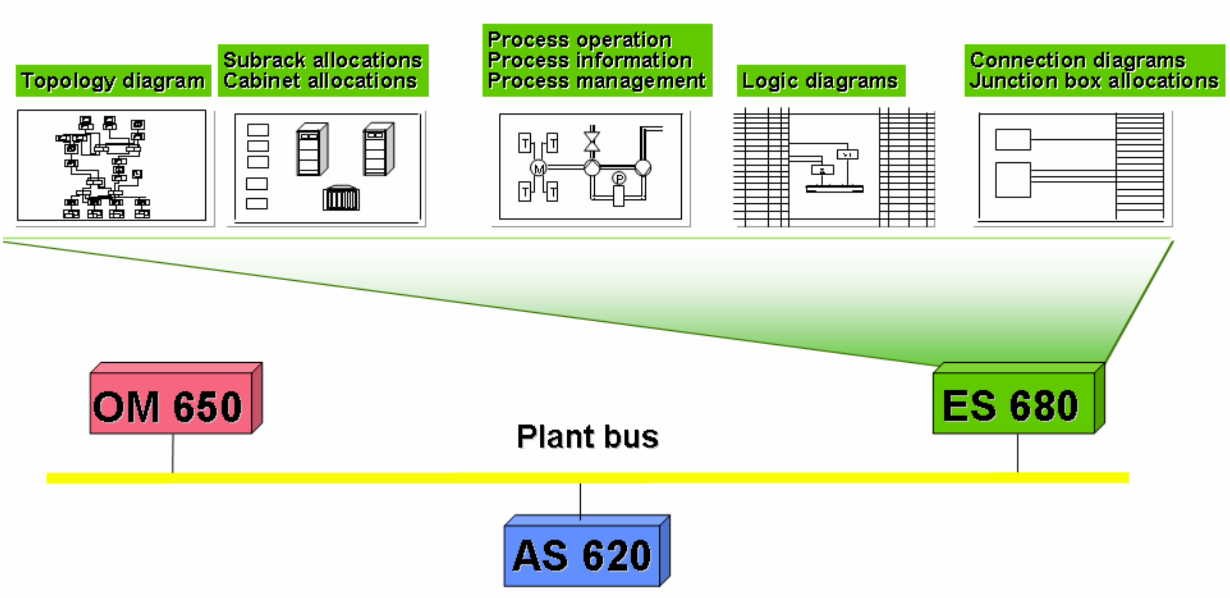


Figure 6.10 Engineering System Arrangement [15]

ES680 is a graphical system based on a database provided by Siemens. ES680 provides standardised software components for the engineering of HMI graphics such as soft buttons and trending diagrams [15]. As shown in Figure 6.10, ES680 uses function block diagrams for the engineering of process control programs.

Function block diagrams need to be created first and then downloaded to the target system. As shown in Figure 6.11, each function block diagram contains inputs area on the left-hand side, a logic area, and outputs area on the right-hand side. Signals are brought in from the input area, logic is performed on them in order from the top to the bottom, and outputs exit on the right-hand side.

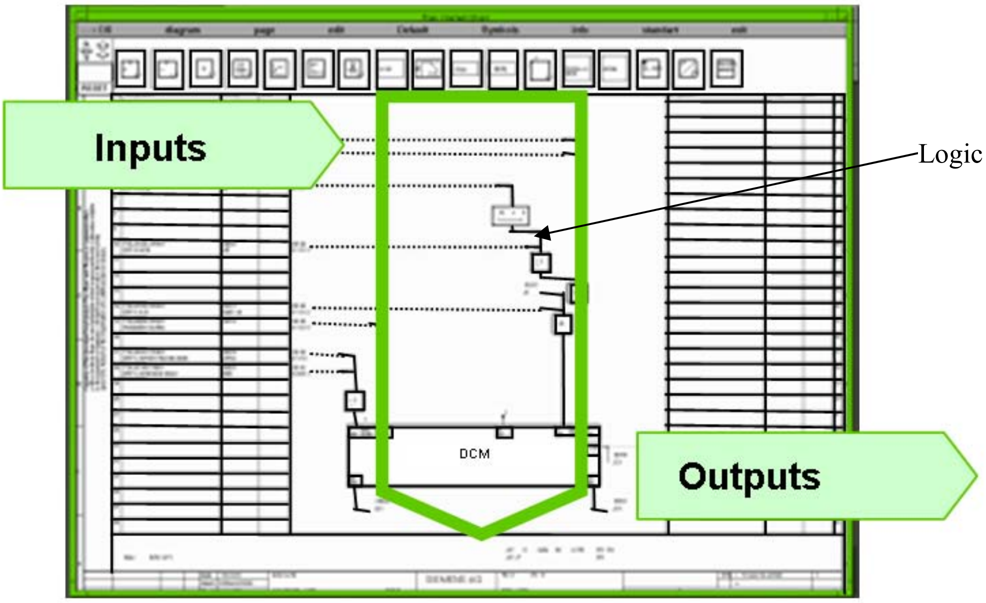


Figure 6.11 Function block diagram [15]

6.3.2 Individual Signal Function Configuration

After SIM-B modules have been configured, the 13 analogue input (AI) signals and 3 digital input (DI) signals from the condensate monitoring system need to be individually configured in the input signal function block.

6.3.2.1 Teleperm XP Linear Signal Configuration

Apart from the two sodium signals, all of the field signals from the condensate monitoring system are linear signals, which means the measured values are proportional to the 4 – 20 mA output current.

Figure 6.12 shows the function block diagram for cation conductivity #1 (10QUC23CQ002). Every function block diagram has a diagram code, which is located at the bottom right-hand corner of the diagram (YFR=*******). The diagram code is usually the same as the signal KKS code but they can be different. The cation conductivity #1 diagram code is 10QUC23CQ002; the same as the signal KKS.

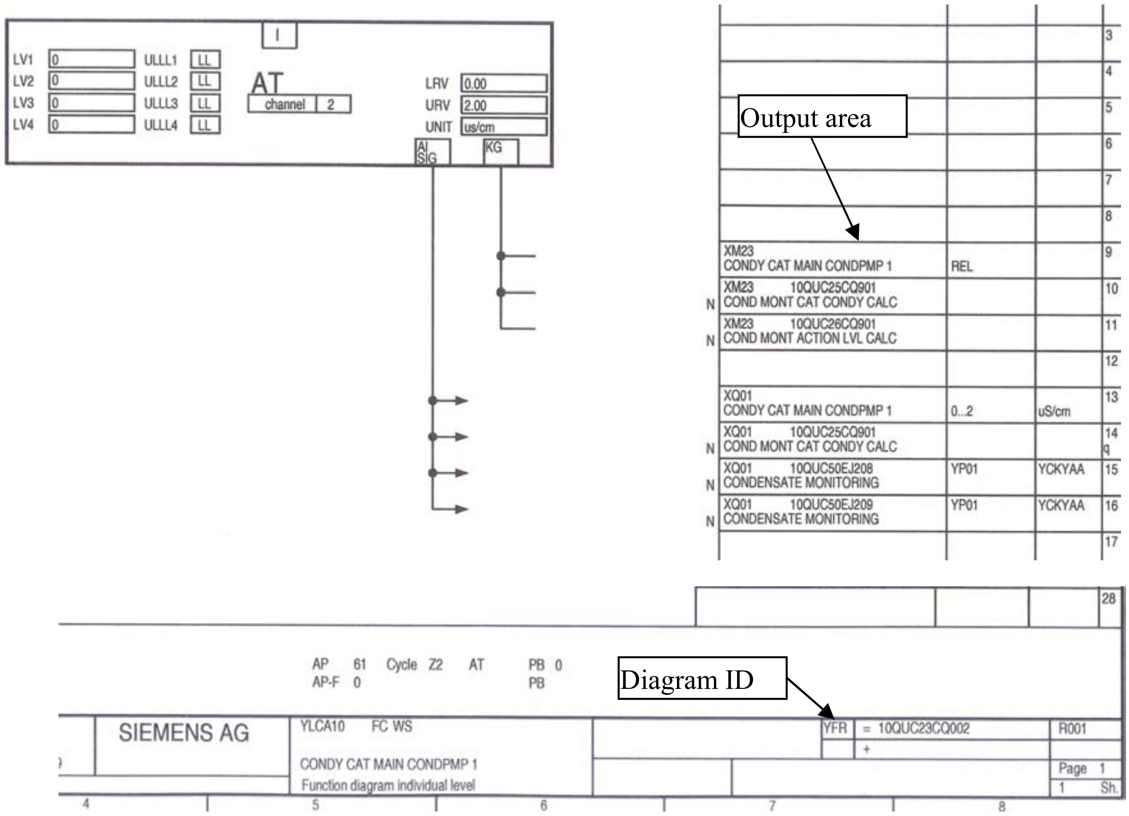


Figure 6.12 Function block diagram layout

AT in Figure 6.12 is the analogue input signal function block. The Low Range Value (LRV) is 0, which is equivalent to a 4 mA output current from the conductivity analyser. The High Range Value (HRV) is 2, which is equivalent to a 20 mA output current. The measured value is proportional to the current value. UNIT indicates the engineering units of the analogue signal, which are μS/cm (conductivity).

The AISIG port at the bottom of the AT function block is used to export the data that has been scaled by AT function block. The exported data can be displayed on the HMI graphics or used for the further calculation in other function block diagrams. As can be seen from Figure 6.12, the data from AISIG port is exported to HMI diagram (10QUC50EJ208) for the display of the real-time value and also to function diagrams 10QUC25CQ901 for further calculation.

The KG port at the bottom of AT function block is used to export a binary signal that represents the validity of this analogue signal channel. When the current of the analogue signal is below 2.4 mA or above 21.6 mA, the channel becomes invalid (KG=FALSE), otherwise the channel is valid (KG=TRUE). KG is usually used to generate an audio and visual alarm from the HMI, or for following Boolean functions in other function diagrams. For example, if the signal circuit is broken (the circuit current is zero) or the circuit current exceeds 21.6 mA, the status of KG will become FALSE, and then a channel fault alarm will be generated on the HMI. As can be seen from Figure 6.12, KG is exported to other function diagrams such as 10QUC25CQ901 and 10QUC26CQ901.

The BT is used to denote a digital input signal function block. These have the same functionality as ATs. Three digital input signals are configured in BT functions. Table 6.2 shows all the signals that need to be configured in AT and BT function blocks. Appendix C includes the detailed function diagrams for these signals. Each function diagram code is the same as the signal KKS code.

Table 6.2 Condensate monitoring system signals

Signal name	**KKS ID**	**Range**
Specific Cond 1	10QUC23CQ001_XQ01	0…50 µS/cm
Cation Cond 1	10QUC23CQ002_XQ01	0…2 µS/cm
Sodium 1	10QUC21CQ001_XQ02	0…800 ppb
Specific Cond 2	10QUC24CQ001_XQ01	0…50 µS/cm
Cation Cond 2	10QUC24CQ002_XQ01	0…2 µS/cm
Sodium 2	10QUC22CQ001_XQ02	0…800 ppb
Specific Cond 3	10QUC25CQ001_XQ01	0…50 µS/cm
Cation Cond 3	10QUC25CQ002_XQ01	0…2 µS/cm
pH	10QUC26CQ001_XQ01	0…14 pH
Infer pH 1	10QUC23CQ003_XQ01	0…14 pH
Infer pH 2	10QUC24CQ003_XQ01	0…14 pH
Infer pH 3	10QUC25CQ003_XQ01	0…14 pH
Temp from pH	10QUC26CT001_XQ01	0…100 ºC
Analyser Power Fault Alarm	10QUC21CE001_XB01	0…1
Low Flow Alarm	10QUC21CF001_XB01	0…1
High Temp Alarm	10QUC21CT001_XB01	0…1

6.3.2.2 Logarithmic Algorithm Deduction

Sodium signal requires high resolution and accuracy at the bottom end of the measurement range in order to meet the measurement requirement. Sodium value under normal operating conditions is between 0.1 ppb and 1 ppb. According to EPRI's guideline, the minimum sodium measurement range is from 0 ppb to 500 ppb in order to detect four contamination levels. However, the change in sodium value from action level 0 to action level 3 is only 12 ppb, which means that these three contamination (action) levels must be differentiated over 2.4 per cent of the sodium measurement range. Once the sodium value exceeds 12 ppb, this just leaves action level 4 needs to be confirmed when the sodium value reaches 500 ppb. Hence, the accuracy at the top end of the measurement range is not required to be as high as at the bottom end of the measurement range.

As shown in Table 6.3, the current value is 4 mA when the sodium value is 0 ppb and the current value is 20 mA when the sodium value is 500 ppb. If the measured sodium value is proportional to the output current value of the analyser, the current values from action level 1 to action level 3 are:

Level 1: $$4+3*\frac{(20-4)}{500}=4.096\text{ mA}$$

Level 2: $$4+6*\frac{(20-4)}{500}=4.192\text{ mA}$$

Level 3: $$4+12*\frac{(20-4)}{500}=4.384\text{ mA}$$

Table 6.3 Sodium action level

Action Level	0	1	2	3	4
Sodium (ppb)	0	3	6	12	500
Linearity (mA)	4	4.096	4.192	4.384	20

The change in the output current value of the analyser from action level 0 to action level 3 is only 0.384 mA if the output channel of the analyser were to use the proportional mode. Because there are 6KV AC electric pumps located near the wet rack where the analysers are installed, the milliampere current signals are vulnerable to the electromagnetic noise generated by this equipment. Any noise superimposed on such a small milliampere signal will generate a considerable error in the measured result. Therefore, the sodium value should not be transmitted using the proportional mode in order to guarantee signal accuracy at the bottom end of the measurement range.

The ABB sodium analyser used provides a logarithmic current output from 4 mA to 20 mA as shown in Figure 6.13. This meets the requirements for sodium measurement. Assuming the measurement range to be 0.1 ppb to 1000 ppb (ug/kg), the current output value at 10 ppb covers 50 per cent of its range (4 mA to 12 mA) as the sodium value changes from 0.1 ppb to 10 ppb. The change in current value is 8 mA, which is much greater than the 0.384 mA that would result in proportional mode, hence logarithmic mode is able to provide a high resolution (ppb/mA) when the sodium value changes from 0.1 ppb to 10 ppb.

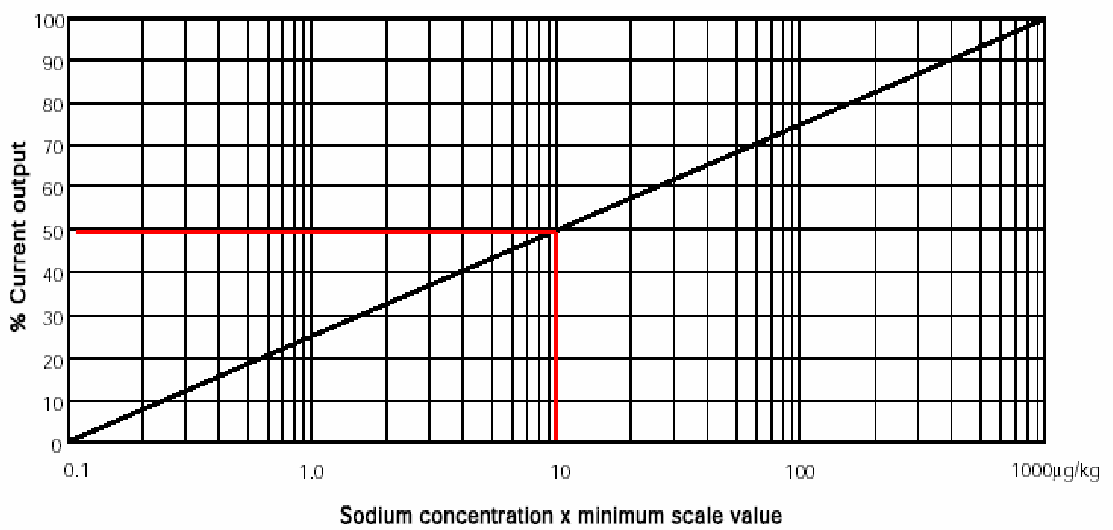


Figure 6.13 Logarithmic current output - four decade [16]

However, ABB’s manual does not describe how the output current matches the sodium value in the logarithmic mode and Teleperm XP does not provide a logarithmic function that matches the logarithmic current from the sodium analyser. Therefore, the relationship between the analyser output current and the sodium value in logarithmic mode must be found and a logarithmic algorithm must be developed in Teleperm XP in order to calculate the sodium value.

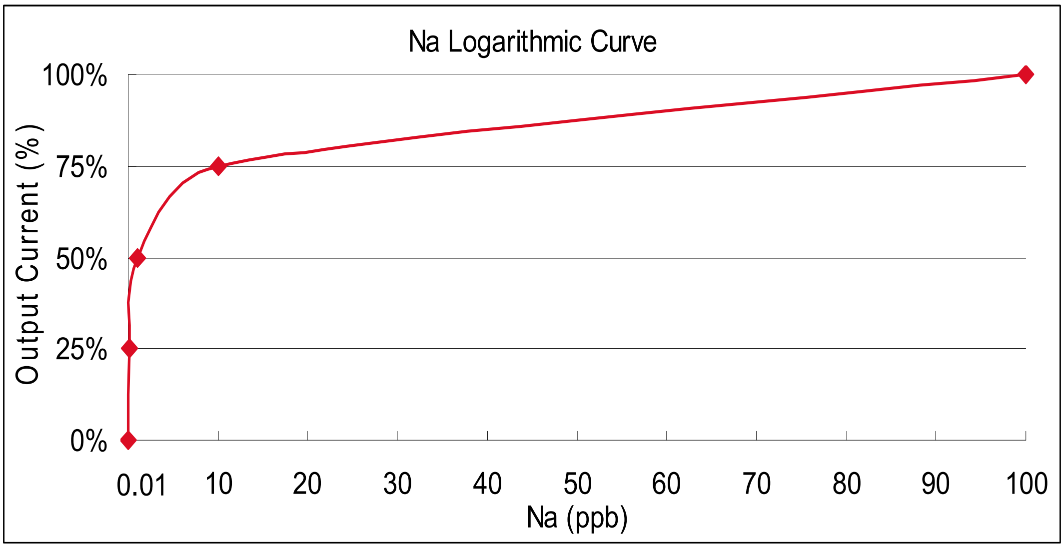


Figure 6.14 Na logarithmic curve in linear scale

Figure 6.14 shows a logarithmic curve with a linear scale, which can be used to represent the relationship between the sodium value and the analyser output current in logarithmic mode. The logarithm of 0 to the base 10 is invalid, and 0.01 ppb is very close to 0 ppb, hence the measurement range is set from 0.01 ppb to 100 ppb, which is a four decade range. The third row in Table 6.4 shows the exponent value of base 10 after converting the sodium value into a base 10 logarithm format. In Figure 6.15, the base 10 logarithmic curve shown in Figure 6.14 becomes a straight line after changing the X-axis from a linear scale to a logarithmic scale.

Table 6.4 Na logarithmic expression format

	0	25	50	75	100
Na (ppb)	0.01	0.1	1	10	100
$\mathrm{Log}_{10}^{\mathrm{Na}}$	-2	-1	0	1	2

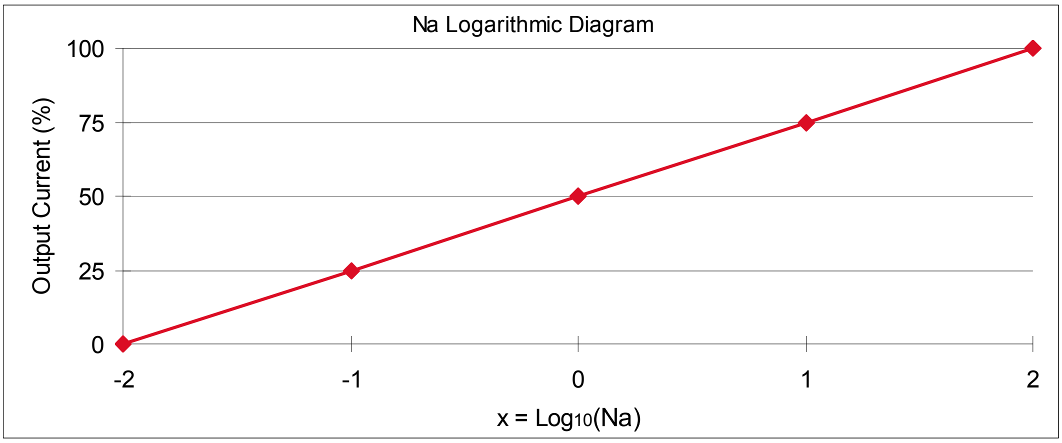


Figure 6.15 Na value with logarithmic scale

As can be seen from the above diagram, the output current is directly proportional to the exponent of base 10. Therefore, the relationship between the exponent of base 10 (X) and the percentage of the output current (Y) can be written:

$$Y = 25 * X + 50 \qquad (6.1)$$

The sodium value (N) in Figure 6.14 can be written:

$$N = 10^{X} \qquad (6.2)$$

Where:

N = Na value (ppb)
X = Exponent of base 10 (-2, -1, 0, 1, 2)

Taking logs of both sides of Equation 6.2, then X is given by:

$$X = \log_{10}^{(N)} \qquad (6.3)$$

Substituting Equation 6.3 into Equation 6.1, the percentage of the output current (Y) is:

$$Y = 25 * \log_{10}^{(N)} + 50 \qquad (6.4)$$

The measurement range constant (K) can be introduced into Equation 6.4 so that the sodium measurement range can be changed. For instance, if the measurement range is from 0.01 to 100 ppb then K equals 1; if the measurement range is from 0.08 to 800 ppb then K equals 8. Therefore, the relationship between the percentage output current (Y) and the sodium value (N) is:

$$Y = 25 * \log_{10}^{(N/K)} + 50 \qquad (6.5)$$

The percentage of the output current (Y) is:

$$Y = \frac{(I - 4)}{(20 - 4)} *100 = (I - 4)*100 / 16 \qquad (6.6)$$

Where:

I = Output current (4 – 20 mA)

Substituting Equation 6.6 into Equation 6.5, the output current (I) is:

$$(I - 4)*100 / 16 = 25 * \log_{10}^{(N/K)} + 50$$

$$I = (50 + 25*\log_{10}^{(N/K)}) * 16 / 100 + 4 \qquad (6.7)$$

Where:

I = Output current (4 – 20 mA)

N= Sodium value (ppb)

K= Measurement range constant

Table 6.5 Analyser output current in logarithmic mode and Proportional mode

Action Level	0	1	2	3	4	4
Sodium (ppb)	0.08	3	6	12	500	800
Logarithmic Calculation (mA)	4	10.4	11.5	12.7	19.18	20
Logarithmic Measurement (mA)	4	10.52	11.55	12.78	19.24	20.03
Proportional (mA)	4	4.06	4.12	4.24	14	20

Equation 6.7 can be used to calculate the analyser output current in the logarithmic mode. In order to verify the correctness of Equation 6.7, an experiment was performed by simulating the Na input value and measuring the current value from the analyser output channel. Table 6.5 shows the analyser output current in logarithmic mode and proportional mode. The calculated and measured results in logarithmic mode are very close but there is a small degree of error. This proves that the calculated results are correct. Hence, Equation 6.7 is the formula that the ABB analyser uses to produce the

output current signal in logarithmic mode.

The noise immunity improvement in logarithmic mode is significant. As shown in Table 6.5, when the sodium value increases from 0.08 ppb (action level 0) to 12 ppb (action level 3), the analyser output current increases by 8.7 mA in logarithmic mode, whereas the current increases by 0.24 mA in proportional mode. When the sodium value is less than 12 ppb, the ratio of ppb to milliampere (ppb/mA) is 5 ppb per 0.1 mA in proportional mode and approximately 0.14 ppb per 0.1 mA in logarithmic mode. If there was a 0.1 mA noise signal interfering with the analyser output circuit, the measurement error will be 5 ppb in proportional mode and only 0.14 ppb in logarithmic mode. Hence, the noise immunity of logarithmic mode is 35 times higher than that of proportional mode at the bottom end of the measurement range. The analyser has to be able to differentiate between three contamination levels from 0 ppb to 12 ppb and without this immunity, the error caused by interference would be unacceptable.

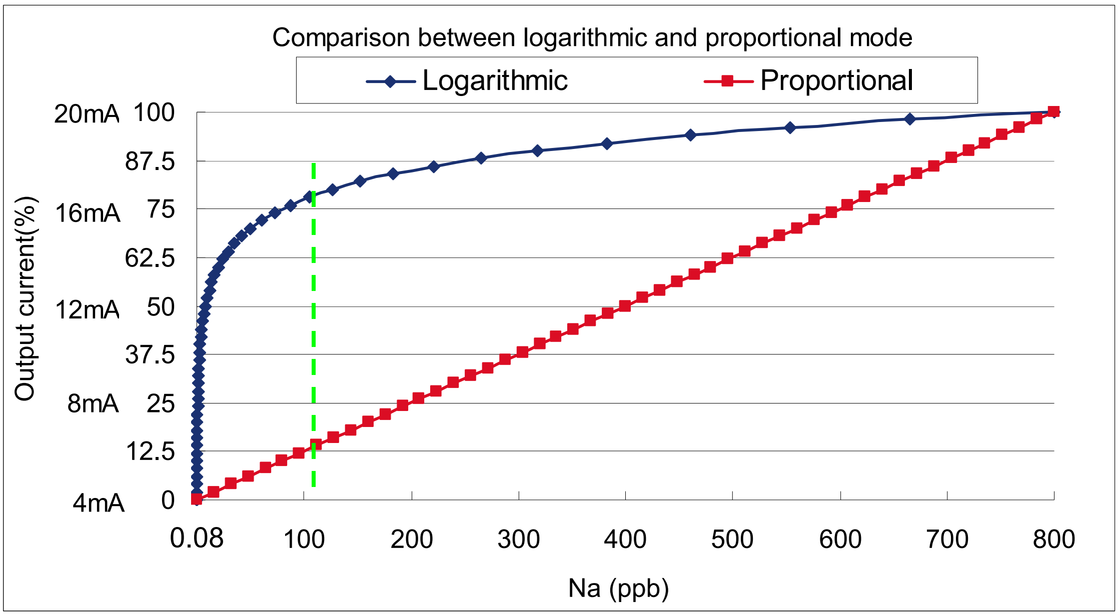


Figure 6.16 Comparison between logarithmic and proportional mode

Figure 6.16 shows the relationship between the sodium value and the output current from the sodium analyser in proportional mode and logarithmic mode. The measurement range constant is eight (K=8), which means that the measurement range covers four decades from 0.08 ppb to 800 ppb. Because the sodium value during normal operation is between 0.1 ppb and 1 ppb, 0.08 ppb is a valid minimum value. As can be seen from the logarithmic curve in Figure 6.16, the output current value increases very quickly from 4 mA to 16 mA as the sodium value changes from 0.08 ppb to 100 ppb. This covers approximately 75 per cent of the output current range (12mA). However, the output current value in proportional mode covers only 12.5 per cent of the current range from 0.08 ppb to 100 ppb. This shows that logarithmic mode dramatically improves the analyser output accuracy (ppb/mA) and noise immunity at the bottom end of the measurement range.

The output current covers 25 per cent of its range in logarithmic mode as the sodium value changes from 100 ppb to 800 ppb. The accuracy of logarithmic mode at the top end of the measurement range is degraded. However, as only action level 4 needs to be detected when the sodium value exceeds 500 ppb, this is acceptable. The value of 500 ppb can be considered as a binary switch value for the activation of action level 4 rather than an analogue signal that needs to be as accurate as the value at the bottom end of the measurement range.

6.3.2.3 Teleperm XP Logarithmic Signal Configuration

The ABB sodium analyser converts the measured sodium value (ppb) to output current (mA) using a four-decade base 10 logarithmic function. Therefore, the current signal must be reconverted to the sodium value (ppb) using an inverse function at the Teleperm XP (TXP) input module. The TXP input module provides a function that converts a 4 – 20 mA signal to a 0 to 100 percent signal. Therefore, Equation 6.5 can be directly converted from a logarithmic function to an exponential function that represents the relationship between the sodium value (N) and the percentage of the input current (Y) at the TXP input module. The conversion steps are as follows:

$$Y = 25 * \log_{10}^{(N/K)} + 50$$

$$(Y - 50) / 25 = \log_{10}^{(N/K)}$$

$$N / K = 10^{(\frac{Y-50}{25})}$$

$$N = K * 10^{(\frac{Y-50}{25})} \qquad (6.8)$$

Where:

N = Sodium value (ppb)
K= Measurement range constant
Y= Percentage of input current (0..100)

Teleperm XP does not provide the base 10 exponential function (10^{X}) that Equation 6.8 requires. However, TXP provides a natural logarithm function ($\log_e$ = **ln**) and an exponential function (e^{X}). In order to apply Equation 6.8 to TXP, Equation 6.8 must be reformatted using $\mathbf{e}^{X}$ and **ln** functions as follows:

$$N = K * 10^{(\frac{Y-50}{25})}$$

$$\ln^{N} = \ln^{K*10^{(\frac{Y-50}{25})}}$$

$$\ln^{N} = \ln^{K} + \frac{(Y - 50)}{25} \ln^{10} \qquad (6.9)$$

Where:

N = Sodium value (ppb)
K= Measurement range constant
Y= Percentage of input current (0..100)

After the value of $\ln^{N}$ has been calculated using Equation 6.9, the sodium value (N) can be obtained using the exponential function (e^{X}):

$$N = e^{\ln N} \qquad (6.10)$$

Figure 6.17 shows the sodium signal (10QUC21CQ001) function diagram in TXP using Equations 6.9 and 6.10. The sodium analyser measurement range is set at 0.08 to 800 ppb hence the measurement range constant in Equation 6.9 is 8 (k=8). Both sodium signal function diagrams are shown in Appendix C. The diagram codes are 10QUC21CQ001 and 10QUC22CQ001.

A test was implemented to verify the accuracy of the sodium signal using the logarithmic configuration. Table 6.6 shows that the analyser output value is almost identical to the value displayed in TXP. The error between the two signals at the bottom end of the measurement range is extremely small and meets the design requirement.

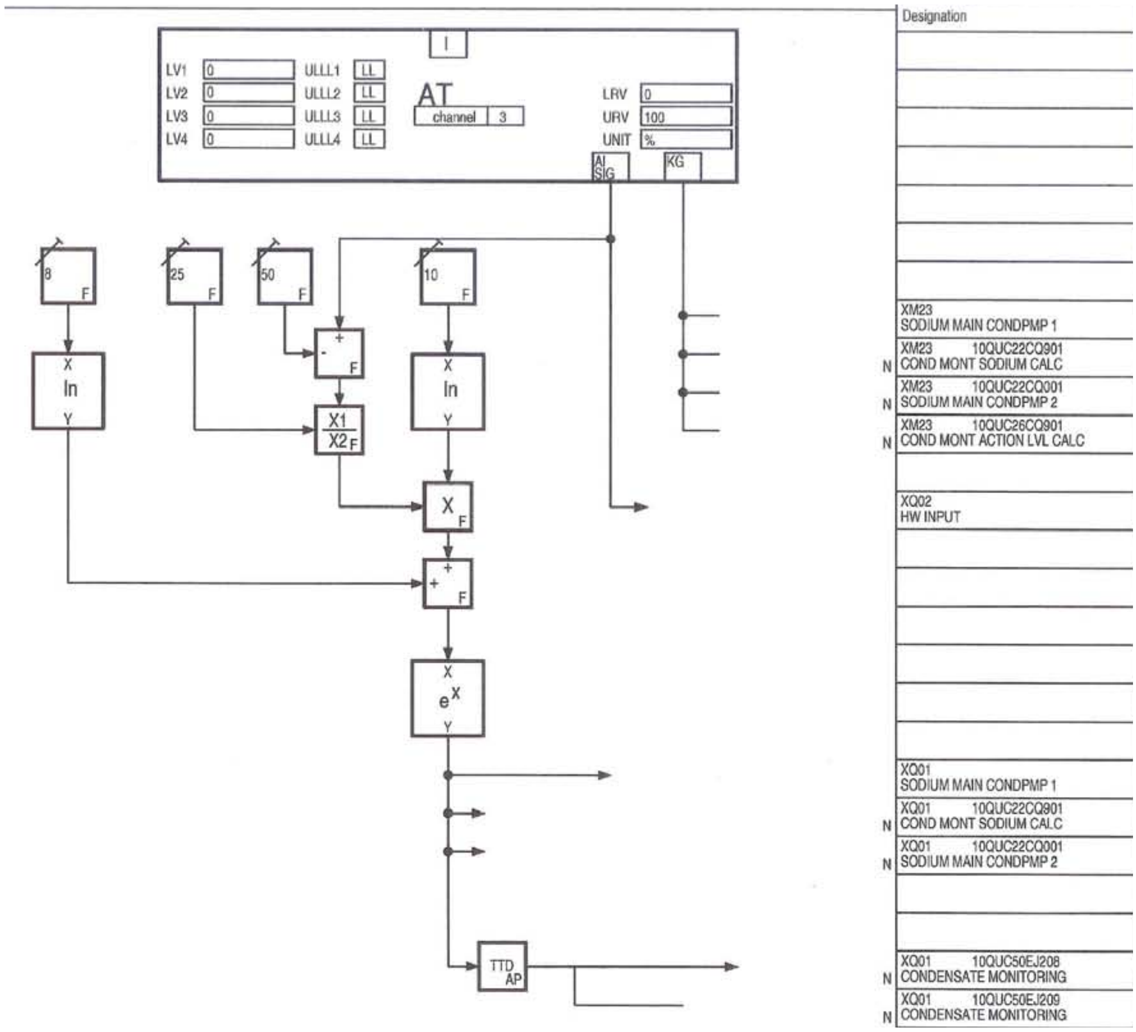


Figure 6.17 TXP Sodium signal function diagram

Table 6.6 Sodium value accuracy test results

Action Level	1	2	3	4	4
Sodium value from analyser output (ppb)	3	6	12	500	800
Sodium value displayed in TXP (ppb)	3.02	6.05	12.01	503	800
Error (ppb)	0.02	0.05	0.01	3	0

The logarithmic function is especially suitable for a signal that requires high accuracy at the bottom end and low accuracy at the high end of the measurement scale. This is the first time a logarithmic function has been used to configure an analogue signal in TXP. The common method used in TXP for similar applications is a bilinear function, however, the bilinear function can not provide the accuracy of a logarithmic function. Therefore, the method developed for the sodium signal can in future be applied to other signals that have the same requirements as the sodium signal in this project.

6.3.3 Redundant Signal Processing

Because cation conductivity and sodium need to be programmed into the control system for contamination level voting in the event of condenser in-leakage, they have redundancy in order to enhance the availability and reliability of the signals. The multiple redundant signals must be processed by a selection function in order to generate a final signal for use in the following programs.

6.3.3.1 Cation Conductivity 2V3 Selection

Teleperm XP provides a 2-out-of-3 analogue selection function (2V3) that can be used to process the three cation conductivity signals. The 2V3 function is usually reserved for critical signals, such as those used for HRSG drum level control. Figure 6.18 shows the cation conductivity 2V3 function. X1, X2 and X3 are connected to the three cation conductivity signals, which are the outputs (AISIG) from their respective AT function blocks. GX1, GX2 and GX3 are the signal validity channels, and are connected to the outputs (KG) from the respective AT function blocks. The 2V3 function is described as follows:

- If all three signals are valid and no illegal deviation is determined between at least 2 of the 3 inputs, the output is the mean value of the analogue input signals.

- If all three signals are valid but there is an unacceptable difference between all 3 signals, an alarm is generated and the output remains unaltered.

- If only two signals are valid and no illegal deviation is determined between the two signals, the output is the mean value of the valid input signals.

- If only one signal is valid, the output is set to zero and an alarm is generated.

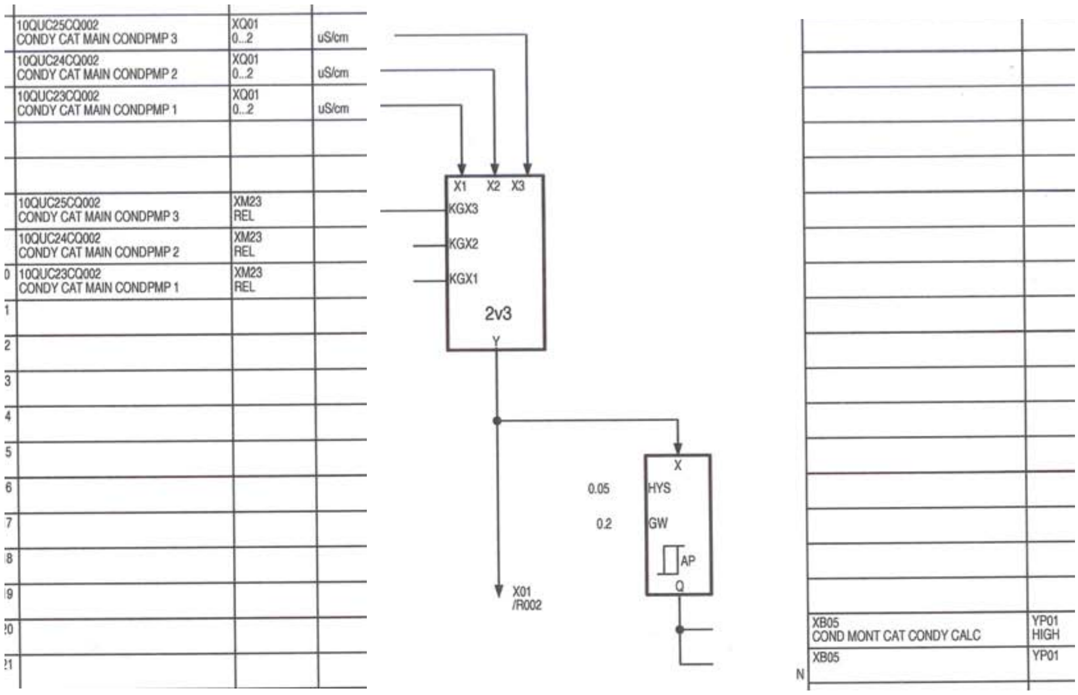


Figure 6.18 Cation conductivity 2-out-of-3 voting function

The function diagram 10QUC25CQ901(Page 1) in Appendix C shows the 2V3 function. In Figure 6.18, if the output value of the 2V3 function exceeds 0.2μS/cm, a “ cation conductivity high” alarm will be generated on the HMI to warn the operator that the cation conductivity is higher than the normal value.

6.3.3.2 Sodium 1V2 Selection

Teleperm XP does not have a 1-out-of-2 selection function (1V2) that can be directly used to process the two analogue sodium signals. A 1V2 function was designed using standard function blocks in TXP. The 1V2 function is described as follows:

- If both signals are valid and the deviation between the two signals is less than the high limit of the corresponding range, the output is the maximum value of the two input signals.

  As analysed in Section 6.3.2.2, the sodium signal at the top end of the measurement range does not have to be as accurate as at the bottom end. Therefore, the allowable deviation between the two sodium signals should become larger as the sodium values increase. The allowable deviation limits are:

  1) If both sodium values are less than 20 ppb, the high deviation limit is 2 ppb.
  2) If both sodium values exceed 100 ppb, the high deviation limit is 50 ppb.
  3) Otherwise, the high deviation limit is 10 ppb.

- If both signals are valid but the deviation value between the two signals exceeds the high limit, the output remains unaltered. Meanwhile, a “Na deviation high” alarm is displayed on the HMI to inform the operator about the deviation. This ensures that the output of the 1V2 function is only the maximum value of the two input signals when both signals are valid and functional.

- If only one signal is valid, the valid signal is the output. When the current of the analogue signal is below 2.4 mA or above 21.6mA, the channel becomes invalid (KG=FALSE).

- If both signals are invalid, the output is set to zero and the “condensate monitoring system fault alarm” is activated.

A schematic logic diagram for the 1V2 function was developed using standard function blocks as shown in Figure 6.19. The meaning of each function block is:

- **&**: AND Boolean function.
- **MAX**: Maximum selection function. Output is the greater value of **a** and **b**.
- **SEL**: Selection function. If the EN is true, the output equals **a,** otherwise the output equals **b**.
- **SUB**: Subtraction function.
- **CMP (a<b)**: Comparison function. If **a** is less than **b,** then the output is TRUE.
- **CMP (a>b)**: Comparison function. If **a** is greater than **b,** then the output is TRUE.
- **ABS**: Absolute value function.
- ⎎ : Switch function with hysteresis. The output is TRUE if **EN** is true and the input value is greater than **grt**. The output will not become FALSE until the input value is less than (**grt – hys**).
- **≥1**: OR Boolean function.

The 1V2 function is related to the function diagrams 10QUC21CQ001, 10QUC22CQ001, and 10QUC22CQ901 (Page 1) in Appendix C. The output of the 1V2 function is the final voted sodium value from the two sodium input signals. In addition, if the voted sodium value exceeds 3 ppb, then a “sodium high” alarm will be generated on the HMI. The alarm logic is created in function diagram 10QUC22CQ901 (Page 5) in Appendix C.

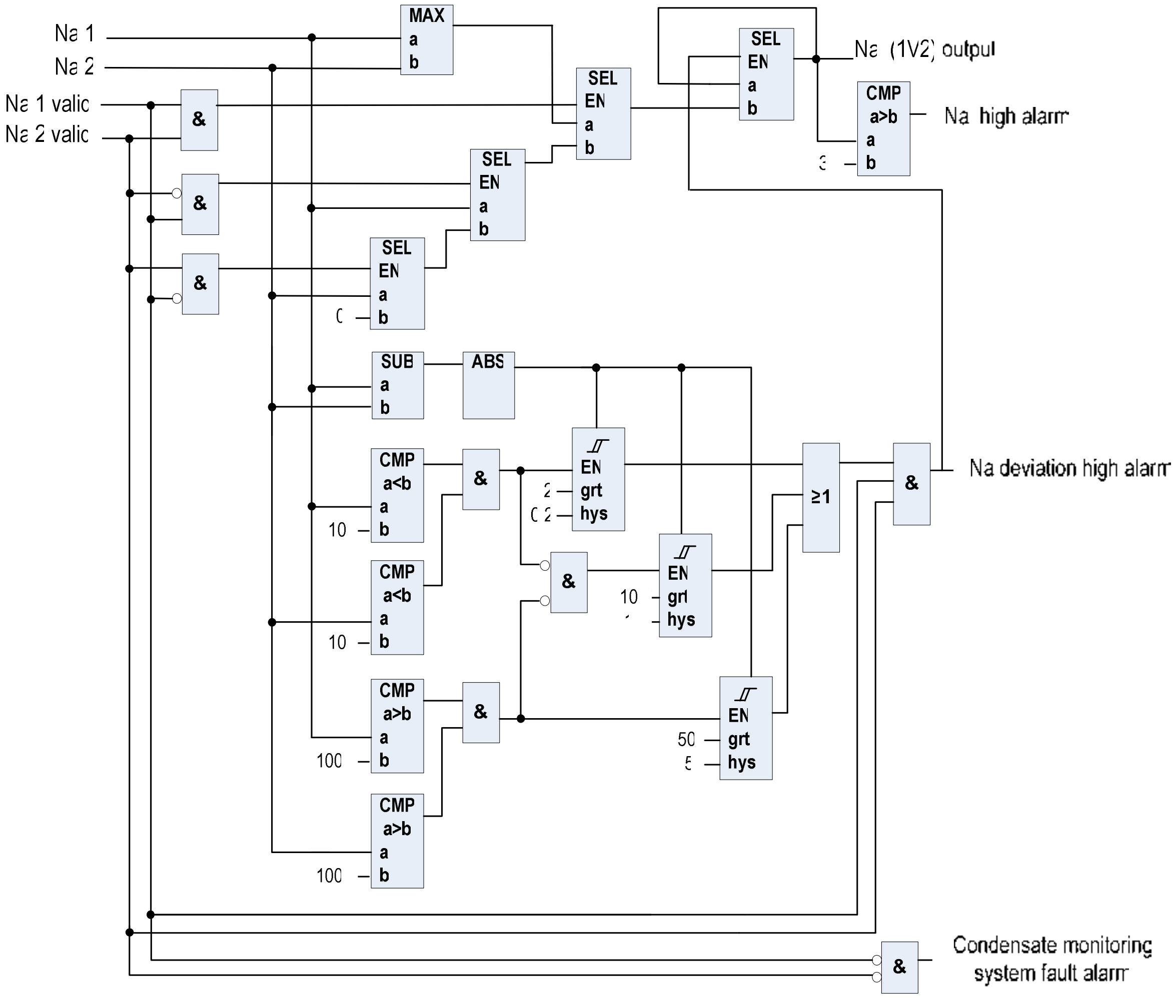


Figure 6.19 1V2 function schematic diagram

6.3.4 System Alarms

The system alarms are used to inform the operator of an abnormal condition. All system alarms are audible and visual. The alarms consist of hard-wired and TXP logic alarms.

6.3.4.1 Hard Wired Alarm

Hard-wired alarms comprise a high temperature alarm, a low sample flow alarm, and an analyser power fault alarm. All of these alarms are critical to the normal operation of the condensate monitoring system. Therefore, the fail-safe principle is applied to these alarms. This means that if an alarm is activated or the signal circuit to the DCS is broken (24V DC is not detected at the digital input module), an alarm is generated on the HMI. The operator must check the instruments locally when these alarms are activated. The functions of the alarms are described as follows:

- **High temperature alarm (10QUC21CT001_XB01)**

  This alarm is used to protect the analyser sensors from high temperature damage. A Thermal Shutoff Valve (TSV) is installed downstream of the sample cooler. The valve is normally open. However, the valve automatically shuts when the sample temperature after the cooler exceeds 49ºC. The normally closed contact in the valve breaks when the valve closes activating an alarm on the HMI.

  When the alarm goes off, the operator needs check the valve locally. The valve will remain closed after it trips and can only be opened again by pushing the local reset button after the sample temperature fall below 49ºC. The function diagram for the high temperature alarm is 10QUC21CT001 in Appendix C.

- **Low sample flow alarm (10QUC21CF001_XB01)**

  This alarm is used to detect a low sample flow at any of the analysers. The six analysers share one common alarm. If any analyser has a low sample flow, an alarm will be activated on the HMI. The operator needs to check the sample flow locally because the common alarm does not tell which analyser flow is low. The alarm can only be reset after the sample flow to all analysers exceeds the lower limit. The function diagram for the low sample flow alarm is 10QUC21CF001 in Appendix C.

- **Analyser power fault alarm (10QUC21CE001_XB01)**

  Each analyser has an individual miniature circuit breaker (MCB) with a normally open contact. These six contacts are connected in series to share one common alarm. If any circuit breaker trips, an alarm will be activated on the HMI. The operator needs to check the circuit breakers locally. The alarm can only be reset when all of the circuit breakers are closed.

6.3.4.2 Teleperm XP Logic Alarm

Teleperm XP logic alarms comprise the conditions that can negatively affect the functionality of the condensate monitoring system. These conditions are:

- Because the final determination of the contamination level relies on sodium and cation conductivity, if the two sodium signals are invalid, the function for the contamination level voting should be disabled until at least one sodium signal becomes valid.

- If both sodium signals are valid but the deviation between the two sodium signals exceeds the limit value, an abnormal condition must have occurred on at least one sodium analyser. Therefore, neither of the two signals should be used for the determination of the contamination level until the abnormal condition is cleared.

- If any two out of three cation conductivity signals are invalid, the output of the 2V3 function returns to zero therefore the cation conductivity signal should be invalid and the function for the contamination level voting should be disabled until at least two of the cation conductivity signals are valid.

The schematic diagram for the system alarms logic is shown in Figure 6.20. The meanings of each function blocks is:

- **BT**: Digital input signal function provided by TXP.
- **&**: AND Boolean function.
- **≥1**: OR Boolean function.
- **TD**: ON delay timer. The delay time is set to 5 seconds.
- **2V3**: Boolean 2-out-of-3 function. If any two inputs are TRUE, the output are TRUE.

As can be seen from Figure 6.20, if any of the following conditions in the logic are TRUE and last for at least 5 seconds, a “monitoring system fault” alarm will be generated on the HMI:

- Sample temperate high
- Sample flow low
- Analyser power fault
- Deviation of sodium signals high
- Both sodium signals invalid
- Two out of three cation conductivity signals invalid

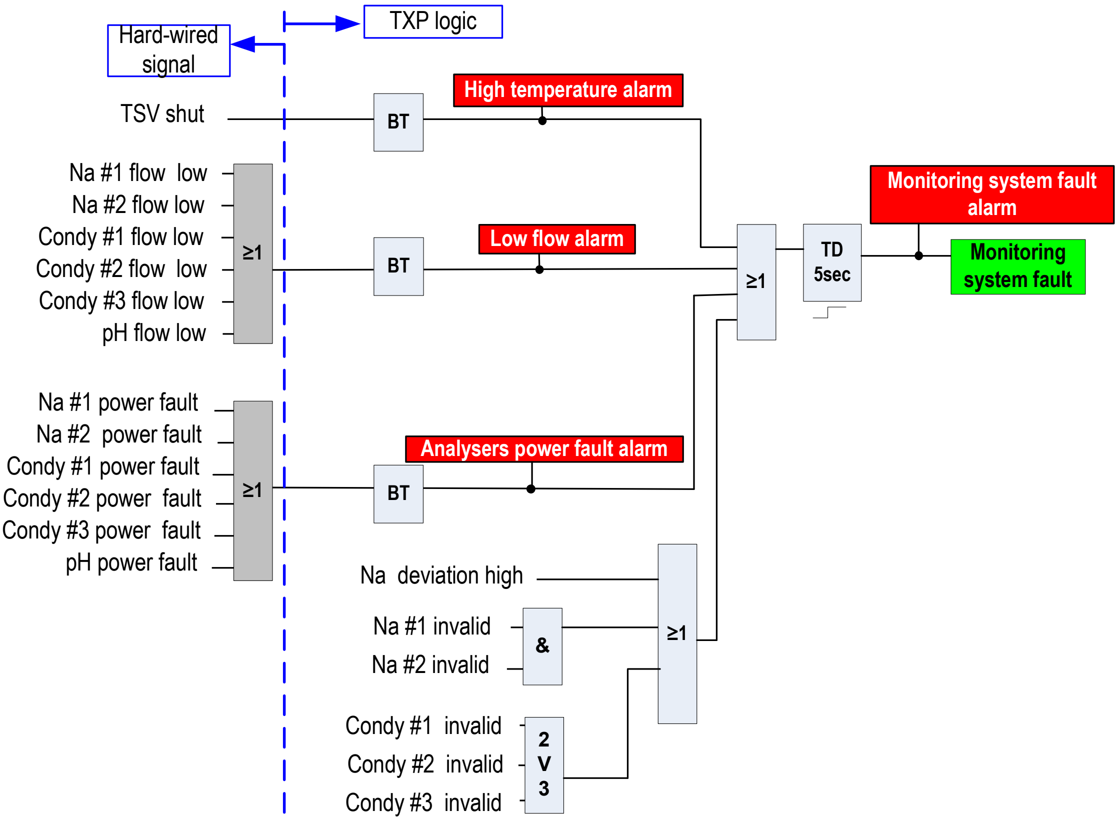


Figure 6.20 System alarms logic schematic diagram

Diagram 10QUC26CQ901 (Page 4) in Appendix C is the system alarms function diagram. If the monitoring system is in fault, a “monitoring system fault” alarm will be activated and functions such as the contamination level voting function and contamination level timing function will be automatically disabled due to malfunction of the system. The operator must find the root cause of the alarm. Once the alarm has been cleared, all the functions will be re-enabled automatically. The five second on-delay timer makes sure that the alarm is not inadvertently triggered by a spike or noise signal.

In order to help the operator find the cause of the alarm, four alarm messages are displayed on the HMI as shown in Figure 6.21. If an alarm is activated, the associated indicator is illuminated in red, otherwise the indicator remains white. In addition, each analogue signal is displayed on the HMI. If a signal is invalid the frame of the signal display turns red, otherwise the frame remains black. For example, as can be seen from Figure 6.21, the frame of three cation conductivity signals are red, which means that all three signals are invalid. According to the logic diagram shown in Figure 6.20, if any two cation conductivity signals are invalid, the “monitoring system fault” alarm will be activated and the indicator for the monitoring system fault will be illuminated in red colour. The operator can therefore deduce that this alarm has been caused by the invalidity of the cation conductivity signals.

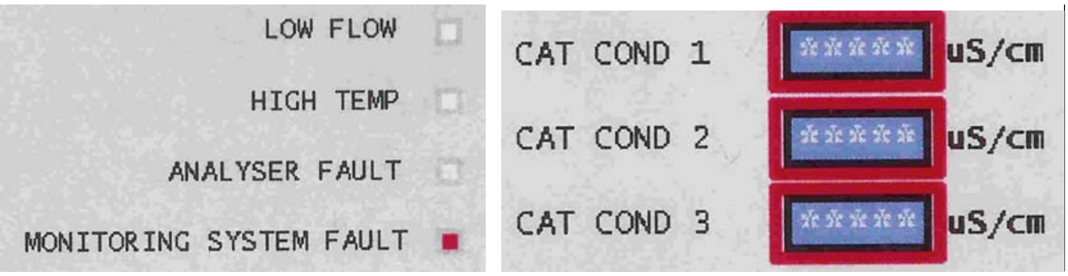


Figure 6.21 Alarms displayed on HMI

6.3.5 Action Level Determination

According to EPRI’s guideline, contamination in the condenser as a result of condenser in-leakage is rated to four action levels and each level has a different allowable running time. Table 2.2 (Page 22) gives detailed information. The operator used to rely on a single analyser to decide what the contamination level was if condenser in-leakage occurred. The operator needed to verify whether the data received is real or not before taking action. As analysed in Chapter 4, the ingress of the cooling water can result in serious consequences within a short time unless the leak is minute. Informing the operator of the action level instantly is a critical requirement as this will allow the operator to take appropriate action according to the level of contamination. Therefore, automatic determination of the action level is an important part of this project.

Determination of the action level relies on both sodium (Na) and cation conductivity (KH+). Therefore, Na and KH+ values must be converted from continuous analogue signals to four discrete values representing EPRI's four action levels. After that, the action level can be voted according to a predetermined algorithm.

6.3.5.1 Sodium Action Level Determination

According to Table 2.2, the sodium (Na) action levels are rated as follows:

- If 3 ppb < Na ≤ 6 ppb, then action level 1.
- If 6 ppb < Na ≤ 12 ppb, then action level 2.
- If 12 ppb < Na ≤ 500 ppb, then action level 3.
- If Na > 500 ppb, then action level 4.

Figure 6.22 shows the schematic diagram for the Na action level voting logic. The meaning of each function blocks is:

- **TD**: ON delay timer. The delay time is set 5 seconds.
- **&**: AND Boolean function.
- **SEL**: Selection function. If the **EN** is true (EN=enabled), the output equals **a,** otherwise the output equals **b**.

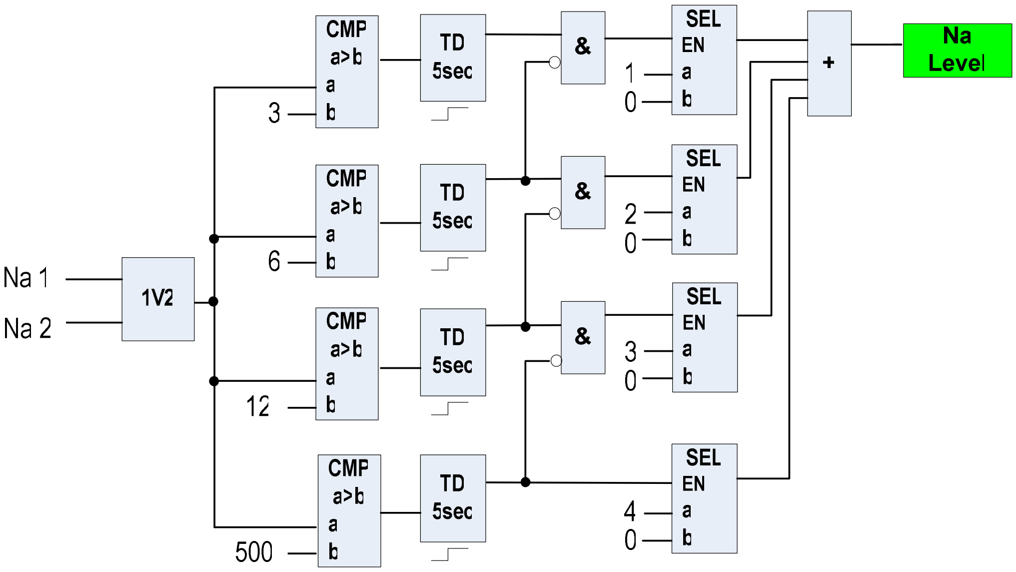


Figure 6.22 Sodium action level voting logic diagram

The output of the 1V2 function is used as the final Na value, which is converted into four action levels using a comparison function (CMP). If the condition is met, the associated selection function (SEL) will be enabled and the corresponding level value will be selected. Because only one SEL function can be enabled at any one time, the outputs of all other SEL functions are zero. Therefore, the output of the sum function (+) is the voted action level. The sum function shown here is equivalent to a multiple channel switch that can be switched from 1 to 4 depending on different conditions. Teleperm XP does not provide a multiple channel switch function so the sum function has been used instead. Function diagram 10QUC22CQ901(Page 2 to 4) in Appendix C is the sodium action level voting logic.

For example, if the Na concentration is 5 ppb, only the output of the first CMP is TRUE. If the Na value remains at 5 ppb for 5 seconds, the output of the first timer becomes TRUE. Then, only the output of first AND function becomes TRUE, which enables the first SEL function. Therefore, the output of the first SEL function becomes 1 while the outputs of other SEL functions remain 0. Hence, the action level is 1, which is the output value of the sum function. The on-delay timer makes sure that the value received by the DCS is not due to a spike or noise signal.

6.3.5.2 Cation Conductivity Action Level Determination

According to Table 2.2, the cation conductivity (KH+) action levels are rated as follows:

- If 0.2 μS/cm < KH+ ≤ 0.35 μS/cm, then action level 1.
- If 0.35 μS/cm < KH+ ≤ 0.5 μS/cm, then action level 2.
- If 0.5 μS/cm < KH+ ≤ 1μS/cm, then action level 3.
- If KH+ > 1 μS/cm, then action level 4.

Figure 6.23 shows the schematic diagram for the cation conductivity action level voting logic. Apart from CMP function setpoint, the logic is the same as the sodium action level voting logic. The function diagram 10QUC25CQ901 (Page 2 to 4) in Appendix C is the cation conductivity action level voting logic.

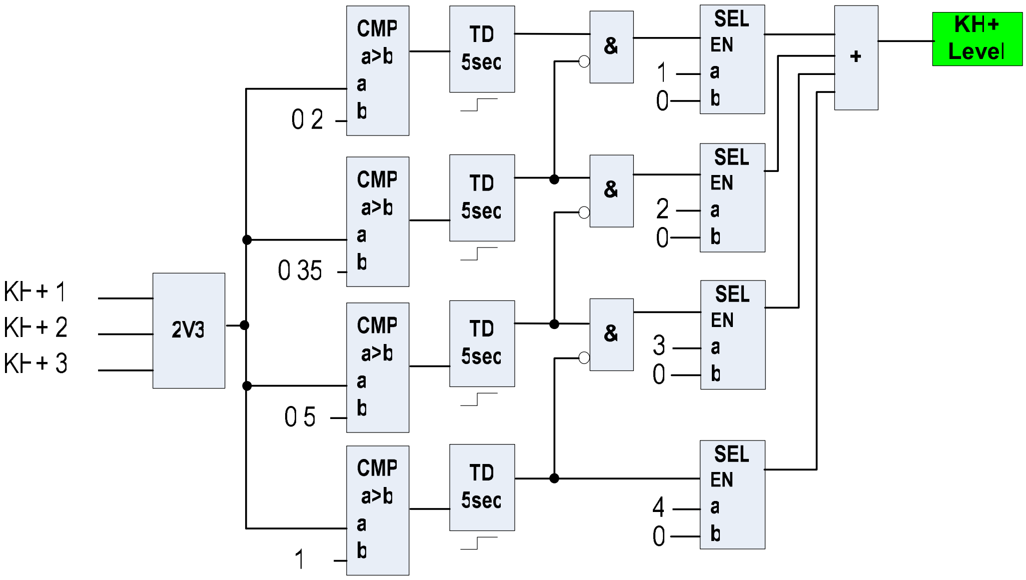


Figure 6.23 Cation conductivity action level voting logic diagram

6.3.5.3 Final Action Level Determination

The final action level is determined using both sodium (Na) and cation conductivity (KH+). The combined action level matrix shown in Table 6.7 is based on EPRI's guideline and the Chemist's recommendation. The top row of the table is the sodium (Na) action level and the left-hand column is the cation conductivity (KH+) action level. Each square in the table represents the action level voted by the sodium and cation conductivity logic.

Table 6.7 Combined action level voting table

		Na				
		0	**1**	**2**	**3**	**4**
KH+	**0**	***0***	*0*	*0*	*0*	*0*
	1	***0***	*1*	*2*	*3*	*4*
	2	***0***	*1*	*2*	*3*	*4*
	3	*0*	*1*	*2*	*3*	*4*
	4	*0*	*3*	*3*	*3*	*4*

The final voted action level is determined using the following logic:

- As long as one parameter remains at action level 0 (normal level), then the final voted action level is 0, highlighted in blue in Table 6.7. For example, as long as the Na is at action level 0, the final voted action level is 0, no matter what the KH+ level is, because detection of condenser in-leakage must be confirmed by the detection of both Na and KH+.

- If KH+ is between action level 1 and action level 3, and Na is above action level 0 then Na will dominate the final voted action level; highlighted in green in Table 6.7. For example, if KH+ is at action level 3 and Na is at action level 2, the final voted action level is 2.

- If KH+ is at action level 4 and Na is between action level 1 and action level 3, then the final voted action level is action level 3; highlighted in orange in Table 6.7.

- If both KH+ and Na are at action level 4, then the final voted action level is 4, highlighted in red in Table 6.7.

Figure 6.24 shows the schematic diagram for the final action level voting logic. The meaning of each function block is:

- **≥1**: OR Boolean function.
- **&**: AND Boolean function.
- **SEL**: Selection function. If the **EN** is true (EN=enabled), the output equals **a,** otherwise the output equals **b**.

The Na level and KH+ level used in Figure 6.24 is the results from each contaminants individual action level voting logic. The final voted action level will be used to activate the contamination level alarm and the contamination level timing function. The function diagram 10QUC26CQ901 (Page 1 to 3) in Appendix C is the final contamination level voting logic.

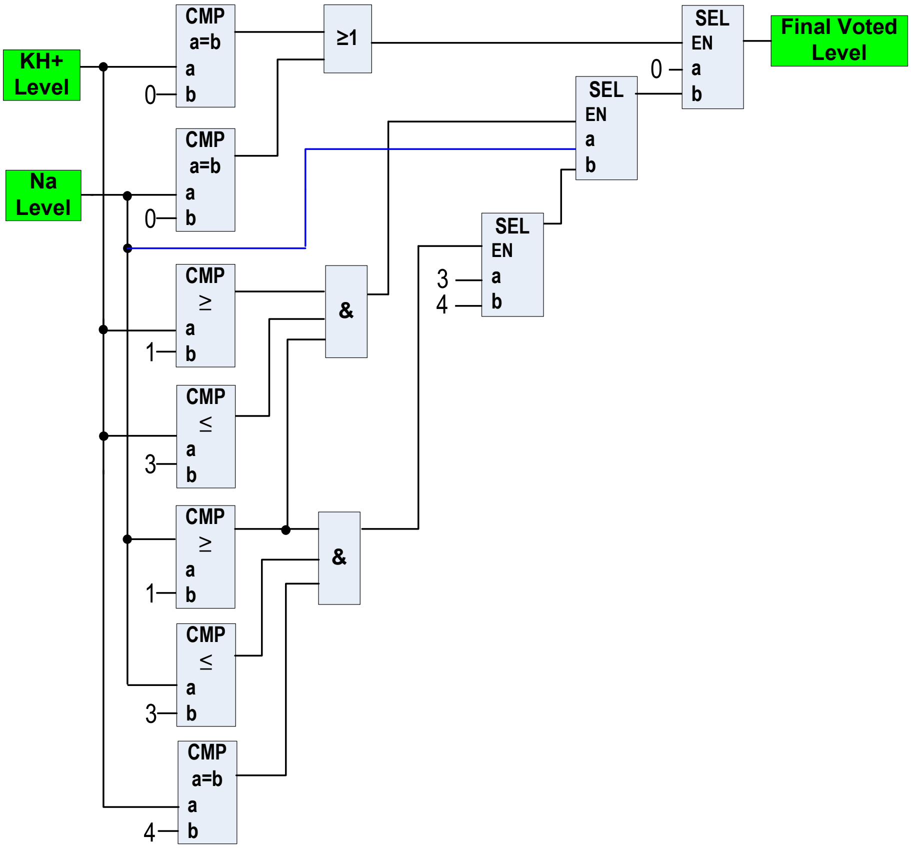


Figure 6.24 Final action level voting logic

6.3.5.4 Action Level Activation

The condensate monitoring system must be fully functional in order to ensure that the action level is not activated by mistake. If the monitoring system is in fault, the action level activation function and the action level timing function will be automatically disabled and the monitoring system fault alarm will be activated. If the monitoring system fault alarm is active, the operator has to rely on the data displayed on the HMI to determine the action level.

Figure 6.25 shows the action level activation logic diagram. If the monitoring system is in fault, the output of the AND logic gate will be FALSE, and the action level active alarm and following actions will be disabled. However, if the system is fully functional, and the final voted action level matches a CMP block, the corresponding alarm and action level will be activated. For example, if the final voted action level is 3 the output of the third comparator (CMP) will be TRUE; and if the system is fully functional action level 3 will be activated as shown in Figure 6.26 and action level 3 active alarm will be generated on the alarm list. The function diagram 10QUC26CQ901(Page 7 and 8) in Appendix C is the action level activation logic.

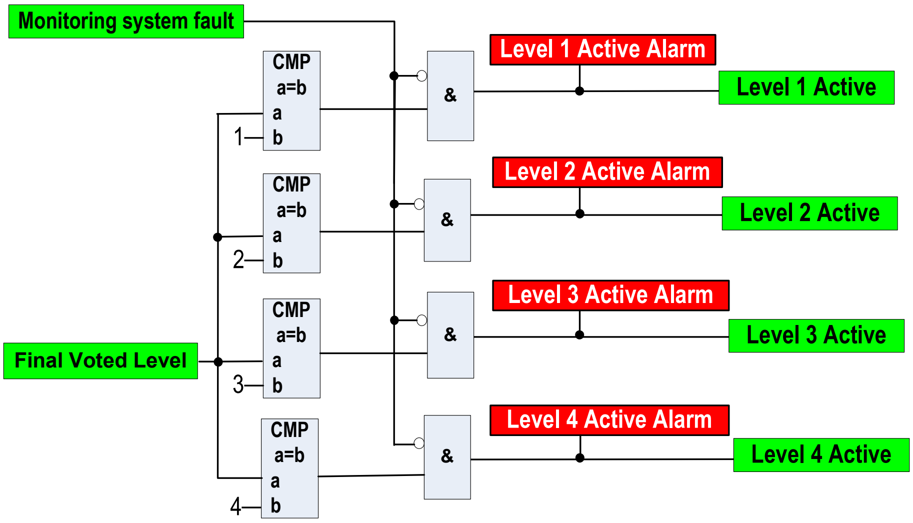
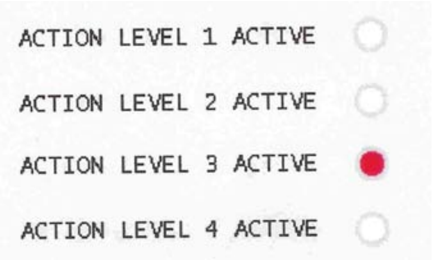


Figure 6.25 Action level activation logic diagram



ACTION LEVEL 1 ACTIVE ○

ACTION LEVEL 2 ACTIVE ○

ACTION LEVEL 3 ACTIVE ●

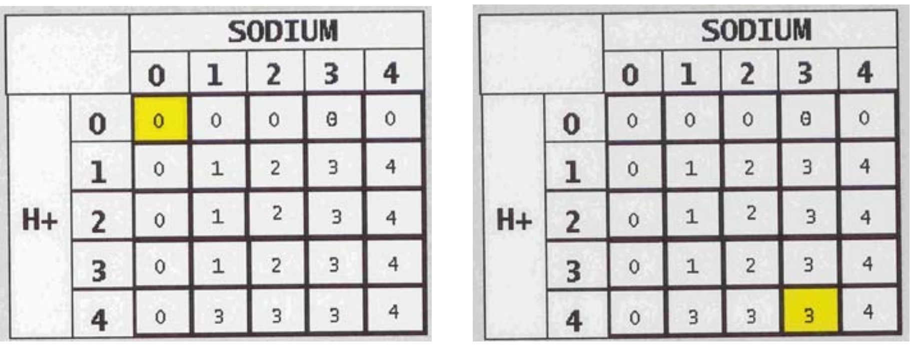
ACTION LEVEL 4 ACTIVE ○

Figure 6.26 Action level active indication on HMI

6.3.5.5 Action Level Matrix Table Animation

In addition to the action level active indications, a action level matrix table is also displayed on the HMI to provide extra detailed information to the operator with regard to action level voting. The table gives a direct visual image so that the operator does not need to refer to the parameter limit chart located o the control desk.

Figure 6.27 illustrates the action level matrix table displayed on the HMI. The format of the matrix table is the same as Table 6.7. The top row of the table is the sodium level (Na) and the left-hand column is the cation conductivity (H+) level. Each square in the table represents the action level voted by the sodium and cation conductivity logic. The matrix table can be considered as a grid with coordinates formatted [H+, Na]. The first coordinate is the cation conductivity (H+) action level and the second coordinate is the sodium (Na) action level. Each square in the grid is an element of the matrix. For example, the value in [2, 1] is 1, which represents action level 1.



		SODIUM				
		0	1	2	3	4
H+	0	0	0	0	0	0
	1	0	1	2	3	4
	2	0	1	2	3	4
	3	0	1	2	3	4
	4	0	3	3	3	4

		SODIUM				
		0	1	2	3	4
H+	0	0	0	0	0	0
	1	0	1	2	3	4
	2	0	1	2	3	4
	3	0	1	2	3	4
	4	0	3	3	3	4

Figure 6.27 Contamination level matrix table

The square highlighted in yellow, representing the current action level, can move as the contamination varies. Once a square is highlighted, the corresponding action level will be active. For example, the left-hand graphic shows the normal situation with sodium and cation conductivity at action level 0. The right-hand graphic shows action level 3, meantime the "ACTION LEVEL 3 ACTIVE" indication will turn red as shown in Figure 6.26. The matrix shows the operator that the cation conductivity has reached action level 4 but the sodium is only at action level 3 ([4,3]=3). In addition, the operator knows from the table that the current situation with [4, 3] at action level 3 is more serious than the action level 3 situations represented by coordinates [1, 3] or [4, 1] although they are rated at the same action level.

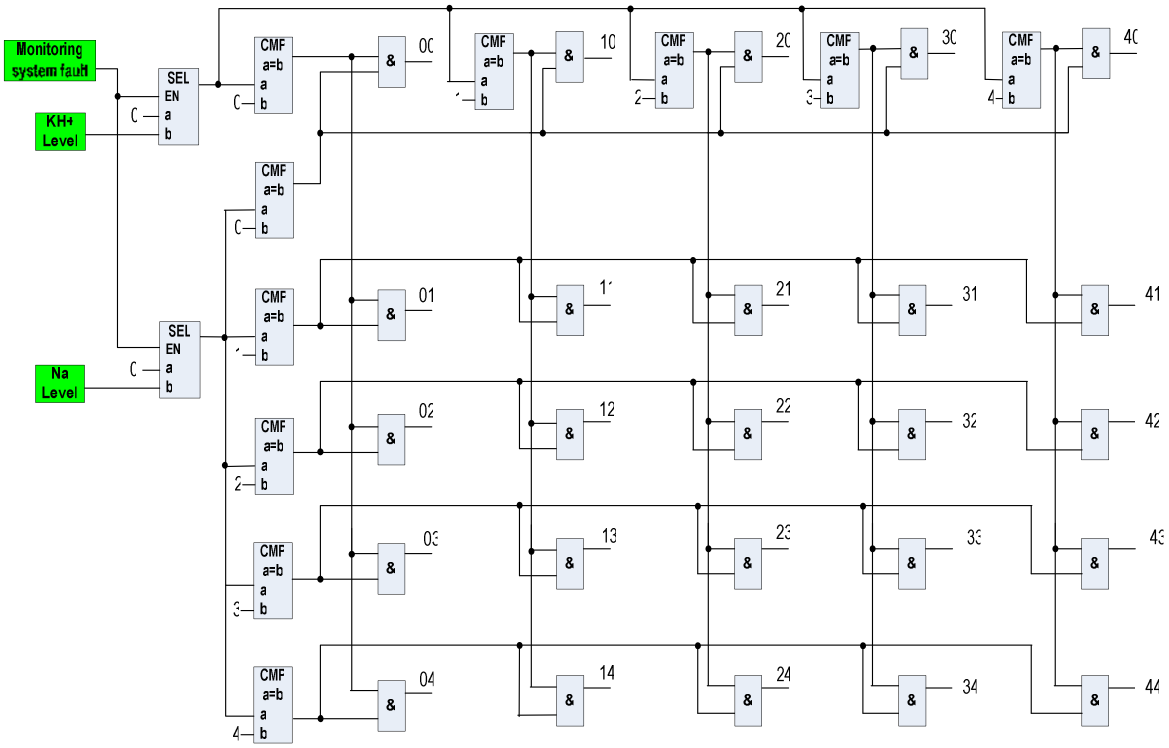


Figure 6.28 Matrix table animation logic diagram

Figure 6.28 shows the logic diagram for the matrix table animation. The output of each AND gate (&) represents a corresponding square in the table. The function diagram 10QUC26CQ901 (Page 9 and 14) in Appendix C is the matrix table animation logic.

6.3.6 Action Level Timing

Table 6.8 shows the time that the plant is allowed to remain in operation at the respective action levels. The permissible running time decreases as the contamination level increases. Once the contamination reaches action level 4, the plant must be shut down immediately because the permissible running time is zero.

Table 6.8 Permissible running time per event

Action Level	1	2	3	4
Time (hour)	100	24	4	0

According to the mathematical modelling results, contamination of the condensate is likely to reach action level 4 within a short time. Therefore, it is important to record the time spent at each action level. It is also important to display the remaining time on the HMI so that the operator can determine the time remaining before the plant must be shut down.

6.3.6.1 Calculation of Remaining Time

The remaining time is the permissible running time before the plant must be shut down in the event of condenser in-leakage. The remaining time at an action level is not the entire permissible time at that level when changing from one action level to another. For example, if the contamination changes from action level 2 to action level 3 after say 21 hours, the remaining time at action level 3 is not 4 hours. It does not make sense for the remaining time after reaching action level 3 to be 4 hours and the remaining time is actually only 3 hours (24−21=3) if the contamination now still remains at action level 2. The remaining time at the previous action levels must be taken into account when calculating the remaining time at the new action level.

An algorithm was developed to calculate the remaining time during a condenser in-leakage event. The entire permissible time is considered as 1 with no engineering units. The percentage of running time at each action level equals the running time at each action level divided by the entire permissible time at that action level. Action level 4 is not included because the permissible time at action level 4 is zero. The remaining time at the current action level equals the multiplication of the entire permissible time at the current action level and the percentage of the total time remaining. Equation 6.11 represents the algorithm and the units of time are minutes not hours.

$$\mathbf{t} = \left(1 - \frac{a}{100*60} - \frac{b}{24*60} - \frac{c}{4*60}\right)*k*60 \qquad (6.11)$$

Where:

t = remaining time (minutes)

$a = a_1+a_2+\ldots+a_n$; total running time at action level 1 (minutes)

$b = b_1+b_2+\ldots+b_n$; total running time at action level 2 (minutes)

$c = c_1+c_2+\ldots+c_n$; total running time at action level 3 (minutes)

k = Entire permissible time at the current action level (hours)

The following example shows how to calculate the remaining time during a condenser in-leakage event using Equation 6.11. The example is not based on a real leak situation but an assumption.

Figure 6.29 shows the running time at different levels during a condenser in-leakage event. As can be seen from the diagram, the running time at action level 1, 2 and 3 are 200, 400, and 100 minutes respectively. The current action level is 3 so the entire permissible time factor **k** is 4 hours. According to Equation 6.11, the remaining time **t** at the point **A** is:

$$\mathbf{t} = \left(1 - \frac{200}{100*60} - \frac{400}{24*60} - \frac{100}{4*60}\right)*4*60 = 65.3 \text{ minutes}$$

The remaining time at Point A is only 65.3 minutes not 140 minutes (4*60 −100=140).

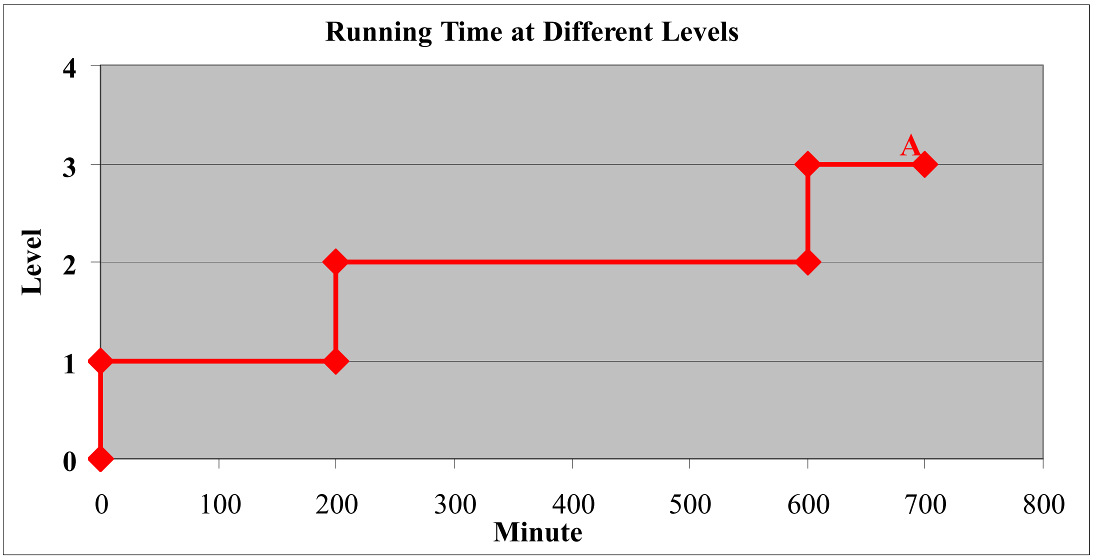


Figure 6.29 Remaining time calculation example

6.3.6.2 Action Level Timing Function

The action level timing function is used to record the duration at each action level and the remaining time before the plant must be shut down. The time function gives the operator a direct visual indication on HMI and acts as a reminder stamp during a condenser in-leakage event.

Figure 6.30 shows the logic diagram for the action level timing function. The meaning of function block is:

- **&**: AND Boolean function.
- **TD**: ON delay timer. The delay time is set to 1 minute.
- **CNT**: Count function.
- **SEL**: Selection function. If the **EN** is true (EN=enabled), the output equals **a,** otherwise the output equals **b**.
- **a/b, X,** +, − : Standard mathematical functions

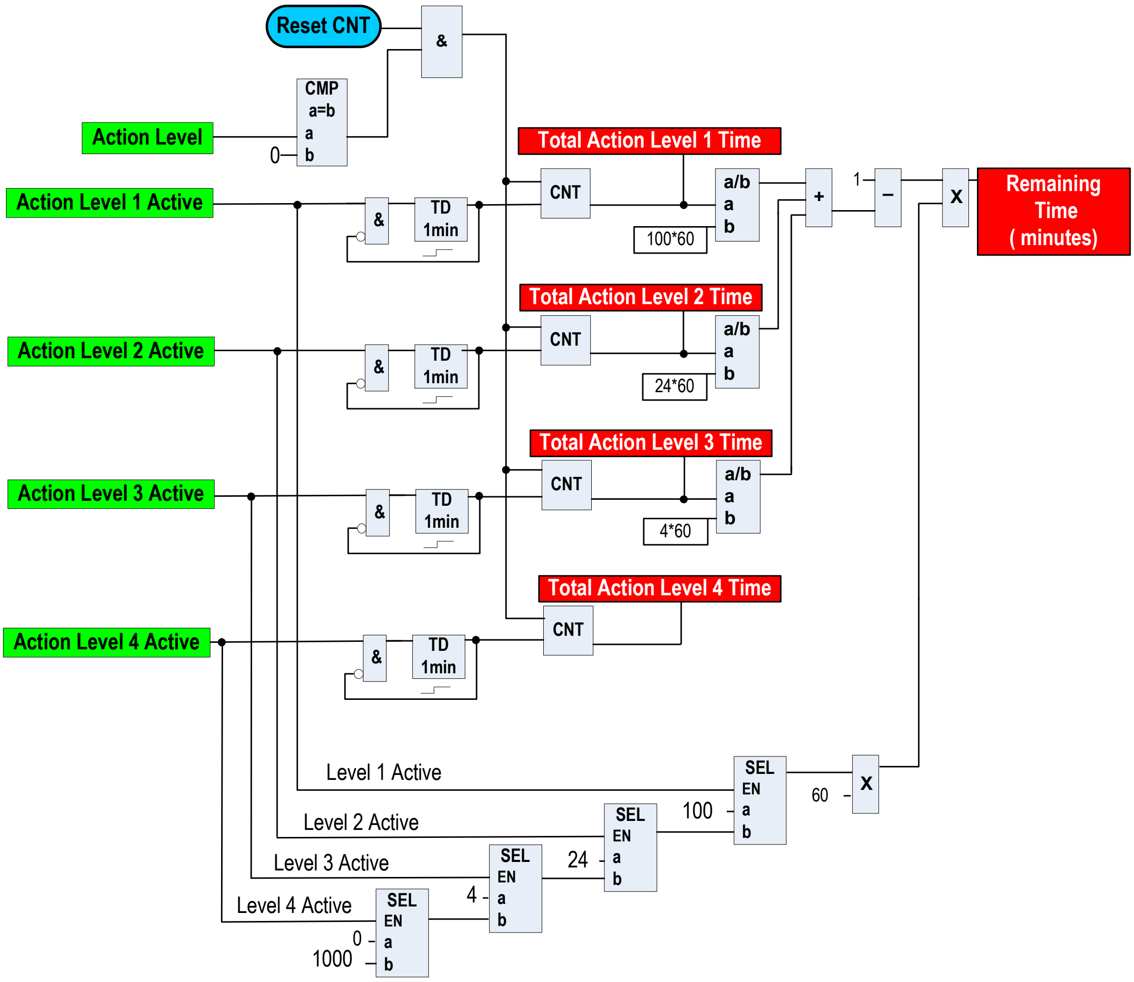
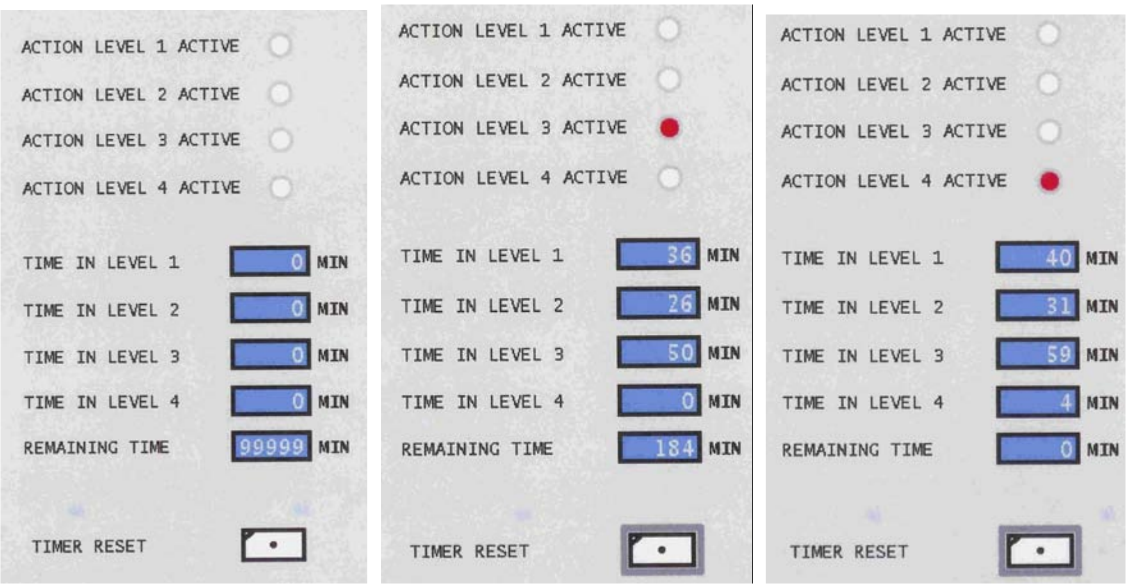


Figure 6.30 Action level timing function logic diagram

For example, if action level 1 is active, the first timer (TD) will be enabled; the timer is reset every one minute, which means that the output of the timer will generate a pulse every minute to trigger the first counter (CNT). The counter increases by one each time the timer is reset. Therefore, the output value of the counter is the time in minutes that the plant has been running at the that action level. The remaining time is calculated using Equation 6.11. If action level 4 is active, then the remaining time immediately becomes zero. The function diagram 10QUC26CQ902 (Page 1 to 6) in Appendix C is the action level timing function logic.

A timer reset soft button (Reset CNT) is displayed on the HMI and is used to reset the counter to zero after contamination in the condenser has been cleared. The four counters can only be reset via the HMI soft button after the action level has returned to the normal. The function diagram 10QUC26DE001 in Appendix C is the reset button logic diagram.

Figure 6.31 shows 3 action level situations on the HMI. These situations were simulated during system commissioning. The left-hand graphic shows the normal situation. The time in each action level is zero; and the remaining time is 99999 minutes; at the bottom is timer reset button. The middle graphic shows that the current action level is 3 and the plant has been running at this level for 50 minutes. In addition, it shows that the plant was at action level 1 for 36 minutes and at action level 2 for 26 minutes. The remaining time is 184 minutes. The right-hand graphic shows that action level 4 is active and the remaining time is zero indicating that the plant has to be shut down immediately.



ACTION LEVEL 1 ACTIVE ○
ACTION LEVEL 2 ACTIVE ○
ACTION LEVEL 3 ACTIVE ○
ACTION LEVEL 4 ACTIVE ○
TIME IN LEVEL 1 0 MIN
TIME IN LEVEL 2 0 MIN
TIME IN LEVEL 3 0 MIN
TIME IN LEVEL 4 0 MIN
REMAINING TIME 99999 MIN
TIMER RESET

ACTION LEVEL 1 ACTIVE ○
ACTION LEVEL 2 ACTIVE ○
ACTION LEVEL 3 ACTIVE ●
ACTION LEVEL 4 ACTIVE ○
TIME IN LEVEL 1 36 MIN
TIME IN LEVEL 2 26 MIN
TIME IN LEVEL 3 50 MIN
TIME IN LEVEL 4 0 MIN
REMAINING TIME 184 MIN
TIMER RESET

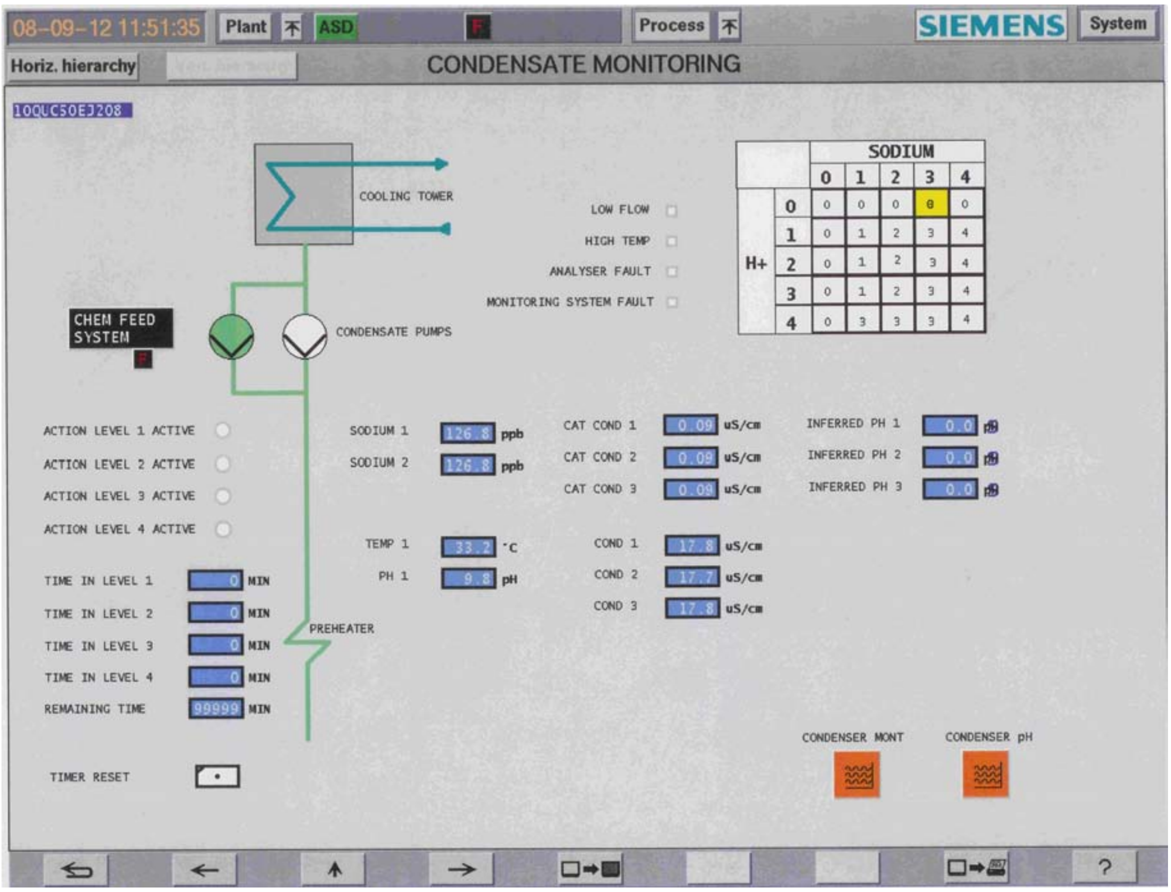
ACTION LEVEL 1 ACTIVE ○
ACTION LEVEL 2 ACTIVE ○
ACTION LEVEL 3 ACTIVE ○
ACTION LEVEL 4 ACTIVE ●
TIME IN LEVEL 1 40 MIN
TIME IN LEVEL 2 31 MIN
TIME IN LEVEL 3 59 MIN
TIME IN LEVEL 4 4 MIN
REMAINING TIME 0 MIN
TIMER RESET

Figure 6.31 Action level timing indication on HMI

6.3.7 Human Machine Interface

The Human Machine Interface (HMI) graphic for the condensate monitoring system has been developed in order to present all of the critical information to the operator. The graphic code in the Teleperm XP is 10QUC50EJ208 (CONDENSATE MONITORING). The layout and colour of the graphic complies with Teleperm XP convention. The major components in the graphic are:

- Thirteen analogue signal displays
- System alarm indications
- Contamination level matrix table
- Action level indications
- Action level time displays
- Trending displays
- Timer reset button



LOW FLOW ☐
HIGH TEMP ☐
ANALYSER FAULT ☐
MONITORING SYSTEM FAULT ☐

		SODIUM				
		0	1	2	3	4
H+	0	0	0	0	0	0
	1	0	1	2	3	4
	2	0	1	2	3	4
	3	0	1	2	3	4
	4	0	3	3	3	4

ACTION LEVEL 1 ACTIVE ○
ACTION LEVEL 2 ACTIVE ○
ACTION LEVEL 3 ACTIVE ○
ACTION LEVEL 4 ACTIVE ○

TIME IN LEVEL 1 0 MIN
TIME IN LEVEL 2 0 MIN
TIME IN LEVEL 3 0 MIN
TIME IN LEVEL 4 0 MIN
REMAINING TIME 99999 MIN

TIMER RESET

SODIUM 1 126.8 ppb
SODIUM 2 126.8 ppb

TEMP 1 33.2 °C
PH 1 9.8 pH

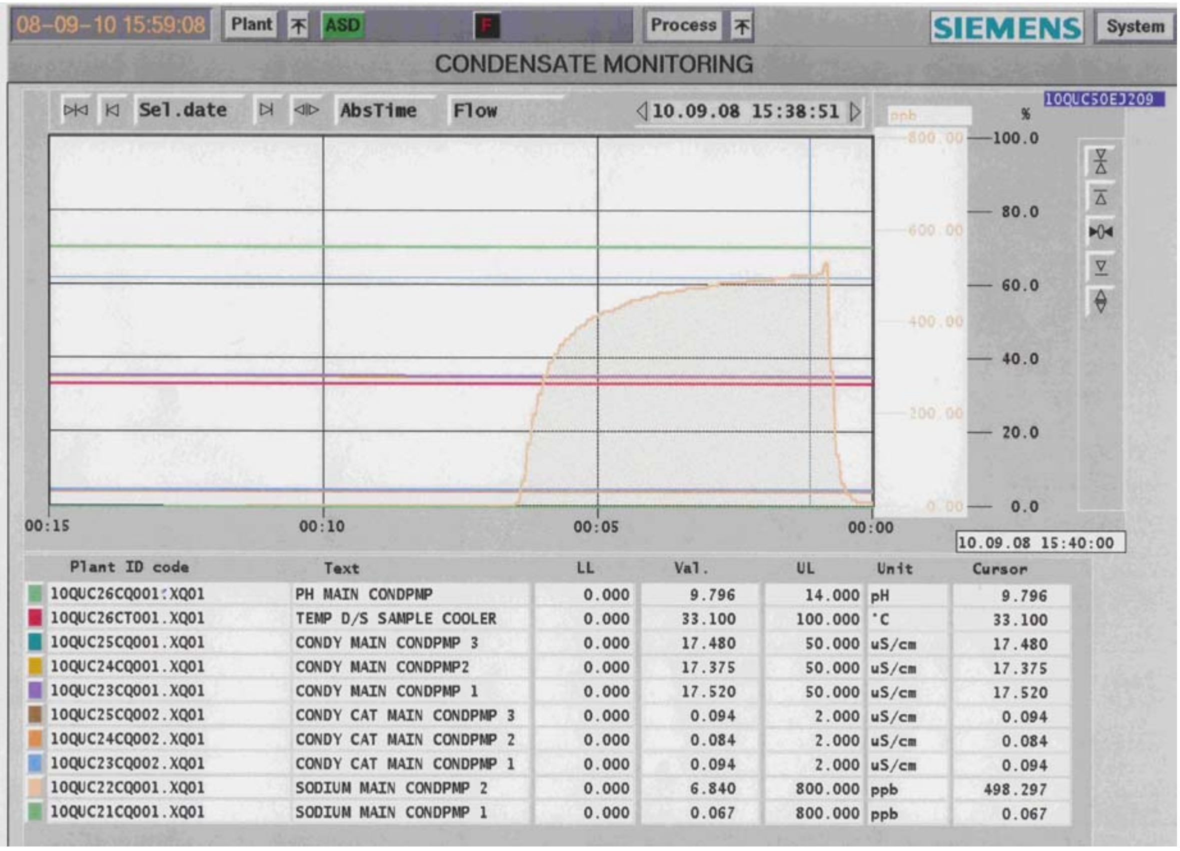
CAT COND 1 0.09 uS/cm
CAT COND 2 0.09 uS/cm
CAT COND 3 0.09 uS/cm

COND 1 17.8 uS/cm
COND 2 17.7 uS/cm
COND 3 17.8 uS/cm

INFERRED PH 1 0.0 pH
INFERRED PH 2 0.0 pH
INFERRED PH 3 0.0 pH

Figure 6.32 Condensate monitoring system HMI graphic

Figure 6.32 shows the condensate monitoring system HMI graphic. The function of each major component in the graphic has been explained in previous sections. The black box labelled “CHEM FEED SYSTEM” is a shortcut navigation button that leads to the feedwater system chemistry graphic. Figure 6.33 shows a data trending graphic monitoring ten signals related to this system. The operator can view current and historical data from these trend screens.



	Plant ID code	Text	LL	Val.	UL	Unit	Cursor
🟩	10QUC26CQ001:XQ01	PH MAIN CONDPMP	0.000	9.796	14.000	pH	9.796
🟥	10QUC26CT001.XQ01	TEMP D/S SAMPLE COOLER	0.000	33.100	100.000	°C	33.100
🟦	10QUC25CQ001.XQ01	CONDY MAIN CONDPMP 3	0.000	17.480	50.000	uS/cm	17.480
🟨	10QUC24CQ001.XQ01	CONDY MAIN CONDPMP2	0.000	17.375	50.000	uS/cm	17.375
🟪	10QUC23CQ001.XQ01	CONDY MAIN CONDPMP 1	0.000	17.520	50.000	uS/cm	17.520
🟫	10QUC25CQ002.XQ01	CONDY CAT MAIN CONDPMP 3	0.000	0.094	2.000	uS/cm	0.094
🟧	10QUC24CQ002.XQ01	CONDY CAT MAIN CONDPMP 2	0.000	0.084	2.000	uS/cm	0.084
🟦	10QUC23CQ002.XQ01	CONDY CAT MAIN CONDPMP 1	0.000	0.094	2.000	uS/cm	0.094
🟧	10QUC22CQ001.XQ01	SODIUM MAIN CONDPMP 2	0.000	6.840	800.000	ppb	498.297
🟩	10QUC21CQ001.XQ01	SODIUM MAIN CONDPMP 1	0.000	0.067	800.000	ppb	0.067

Figure 6.33 Data trending graphic

6.4 System Commissioning

System commissioning consists of two major steps. The first step is a dry test; the second step is a wet test.

- **Dry Test**

The purpose of the dry test is to ensure that:

- All hard-wired signal loops are valid
- All logic programs in Teleperm XP are fully functional including the action level voting, action level timing, system alarms, data displays and trends.

FLUKE process multimeters were used during the dry test to generate 4 – 20mA simulation signals from the signal terminals located in the distribution box for the analyser rack. All the signals were checked one by one to make sure that the analogue signal simulated in the field was correctly displayed on the HMI. The three hard-wired alarms were tested by disconnecting their circuit. When each circuit was broken, the alarm was activated on the HMI due to their the fail-safe configuration. The action level voting and action level timing logic was tested using five FLUKE process multimeters. Two multimeters were used to simulate two sodium signals, and the other three were used to simulate the three cation conductivity signals. No errors were found during the dry test.

- **Wet Test**

The wet test is the last procedure before the condensate monitoring system goes alive. The purpose of the wet test is to ensure that:

- The condensate sample loop is properly setup so that the analyser sample flow are smooth and adequate;
- All analysers are properly installed and calibrated;
- The hardware protection and alarms are fully functional;
- The field data displayed on analyser display panels is the same as the data displayed on the control room HMI.

An ABB technician was involved in the wet testing and commissioning. The condensate monitoring system is currently alive.

6.5 Chapter Summary

Teleperm XP (TXP) is a distributed control system that offers all of the process and control utilities required for the automation, operation, monitoring, and recording of the process. The functions of the control system are distributed between individual sub-systems, which together form a complete process and control system. The Automation System 620 (AS620) is the control centre of the plant and performs all of the automation tasks. The logic program for the new condensate monitoring system runs in the AS620B system.

Sodium and cation conductivity are used for action level voting in the event of condenser in-leakage. Two sodium signals and three cation conductivity signals are connected to SIM input modules in separate groups in order to enhance the availability of the signals. Each group consists of one sodium and one cation conductivity signal. If the signals in any one group fail, the signals in the other two groups will not be affected.

Analogue signals in the system are normally configured as proportional signals. However, the sodium signal has been configured as logarithmic signals because this signal requires high resolution and accuracy at the bottom end of the measurement range in order to meet the measurement requirements. The calculated and experimental results have proved that a logarithmic signal provides not only a high resolution, but also high noise immunity at the bottom end of the measurement range.

The action level voting function and action level timing function has been programmed into the AS620B automation system. Final action levels are determined by a 1-out-of -2 sodium and a 2-out-of-3 cation conductivity system. A dedicated HMI graphic page has been created as part of the new condensate monitoring system to provide the operator with all of the critical real-time information related to the detection and management of condenser in-leakage. The system alarms have been programmed to inform the operator of any abnormal system conditions. Historical data trends have been made available for monitoring and event investigation. The condensate monitoring system has remained fully functional since it was commissioned.

CHAPTER 7

CONCLUSION

7.1 Conclusion

Considerable ongoing risk of condenser in-leakage exists at Otahuhu B (OTB) Power Station. The condenser cooling water used at OTB station is corrosive brackish water with exceedingly high sodium and chloride concentrations. However, OTB station does not have the usual plant provisions expected for the rapid detection of a condenser tube leak. This is an unusual situation for a modern seawater-cooled power station. In the event of condenser in-leakage, salt contaminants in the cooling water will directly enter the HRSG with the potential to cause significant and costly damage, and a long plant outage.

A dynamic mathematical model has been developed to analyse the consequences of condenser in-leakage at OTB station. The mathematical model consists of a condenser hotwell model, HRSG drum system model and an entire water cycle model. After studying the condenser model, it was concluded that the tolerance of the condenser to cooling water leakage is almost zero. The results of the analysis show that even a very small amount of ingress of salty cooling water will cause serious contamination in the condensate within a very short time, and will necessitate an immediate plant shutdown to avoid catastrophic consequences. For example, a 2 mm diameter orifice in a condenser tube wall will result in a leakage rate that will raise Na and Cl concentrations in the condenser hotwell above the plant shutdown level within one minute of the leak occurring.

The results of the HRSG drum model analysis show that contamination in the drums increases at an accelerating rate. The higher the load, the more severe and faster the contamination in the HRSG.. Of the three drum systems, contamination in the HP drum increases fastest but the LP drum system is the highest priority in the event of condenser in-leakage. This is because the LP drum system will be contaminated first and contamination in the LP drum is likely to reach the plant shutdown level much earlier than the IP and HP drum systems.

Compared to the condenser hotwell, the contamination rates in the drums are much slower. Contamination of the drums will not take place immediately after a condenser leak occurs because of the physical distance between the condenser and the drums. However, contamination of all of the drum systems requires close monitoring because once the Na and Cl concentrations reach their respective saturation level, they will carry over to the steam cycle and to the steam turbine. The consequences of carryover are extremely serious and must be avoided.

According to the results of the analysis, it is concluded that the condenser is the most vulnerable component of the entire water steam cycle. In order to minimise the consequences of a condenser in-leakage event, an urgent plant shutdown is required once contamination in the condenser reaches the plant shutdown level. However, an instantaneous plant trip from a high load, and from full load in particular, will impair the plant service life and cause a grid frequency excursion. If possible, the plant load should be quickly reduced in a controlled manner after a leak has been detected; and the plant trips from a load that will not significantly impact on the grid frequency if contamination in the condenser reaches the plant shut down level.

A condenser tube leak may rapidly worsen after a leak occurs because the leak orifice will enlarge as cooling water flows through the orifice. The response time to any tube leak therefore becomes critical, and requires on-line analytical instrumentation for the instant and accurate detection of in-leakage rather than relying on human intervention and confirmation.

The new dedicated fast response condensate monitoring system has been engineered and installed at OTB station. The new system dramatically reduces the response time to condenser in-leakage. The parameters used for the detection of condenser in-leakage consist of sodium, cation conductivity, specific conductivity and pH. Sodium and cation conductivity are used for the action level voting, whereas pH and specific conductivity are used for reference purpose only. In order to enhance the availability and reliability of the system, multiple redundancy schemes have been applied to the sodium and conductivity analysers, and to the 230V AC power supplies. In addition, automatic protection devices and alarms have been included in the system to protect the analytical instruments and to inform the operator of abnormal situations. Not only does the new condensate monitoring system meet the requirements of fast response and high reliability, but also easy of maintenance and operation.

A dedicated HMI graphic page was created for the new condensate monitoring system to provide the operator with all of the critical real-time information required for the detection and management of condenser in-leakage. Action level voting, timing, and alarming have been automated to assist the operators with their decision making. The system alarms have been programmed to inform the operator of any abnormal system conditions. Historical data trends have been made available for monitoring and event investigation. The new condensate monitoring system is currently alive and fully functional.

Dr. Barry Dooley, a worldwide independent expert, performed an assessment on OTB station water and steam cycle chemistry after this project was completed. As can be seen from Section 4 (b) in the assessment report in Appendix D, the expert gave the following positive comments on the new condensate monitoring system:

> "An excellent condensate monitoring system has been installed at the CPD with two sodium, two cation conductivity and two specific conductivity monitors. This will eventually provide direct control to the operators in the event of a condenser leak."

The assessment report confirms that the project has successfully achieved the objective of controlling the risk of condenser in-leakage events and minimising damage and negative effects on the plant.

7.2 Future Work

Dedicated sodium analysers for monitoring sodium concentration in the water and saturated steam phases of three drum systems should be installed. This will allow the saturation level of Na concentration in the three drums to be closely monitored. This is vital for the avoidance of sodium carryover into the steam cycle and to the steam turbine. This suggestion had been made before the assessment report was received. The report gave the same suggestion as shown in Section 3 (c), (d) and the second paragraph in Section 6. The assessment report confirms the importance of monitoring sodium concentration in the water and saturated steam phases of three drum systems.

Caustic dosing of the IP and HP drums in the event of condenser in-leakage should be examined and justified from a water and steam cycle chemistry perspective. Because the IP and HP drums have not required any emergency caustic dosing since the station was commissioned, it is unknown whether or not caustic should be dosed to the IP and HP drums in the event of condenser in-leakage and how much caustic should be dosed.

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Appendix A Mathematical Modelling Data Tables

Appendix A consists of detailed data tables that have been used to demonstrate the modelling and analysis results in Chapter 4. The line charts in Chapter 4 are drawn based on these data tables. These tables provide detailed data in order to help the reader go through the analysis process. Figures A.1 and A.2 show the reader detailed water and steam cycle diagram and HRSG overview diagram.

Table A. 1 Leakage rate comparison between experimental and calculated results
(Refer to Figure 4.4 and 4.5)

$\Delta P=P_1-P_2$	Experimental Flow	Calculated Flow	Error
(bar)	(litre/min)	(litre/min)	(litre/min)
	r = 1 mm	r = 1 mm	
2.4	2.72	2.56	0.16
2.2	**2.6**	**2.45**	**0.15**
2	2.5	2.34	0.16
1.8	2.32	2.22	0.1
1.6	2.2	2.09	0.11
1.4	2.1	1.95	0.15
1.2	1.9	1.81	0.09
1	1.78	1.65	0.13
0.8	1.58	1.48	0.1
0.6	1.34	1.28	0.06
0.4	1.1	1.05	0.05
*** r is the orifice radius**			

Table A. 2 Leakage rate through different radius orifices with different DP
(Refer to Figure 4.6)

	r (mm)	**DP (Bar)**										
		0.4	***0.6***	***0.8***	***1.0***	***1.2***	***1.4***	***1.6***	***1.8***	***2.0***	***2.2***	***2.4***
Calculated leakage rate through an orifice (litre/min)	***0.5***	0.261	0.320	0.369	0.413	0.452	0.489	0.522	0.554	0.584	0.613	0.640
	0.75	0.588	0.720	0.831	0.929	1.018	1.099	1.175	1.247	1.314	1.378	1.440
	1	1.045	1.280	1.478	1.652	1.810	1.955	2.090	2.216	2.336	**2.450**	2.559
	2	4.179	5.118	5.910	6.608	7.238	7.818	8.358	8.865	9.345	9.801	10.237
	3	9.403	11.51	13.29	14.86	16.28	17.59	18.80	19.94	21.02	22.05	23.032
	4	16.71	20.47	23.64	26.43	28.95	31.27	33.43	35.46	37.37	39.20	40.946

Table A. 3 Na and Cl concentrations in condenser hotwell
(Refer to Figure 4.8 and 4.9)

Leak time		**Na**	**Na**	**Cl**
Second	**Minute**	**mg/l**	**ppb**	**ppb**
0	0.00	0.0000	0	0
5	0.08	0.1215	121	215
10	0.17	0.2402	240	425
15	0.25	0.3562	356	630
20	0.33	0.4695	469	831
25	0.42	0.5802	580	1,027
30	0.50	0.6884	688	1,218
35	0.58	0.7941	794	1,405
40	0.67	0.8974	897	1,588
45	0.75	0.9984	998	1,766
50	0.83	1.0970	1,097	1,941
55	0.92	1.1934	1,193	2,111
60	1.00	1.2876	1,288	2,278
65	1.08	1.3796	1,380	2,441
70	1.17	1.4695	1,469	2,600
75	1.25	1.5573	1,557	2,755

Leak time		**Na**	**Na**	**Cl**
Second	**Minute**	**mg/l**	**ppb**	**ppb**
0	0.00	0.0000	0	0
10	0.17	0.2402	240	425
20	0.33	0.4695	469	831
30	0.50	0.6884	688	1218
40	0.67	0.8974	897	1588
50	0.83	1.0970	1097	1941
60	1.00	1.2876	1288	2278
80	1.33	1.6432	1643	2907
100	1.67	1.9673	1967	3481
120	2.00	2.2628	2263	4003
150	2.50	2.6578	2658	4702
200	3.33	3.2056	3206	5671
300	5.00	3.9850	3985	7050
400	6.67	4.4755	4476	7918
600	10.00	4.9787	4979	8808
800	13.33	5.1780	5178	9161
1000	16.67	5.2569	5257	9301
1500	25.00	5.3036	5304	9383

Table A. 4 Na Concentration in condensate at 380MW and 240MW
(Refer to Figure 4.10 and 4.11)

Leak time		**380MW**	**240MW**		**Leak time**		**380MW**	**240MW**
Second	**Minute**	**Na (ppb)**	**Na (ppb)**		**Second**	**Minute**	**Na (ppb)**	**Na (ppb)**
0	0.00	0	0		0	0.00	0	0
5	0.08	121	122		10	0.17	240	242
10	0.17	240	242		20	0.33	469	476
15	0.25	356	360		30	0.50	688	703
20	0.33	469	476		40	0.67	897	922
25	0.42	580	590		50	0.83	1097	1134
30	0.50	688	703		60	1.00	1288	1340
35	0.58	794	813		80	1.33	1643	1732
40	0.67	897	922		100	1.67	1967	2099
45	0.75	998	1029		120	2.00	2263	2443
50	0.83	1097	1134		150	2.50	2658	2920
55	0.92	1193	1238		200	3.33	3206	3617
60	1.00	1288	1340		300	5.00	3985	4715
65	1.08	1380	1440		400	6.67	4476	5509
70	1.17	1469	1539		600	10.00	4979	6499
75	1.25	1557	1636		800	13.33	5178	7016
* Condensate flow rate varies with plant MW output. 6000L/min at full load 380MW. 4500L/min at minimum combined cycle load 240MW.					1000	16.67	5257	7287
					1500	25.00	5304	7525

Table A. 5 Cl Concentrations in condensate with different radius orifices
(Refer to Figure 4.12)

Leak time		r = 0.5 mm	r = 1 mm
Second	Minute	Cl (ppb)	Cl (ppb)
0	0	0	0
5	0.08	54	215
10	0.17	106	425
15	0.25	158	630
20	0.33	208	831
25	0.42	257	1027
30	0.50	304	1218
35	0.58	351	1405
40	0.67	397	1588
45	0.75	442	1766
50	0.83	485	1941
55	0.92	528	2111
60	1.00	569	2278

Table A. 6 Na and Cl concentration in condensate with different samples (Refer to Figure 4.13)

Leaking time		9/07/2004		9/03/2007	
		Na	**Cl**	**Na**	**Cl**
Second	**Minute**	**ppb**	**ppb**	**ppb**	**ppb**
0	0.00	0	0	0	0
5	0.08	42	75	121	215
10	0.17	83	148	240	425
15	0.25	123	219	356	630
20	0.33	163	289	469	831
25	0.42	201	357	580	1027
30	0.50	238	424	688	1218
35	0.58	275	489	794	1405
40	0.67	311	552	897	1588
45	0.75	346	614	998	1766
50	0.83	380	675	1097	1941
55	0.92	413	734	1193	2111
60	1.00	446	792	1288	2278
65	1.08	478	849	1380	2441
70	1.17	509	904	1469	2600
75	1.25	539	958	1557	2755
80	1.33	569	1011	1643	2907

Table A. 7 Cl and Na concentrations in HP drum
(Refer to Figure 4.16)

Leaking time		Na	Cl
Second	Minute	ppb	ppb
0	0.00	0	0
10	0.17	1	1
20	0.33	2	4
30	0.50	5	8
40	0.67	8	15
50	0.83	13	23
60	1.00	18	32
80	1.33	31	55
100	1.67	47	84
120	2.00	66	118
140	2.33	88	156
180	3.00	138	244
220	3.67	195	345
260	4.33	259	458
300	5.00	328	580
340	5.67	402	710
380	6.33	479	847
420	7.00	559	989

Table A. 8 Cl concentrations in three drum systems
(Refer to Figure 4.17)

Leak time		HP	IP	LP
Second	Minute	ppb	ppb	ppb
0	0.00	0.0	0.0	0.0
10	0.17	1.0	0.7	0.3
20	0.33	3.8	2.6	1.2
30	0.50	8.4	5.7	2.6
40	0.67	14.7	10.0	4.6
50	0.83	22.6	15.4	7.1
60	1.00	32.0	21.9	10.0
80	1.33	55.3	37.8	17.3
100	1.67	84.0	57.4	26.3
140	2.33	155.6	106.4	48.7
180	3.00	243.6	166.5	76.2
220	3.67	345.2	236.0	108.0
260	4.33	458.1	313.1	143.3
300	5.00	580.4	396.7	181.6
340	5.67	710.5	485.6	222.2
380	6.33	847.0	578.9	265.0

Table A. 9 Cl concentrations at different locations of water cycle system
(Refer to Figure 4.22)

Leak time	Condenser	Preheater	LP Drum	IP ECO	IP Drum	HP ECO#1	HP Drum
Minute	ppb	ppb	ppb	ppb	ppb	ppb	ppb
0.00	0	0	0	0	0	0	0
0.17	425	0	0	0	0	0	0
0.33	831	0	0	0	0	0	0
0.50	1218	0	0	0	0	0	0
0.58	1405	0	0	0	0	0	0
0.67	1588	0	0	0	0	0	0
0.83	1941	0	0	0	0	0	0
1.00	2278	0	0	0	0	0	0
1.17	2600	425	0	0	0	0	0
1.33	2907	831	0	0	0	0	0
1.67	3480	1588	0	0	0	0	0
2.00	4003	2278	0	0	0	0	0
2.33	4480	2907	0	0	0	0	0
2.67	4914	3480	0	0	0	0	0
3.00	5310	4003	0	0	0	0	0
3.33	5671	4480	0	0	0	0	0
3.67	6000	4914	0	0	0	0	0
4.00	6300	5310	0	0	0	0	0
4.33	6573	5671	0	0	0	0	0
4.67	6823	6000	0	0	0	0	0
5.00	7050	6300	0	0	0	0	0
5.33	7257	6573	0	0	0	0	0
5.67	7446	6823	0	0	0	0	0
6.00	7618	7050	0	0	0	0	0
6.33	7775	7257	0	0	0	0	0
6.67	7918	7446	0	0	0	0	0
6.75	7951	7490	0	0	0	0	0
7.00	8048	7618	1	0	0	0	0
7.17	8109	7698	2	0	0	0	0
7.33	8167	7775	4	0	0	425	0
7.50	8222	7848	6	425	0	831	0
7.67	8275	7918	8	831	0	1218	0
8.00	8374	8048	15	1588	0	1941	0
8.33	8464	8167	24	2278	0	2600	0
8.67	8546	8275	34	2907	0	3200	0
9.00	8621	8374	46	3480	0	3748	0
9.33	8689	8464	58	4003	0	4247	0

Leak time	Condenser	Preheater	LP Drum	IP ECO	IP Drum	HP ECO#1	HP Drum
Minute	ppb	ppb	ppb	ppb	ppb	ppb	ppb
10.33	8859	8689	104	5310	0	5495	0
10.67	8906	8751	121	5671	0	5839	0
11.00	8949	8808	139	6000	0	6153	0
11.33	8988	8859	157	6300	0	6440	0
11.67	9024	8906	177	6573	0	6701	0
12.00	9057	8949	197	6823	0	6939	0
12.33	9086	8988	217	7050	0	7156	0
12.67	9113	9024	238	7257	0	7354	0
13.00	9138	9057	260	7446	0	7534	0
13.33	9160	9086	281	7618	0	7698	0
13.50	9171	9100	293	7698	0.0	7775	0
13.75	9186	9120	309	7812	1.5	7883	0
14.00	9199	9138	326	7918	5.7	7984	0
14.33	9216	9160	349	8048	15.4	8109	0
14.67	9232	9181	373	8167	29.4	8222	0
15.00	9246	9199	396	8275	47.2	8326	0
15.33	9259	9216	420	8374	68.5	8420	0
15.67	9271	9232	444	8464	93.0	8506	0
16.00	9281	9246	468	8546	120.4	8584	0
16.33	9291	9259	493	8621	150.5	8656	0
16.67	9300	9271	517	8689	183.1	8721	0
17.00	9308	9281	542	8751	217.8	8780	0
17.33	9316	9291	567	8808	254.6	8834	0
17.67	9322	9300	592	8859	293.2	8883	0
18.00	9328	9308	617	8906	333.4	8928	0
18.33	9334	9316	642	8949	375.2	8969	0
18.67	9339	9322	668	8988	418.4	9007	0
19.00	9344	9328	693	9024	462.9	9041	0
19.33	9348	9334	718	9057	508.5	9072	0
19.67	9352	9339	744	9086	555.2	9100	0
19.88	9354	9342	761	9104	586.0	9117	0.0
20.00	9355	9344	770	9113	602.8	9126	0.5
20.33	9359	9348	795	9138	651.3	9149	6.9
20.67	9361	9352	821	9160	700.6	9171	20.2
21.00	9364	9355	847	9181	750.7	9190	39.8
21.33	9367	9359	873	9199	801.4	9208	65.1
21.67	9369	9361	899	9216	852.7	9224	95.6
22.00	9371	9364	925	9232	904.6	9239	130.8
22.33	9373	9367	951	9246	956.9	9253	170.4
22.67	9374	9369	977	9259	1009.7	9265	213.9

Leak time	Condenser	Preheater	LP Drum	IP ECO	IP Drum	HP ECO#1	HP Drum
Minute	ppb	ppb	ppb	ppb	ppb	ppb	ppb
23.00	9376	9371	1003	9271	1063.0	9276	261.0
23.33	9377	9373	1029	9281	1116.6	9286	311.4
23.67	9379	9374	1055	9291	1170.6	9296	364.8
24.00	9380	9376	1081	9300	1224.9	9304	420.9
24.33	9381	9377	1107	9308	1279.4	9312	479.5
24.50	9381	9378	1120	9312	1306.8	9316	509.6
24.67	9382	9379	1133	9316	1334.3	9319	540.3
25.00	9383	9380	1159	9322	1389.3	9325	603.3
25.33	9383	9381	1186	9328	1444.6	9331	668.1
25.67	9384	9382	1212	9334	1500.1	9337	734.6
26.00	9385	9383	1238	9339	1555.8	9341	802.7
26.33	9385	9383	1264	9344	1611.6	9346	872.2
26.67	9386	9384	1290	9348	1667.6	9350	943.0
27.00	9386	9385	1317	9352	1723.8	9354	1015.0
27.33	9387	9385	1343	9355	1780.0	9357	1088.0
27.67	9387	9386	1369	9359	1836.4	9360	1162.1
28.00	9388	9386	1395	9361	1892.9	9363	1237.1
28.33	9388	9387	1422	9364	1949.4	9365	1312.8
28.67	9388	9387	1448	9367	2006.1	9368	1389.3
29.00	9389	9388	1474	9369	2062.8	9370	1466.5
29.33	9389	9388	1501	9371	2119.6	9372	1544.3
29.67	9389	9388	1527	9373	2176.5	9374	1622.7
30.00	9389	9389	1553	9374	2233.4	9375	1701.6
30.33	9390	9389	1579	9376	2290.4	9377	1781.0
30.67	9390	9389	1606	9377	2347.4	9378	1860.8
31.00	9390	9389	1632	9379	2404.5	9379	1941.0
31.33	9390	9390	1658	9380	2461.6	9380	2021.5
31.67	9390	9390	1685	9381	2518.8	9381	2102.4
32.00	9390	9390	1711	9382	2576.0	9382	2183.5
32.33	9390	9390	1737	9383	2633.2	9383	2264.9
32.67	9391	9390	1764	9383	2690.5	9384	2346.6
33.00	9391	9390	1790	9384	2747.8	9384	2428.5
33.33	9391	9390	1816	9385	2805.1	9385	2510.6
33.67	9391	9391	1843	9385	2862.4	9386	2592.9
34.00	9391	9391	1869	9386	2919.7	9386	2675.3
34.33	9391	9391	1895	9386	2977.1	9387	2757.9
34.67	9391	9391	1922	9387	3034.5	9387	2840.7
35.00	9391	9391	1948	9387	3091.9	9388	2923.6
35.33	9391	9391	1974	9388	3149.3	9388	3006.6
35.67	9391	9391	2001	9388	3206.7	9388	3089.7

Leak time	Condenser	Preheater	LP Drum	IP ECO	IP Drum	HP ECO#1	HP Drum
Minute	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**
36.00	9391	9391	2027	9388	3264.1	9389	3172.8
36.33	9391	9391	2053	9389	3321.6	9389	3256.1
36.67	9391	9391	2080	9389	3379.0	9389	3339.5
37.00	9391	9391	2106	9389	3436.5	9389	3422.9
37.33	9391	9391	2132	9389	3493.9	9390	3506.4
37.67	9391	9391	2159	9390	3551.4	9390	3590.0
38.00	9391	9391	2185	9390	3608.9	9390	3673.6
38.33	9391	9391	2211	9390	3666.4	9390	3757.3
38.67	9391	9391	2238	9390	3723.9	9390	3841.0
39.00	9391	9391	2264	9390	3781.4	9390	3924.8
39.33	9391	9391	2290	9390	3838.9	9390	4008.6
39.67	9392	9391	2317	9390	3896.4	9391	4092.4
40.00	9392	9391	2343	9391	3953.9	9391	4176.3

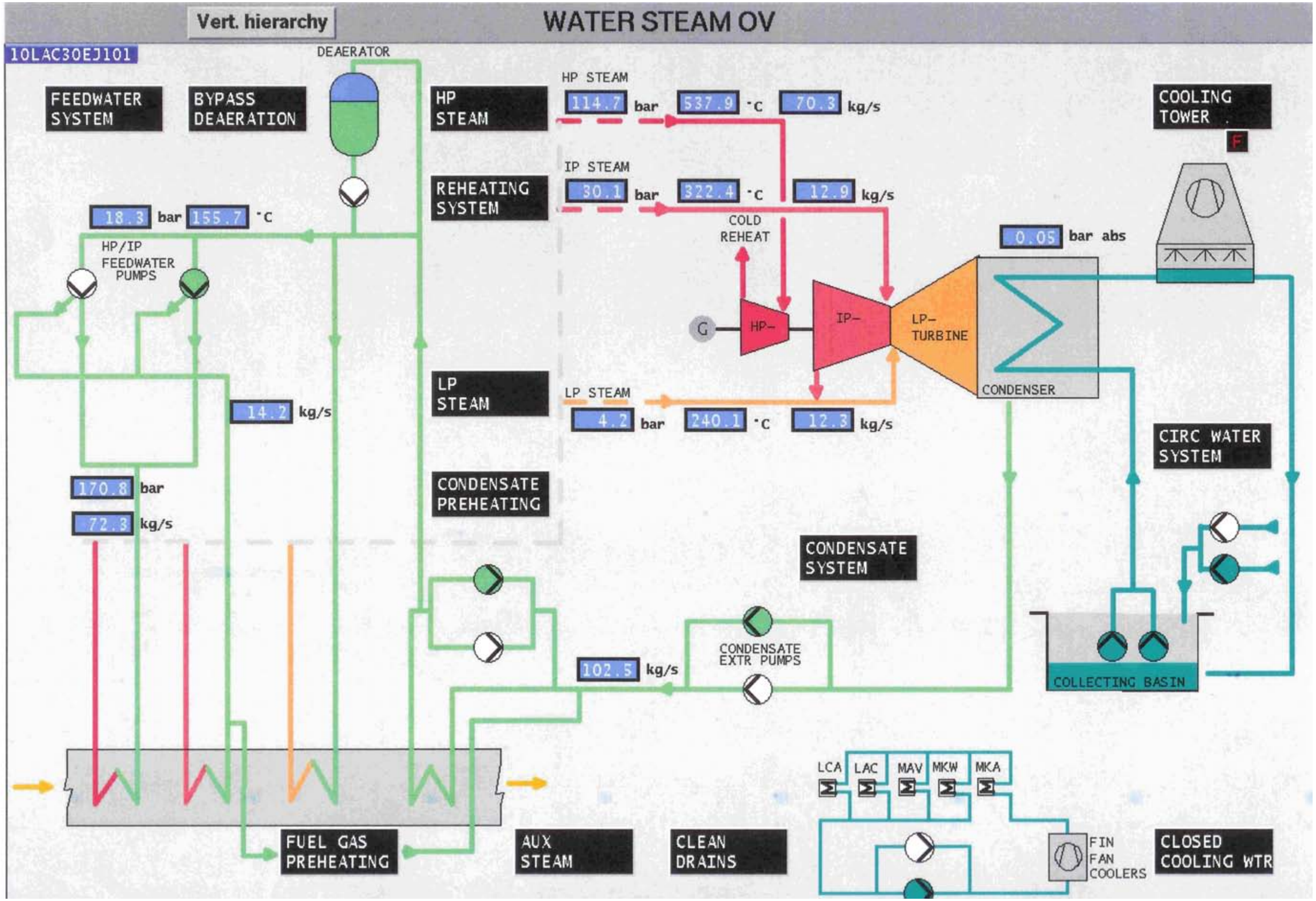


Figure A.1 Water steam cycle overview diagram

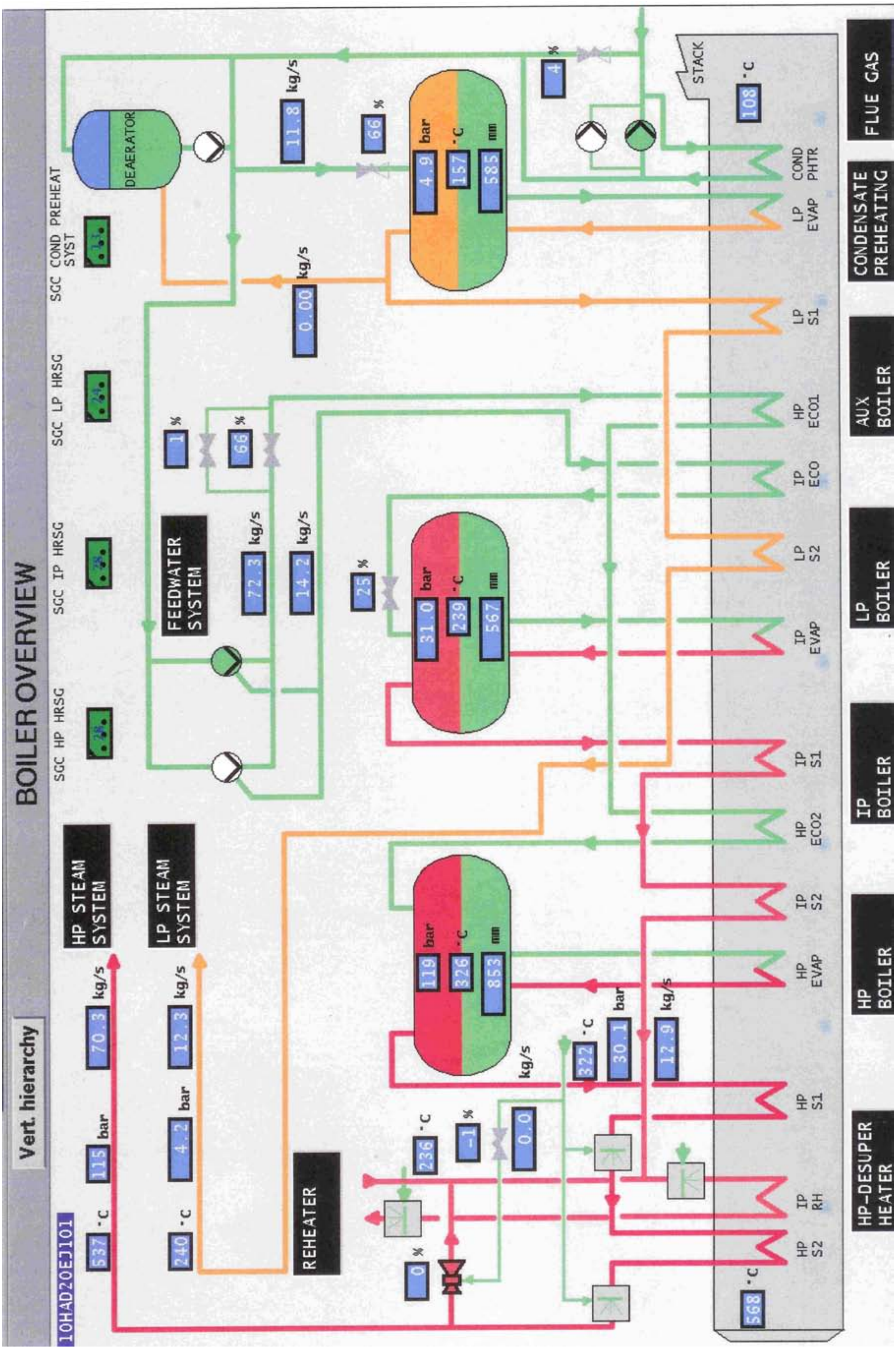


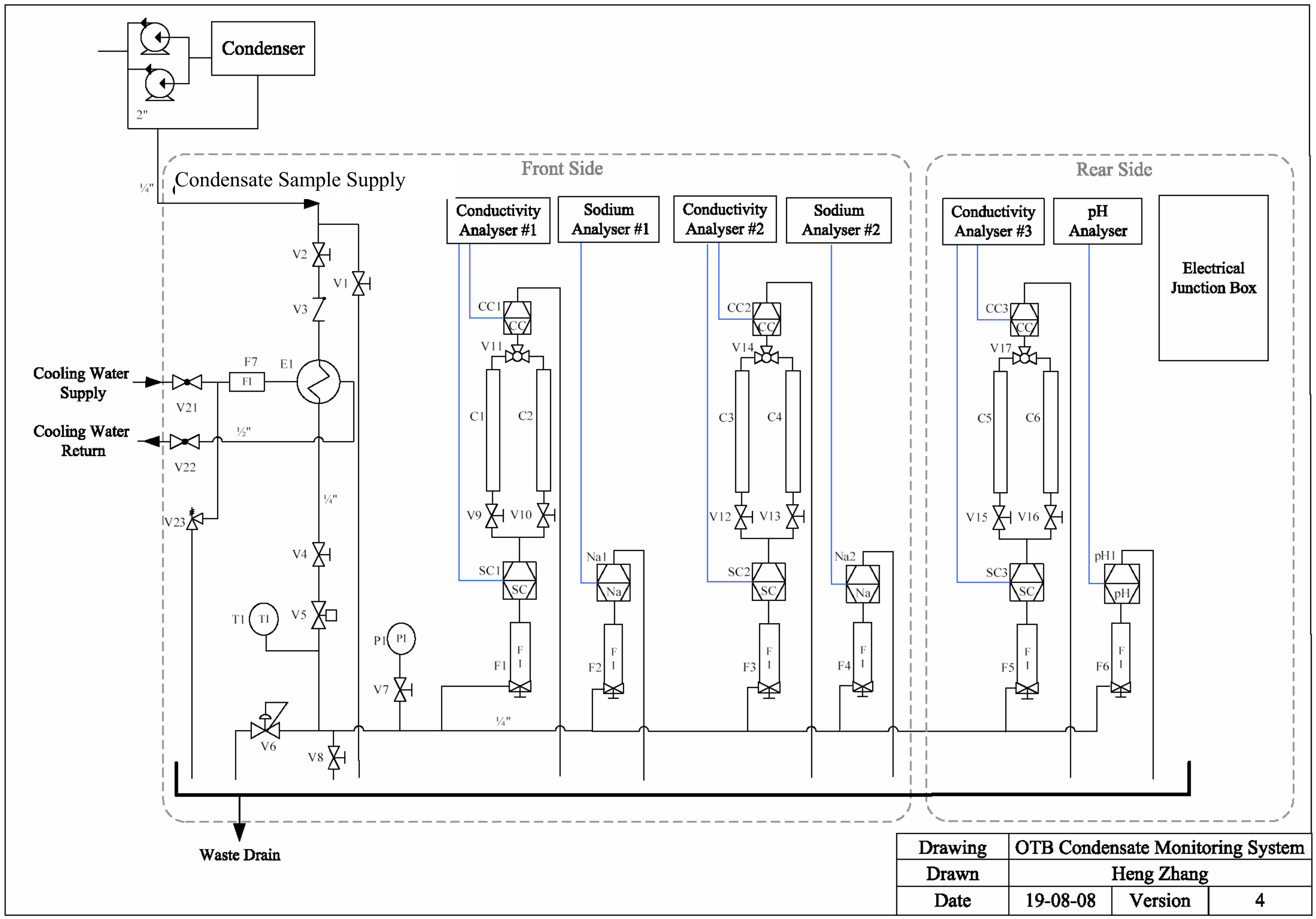
Figure A.2 HRSG overview diagram

Appendix B   Condensate Monitoring System Diagrams

Appendix B consists of P&ID, electrical cabling diagram, instrumentation wiring diagram and the photographs of the new condensate monitoring system. These diagrams provide detailed information on the condensate monitoring system.

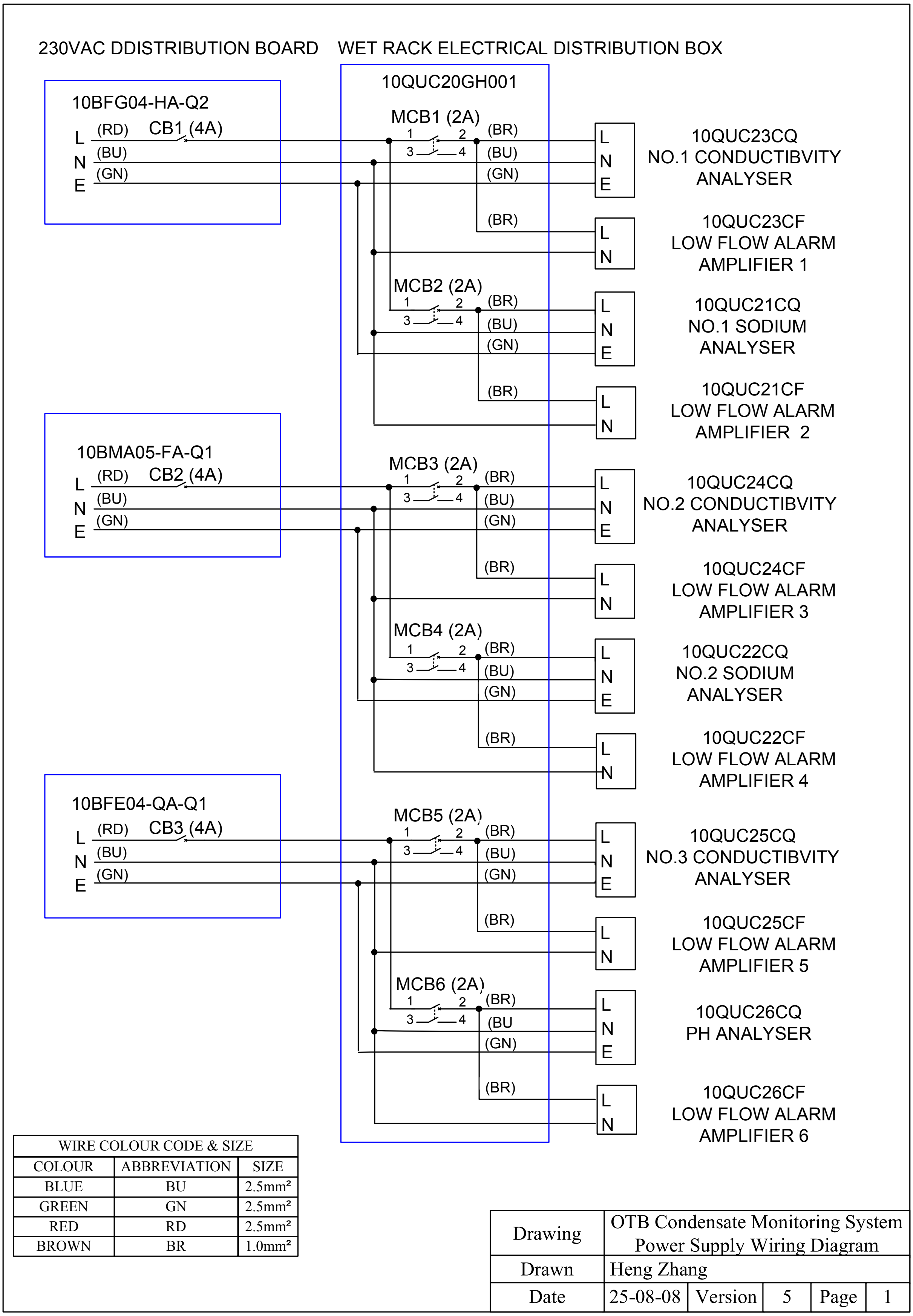
Figure B. 1 Front side of the analysis rack

Figure B. 2 Back side of the analysis rack



Drawing	OTB Condensate Monitoring System		
Drawn	Heng Zhang		
Date	19-08-08	Version	4

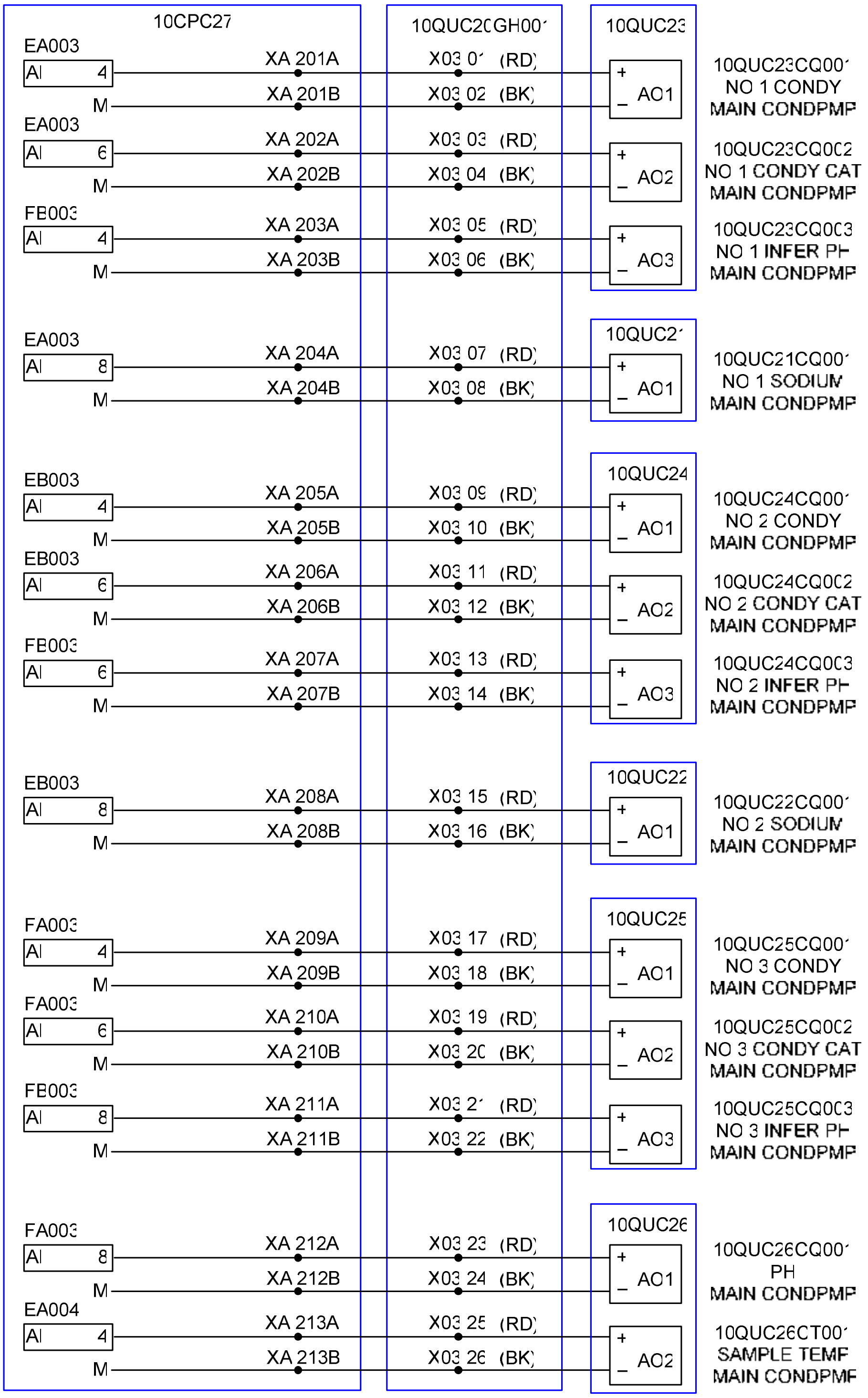
Figure B.3 Condensate monitoring system P&ID diagram



WIRE COLOUR CODE & SIZE		
COLOUR	ABBREVIATION	SIZE
BLUE	BU	2.5mm²
GREEN	GN	2.5mm²
RED	RD	2.5mm²
BROWN	BR	1.0mm²

Drawing	OTB Condensate Monitoring System Power Supply Wiring Diagram				
Drawn	Heng Zhang				
Date	25-08-08	Version	5	Page	1

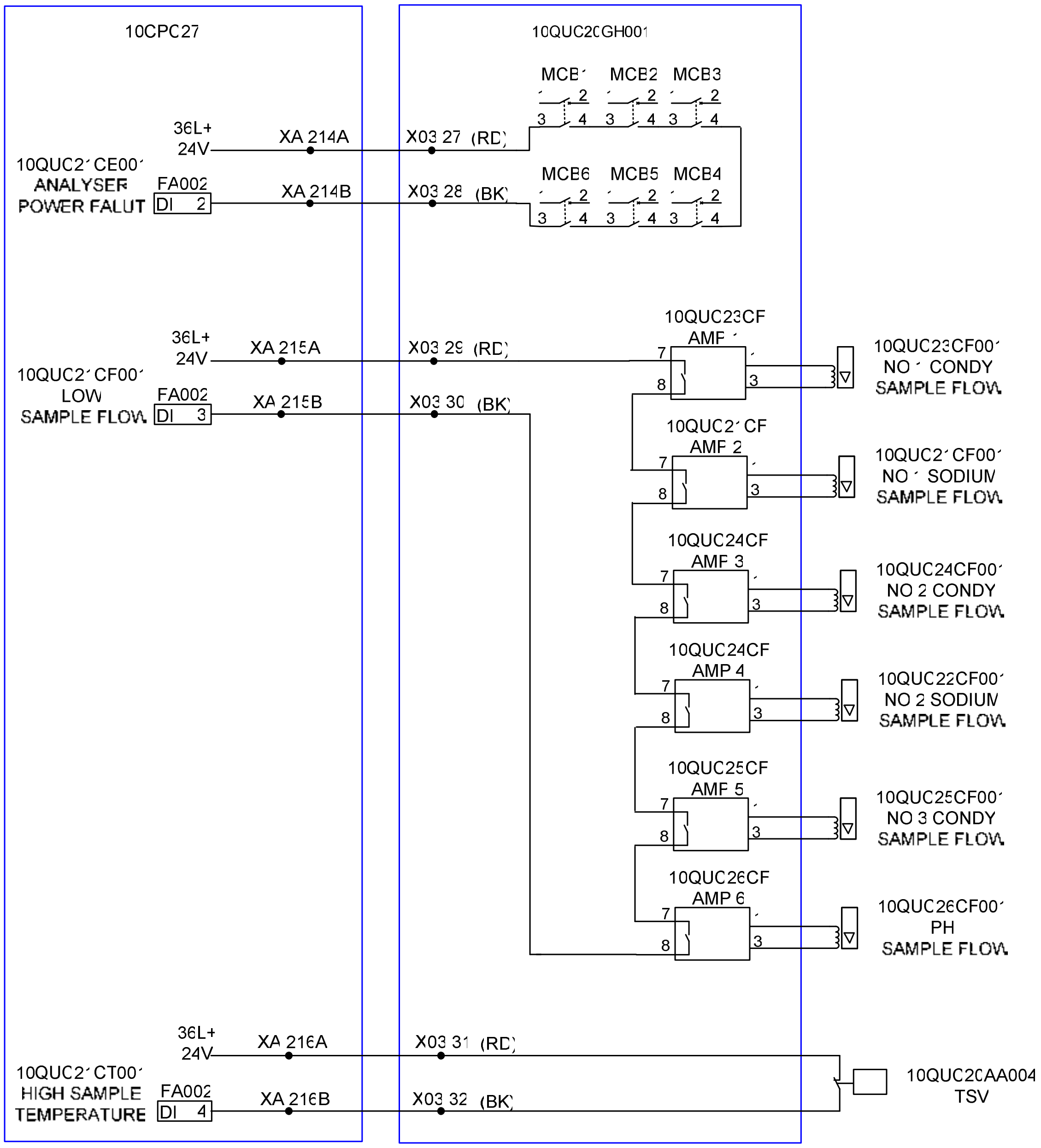
Figure B. 4 Power distribution schematic wiring diagram



WIRE COLOUR CODE & SIZE		
COLOUR	ABBREVIATION	SIZE
BLACK	BK	0.5mm²
RED	RD	0.5mm²

Drawing	OTB Condensate Monitoring System Analogue Signal Wiring Diagram				
Drawn	Heng Zhang				
Date	25-08-08	Version	5	Page	1

Figure B. 5 Analogue signal wiring diagram



WIRE COLOUR CODE & SIZE		
COLOUR	ABBREVIATION	SIZE
BLACK	BK	0.5mm^2
RED	RD	0.5mm^2

Drawing	OTB Condensate Monitoring System Digital Signal Wiring Diagram				
Drawn	Heng Zhang				
Date	25-08-08	Version	5	Page	1

Figure B. 6 Digital signal wiring diagram

Table B. 1 Condensate Monitoring System Component KKS Codes

KKS	LABEL DESCRIPTION	FULL DESCRIPTION
10QUC20BR001	CONDENSATE SAMPLING	Sample line to cooler
10QUC20AA001	DIS CEP INL-V	Sample inlet valve to cooler
10QUC20AA002	DIS CEP B/D-V	Sample blowdown valve
10QUC20AA401	CHK-V	Sample non return valve
10QUC20AC001	SAMPLE COOLER	Sample cooler
10QUC20CT501		Sample temperature after cooler
10QUC20AA003	PRES RED-V	Sample pressure control valve
10QUC20AA004	TS-V	Sample thermal shut off valve
10QUC20AA005	PRES GUAGE INL-V	Pressure gauge inlet valve
10QUC20CP501		Sample pressure after pressure control valve
10QUC20AA191	PRES REL-V	Sample pressure relief valve
10QUC20AA006	MAN SAMP-V	Manual sample valve
10PGB20AA031	CW INL-V	Cooling water inlet valve
10PGB20AA032	CW OUTL-V	Cooling water oulet valve
10QUC20CF001	CW FLOW	Cooling water flow indicator
10QUC20AA192	PRES REL-V	Cooling water pressure relief valve
Sodium System Number 1		
10QUC21CF001	NO.1 SODIUM SAMPLE FLOW	NO.1 Sodium analyser sample flow meter
10QUC21CQ001	NO.1 SODIUM MAIN CONDPMP	NO.1 Sodium analyser
10QUC21CQ001	NO.1 SODIUM MAIN CONDPMP	NO.1 Sodium transmitter
Sodium System Number 2		
10QUC22CF001	NO.2 SODIUM SAMPLE FLOW	NO.2 Sodium sample flow meter
10QUC22CQ001	NO.2 SODIUM MAIN CONDPMP	NO.2 Sodium analyser
10QUC22CQ001	NO.2 SODIUM MAIN CONDPMP	NO.2 Sodium transmitter
Conductivity System Number 1		
10QUC23CF001	NO.1 CONDY SAMPLE FLOW	NO.1 Conductivity sample flow meter
10QUC23CQ001	NO.1 CONDY MAIN CONDPMP	NO.1 Conductivity transmitter
10QUC23CQ001	NO.1 CONDY MAIN CONDPMP	NO.1 Specific conductivity sensor
10QUC23CQ002	NO.1 CONDY CAT MAIN CONDPMP	NO.1 Cation conductivity sensor
10QUC23AT001	NO.1 CAT FILTER A	NO.1 Cation column A
10QUC23AT002	NO.1 CAT FILTER B	NO.1 Cation column B
10QUC23AA001	NO.1 CAT FILTER A INL-V	NO.1 Cation column A inlet valve
10QUC23AA002	NO.1 CAT FILTER B INL-V	NO.1 Cation column B inlet valve
10QUC23AA003	NO.1 CAT FILTER OUTL-V	NO.1 Cation column outlet valve
Conductivity System Number 2		
10QUC24CF001	NO.2 CONDY SAMPLE FLOW	NO.2 Conductivity sample flow meter
10QUC24CQ001	NO.2 CONDY MAIN CONDPMP	NO.2 Conductivity transmitter
10QUC24CQ001	NO.2 CONDY MAIN CONDPMP	NO.2 Specific conductivity sensor
10QUC24CQ002	NO.2 CONDY CAT MAIN CONDPMP	NO.2 Cation conductivity sensor

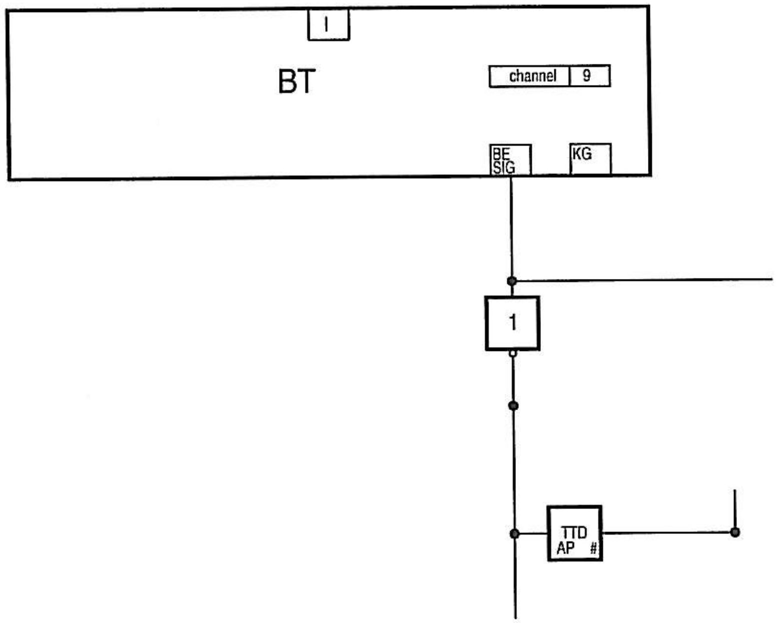
KKS	**LABEL DESCRIPTION**	**FULL DESCRIPTION**
10QUC24AT001	NO.2 CAT FILTER A	NO.2 Cation column A
10QUC24AT002	NO.2 CAT FILTER B	NO.2 Cation column B
10QUC24AA001	NO.2 CAT FILTER A INL-V	NO.2 Cation column A inlet valve
10QUC24AA002	NO.2 CAT FILTER B INL-V	NO.2 Cation column B inlet valve
10QUC24AA003	NO.2 CAT FILTER OUTL-V	NO.2 Cation column outlet valve
Conductivity System Number 3		
10QUC25CF001	NO.3 CONDY SAMPLE FLOW	NO.3 Conductivity sample flow meter
10QUC25CQ001	NO.3 CONDY MAIN CONDPMP	NO.3 Conductivity transmitter
10QUC25CQ001	NO.3 CONDY MAIN CONDPMP	NO.3 Specific conductivity sensor
10QUC25CQ002	NO.3 CONDY CAT MAIN CONDPMP	NO.3 Cation conductivity sensor
10QUC25AT001	NO.3 CAT FILTER A	NO.3 Cation column A
10QUC25AT002	NO.3 CAT FILTER B	NO.3 Cation column B
10QUC25AA001	NO.3 CAT FILTER A INL-V	NO.3 Cation column A inlet valve
10QUC25AA002	NO.3 CAT FILTER B INL-V	NO.3 Cation column B inlet valve
10QUC25AA003	NO.3 CAT FILTER OUTL-V	NO.3 Cation column outlet valve
PH System		
10QUC26CF001	PH SAMPLE FLOW	PH analyser sample flow meter
10QUC26CQ001	PH MAIN CONDPMP	PH sensor
10QUC26CQ001	PH MAIN CONDPMP	PH Transmitter

Appendix C Teleperm XP Logic Function Diagrams

Appendix C consists of the detailed Teleperm XP logic function diagram for the new condensate monitoring system.

No. ID-code	FGC	Signal	SEC ☒	Dest. ☒
Ind. Designation		Setting		Unit
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				

Function



Signal ☒ ID-code	Dest. ☒ SEC	FGC	No.
Designation	Setting	Unit	Ind.
			1
			2
			3
			4
			5
			6
			7
			8
XB02 COND MONITORING CB	TRIPPED		9
			10
			11
XB01 COND MONITORING CB	TRIPPED		12
			13
N XB01	YP01		14
N XB01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	15
			16
N XB01 10QUC26CQ901 COND MONT ACTION LVL CALC			17
			18
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AP 61 Cycle Z2 AT PB 121
AP-F 0 PB

o02es1::olahu1
2008-08-29 Dep.: KWU FTP1
2008-10-22

				Date	19.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC21CE001	R001
				Drawn	TYTS				+	
				Check	SCHLEMPER	CCP Olahuhu NSL159		COND MONITORING CB		Page 1
Status	Modification	Date	Name	Stand.	LANGE	Original replaced by.		Function diagram individual level		1 Sh.

No. / Ind.	ID-code / Designation	FGC	Signal SEC ☒ / Setting	Dest. ☒ / Unit
1				
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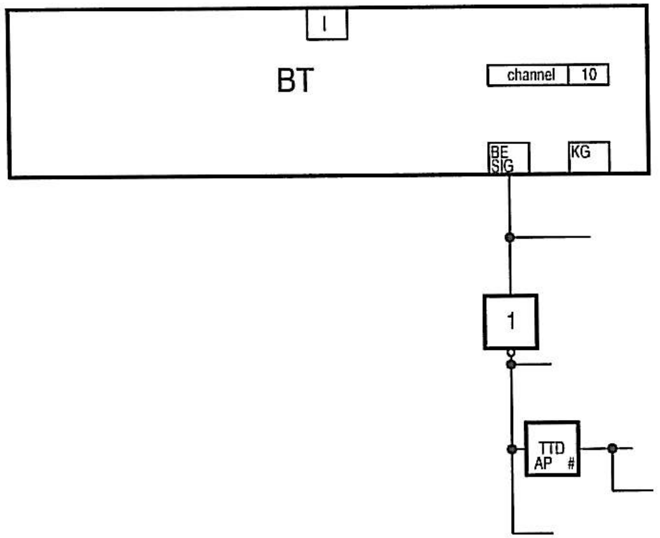
Function



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
			1
			2
			3
			4
			5
			6
XB01 COND MONITORING FLOW	LOW		7
			8
			9
XB04 COND MONITORING FLOW	LOW		10
			11
N XB04	YP01		12
N XB04 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	13
N XB04 10QUC26CQ901 COND MONT ACTION LVL CALC			14
			15
			16
			17
			18
			19
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			21
			22
			23
			24
			25
			26
			27
			28

AP 61 Cycle Z3 AT PB 114
AP-F 0 PB

o02es1::otahu1
2008-08-27 Dep.: KWU FTP1
2008-10-22

Status	Modification	Date	Name		
				Date	19.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONITORING FLOW
Function diagram individual level

YFR = 10QUC21CF001
+
R001
Page 1
1 Sh.

No. ID-code	FGC	Signal SEC ☒ Dest.	☒
Ind. Designation		Setting	Unit
1			
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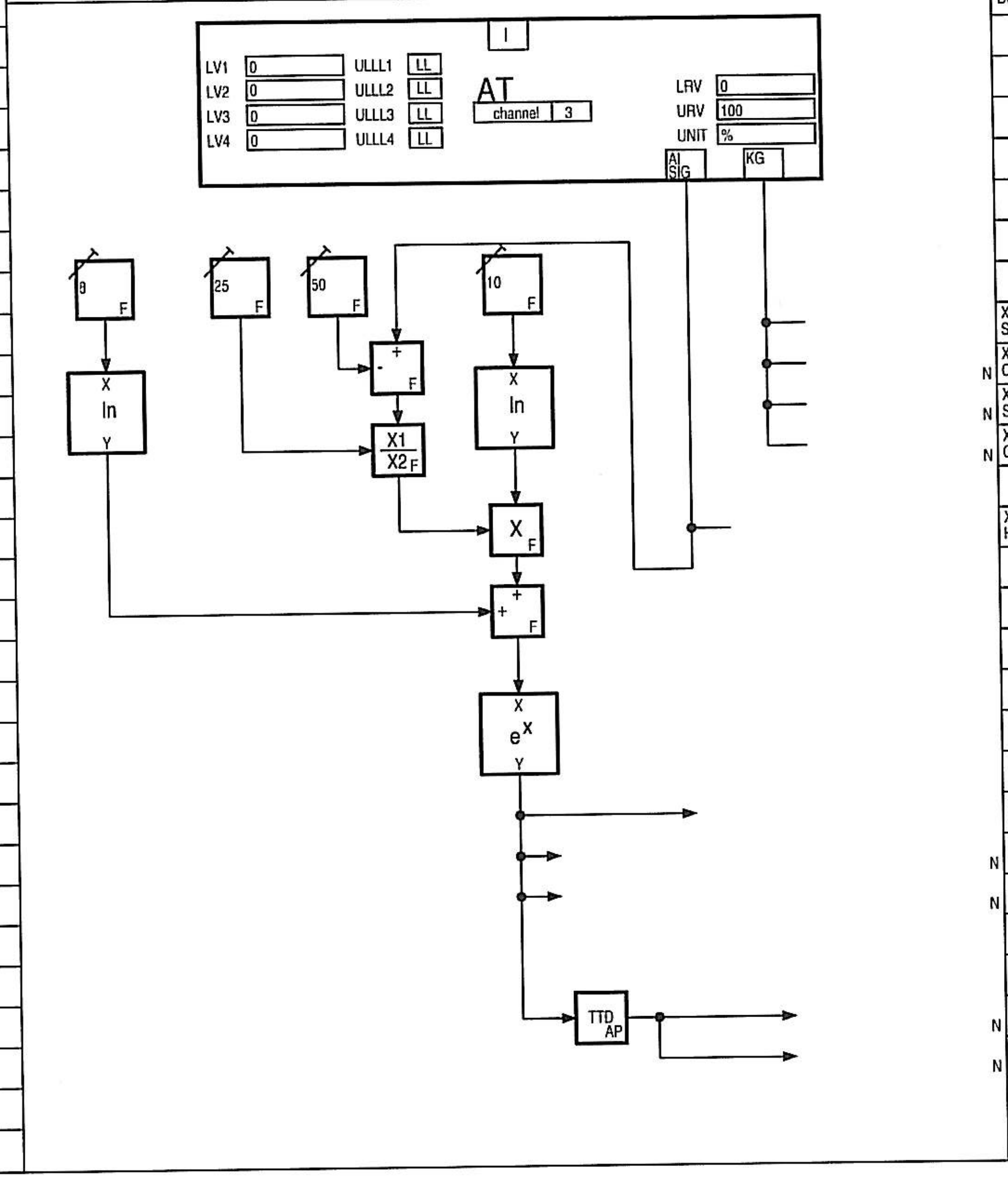
Function



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
			1
			2
			3
			4
			5
			6
			7
XM23 SODIUM MAIN CONDPMP 1	REL		8
N XM23 10QUC22CQ901 COND MONT SODIUM CALC			9
N XM23 10QUC22CQ001 SODIUM MAIN CONDPMP 2			10 q
N XM23 10QUC26CQ901 COND MONT ACTION LVL CALC			11 q
			12
XQ02 HW INPUT	0..100	%	13
			14
			15
			16
			17
			18
			19
XQ01 SODIUM MAIN CONDPMP 1	0..800	ppb	20
N XQ01 10QUC22CQ901 COND MONT SODIUM CALC			21
N XQ01 10QUC22CQ001 SODIUM MAIN CONDPMP 2			22
			23
			24
N XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	25
N XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	26
			27
			28

AP 61 Cycle Z2 AT PB 122
AP-F 0 PB

o02es1::otahu1
2008-09-11 Dep.: KWU FTP1
2008-10-22

				Date	18.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
Status	Modification	Date	Name	Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
SODIUM MAIN CONDPMP 1
Function diagram individual level

YFR = 10QUC21CQ001
+

R001
Page 1
1 Sh.

No. Ind.	ID-code FGC Designation	Signal SEC ☒ Setting	Dest. ☒ Unit
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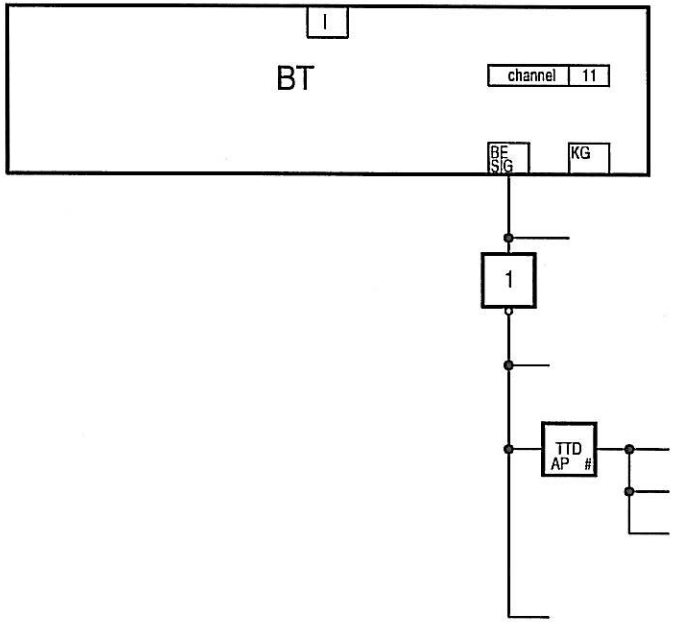
Function



	Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
				1
				2
				3
				4
				5
				6
	XB01 COND MONITORING TEMP			7
				8
				9
	YP12 COND MONITORING TEMP	HIGH		10
				11
N	YP12	YP01		12
N	YP12 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	13
N	YP12 10QUC50EJ209	YP01		14
				15
N	YP12 10QUC26CQ901 COND MONT ACTION LVL CALC			16
				17
				18
				19
				20
				21
				22
				23
				24
				25
				26
				27
				28

o02es1::olahu1
2008-08-29
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z3 AT PB 115
AP-F 0 PB

			Date	19.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Olahuhu NSL159
Status	Modification	Date	Name	Stand. LANGE	Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONITORING TEMP
Function diagram individual level

YFR = 10QUC21CT001
+
R001
Page 1
1 Sh.

No. Ind.	ID-code / Designation	FGC	Signal / Setting	SEC	Dest. / Unit	
1						
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16						
17						
18	10QUC21CQ001 SODIUM MAIN CONDPMP 1		XQ01 0..800		ppb	N
19						
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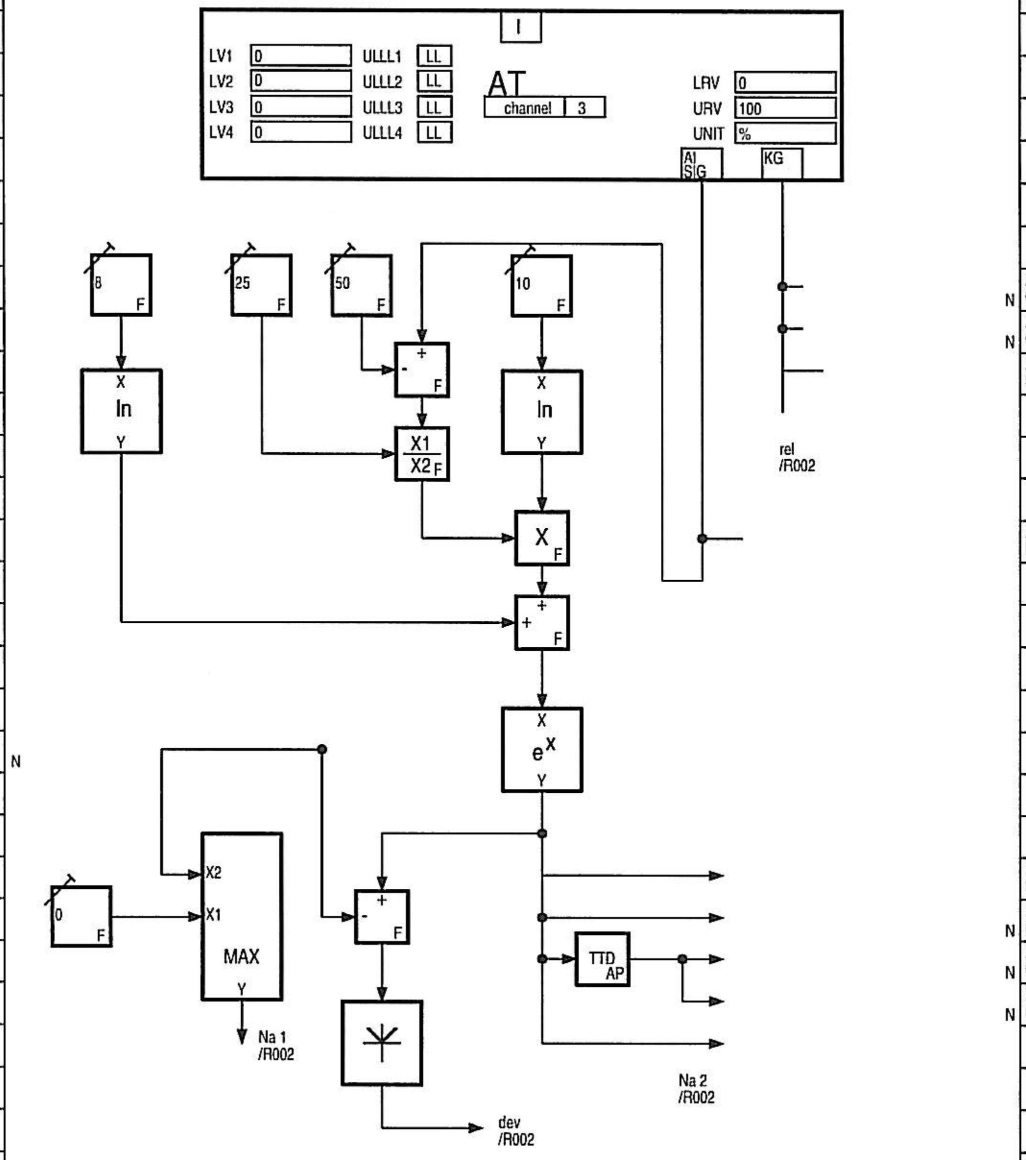
27						
28						

Function



	Signal / Designation	ID-code	Dest. / Setting	SEC	FGC / Unit	No. Ind.
						1
						2
						3
						4
						5
						6
N	XM23 COND MONT SODIUM CALC	10QUC22CQ901				7 q
N	XM23 COND MONT ACTION LVL CALC	10QUC26CQ901				8 q
	XM23 SODIUM MAIN CONDPMP 2		REL			9
						10
						11
						12
	XQ02 HW INPUT		0..100		%	13
						14
						15
						16
						17
						18
						19
						20
	XQ01 SODIUM MAIN CONDPMP 2		0...800		ppb	21
N	XQ01 COND MONT SODIUM CALC	10QUC22CQ901				22
N	XQ01 CONDENSATE MONITORING	10QUC50EJ209	YP01		YCKYAA	23
N	XQ01 CONDENSATE MONITORING	10QUC50EJ208	YP01		YCKYAA	24
						25
						26
						27
						28

o02es1::olahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 117
AP-F 0 PB

Date	18.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC22CQ001 R001
Drawn	TYTS				+
Check	SCHLEMPER	CCP Otahuhu NSL159		SODIUM MAIN CONDPMP 2	Page 1
Status / Modification / Date / Name / Stand.	LANGE	Original replaced by.		Function diagram individual level	2 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC ☒ Dest. / Unit
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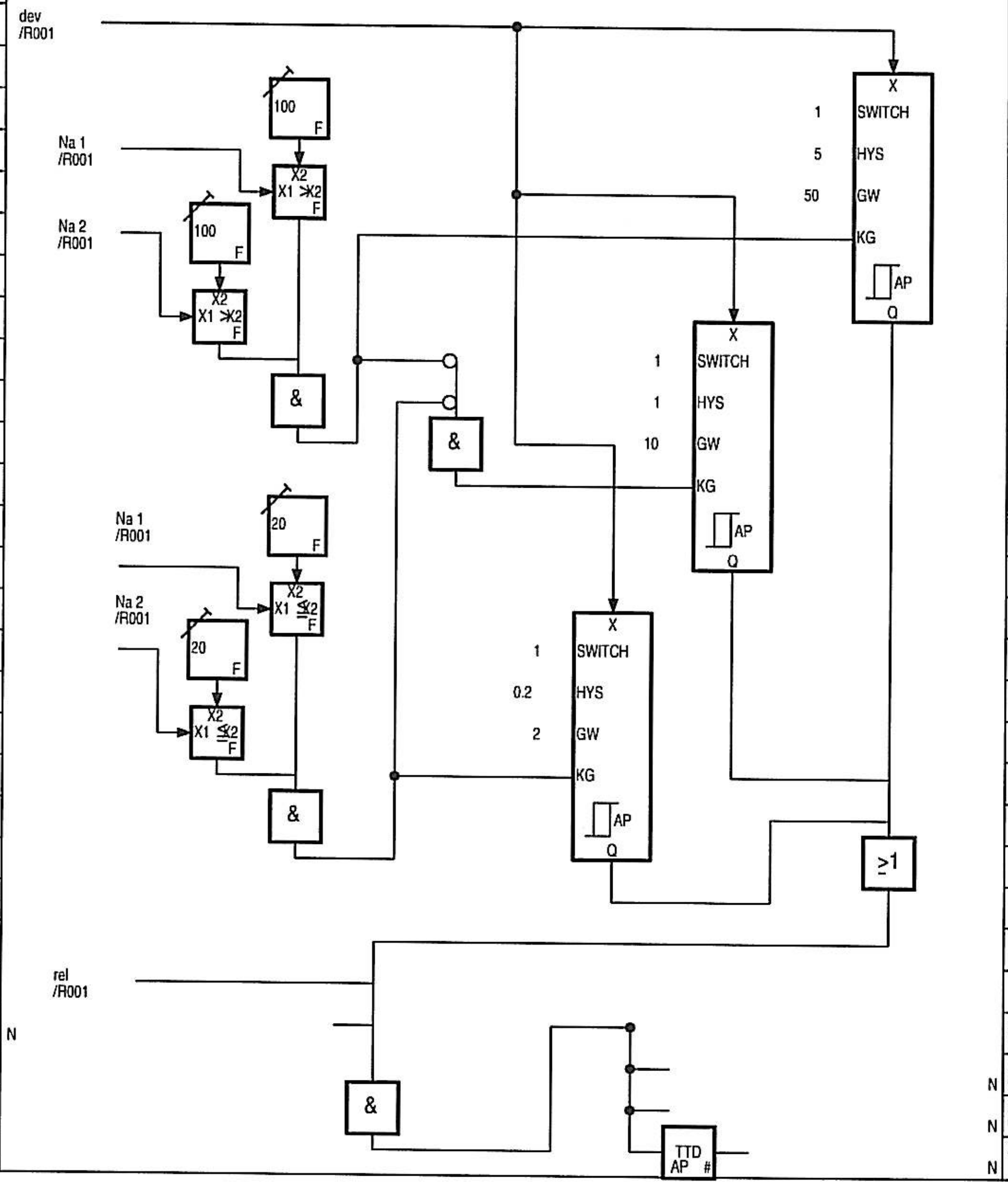
25 q	10QUC21CQ001 SODIUM MAIN CONDPMP 1		XM23 REL	
26				
27				
28				

Function



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
			1
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			6
			7
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			19
			20
			21
			22
			23
			24
XG01 SODIUM MAIN CONDPMP DEV	HIGH		25
XG01 10QUC26CQ901 COND MONT ACTION LVL CALC			26
XG01 10QUC22CQ901 COND MONT SODIUM CALC			27
XG01	YP01		28

o02es1::olahu1
2008-10-22
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 117
AP-F 0 PB

			Date	18.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Otahuhu NSL159
Status	Modification	Date	Name	Stand. LANGE	Original replaced by.

SIEMENS AG

YLCA10 FC WS

SODIUM MAIN CONDPMP 2

Function diagram individual level

YFR = 10QUC22CQ001
\+

R002

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒ Dest. ☒ Unit	
1					
2	10QUC22CQ001 SODIUM MAIN CONDPMP 2		XQ01 0...800	ppb	N
3	10QUC21CQ001 SODIUM MAIN CONDPMP 1		XQ01 0..800	ppb	N
4	10QUC21CQ001 SODIUM MAIN CONDPMP 1		XM23 REL		N
5					
6 q	10QUC22CQ001 SODIUM MAIN CONDPMP 2		XM23 REL		N
7					
8					
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12					
13					
14					
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16					
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21					
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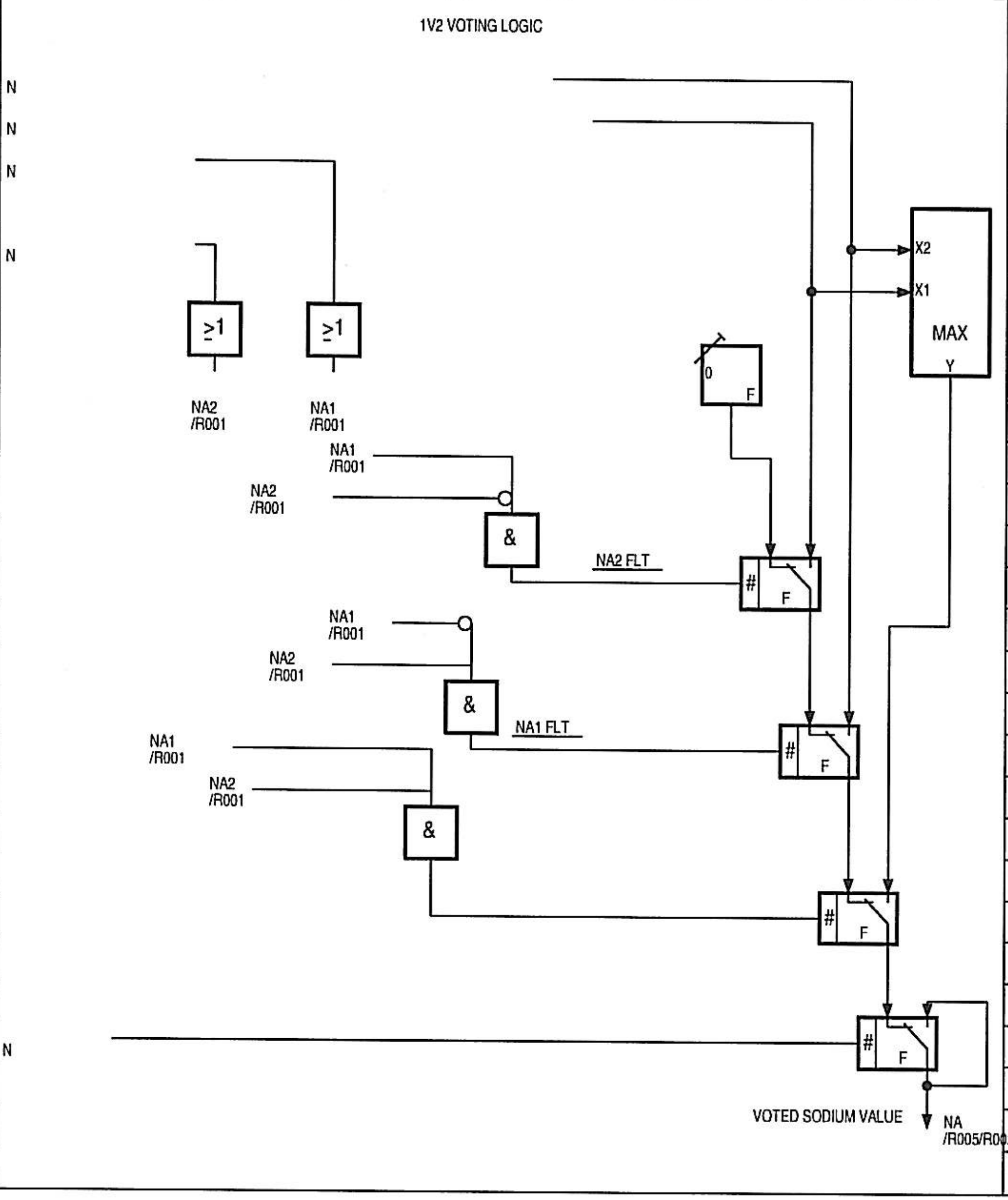
24					
25	10QUC22CQ001 SODIUM MAIN CONDPMP DEV		XG01 HIGH		N
26					
27					
28					

Function



Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
			1
			2
			3
			4
			5
			6
			7
			8
			9
			10
			11
			12
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o02es1::otahu1
2008-10-22
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 116
AP-F 0 PB

Date	20.08.2008	Contact Energy Ltd.		SIEMENS AG	YLCA10 FC WS
Drawn	TYTS				
Check	SCHLEMPER	CCP Otahuhu	NSL159		COND MONT SODIUM CALC
Stand	LANGE	Original replaced by.			Function diagram individual level

Status | Modification | Date | Name

YFR = 10QUC22CQ901 R001
+
Page 1
5 Sh.

No.	ID-code	FGC	Signal	SEC ☒ Dest. ☒
Ind.	Designation		Setting	Unit
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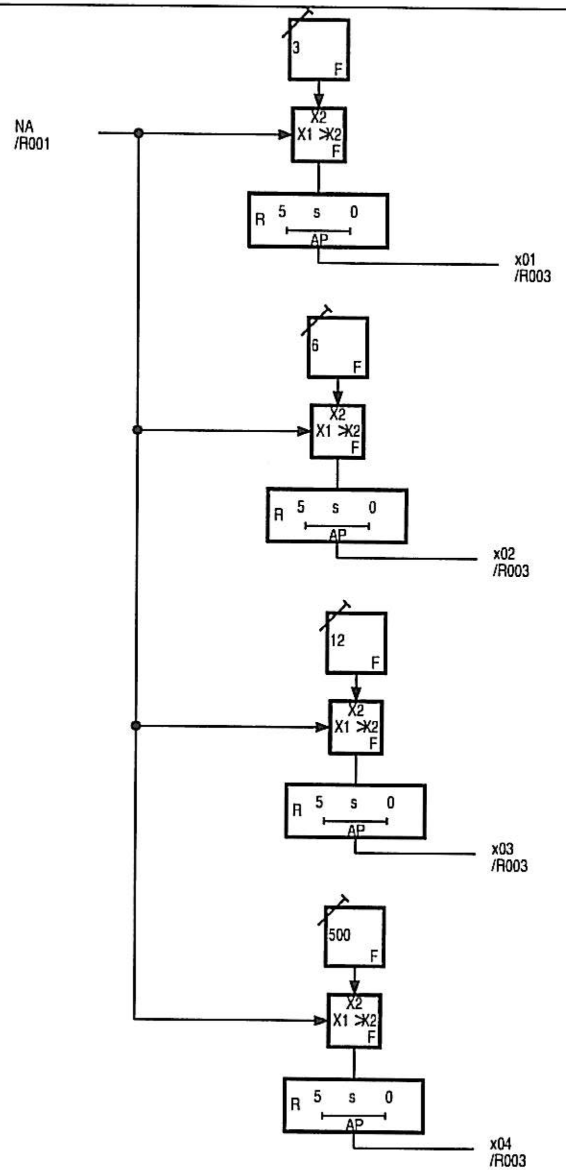
Function



Signal ☒ ID-code	Dest. ☒SEC	FGC	No.
Designation	Setting	Unit	Ind.
			1
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o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 116
AP-F 0 PB

			Date	20.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Otahuhu NSL159
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT SODIUM CALC
Function diagram individual level

YFR = 10QUC22CQ901
+
R002
Page 2
5 Sh.

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No.	ID-code	FGC	Signal	SEC ☒	Dest. ☒
Ind.	Designation		Setting		Unit
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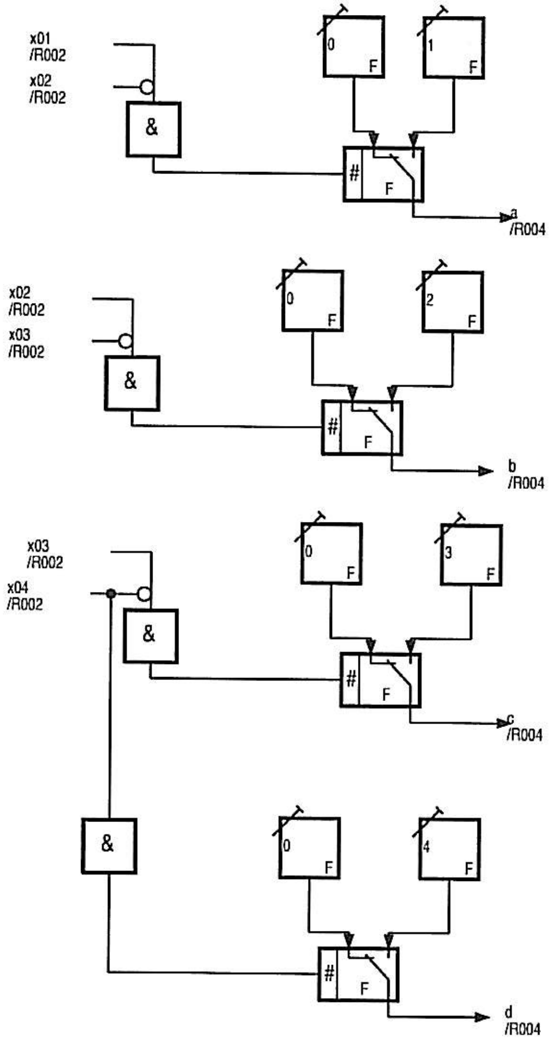
Function



Signal ☒	ID-code	Dest. ☒	SEC	FGC	No.
Designation		Setting		Unit	Ind.
					1
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o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 116
AP-F 0 PB

Status	Modification	Date	Name		
				Date	20.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT SODIUM CALC
Function diagram individual level

YFR = 10QUC22CQ901
+

R003
Page 3
5 Sh.

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No. Ind.	ID-code Designation	FGC	Signal SEC ☒ Setting	Dest. ☒ Unit
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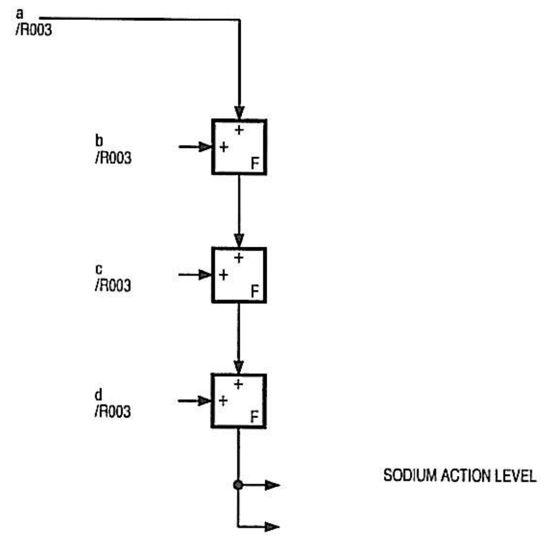
Function



Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
			1
			2
			3
			4
			5
			6
			7
			8
			9
			10
			11
XQ05 COND MONT SODIUM CALC	0...4		12
N XQ05 10QUC26CQ901 COND MONT ACTION LVL CALC			13
			14
			15
			16
			17
			18
			19
			20
			21
			22
			23
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			25
			26
			27
			28

o02es1::otahu1
2008-10-22 Dep.: KWU FTP1
2008-10-22

AP 61 Cycle Z1 AT PB 116
AP-F 0 PB

				Date	20.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
Status	Modification	Date	Name	Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT SODIUM CALC
Function diagram individual level

YFR = 10QUC22CQ901
+

R004
Page 4
5 Sh.

No.	ID-code	FGC	Signal	SEC ☒	Dest. ☒
Ind.	Designation		Setting		Unit
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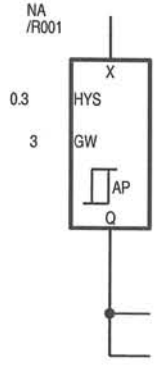
Function



N

Signal ☒ ID-code	Dest.	☒SEC	FGC	No.
Designation	Setting		Unit	Ind.
				1
				2
				3
				4
				5
				6
				7
				8
				9
XB05 COND MONT SODIUM CALC	YP01 HIGH			10
XB05	YP01			11
				12
				13
				14
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				27
				28

o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 116
AP-F 0 PB

Status	Modification	Date	Name						
			Date	20.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC22CQ901	R005
			Drawn	TYTS				+	
			Check	SCHLEMPER	CCP Otahuhu	NSL159	COND MONT SODIUM CALC		Page 5
			Stand.	LANGE	Original replaced by.		Function diagram individual level		5 Sh.

No.	ID-code	FGC	Signal	SEC ☒ Dest. ☒
Ind.	Designation		Setting	Unit
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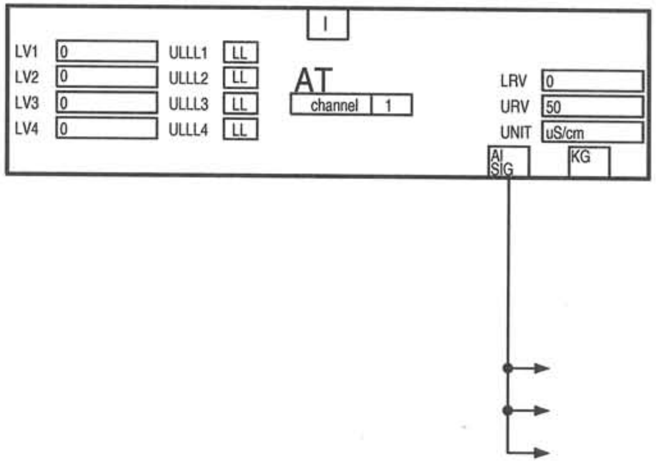
Function



	Signal ☒ ID-code	Dest. ☒SEC	FGC	No.
	Designation	Setting	Unit	Ind.
				1
				2
				3
				4
				5
				6
				7
				8
				9
	XQ01 CONDY MAIN CONDPMP 1	0...50	uS/cm	10
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	11
N	XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	12
				13
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o02es1::otahu1
2008-08-28
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name		
				Date	18.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
CONDY MAIN CONDPMP 1
Function diagram individual level

YFR = 10QUC23CQ001
+
R001
Page 1
1 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. Unit	☒
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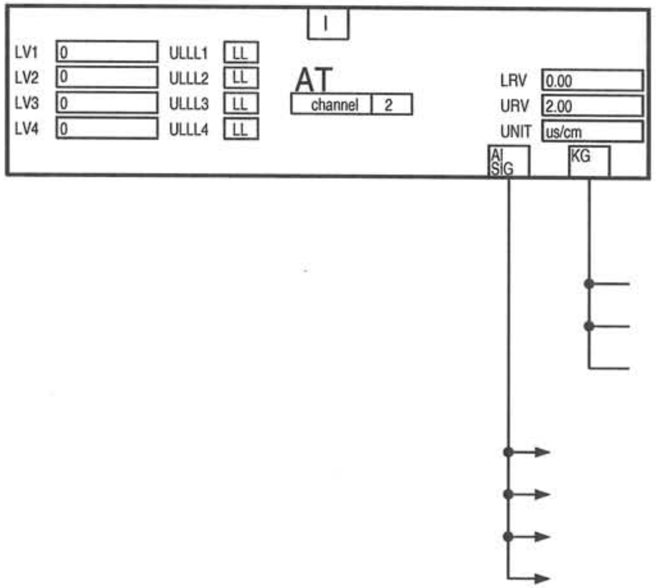
Function



	Signal ☒ ID-code Designation	Dest. Setting	☒ SEC	FGC Unit	No. Ind.
					1
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					8
	XM23 CONDY CAT MAIN CONDPMP 1	REL			9
N	XM23 10QUC25CQ901 COND MONT CAT CONDY CALC				10
N	XM23 10QUC26CQ901 COND MONT ACTION LVL CALC				11
					12
	XQ01 CONDY CAT MAIN CONDPMP 1	0...2		uS/cm	13
N	XQ01 10QUC25CQ901 COND MONT CAT CONDY CALC				14 q
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01		YCKYAA	15
N	XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01		YCKYAA	16
					17
					18
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AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

o02es1::otahu1
2008-09-01
2008-10-22

Dep.: KWU FTP1

Status	Modification	Date	Name		
				Date	18.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
CONDY CAT MAIN CONDPMP 1
Function diagram individual level

YFR = 10QUC23CQ002
\+
R001
Page 1
1 Sh.

No.	ID-code	FGC	Signal	SEC ☒	Dest. ☒
Ind.	Designation		Setting		Unit
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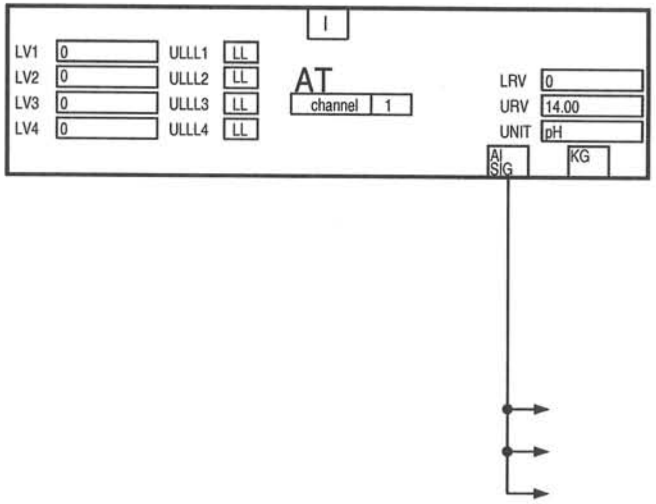
Function



	Signal ☒ ID-code	Dest. ☒SEC	FGC	No.
	Designation	Setting	Unit	Ind.
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	XQ01 INFER PH MAIN CONDPMP 1	0..14	pH	13
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	14
N	XQ01 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	15
				16
				17
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o02es1::otahu1
2008-08-28
2008-10-22
Dep.: FTP1

AP 72 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name						
				Date	18.08.2008	Contact Energy Ltd.	SIEMENS AG	YPUN00 FC AA	YFR = 10QUC23CQ003 R001
				Drawn	STEINLE				+
				Check	STEINLE	CCP Otahuhu NSL159		INFER PH MAIN CONDPMP 1	Page 1
				Stand.	LANGE	Original replaced by.		Function diagram individual level	1 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal SEC ☒ / Setting	Dest. ☒ / Unit
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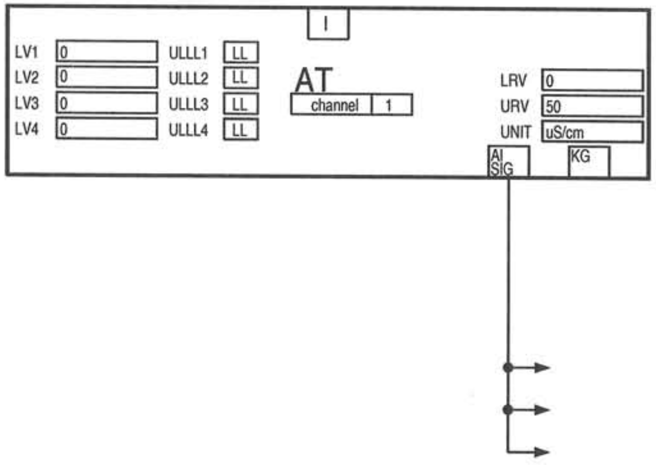
Function



	Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
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				10
	XQ01 CONDY MAIN CONDPMP2	0...50	uS/cm	11
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	12
N	XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	13
				14
				15
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o02es1::otahu1
2008-08-28
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name		
				Date	18.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
CONDY MAIN CONDPMP2
Function diagram individual level

YFR = 10QUC24CQ001
+
R001
Page 1
1 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒ Dest. Unit	☒
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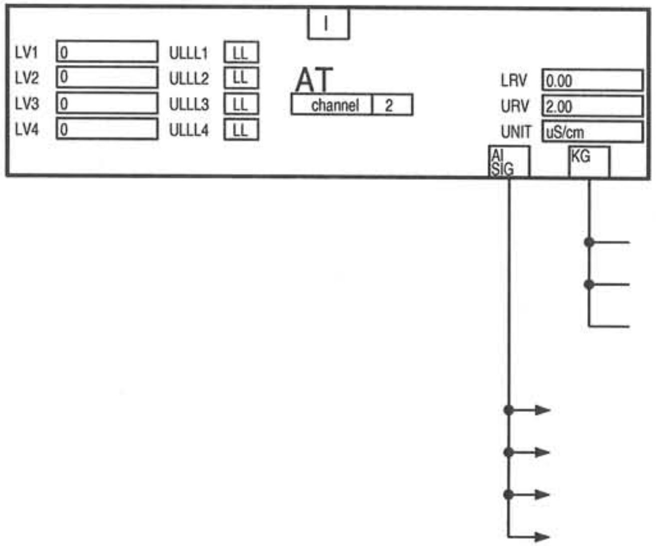
Function



	Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
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				6
				7
	XM23 CONDY CAT MAIN CONDPMP 2	REL		8
N	XM23 10QUC25CQ901 COND MONT CAT CONDY CALC			9
N	XM23 10QUC26CQ901 COND MONT ACTION LVL CALC			10
				11
	XQ01 CONDY CAT MAIN CONDPMP 2	0...2	uS/cm	12
N	XQ01 10QUC25CQ901 COND MONT CAT CONDY CALC			13 q
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	14
N	XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	15
				16
				17
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o02es1::otahu1
2008-08-28
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name				
			Date	18.08.2008	Contact Energy Ltd.		
			Drawn	TYTS			
			Check	SCHLEMPER	CCP Otahuhu	NSL159	
			Stand.	LANGE	Original replaced by.		

SIEMENS AG

YLCA10 FC WS
CONDY CAT MAIN CONDPMP 2
Function diagram individual level

YFR = 10QUC24CQ002
\+
R001
Page 1
1 Sh.

No. Ind.	ID-code Designation	FGC	Signal SEC ☒ Setting	Dest. ☒ Unit
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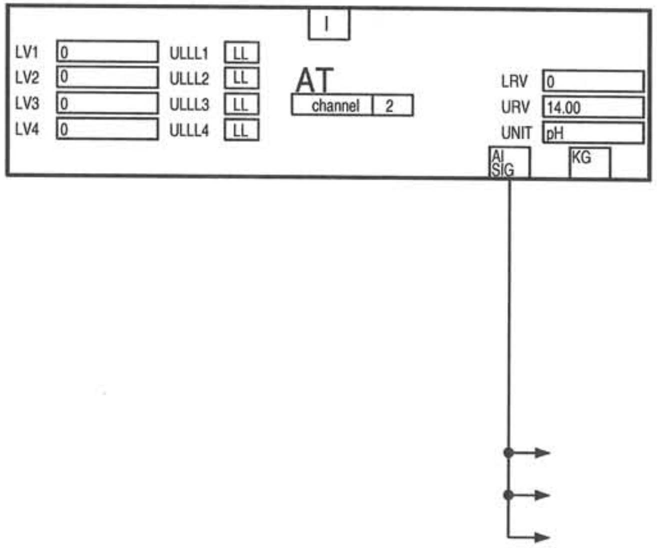
Function



Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
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			2
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			7
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			9
			10
			11
			12
XQ01 INFER PH MAIN CONDPMP 2	0...14	pH	13
N XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	14
N XQ01 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	15
			16
			17
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o02es1::otahu1
2008-08-28
2008-10-22
Dep.: FTP1

AP 72 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name		
				Date	18.08.2008
				Drawn	STEINLE
				Check	STEINLE
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YPUN00 FC AA
INFER PH MAIN CONDPMP 2
Function diagram individual level

YFR = 10QUC24CQ003
+

R001
Page 1
1 Sh.

No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC ☒	Dest. / Unit ☒
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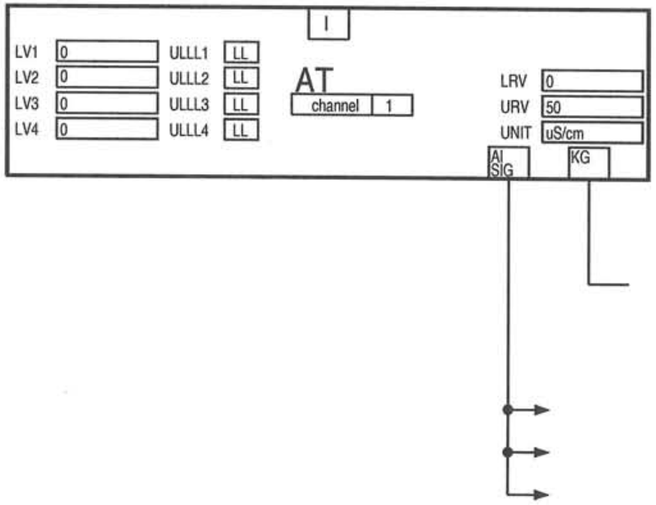
Function



	Signal ☒ ID-code / Designation	Dest. / Setting	☒SEC	FGC / Unit	No. / Ind.
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					7
					8
	XM23 CONDY MAIN CONDPMP 3	REL			9
					10
					11
	XQ01 CONDY MAIN CONDPMP 3	0...50		uS/cm	12
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01		YCKYAA	13
N	XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01		YCKYAA	14
					15
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o02es1::otahu1
2008-08-28
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

			Date	18.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS
			Drawn	TYTS			
			Check	SCHLEMPER	CCP Otahuhu NSL159		CONDY MAIN CONDPMP 3
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.		Function diagram individual level

YFR = 10QUC25CQ001
+

R001
Page 1
1 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal SEC ☒ / Setting	Dest. ☒ / Unit
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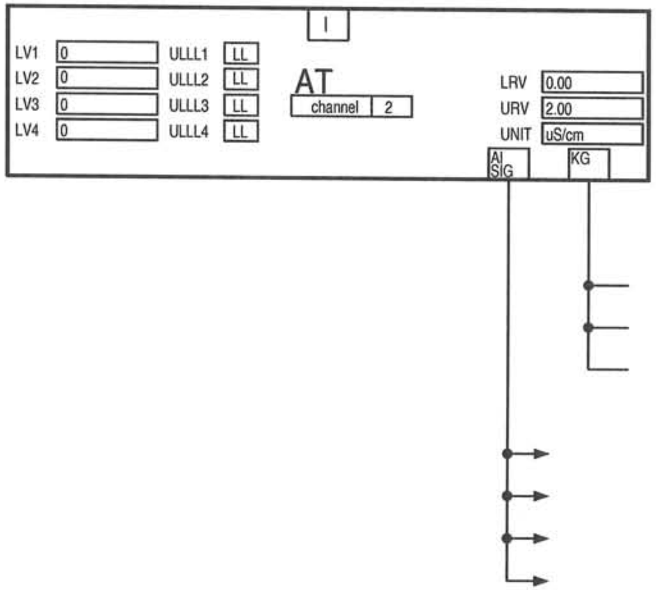
Function



	Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
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				4
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				6
				7
				8
	XM23 CONDY CAT MAIN CONDPMP 3	REL		9
N	XM23 10QUC25CQ901 COND MONT CAT CONDY CALC			10
N	XM23 10QUC26CQ901 COND MONT ACTION LVL CALC			11 q
				12
	XQ01 CONDY CAT MAIN CONDPMP 3	0...2	uS/cm	13
N	XQ01 10QUC25CQ901 COND MONT CAT CONDY CALC			14
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	15
N	XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	16
				17
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o02es1::otahu1
2008-08-28
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name							
				Date	18.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC25CQ002	R001
				Drawn	TYTS				+	
				Check	SCHLEMPER	CCP Otahuhu NSL159		CONDY CAT MAIN CONDPMP 3		Page 1
				Stand.	LANGE	Original replaced by.		Function diagram individual level		1 Sh.

No. / Ind.	ID-code / Designation	FGC	Signal ☒ SEC / Setting	Dest. ☒ / Unit
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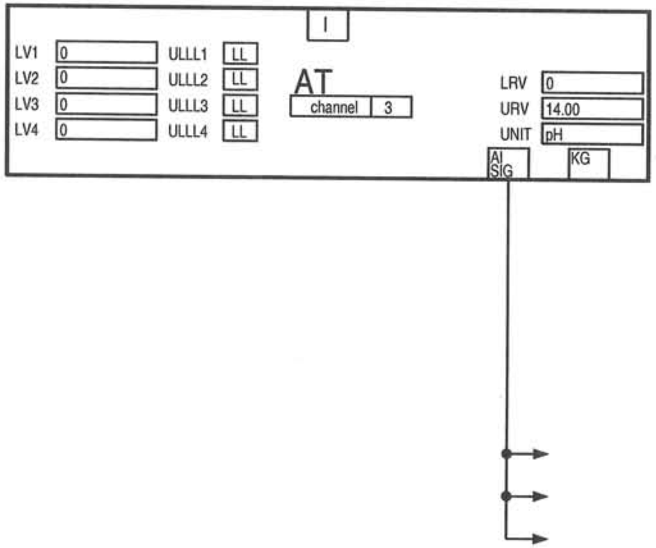
Function



	Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
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				6
				7
				8
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				10
				11
				12
	XQ01 INFER PH MAIN CONDPMP 3	0...14	pH	13
N	XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	14
N	XQ01 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	15
				16
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o02es1::otahu1
2008-08-28
2008-10-22
Dep.: FTP1

AP 72 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name		
				Date	18.08.2008
				Drawn	STEINLE
				Check	STEINLE
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YPUN00 FC AA
INFER PH MAIN CONDPMP 3
Function diagram individual level

YFR = 10QUC25CQ003
\+
R001
Page 1
1 Sh.

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No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. Unit	☒
1						
2						
3	10QUC25CQ002 CONDY CAT MAIN CONDPMP 3		XQ01 0...2		uS/cm	N
4 q	10QUC24CQ002 CONDY CAT MAIN CONDPMP 2		XQ01 0...2		uS/cm	N
5 q	10QUC23CQ002 CONDY CAT MAIN CONDPMP 1		XQ01 0...2		uS/cm	N
6						
7						
8	10QUC25CQ002 CONDY CAT MAIN CONDPMP 3		XM23 REL			N
9	10QUC24CQ002 CONDY CAT MAIN CONDPMP 2		XM23 REL			N
10	10QUC23CQ002 CONDY CAT MAIN CONDPMP 1		XM23 REL			N
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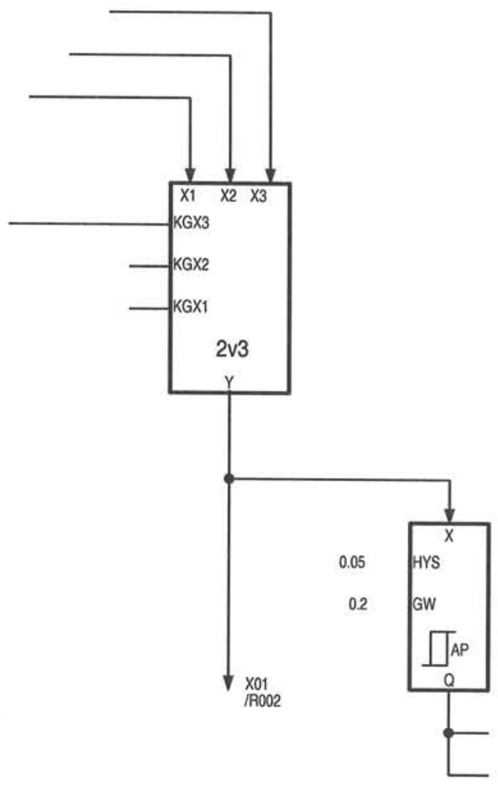
Function



	Signal ☒ ID-code Designation	Dest. ☒SEC Setting	FGC Unit	No. Ind.
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				18
				19
	XB05 COND MONT CAT CONDY CALC	YP01 HIGH		20
N	XB05	YP01		21
				22
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o02es1::otahu1
2008-09-11
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 110
AP-F 0 PB

Status	Modification	Date	Name						
				Date	20.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC25CQ901	R001
				Drawn	TYTS				+	
				Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONT CAT CONDY CALC		Page 1
				Stand.	LANGE	Original replaced by.		Function diagram individual level		4 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC	Dest. / Unit
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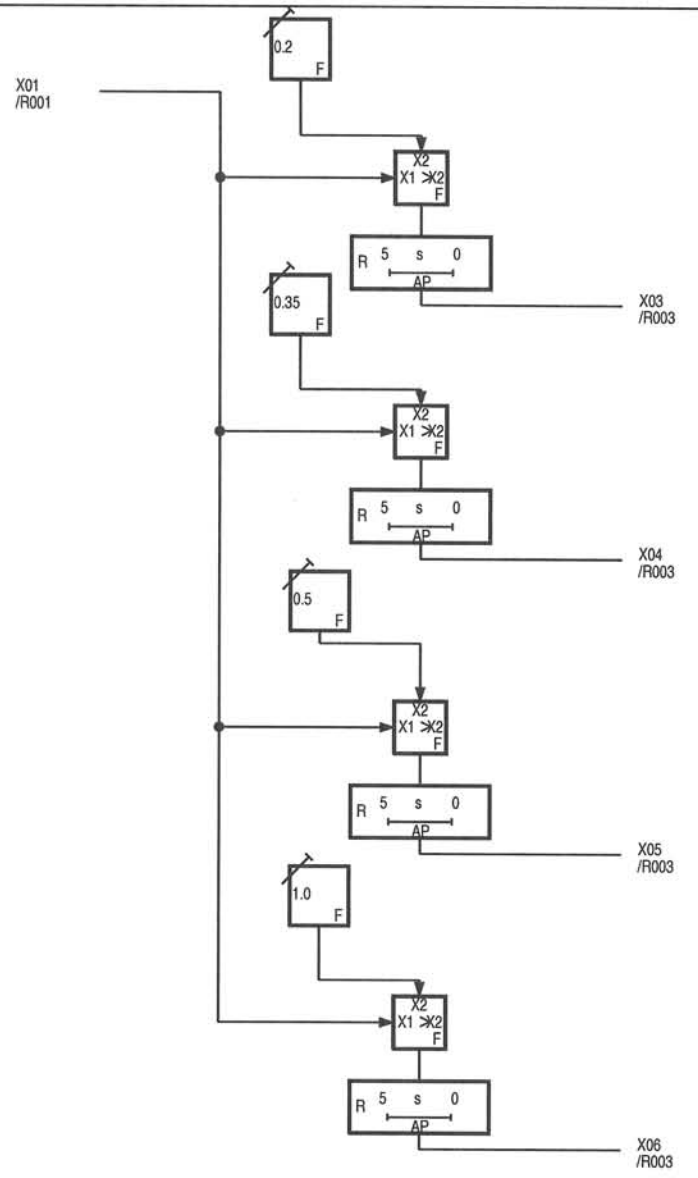
Function



Signal / Designation	ID-code	Dest. / Setting	SEC	FGC / Unit	No. / Ind.
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o02es1::otahu1
2008-09-11
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 110
AP-F 0 PB

Date	20.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC25CQ901
Drawn	TYTS				+
Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONT CAT CONDY CALC	R002
Stand.	LANGE	Original replaced by.		Function diagram individual level	Page 2 / 4 Sh.

Status | Modification | Date | Name

No.	ID-code	FGC	Signal	SEC	Dest.
Ind.	Designation		Setting		Unit
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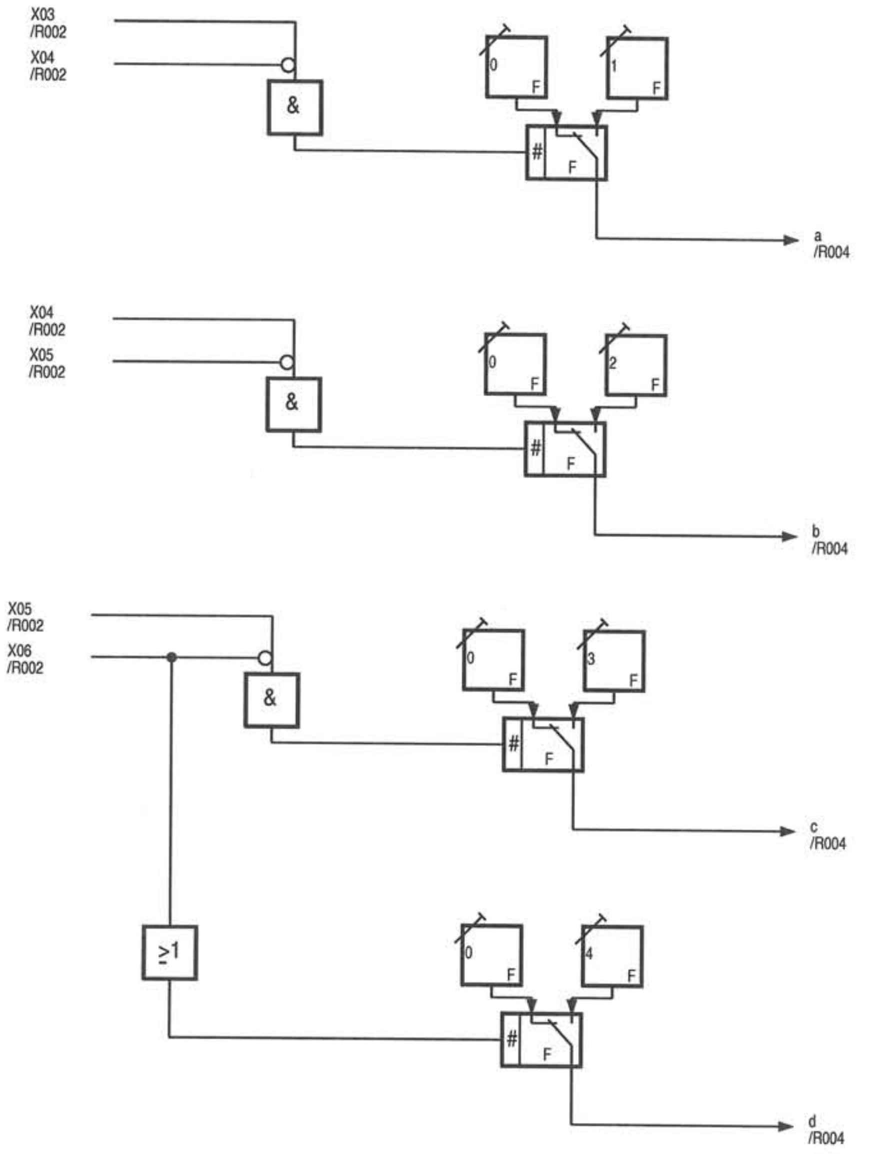
Function



Signal	ID-code	Dest.	SEC	FGC	No.
Designation		Setting		Unit	Ind.
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o02es1::otahu1
2008-09-11
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 110
AP-F 0 PB

			Date	20.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC25CQ901	R003
			Drawn	TYTS				+	
			Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONT CAT CONDY CALC		Page 3
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.		Function diagram individual level		4 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. ☒ Unit
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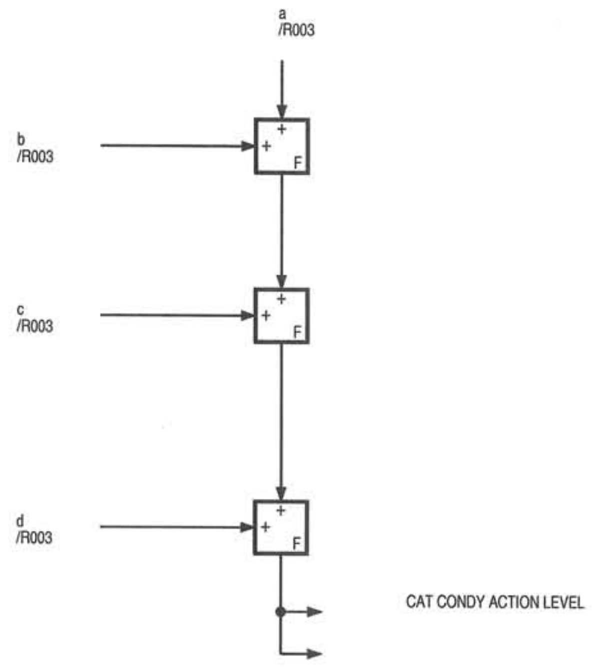
Function



CAT CONDY ACTION LEVEL

Signal ☒ ID-code Designation	Dest. Setting	☒ SEC	FGC Unit	No. Ind.
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				11
				12
				13
				14
				15
XQ04 COND MONT CAT CONDY CALC	0...4			16
N XQ04 10QUC26CQ901 COND MONT ACTION LVL CALC				17
				18
				19
				20
				21
				22
				23
				24
				25
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o02es1::otahu1
2008-09-11
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 110
AP-F 0 PB

			Date	20.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC25CQ901	R004
			Drawn	TYTS				+	
			Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONT CAT CONDY CALC		Page 4
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.		Function diagram individual level		4 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC ☒ Dest. ☒ / Unit
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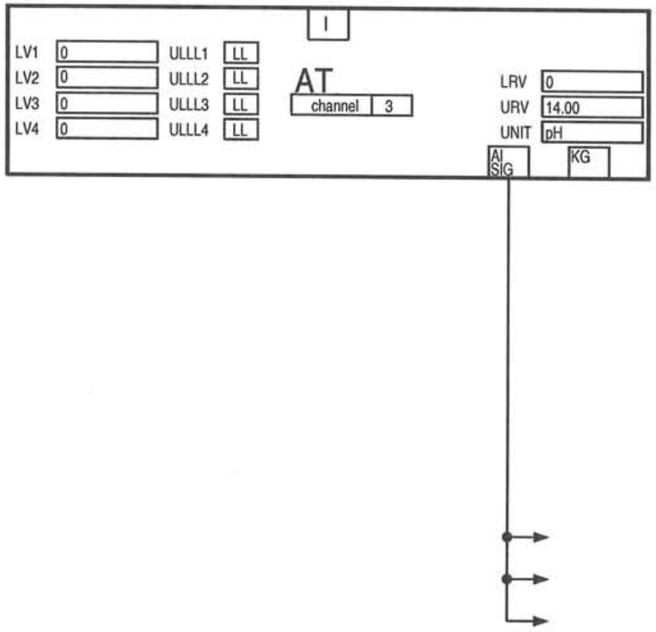
Function



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
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XQ01 PH MAIN CONDPMP	0...14.0	pH	15
N XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	16
N XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	17
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o02es1::otahu1
2008-08-28
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

			Date	18.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Otahuhu NSL159
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.

SIEMENS AG

YLCA10 FC WS

PH MAIN CONDPMP

Function diagram individual level

YFR = 10QUC26CQ001

+

R001

Page 1

1 Sh.

No. Ind.	ID-code Designation	FGC	Signal SEC ☒ Dest. Setting	☒ Unit
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2				
3	10QUC25CQ901 COND MONT CAT CONDY CALC		XQ04 0...4	
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10				
11	10QUC22CQ901 COND MONT SODIUM CALC		XQ05 0...4	
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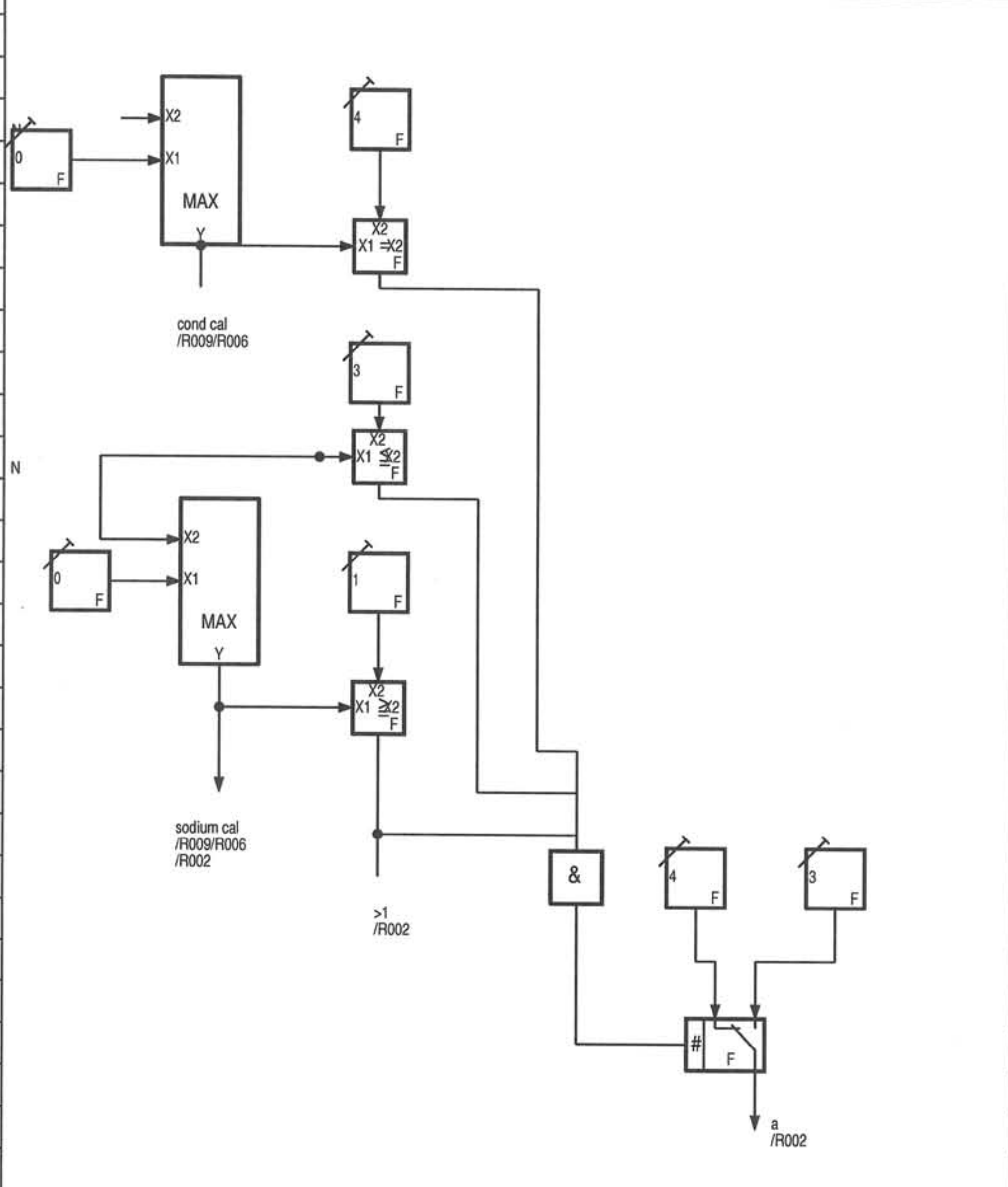
Function



Signal ☒ ID-code Designation	Dest. ☒SEC Setting	FGC Unit	No. Ind.
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o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name								
				Date	21.08.2008	Contact Energy Ltd.		SIEMENS AG	YLCA10 FC WS	YFR = 10QUC26CQ901	R001
				Drawn	TYTS					+	
				Check	SCHLEMPER	CCP Otahuhu	NSL159		COND MONT ACTION LVL CALC		Page 1
				Stand.	LANGE	Original replaced by.			Function diagram individual level		14 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC	Dest. Unit
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2					
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4					
5	10QUC25CQ901 COND MONT CAT CONDY CALC		XQ04 0...4		
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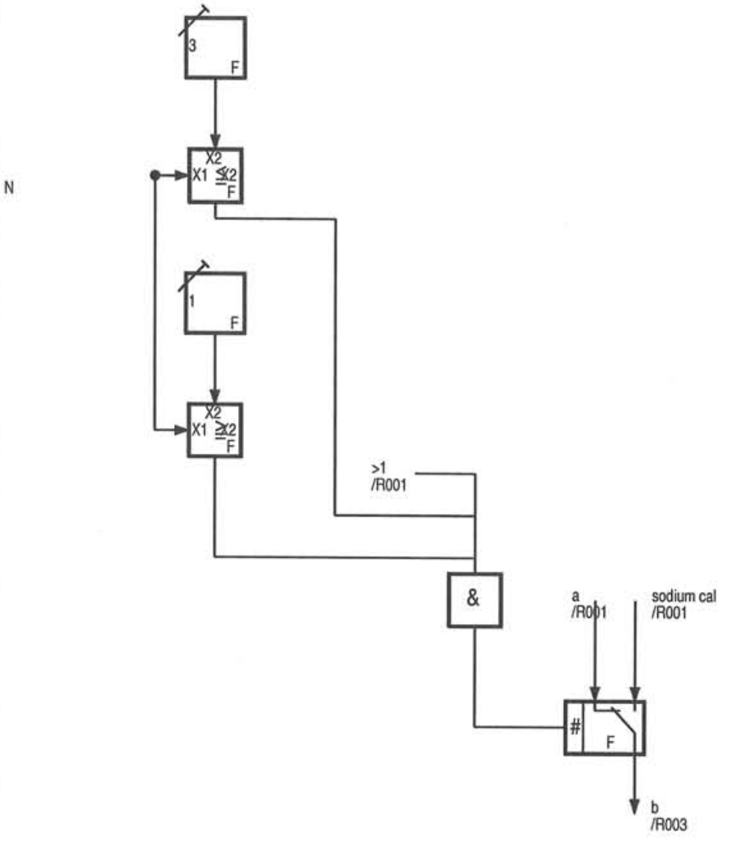
Function



Signal ID-code Designation	Dest. Setting	SEC	FGC Unit	No. Ind.
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o02es1::otahu1
2008-10-22
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name		
				Date	21.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+

R002
Page 2
14 Sh.

No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC	Dest. / Unit
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5					
6	10QUC22CQ901 COND MONT SODIUM CALC		XQ05 0...4		
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14	10QUC25CQ901 COND MONT CAT CONDY CALC		XQ04 0...4		
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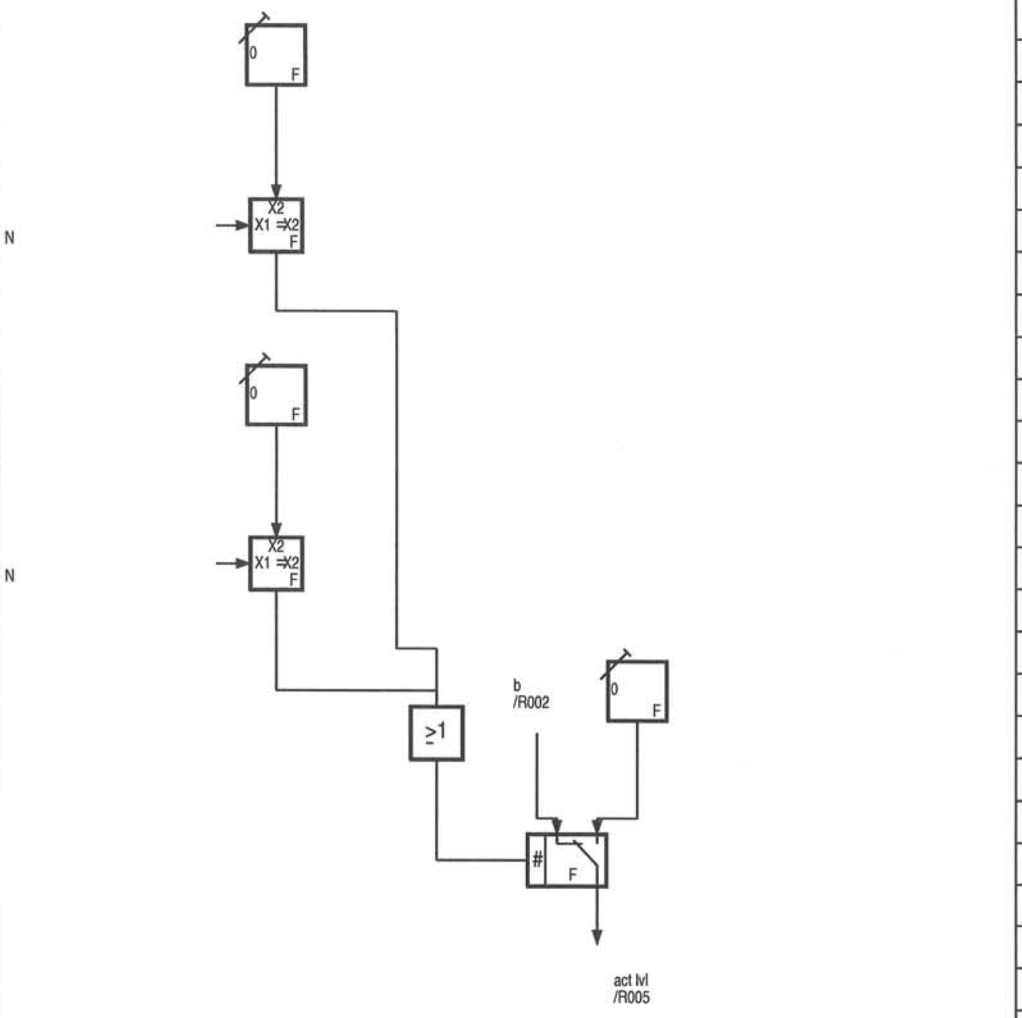
Function



Signal / Designation	ID-code	Dest. / Setting	SEC	FGC / Unit	No. / Ind.
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o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name		
				Date	21.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+
R003
Page 3
14 Sh.

No. ID-code Ind. Designation	FGC	Signal Setting	SEC ☒	Dest. ☒ Unit	
1					
2 10QUC22CQ001 SODIUM MAIN CONDPMP DEV		XG01 HIGH			N
3 10QUC21CF001 COND MONITORING FLOW		XB04 LOW			N
4 10QUC21CT001 COND MONITORING TEMP		YP12 HIGH			N
5 10QUC21CE001 COND MONITORING CB		XB01 TRIPPED			N
6					
7					
8 q 10QUC22CQ001 SODIUM MAIN CONDPMP 2		XM23 REL			N
9 q 10QUC21CQ001 SODIUM MAIN CONDPMP 1		XM23 REL			N
10 q 10QUC25CQ002 CONDY CAT MAIN CONDPMP 3		XM23 REL			N
11					
12 10QUC24CQ002 CONDY CAT MAIN CONDPMP 2		XM23 REL			N
13 10QUC23CQ002 CONDY CAT MAIN CONDPMP 1		XM23 REL			N
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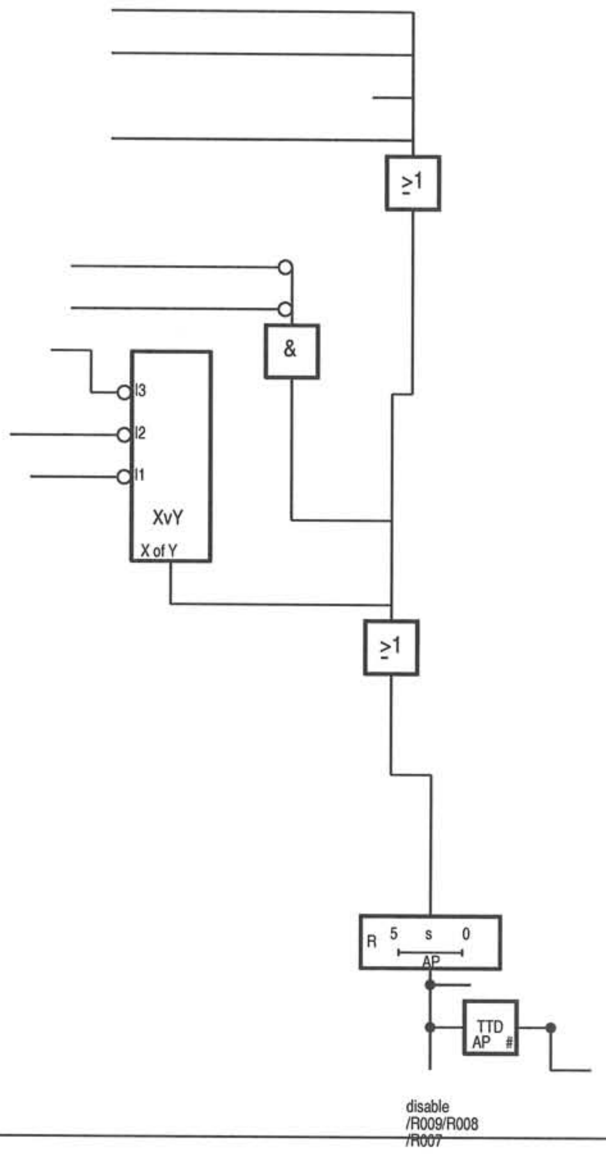
Function



	Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
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	XB03 COND MONT SYSTEM	FAULT		25
N	XB03	YP01		26
N	XB03 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	27
				28

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

				Date	21.08.2008	Contact Energy Ltd.
				Drawn	TYTS	
				Check	SCHLEMPER	CCP Otahuhu NSL159
Status	Modification	Date	Name	Stand.	LANGE	Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+
R004
Page 4
14 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC	Dest. / Unit
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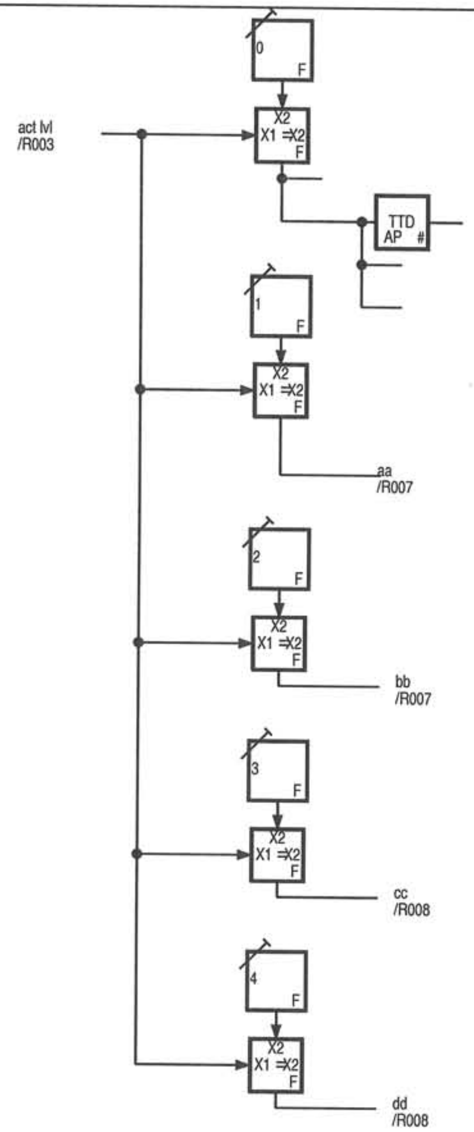
Function



	Signal ☒ ID-code / Designation	Dest. / Setting	SEC	FGC / Unit	No. / Ind.
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	XQ10 COND MONT ACTION LVL	LEVEL 0			4
N	XQ10 10QUC50EJ208				5
N	XQ10 10QUC26DE001 COND MONITORING RESET				6
N	XQ10 10QUC26CQ902 COND MONT TIME CALC				7
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2008-10-22
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Date	21.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC26CQ901
Drawn	TYTS				+
Check	SCHLEMPER	CCP Otahuhu	NSL159	COND MONT ACTION LVL CALC	R005
Stand.	LANGE	Original replaced by.		Function diagram individual level	Page 5 14 Sh.

Status	Modification	Date	Name

No. ID-code	FGC	Signal	SEC ☒ Dest. ☒
Ind. Designation		Setting	Unit
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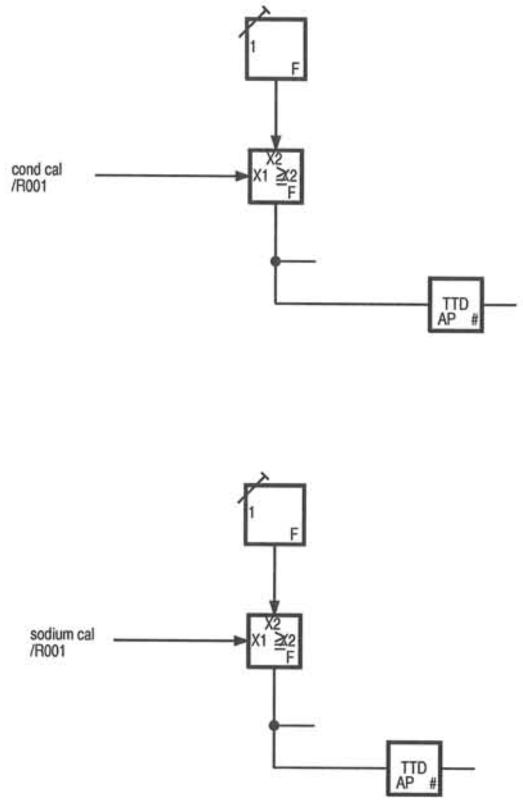
Function



	Signal ☒ ID-code	Dest. ☒SEC	FGC	No.
	Designation	Setting	Unit	Ind.
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	XG08 COND MONT CAT CONDY	HIGH		8
N	XG08	YP01		9
				10
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	XG09 COND MONT SODIUM	HIGH		19
N	XG09	YP01		20
				21
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2008-10-22 Dep.: KWU FTP1
2008-10-22

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

			Date	21.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Otahuhu NSL159
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+
R006
Page 6
14 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. Unit
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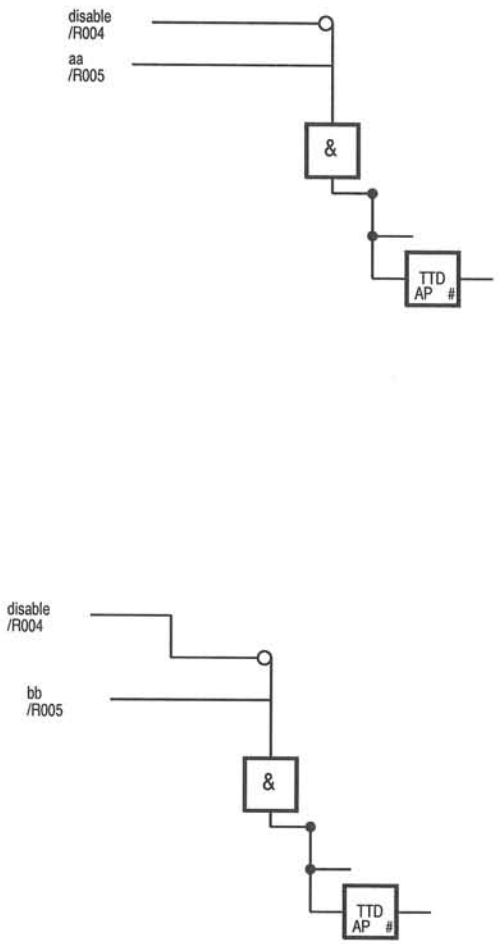
Function



	Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
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	XB01 COND MONT ACTION LVL	LEVEL 1		5
N	XB01 10QUC26CQ902 COND MONT TIME CALC			6
N	XB01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	7
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	XB02 COND MONT ACTION LVL	LEVEL 2		20
N	XB02 10QUC26CQ902 COND MONT TIME CALC			21
N	XB02 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	22
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2008-10-22 Dep.: KWU FTP1
2008-10-22

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name				
			Date	21.08.2008	Contact Energy Ltd.		
			Drawn	TYTS			
			Check	SCHLEMPER	CCP Otahuhu	NSL159	
			Stand.	LANGE	Original replaced by.		

SIEMENS AG

YLCA10 FC WS

COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901 R007
+

Page 7
14 Sh.

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No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC	Dest. / Unit
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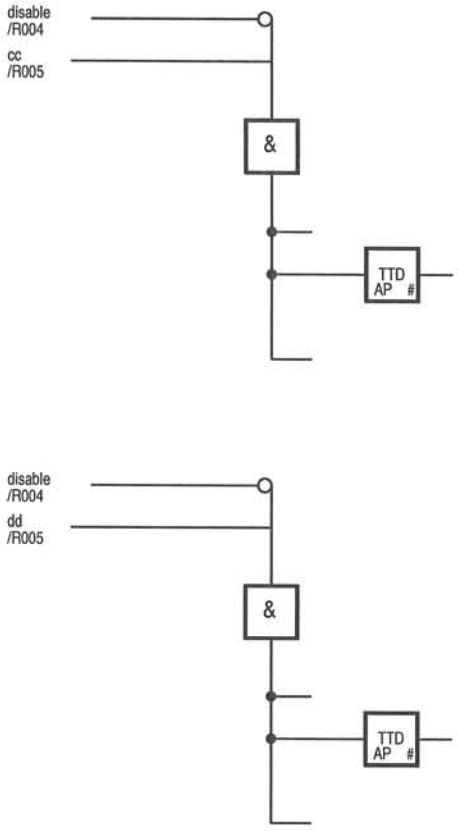
Function



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	XB06 COND MONT ACTION LVL	LEVEL 3			6
N	XB06 10QUC50EJ208 CONDENSATE MONITORING	YP01		YCKYAA	7
					8
N	XB06 10QUC26CQ902 COND MONT TIME CALC				9
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					16
	XB07 COND MONT ACTION LVL	LEVEL 4			17
N	XB07 10QUC50EJ208 CONDENSATE MONITORING	YP01		YCKYAA	18
					19
N	XB07 10QUC26CQ902 COND MONT TIME CALC				20
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o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name

Date 21.08.2008
Drawn TYTS
Check SCHLEMPER
Stand. LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
\+
R008
Page 8
14 Sh.

No.	ID-code	FGC	Signal	SEC ☒	Dest. ☒
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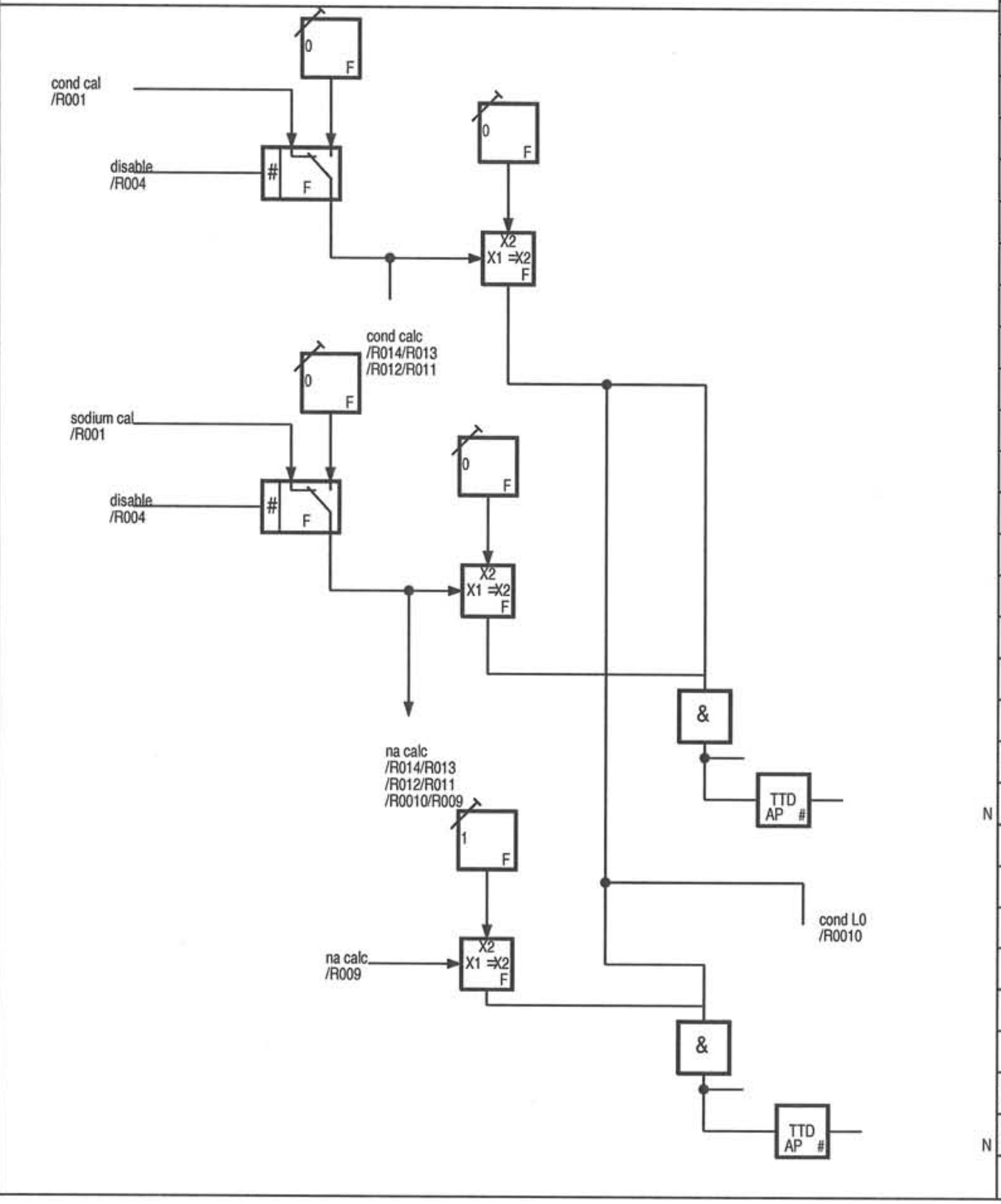
Function



Signal ☒ ID-code		Dest. ☒ SEC	FGC	No.
Designation		Setting	Unit	Ind.
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	XG01 COND MONT ACTION LVL CALC	00		18
N	XG01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	19
				20
				21
				22
				23
				24
				25
	XG02 COND MONT ACTION LVL CALC	01		26
N	XG02 10QUC50EJ208 CONDENSATE MONITORING		YCKYAA	27
				28

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2008-10-22
2008-10-22

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AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Date	21.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC26CQ901 R009
Drawn	TYTS				+
Check	SCHLEMPER	CCP Otahuhu	NSL159	COND MONT ACTION LVL CALC	Page 9
Stand.	LANGE	Original replaced by.		Function diagram individual level	14 Sh.

Status | Modification | Date | Name

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No. Ind.	ID-code FGC Designation	Signal SEC Setting	Dest. Unit
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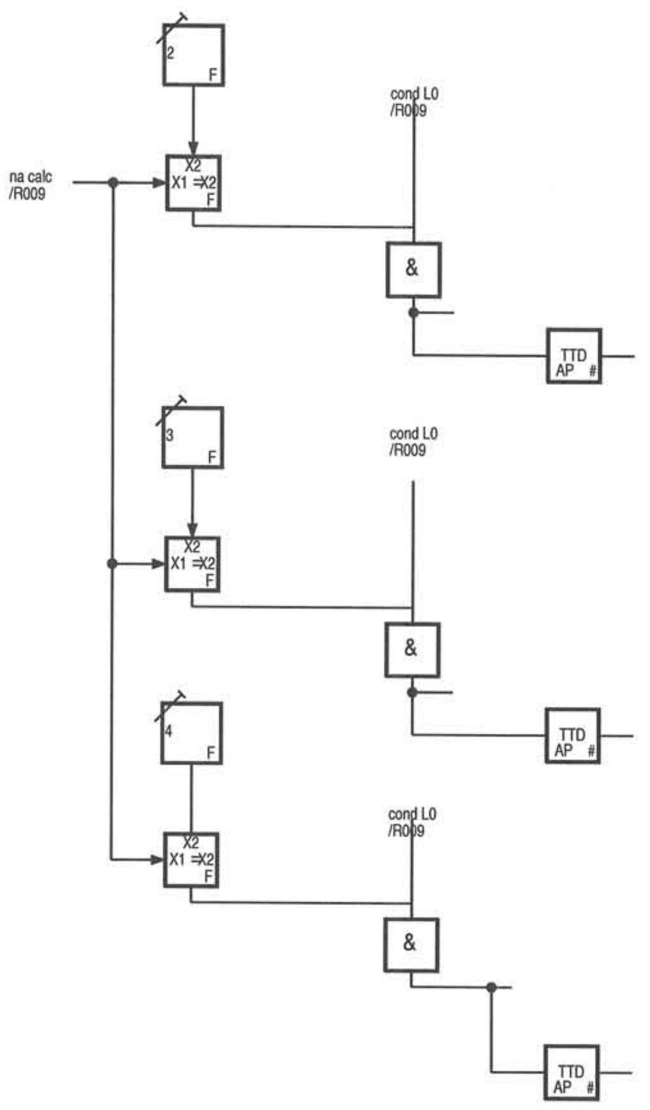
Function



	Signal ID-code Designation	Dest. SEC Setting	FGC Unit	No. Ind.
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	XG03 COND MONT ACTION LVL CALC	02		8
N	XG03 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	9
				10
				11
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				14
				15
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	XG04 COND MONT ACTION LVL CALC	03		17
N	XG04 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	18
				19
				20
				21
				22
				23
	XG05 COND MONT ACTION LVL CALC	04		24
				25
N	XG05 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	26
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o02es1::otahu1
2008-10-22 Dep.: KWU FTP1
2008-10-22

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name		
				Date	21.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
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R0010
Page 10
14 Sh.

No. ID-code Ind. Designation	FGC	Signal SEC Setting	Dest. Unit
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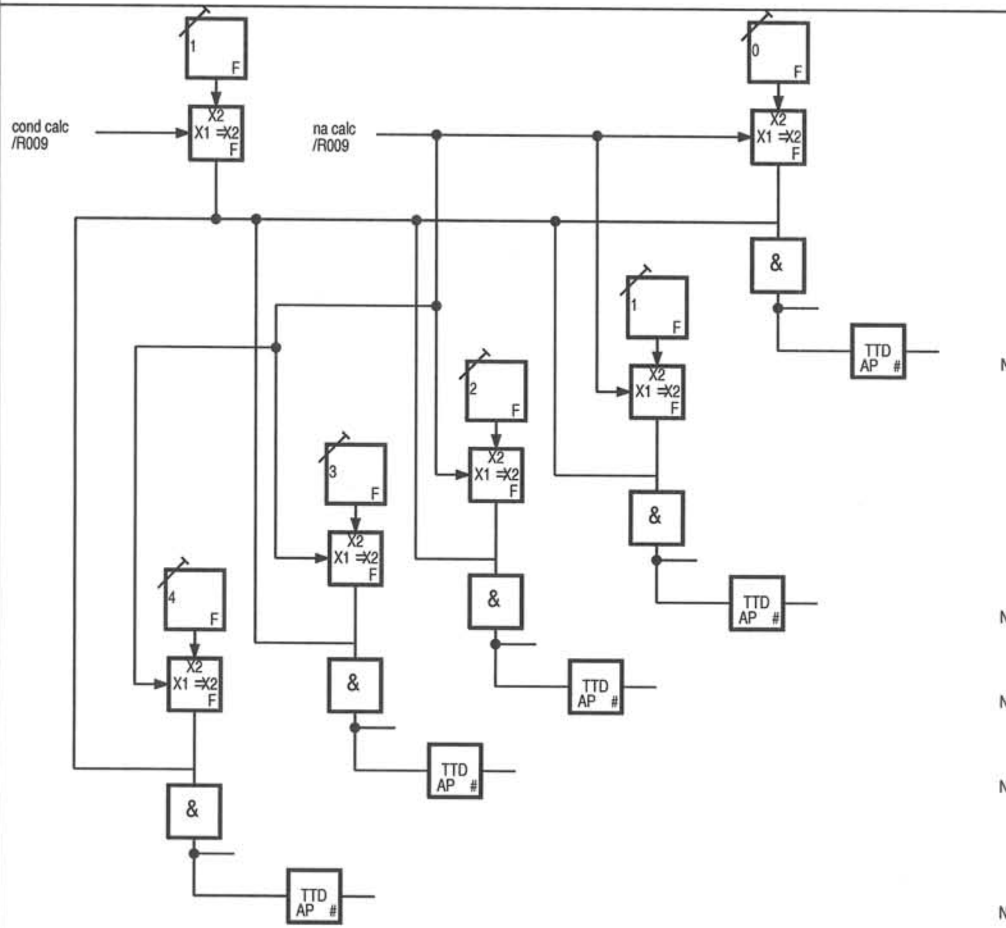
Function



	Signal ID-code Designation	Dest. SEC Setting	FGC Unit	No. Ind.
				1
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	XG06 COND MONT ACTION LVL CALC	10		7
N	XG06 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	8
				9
				10
				11
				12
	XG11 COND MONT ACTION LVL CALC	11		13
N	XG11 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	14
	XG12 COND MONT ACTION LVL CALC	12		15
N	XG12 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	16
	XG13 COND MONT ACTION LVL CALC	13		17
N	XG13 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	18
				19
	XG14 COND MONT ACTION LVL CALC	14		20
N	XG14 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	21
				22
				23
				24
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o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name	
			Date	21.08.2008
			Drawn	TYTS
			Check	SCHLEMPER
			Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+
R011
Page 11
14 Sh.

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No. Ind.	ID-code FGC Designation	Signal SEC Dest. Setting	Unit
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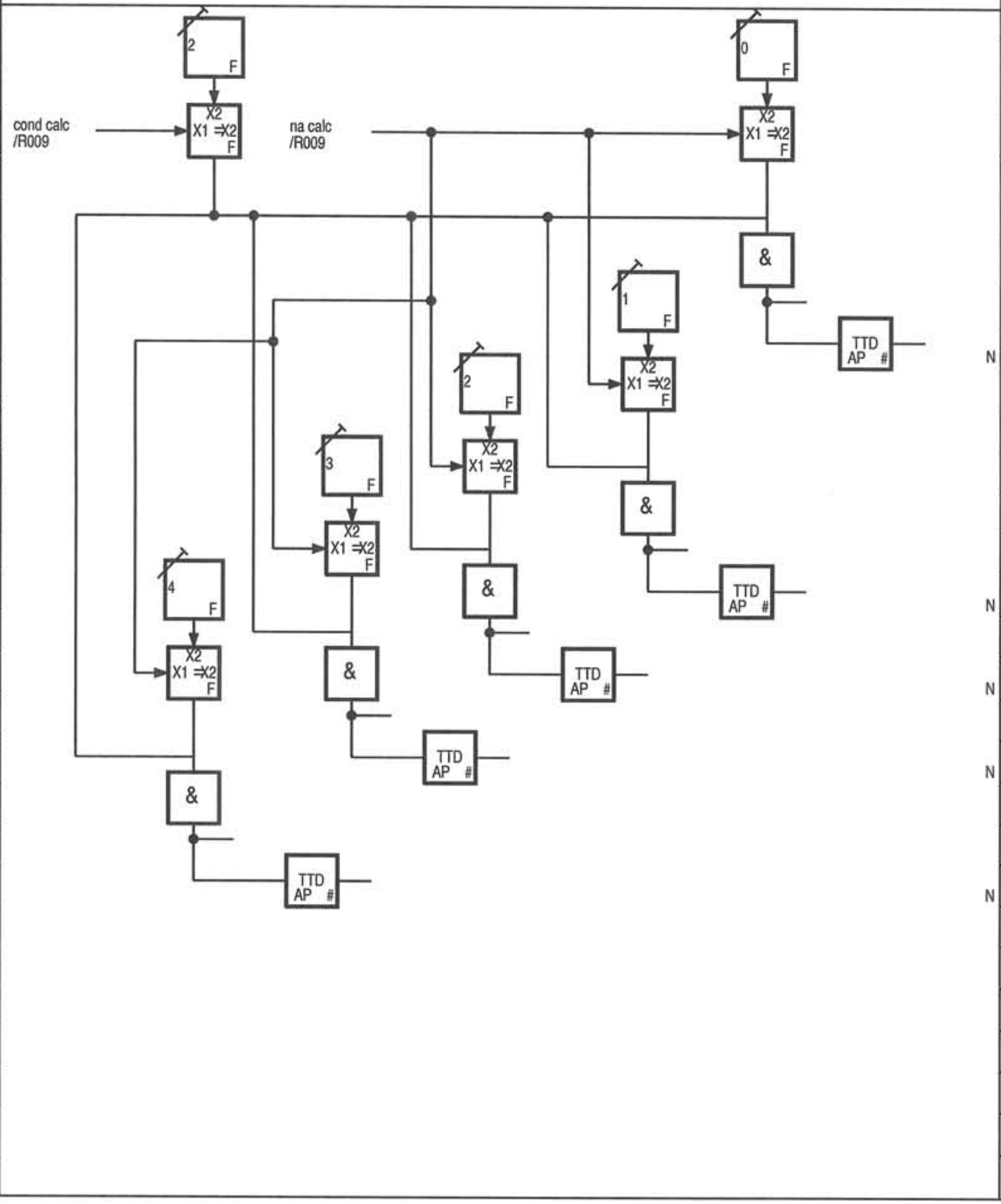
Function



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				6
	XG20 COND MONT ACTION LVL CALC	20		7
N	XG20 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	8
				9
				10
				11
				12
	XG21 COND MONT ACTION LVL CALC	21		13
N	XG21 10QUC50EJ208 CONDENSATE MONITORING		YCKYAA	14
	XG22 COND MONT ACTION LVL CALC	22		15
N	XG22 10QUC50EJ208 CONDENSATE MONITORING		YCKYAA	16
	XG23 COND MONT ACTION LVL CALC	23		17
N	XG23 10QUC50EJ208 CONDENSATE MONITORING		YCKYAA	18
				19
	XG24 COND MONT ACTION LVL CALC	24		20
N	XG24 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	21
				22
				23
				24
				25
				26
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o02es1::otahu1
2008-10-22
2008-10-22 Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name								
				Date	21.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR	= 10QUC26CQ901	R012
				Drawn	TYTS					+	
				Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONT ACTION LVL CALC			Page 12
				Stand.	LANGE	Original replaced by.		Function diagram individual level			14 Sh.

No.	ID-code	FGC	Signal	SEC	Dest.
Ind.	Designation		Setting		Unit
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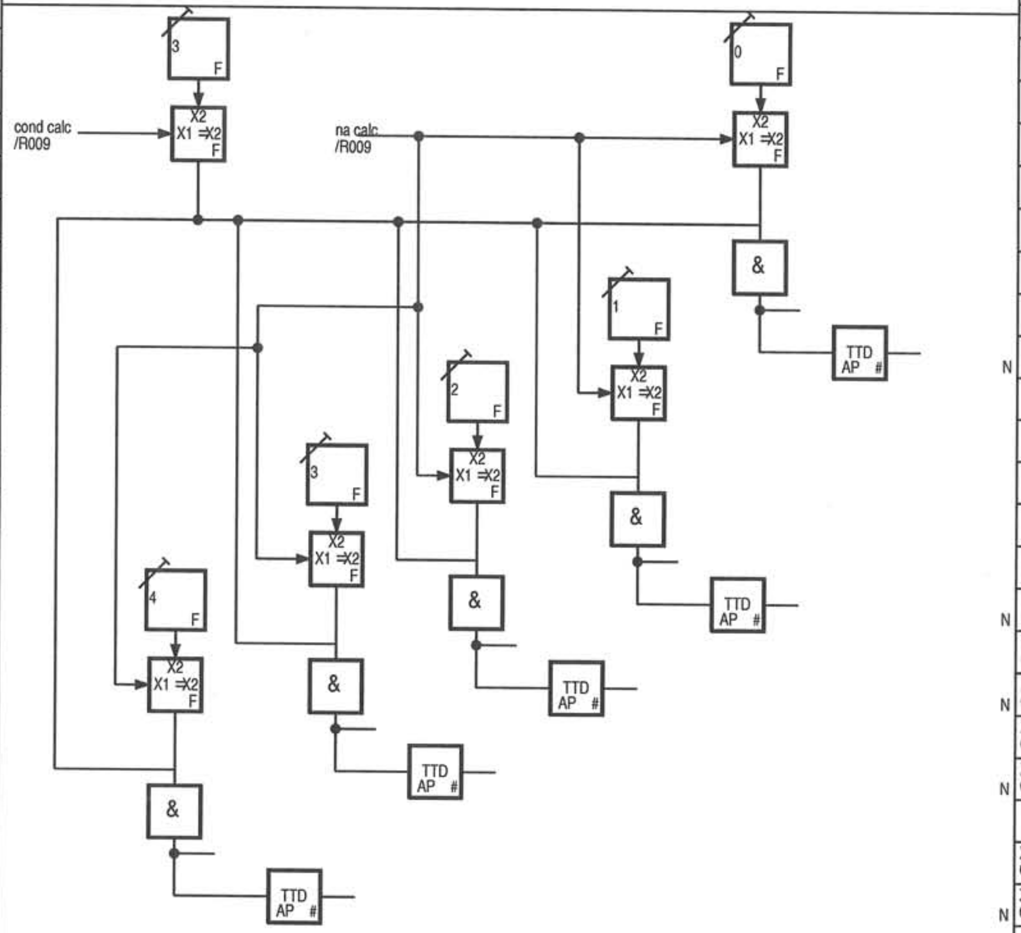
Function



	Signal ☒ ID-code	Dest. ☒ SEC	FGC	No.
	Designation	Setting	Unit	Ind.
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				2
				3
				4
				5
				6
	XG30 COND MONT ACTION LVL CALC	30		7
N	XG30 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	8
				9
				10
				11
				12
	XG31 COND MONT ACTION LVL CALC	31		13
N	XG31 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	14
	XG32 COND MONT ACTION LVL CALC	32		15
N	XG32 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	16
	XG33 COND MONT ACTION LVL CALC	33		17
N	XG33 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	18
				19
	XG34 COND MONT ACTION LVL CALC	34		20
N	XG34 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	21
				22
				23
				24
				25
				26
				27
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2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

			Date	21.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Otahuhu
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.

NSL159

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+
R013
Page 13
14 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. Unit
1					
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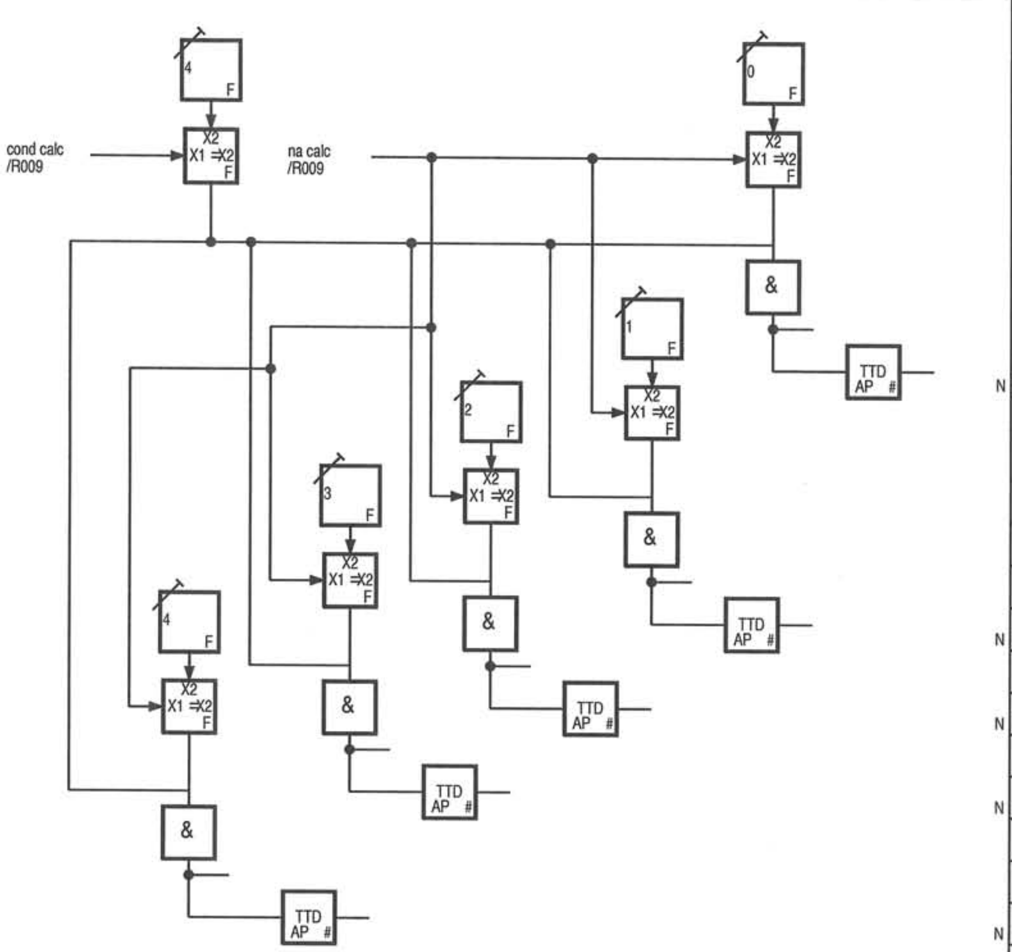
28					

Function



Signal ☒ ID-code Designation	Dest. ☒SEC Setting	FGC Unit	No. Ind.
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			2
			3
			4
			5
			6
			7
XG40 COND MONT ACTION LVL CALC	40		8
XG40 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	9
			10
			11
			12
			13
XG41 COND MONT ACTION LVL CALC	41		14
XG41 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	15
XG42 COND MONT ACTION LVL CALC	42		16
XG42 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	17
XG43 COND MONT ACTION LVL CALC	43		18
XG43 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	19
			20
XG44 COND MONT ACTION LVL CALC	44		21
XG44 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	22
			23
			24
			25
			26
			27
			28

o02es1::otahu1
2008-10-22
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 119
AP-F 0 PB

Status	Modification	Date	Name		
				Date	21.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT ACTION LVL CALC
Function diagram individual level

YFR = 10QUC26CQ901
+
R014
Page 14
14 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. ☒ Unit
1	10QUC26DE001 COND MONITORING RESET		XA01 on		
2					
3	10QUC26CQ901 COND MONT ACTION LVL		XB01 LEVEL 1		
4					
5					
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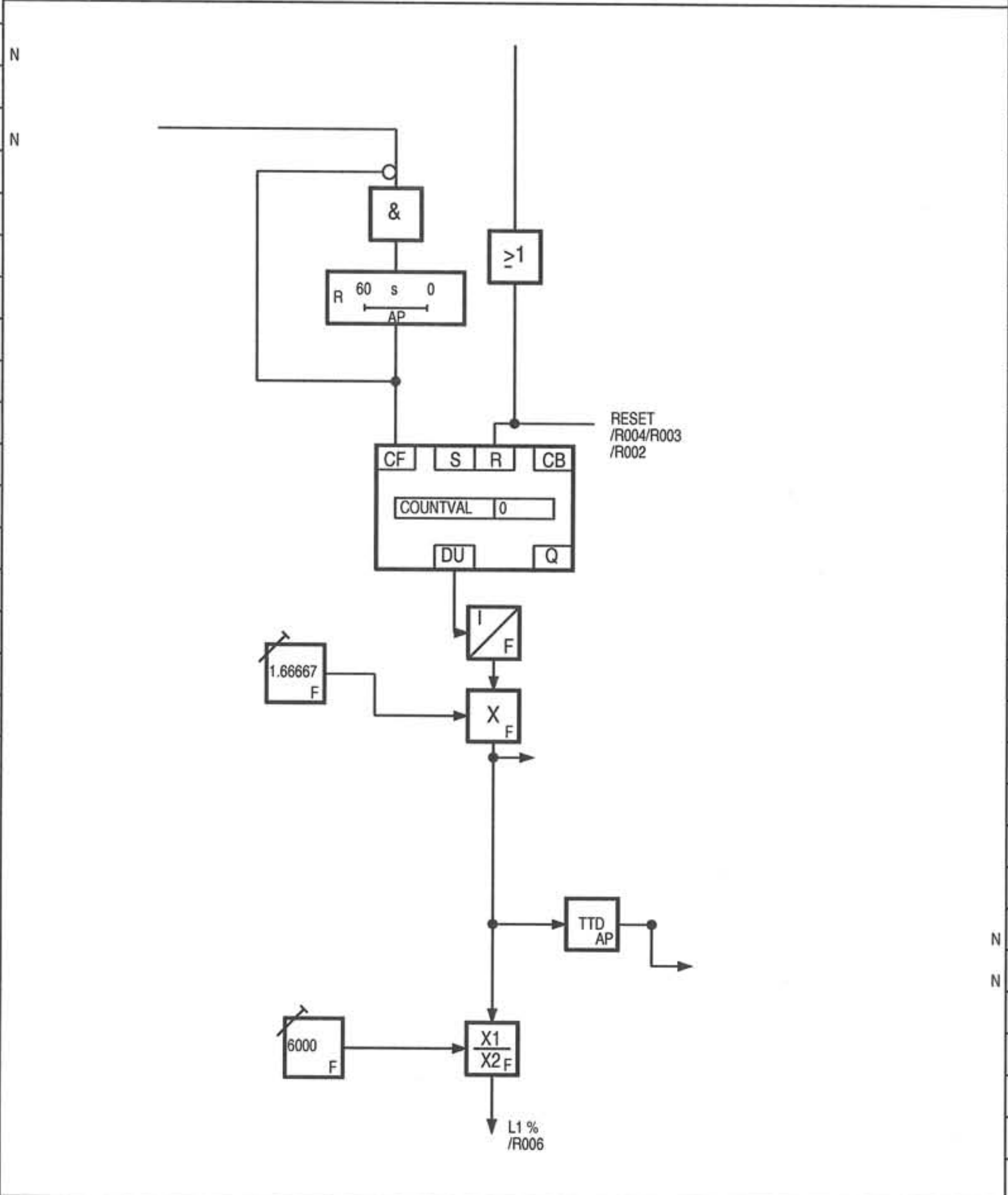
Function



Signal ☒ ID-code Designation	Dest. ☒ SEC Setting	FGC Unit	No. Ind.
			1
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			7
			8
			9
			10
			11
			12
			13
			14
			15
			16
			17
XQ01 COND MONT TIME LEVEL 1	0...6000	MIN	18
			19
			20
			21
XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	22
XQ01 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	23
			24
			25
			26
			27
			28

o02es1::otahu1
2008-09-02
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 120
AP-F 0 PB

				Date	21.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
Status	Modification	Date	Name	Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
Original replaced by.
NSL159

SIEMENS AG

YLCA10 FC WS
COND MONT TIME CALC
Function diagram individual level

YFR = 10QUC26CQ902
+

R001
Page 1
6 Sh.

No. ID-code Ind. Designation	FGC	Signal SEC ☒ Dest. ☒ Setting	Unit
1			
2			
3 10QUC26CQ901 COND MONT ACTION LVL		XB02 LEVEL 2	
4			
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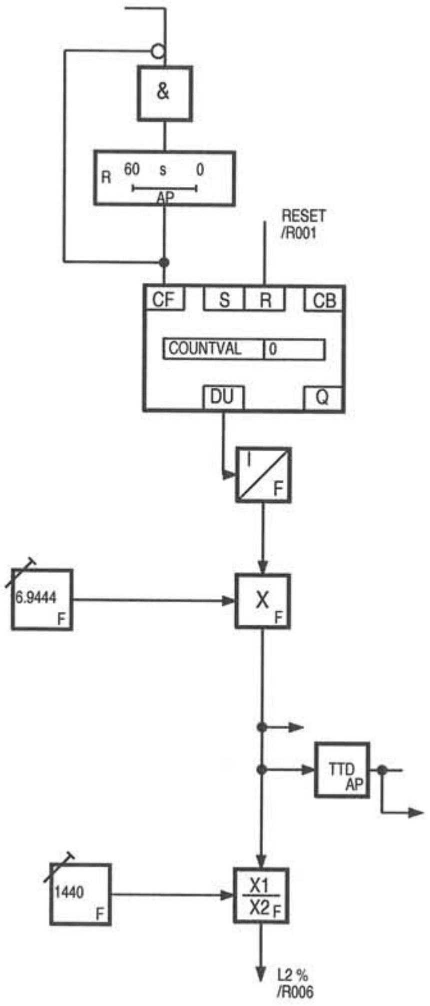
Function

N



	Signal ☒ ID-code Designation	Dest. ☒SEC Setting	FGC Unit	No. Ind.
				1
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				3
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				5
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				7
				8
				9
				10
				11
				12
				13
				14
				15
				16
				17
				18
				19
	XQ02 COND MONT TIME LEVEL 2	0...1440	MIN	20
N	XQ02 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	21
N	XQ02 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	22
				23
				24
				25
				26
				27
				28

o02es1::otahu1
2008-09-02
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 120
AP-F 0 PB

Status	Modification	Date	Name	
Date	21.08.2008	Contact Energy Ltd.		
Drawn	TYTS			
Check	SCHLEMPER	CCP Otahuhu	NSL159	
Stand.	LANGE	Original replaced by.		

SIEMENS AG

YLCA10 FC WS

COND MONT TIME CALC

Function diagram individual level

YFR = 10QUC26CQ902

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R002

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No. / Ind.	ID-code / Designation	FGC	Signal / Setting	SEC ☒ Dest. / Unit
1				
2	10QUC26CQ901 COND MONT ACTION LVL		XB06 LEVEL 3	
3				
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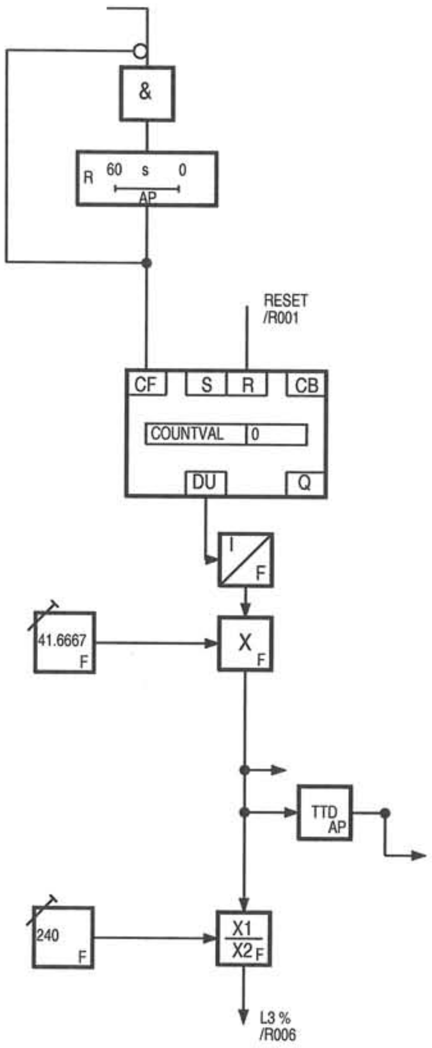
Function

N



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
			1
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			14
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			19
XQ03 COND MONT TIME LEVEL 3	0...240	MIN	20
N XQ03 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	21
N XQ03 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	22
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o02es1::otahu1
2008-09-02
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 120
AP-F 0 PB

			Date	21.08.2008	Contact Energy Ltd.
			Drawn	TYTS	
			Check	SCHLEMPER	CCP Otahuhu
Status	Modification	Date	Name	Stand. LANGE	Original replaced by.

NSL159

SIEMENS AG

YLCA10 FC WS

COND MONT TIME CALC

Function diagram individual level

YFR = 10QUC26CQ902

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R003

Page 3

6 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC ☒	Dest. ☒ Unit
1					
2	10QUC26CQ901 COND MONT ACTION LVL		XB07 LEVEL 4		
3					
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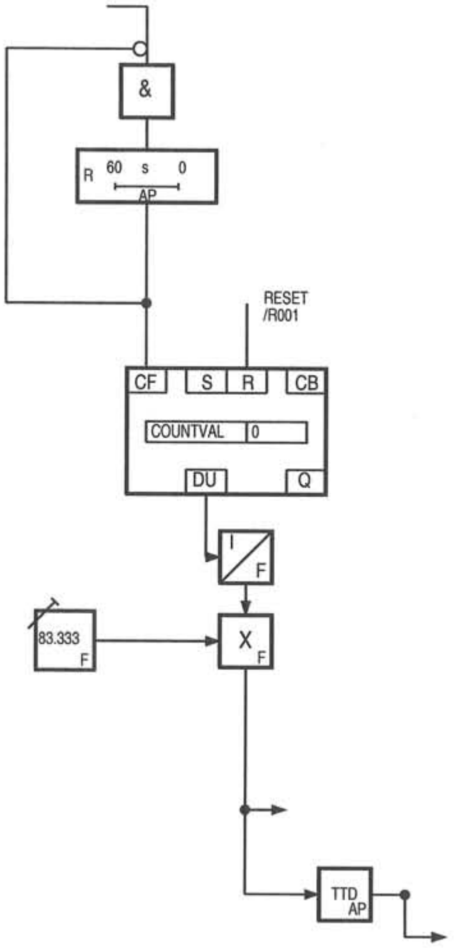
Function

N



Signal ☒ ID-code Designation	Dest. ☒SEC Setting	FGC Unit	No. Ind.
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			16
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			19
			20
XQ04 COND MONT TIME LEVEL 4	1...120	MIN	21
			22
N XQ04 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	23
N XQ04 10QUC26EJ210 CONDENSER MONITORING	YP01	YCKYAA	24
			25
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			27
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o02es1::otahu1
2008-09-02
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 120
AP-F 0 PB

Status	Modification	Date	Name						
				Date	21.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC26CQ902 + R004
				Drawn	TYTS				
				Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONT TIME CALC	
				Stand.	LANGE	Original replaced by.		Function diagram individual level	Page 4 6 Sh.

No. / Ind.	ID-code FGC / Designation	Signal ☒ SEC / Setting	Dest. ☒ / Unit	
1				
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6	10QUC26CQ901 COND MONT ACTION LVL	XB07 LEVEL 4		N
7				
8				
9				
10	10QUC26CQ901 COND MONT ACTION LVL	XB06 LEVEL 3		N
11				
12				
13				
14	10QUC26CQ901 COND MONT ACTION LVL	XB02 LEVEL 2		N
15				
16				
17				
18	10QUC26CQ901 COND MONT ACTION LVL	XB01 LEVEL 1		N
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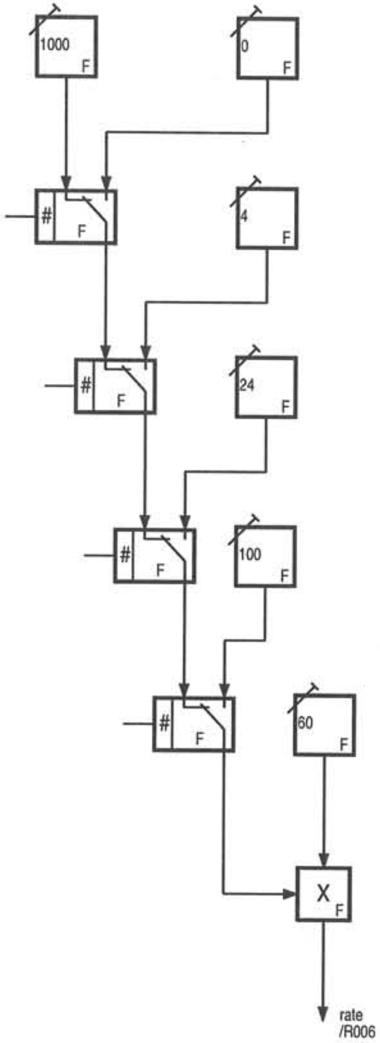
Function



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
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o02es1::otahu1
2008-09-02
2008-10-22

Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 120
AP-F 0 PB

Status	Modification	Date	Name	Date	21.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
COND MONT TIME CALC
Function diagram individual level

YFR = 10QUC26CQ902
+

R005
Page 5
6 Sh.

No. / Ind.	ID-code / Designation	FGC	Signal ☒ SEC / Setting	Dest. ☒ / Unit
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16	10QUC26CQ901 COND MONT ACTION LVL		XQ10 LEVEL 0	
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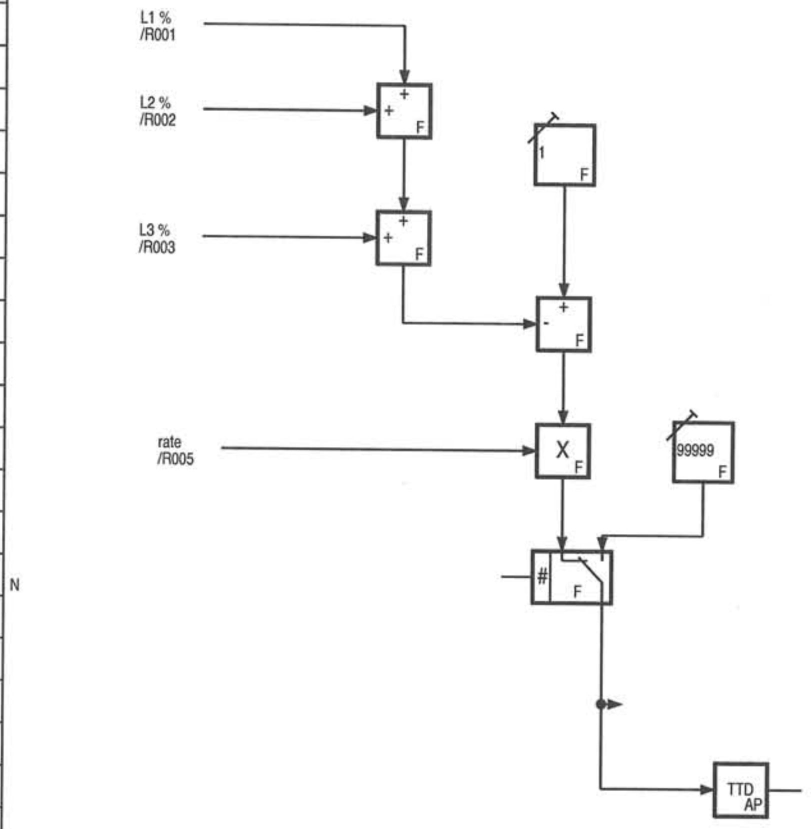
Function



Signal ☒ ID-code / Designation	Dest. ☒ SEC / Setting	FGC / Unit	No. / Ind.
			1
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			14
			15
			16
			17
			18
XQ06 COND MONT TIME LEFT	0...9999	MIN	19
			20
N XQ06 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	21
			22
			23
			24
			25
			26
			27
			28

o02es1::otahu1
2008-09-02
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z1 AT PB 120
AP-F 0 PB

Status	Modification	Date	Name							
				Date	21.08.2008	Contact Energy Ltd.	SIEMENS AG	YLCA10 FC WS	YFR = 10QUC26CQ902	R006
				Drawn	TYTS				+	
				Check	SCHLEMPER	CCP Otahuhu	NSL159	COND MONT TIME CALC		Page 6
				Stand.	LANGE	Original replaced by.		Function diagram individual level		6 Sh.

No.	ID-code	FGC	Signal	SEC ☒ Dest.	☒
Ind.	Designation		Setting	Unit	
1					
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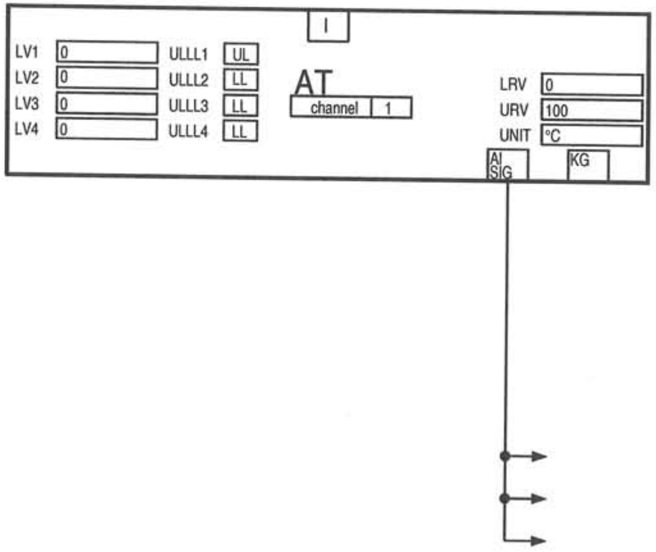
Function



Signal ☒ ID-code	Dest. ☒SEC	FGC	No.
Designation	Setting	Unit	Ind.
			1
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			3
			4
			5
			6
			7
			8
			9
			10
			11
XQ01 TEMP D/S SAMPLE COOLER	0...100	°C	12
N XQ01 10QUC50EJ208 CONDENSATE MONITORING	YP01	YCKYAA	13
N XQ01 10QUC50EJ209 CONDENSATE MONITORING	YP01	YCKYAA	14
			15
			16
			17
			18
			19
			20
			21
			22
			23
			24
			25
			26
			27
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o02es1::otahu1
2008-09-01
2008-10-22
Dep.: KWU FTP1

AP 61 Cycle Z2 AT PB 0
AP-F 0 PB

Status	Modification	Date	Name		
				Date	19.08.2008
				Drawn	TYTS
				Check	SCHLEMPER
				Stand.	LANGE

Contact Energy Ltd.
CCP Otahuhu
NSL159
Original replaced by.

SIEMENS AG

YLCA10 FC WS
TEMP D/S SAMPLE COOLER
Function diagram individual level

YFR = 10QUC26CT001
+
R001
Page 1
1 Sh.

No. Ind.	ID-code Designation	FGC	Signal Setting	SEC	Dest. Unit
1					
2					
3	10QUC26CQ901 COND MONT ACTION LVL		XQ10 LEVEL 0		
4					
5					
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7					
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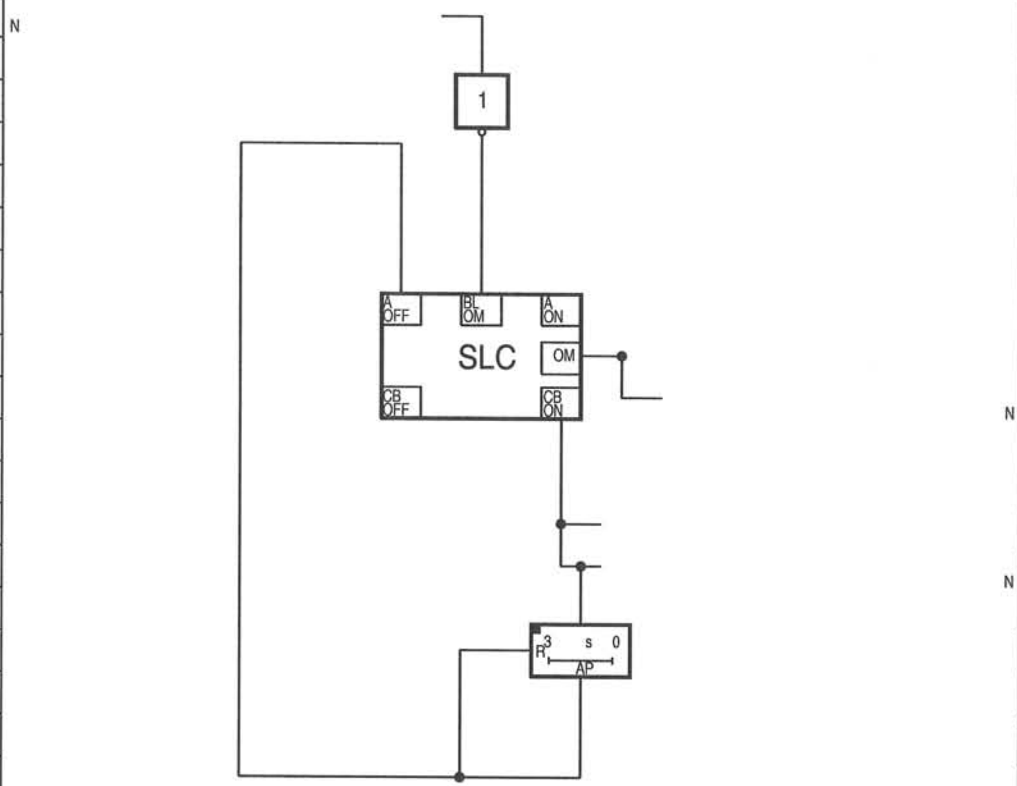
Function



Signal Designation	ID-code	Dest. Setting	SEC	FGC Unit	No. Ind.
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XA92 COND MONITORING RESET		OM			11
XA92 CONDENSATE MONITORING	10QUC50EJ208	YP01		YCKYAA	12
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XA01 COND MONITORING RESET		on			15
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2008-08-27
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			Check	SCHLEMPER	CCP Otahuhu NSL159		COND MONITORING RESET	Page 1
Status	Modification	Date	Name Stand.	LANGE	Original replaced by.		Function diagram individual level	1 Sh.

Appendix D OTB Station Level One HRSG Assessment Report

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November 12, 2008

Mr. John Rickerby
Contact Energy, Otahuhu Power Station
67 Hellabys Road
Otahuhu, Auckland, New Zealand

Subject: **Level One HRSG Assessment**
Contact Energy's Otahuhu Combined Cycle Plant
SI Project and Report Number: 0800963.00

Dear John,

As you know, Bob Anderson and I visited the Otahuhu plant on the 20th October 2008 for a review of the cycle chemistry and thermal transient aspects of the Otahuhu HRGS. We have subsequently had the third member of our team, Mike Pearson, review the thermal transient assessments, and the fourth member of our team, Kevin Shields, review the cycle chemistry items. The following represents a summary of the items relating to these assessments written by Bob, Mike and myself. We look forward to your feedback, discussions and questions on this assessment and to working further with you to implement some of the suggestions.

Very truly yours,

Barry Dooley PhD., DSc.
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1.0 Background

The Otahuhu plant is a 380MW combined cycle plant. The major equipment consists of:

a) Nooter Eriksen triple-pressure HRSG. Following a preheater there is a separate deaerator which feeds the LP drum and the HP/IP BFP. The HPSH and RH attemperation are fed from this BFP. The HP, RH and LP steam conditions are 565°C 12 MPa, 565°C 3.1 MPa, and 570°F 0.49 MPa respectively.

b) Single shaft Siemens CT V94.3A and Siemens steam turbine. A dehumidification system is available to provide shutdown protection to the LP turbine, but has not been used.

c) Water cooled condenser (WCC) with titanium tubes with saline cooling water and a cooling tower

d) Operating fired hours/starts to end of September 2008 were:

- HRSG: 73,000 hrs, 339 starts on CT and 128 on ST (Hot, Cold, Warm starts not recorded)

A few major observations from previous inspections and damage/failure include:

e) An HRSG SH tube failure in T91 at the junction to a P22 header. Metallurgical analysis indicated creep as the failure mechanism. Nine other indications of damage out of 32 attachment welds were also found.

f) Photographs of the three drums taken about one year ago indicated: LP drum was patchy red with incomplete passivation, IP and HP drums showed very little red coloration. Update e-mail and photos from Morris Young (30 October 2008) continue to support the observations that the LP drum is mostly grey with some loose magnetite. The IP drum is more red above the water line than below, and the HP drum is essentially grey magnetite.

2.0 Benchmarking

The Otahuhu combined cycle/HRSG plant was benchmarked according to worldclass standards and scored 28, which is in the “Average” category. The following are the areas which were identified as contributing to this ranking:

- One HRSG Tube Failure (HTF) in the superheater due to the creep mechanism
- The plant has 10 out of 19 of the SI Fundamental Level of Cycle Chemistry Instruments. The following ones were missing: a) sodium in the feedwater (exhaust of BFP), each drum and steam (main or RH steam), b) oxygen in the feedwater, c) specific conductivity in the IP and HP drums, and d) pH on the IP drum.

- Monitoring results indicated that the iron level in the feedwater and IP and HP drums was around 10ppb, and was generally more than 30ppb in the LP drum. Worldclass is considered to be less than 2ppb in the feedwater and less than 5ppb in each drum.
- No temperature monitoring has been conducted to assess thermal or creep fatigue in the economizer, HPSH or RH circuits.
- No written action plans are in place to address root causes or damage of potential HRSG tube failures (HTF).

3.0 Chemical Control of Plant

The key cycle chemistry aspects of the plant are:

a) Makeup. The source is potable water. The makeup system consists of an activated carbon filter, strong cation and anion ion exchangers, and a mixed-bed ion exchanger. The makeup is stored in a vented storage tank and added to the cycle in the WCC which has some deaerating capability.

b) The feedwater treatment. Only ammonia is injected after the CPD to achieve a specific conductivity target of about 18µS/cm. Oxygen at the CPD is usually low and on the day of the visit was 5-7ppb. Oxygen is not measured in the feedwater after the HP/IP BFP.

c) LP Drum. NaOH is added to the LP drum. There are no sodium instruments on the LP drum (blowdown or saturated/LP steam). The normal pH range is 9.5-9.7. Specific conductivity on the day of visit was 9.7µS/cm. Carryover is not measured.

d) HP and IP Drums treatment. Nothing is added to either drum. The usual operating pH range on the HP drum is 9.6-9.7. There is no pH or specific conductivity on the IP drum. On the day of visit the HP drum was running around 9.6. The blowdowns on the IP and HP drums are usually closed. The HP drum blowdown is opened when HP evaporator chloride levels exceed 100ppb. Carryover is not measured on either drum.

e) Shutdown conditions. Although the connections and systems are in place to apply dehumidified air to the steam turbine on shutdown, the plant operators have not used this important system. The HRSG is blown down when hot on shutdown and a nitrogen cap is applied.

4.0 Corrosion and Cycle Chemistry Review and Preliminary Action Plans

The following items represent the various cycle chemistry and FAC reviews conducted and the preliminary Action Plans discussed during the visit day. Some embellishment and additional explanations have been added here.

a) Overall Chemistry Control #1 relating to FAC. The plant currently has not experienced any cycle chemistry influenced failures or damage. As indicated in Section 3, the chemistry runs in the oxidizing mode (AVT (O)) at relatively high pH (9.5-9.7) to respectively provide protection for single-and two-phase FAC. However, the photographs from previous inspections of the LP and IP drums indicate that full passivation has not been achieved especially in the LP drum where the red appearance is rather patchy. This is almost certainly due to the low level of air in-leakage and oxygen levels at the CPD (5-7ppb). No information is available for oxygen levels at the BFP, but this should be lower than at the CPD as the BFP is fed from the deaerator outlet. Such a level of low oxidizing power (low oxygen) will not satisfactorily passivate the total LP evaporator circuit. The possibility of increasing the level of oxygen will need to be investigated. Possible methods include closing the vents on the deaerator or adding oxygen into the feed line to the LP drum. About 800ppb NaOH is currently fed to the LP Drum: this is designed to provide protection for two-phase FAC locations in the LP circuits. Clearly the current combination of AVT(O) for the single-phase regions and NaOH for the two-phase regions is not optimized to provide overall protection for corrosion/FAC as the iron levels monitored in the LP drum are usually more than 30ppb and sometimes over 100ppb, which are excessively high and indicative of FAC in the circuit. A number of items were discussed during the visit, which need attention to ensure that a minimum level of FAC is experienced in the cycle and that the rule of 2 and 5 is consistently met. These are covered in items c, d and f.

b) Overall Chemistry Control #2 relating to Contaminants. The plant is cooled by saline water and no recent titanium condenser tube leaks have occurred. An excellent condensate monitoring system has been installed at the CPD with two sodium, two cation conductivity and two specific conductivity monitors. This will eventually provide direct control to the operators in the event of a condenser leak. The HP drum usually operates with cation conductivity less than 1.5 µS/cm and on the day of the visit it was running at 1.2 µS/cm with the IP drum running at 0.9 µS/cm. Morris Young reported that chloride is measured in the HP by grab sample and is typically kept at around 100ppb by blowdown. A typical normal limit for chloride in an HP drum of 12 MPa pressure is around 170ppb.The HP evaporator on a seawater cooled unit is most susceptible to under-deposit hydrogen damage, so a number of items were discussed during the visit which relate to ensuring that the internal surfaces are kept as clean as possible and that an on-line indicator for contaminant ingress is incorporated into the plant instrumentation. These are covered in items d, e, g, and h.

c) The iron monitoring conducted todate has used the ferrozine method which provides a reasonable relative comparison between the monitored locations. It is suggested however that a more accurate method using an integrated sampling device is employed in the plant optimization process.

6.0 Concluding Remarks

Contact has shown a keen interest in the Cycle Chemistry aspects of combined cycle/HRSG dependability as reflected in the commitment to focus on an effective selection for Otahuhu of the oxidizing feedwater chemistry from the very beginning. This action has served to avoid serious issues with single-phase FAC. However, it is clear that the current cycle chemistry regimes are not fully optimized and that there appears to be a number of remaining corrosion and FAC issues, which need to be addressed. The first issue is to ensure that the single-phase flow locations are fully passivated and protected by the oxidizing treatment. This means increasing the oxidizing power of the single-phase flow regions within the LP and IP circuits. The second issue is to assess two-phase FAC in the LP evaporator and maybe other circuits such as the IP economizer, evaporator and risers. These circuits are in the susceptible temperature range. The challenge here is to ensure that the optimum cycle pH is adopted to minimize corrosion/FAC in these circuits by application of ammonia and NaOH. Overall the measure of success against FAC will be more continuously red LP and IP drums, and iron levels in these drums which are consistently less than 5ppb. SI has much experience in dealing with FAC/corrosion in multiple pressure HRSGs and can assist Contact if requested.

Contact only has about 50% of SI’s fundamental level of cycle chemistry instrumentation which should provide the first level of control for the operators. The key missing instruments are oxygen in the feedwater and sodium in steam. The latter will be vital so that the plant can assess carryover in the future.

In the proactive mode, probably the most important aspect is for Contact to assess the potential for under-deposit corrosion in the HP evaporator by removing samples for comprehensive analysis and by incorporating chloride into the HP drum target and action limits.

SI analysis of thermal transients in the HRSGs at Otahuhu has identified a number of items deserving of further consideration and action so as to ensure suitable component life and avoid premature failures due to thermal fatigue. The most urgent recommended action is confirmation of the materials and dimensions of all superheater and reheater headers prior to ordering replacement secondary superheater inlet headers. Based upon reliable knowledge regarding the foregoing, Contact Energy can then confirm that the secondary superheater inlet header replacement project scope and logistics are optimum.

The highest priority to prevent future thermal fatigue damage should be to improve drainage of the HP superheater, reheater and cold reheat pipe. Should Contact Energy wish to pursue modifications to drain related equipment and operating practices SI recommends a phased approach. The first phase would consist of an engineering study utilizing existing plant documents, operating data, results of internal HRSG inspections and data from temporary thermocouples if installed. The deliverables from Phase I would include calculation of condensate formation rates, preliminary drains modification work scope, proposed equipment arrangements and budgetary cost estimates for detailed design and installation of the modifications. SI recommends utilizing the services of GIE Niagara Engineering Inc. of St. Catharines, Ontario, Canada for this work. GIE has extensive experience as Architect/Engineer on a number of combined cycle/cogeneration plants worldwide and has already developed reliable methods for calculating condensation rates, drain pipe size, drain pot size, etc.

Should Contact Energy decide to proceed with the recommendations in Phase I, the second phase would consist of developing detailed designs and drawings suitable for installation of the agreed modifications. Again, SI recommends utilizing the services of GIE Niagara Engineering Inc. for the design work.

If a shift from base loaded operation to even a moderate amount of two-shifting is anticipated for Otahuhu it is important that the plant's shutdown procedure, and possibly its startup procedures be optimized for reduction of thermal fatigue damage. SI can assist in determining safe superheater header, reheater header and drum ramp rates and work with Contact Energy to work out the details of optimized procedures.

We suggest a number of possible approaches Contact Energy might follow in executing the Phase I and II drains improvement project described above.

a) Contact Energy might go directly to GIE and contract for their services

b) Contact Energy work through SI using Bob Anderson as our team member

c) Contact Energy might contract directly with Bob Anderson

Due to the difficulty and complexity of executing an effective superheater and reheater drains retrofit and associated operating procedures SI believes that Contact Energy would benefit by utilizing the SI team's experience in this specialty area. While SI will strive to provide whatever support Contact Energy requests, we recommend Contact Energy select option b) or c) from the above list.