Eskom	Guideline	Technology

Title: **Power Plant Controls and Instrumentation; Control Systems; Level of Automation; System Hierarchy and Control Philosophy Guideline**

Unique Identifier:	**240-129686484**
Alternative Reference Number:	**N/A**
Area of Applicability:	**Engineering**
Documentation Type:	**Guideline**
Revision:	**1**
Total Pages:	**28**
Next Review Date:	**February 2025**
Disclosure Classification:	**CONTROLLED DISCLOSURE**

APPROVED FOR AUTHORISATION
TECHNOLOGY ENGINEERING
DOCUMENT CENTRE ☎ X4962

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Date: 17/02/2020	Date: 17/02/2020	Date: 2020/02/27

Supported by SCOT SC

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Date: 17/02/2020

SCOT Study Committee Number: **SC08-03-W-21**

SCOT Study Committee Name : **Power Plant Control and Instrumentation**

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1. INTRODUCTION

The level of automation at Eskom's existing coal-fired power station fleet is high, considering the technologies that were available when they were built (1970s-1990s). DCS technology available today affords the control engineer an opportunity to provide highly automated start-up and shutdown control strategies for operations.

Changes in the industry have stimulated interest in plant automation. Base load stations are being used in cycling service and two shift operation. Modern DCS are easily able to accommodate additional IO required for start-up and shutdown automation and have extended functionality to be able to keep the operator informed of start-up and shutdown progress. The demands of reliability and availability on our plant and the introduction of legislation which governs the minimum network connection conditions (the South African Grid Code), requires a certain level of automation from our new plant that must not compromise on operational flexibility, reliability and availability of the plant.

Power plant automation requires significant investment for implementation and therefore, cost savings from improved operations (Consistent best practice operation, optimised start-up and shutdown times, real-time operator guidance) need to justify this investment.

2. SUPPORTING CLAUSES

2.1 SCOPE

This guideline covers the typical level of automation typically expected at an Eskom Coal Fired Power Plant with a focus on the Control System hierarchical structures and operational requirements.

2.1.1 Purpose

Eskom Power Station plant designs vary widely from station to station including the level of automation that was implemented at the station at the time of construction. This document describes to the reader the minimum level of automation for Eskom power plants expected to achieve ESKOM's operational requirements for high plant reliability, availability and flexibility.

2.1.2 Applicability

This document applies to Unitised (Boiler and Turbine) and Balance of plant control systems of the coal fleet of power stations at Eskom Holdings SOC for Greenfield (New) and Brownfield (Refurbishment) projects. While this document provides examples for supercritical boilers, the requirements apply to drum type boilers as well.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] VGB R 170Ce: Function-related documentation of power plant instrumentation and control in line with operational requirements.

[2] VGB R 170B2e: Design standards for instrumentation and control equipment-Automation function.

[3] VGB B 106B4e: Identification of instrumentation and control tasks/functions in process systems and identification of functions in instrumentation and control systems.

[4] 240-56030600: Steam Turbine Unit Islanding, Load Rejection and Speed Control Verification Standard.

[5] 240-105453648: Fossil Fuel Firing Regulations Standard

2.2.2 Informative

[6] Chambers Dictionary of Science and Technology – 2007 edition.

[7] Automation of Fossil Plant Startup/Shutdown, Instrumentation and Controls Technology Assessment, 1015710. Technical Update, March 2009, EPRI.

[8] 240 - 119416400 Generation AGC Design Standard for Power Plants

[9] The South African Grid Code as specified in the terms of the South African Electricity Regulation Act

[10] SPC 46-8: Certification and Performance Monitoring Of Generation Reserves - System Operations and Planning Procedure.

2.3 DEFINITIONS

Automation

Industrial closed-loop control system in which manual operation of controls is replaced by servo operation.

Balance of Plant

The Balance of Plant refers to the supporting process plant that are common to all unitised process plant areas of a Power Station. The balance of plant is required to be operational for the unit plants (Boiler and Turbine) to operate. For Coal Fired Power Stations the balance of plant typically includes the following plant areas:

- Water Treatment plant including Condensate Polishing Plant
- Coal Handling Plant
- Ash Handling Plant
- Low Pressure Services:
- Compressor Plant
- Auxiliary Cooling plant
- Demineralised, Potable and Raw Water Distribution Plant
- Fuel Oil Plant
- Flue-gas desulfurization (FGD) plant

Decentralised control system structure

A control system structure in which the software is functionally distributed at all hierarchical levels of control.

Level of Automation

The level of automation states the general functions and the structure of automation of a power plant (technological) process.

Operating Modes

Where local control in the plant is required, three distinct modes of operation are provided at control system level to the control room operator: Remote (also referred to Automatic), Remote Manual and Local Manual. Selection of the mode of control can be available at group, sub group, auxiliary group and drive level depending on the particular process plant at hand. For the Local Manual Control Mode, a Local Control Station (LCS) or Local Control Panel (LCP) is provided to the local operator. The LCS / LCP typically have the following operating modes: Remote, Local and Maintenance. Sections 3.5.1, 3.5.2 and 3.5.3 detail the operating modes further.

Hierarchical structure

The control system is divided into several control levels forming a hierarchical structure, as shown in Figure 1.

Unit

A unit is a steam generator, steam turbine-alternator and all the related equipment, including the step-up transformer, operating together to produce electricity.

Unit co-ordinator

The Unit co-ordinator, residing within the highest automation level for a unit, co-ordinates the unit and includes a unit start-up and shut-down sequencer and handling of major disturbances via capability computation.

Supervised Fully Automatic

The term “supervised fully automatic” refers to an operating scenario where the operator monitors the sequence steps of the fully automatic start-up or shut-down sequence. The sequence steps will typically have hold points, where essential plant parameters to be aligned and checked or actions required by the operator, (with the possibility of hold points being programmed) will be implemented in the start-up and shut-down sequences.

Operator guide

A function within an automation Group or Sub-group sequencer that allows the operator to temporarily pause a start-up or shut-down sequence at the specific step that the programme is in. This function negates having to stop a running step programme completely and having to restart it from the first step.

Automatic Generation Control AGC – (Not to be confused with Auxiliary Group Control AXGC)

This is the automatic centralised closed loop control of generating units by means of the computerised Energy Management System (EMS), currently TEMSE, at National Control. The AGC control system regulates the system frequency during normal conditions by adjusting the power set-points of individual generators.

Primary Frequency Control – Instantaneous Reserve

Primary Frequency Control is the automatic adjustment of a generator output (or customer load reduction) in response to deviations in the system frequency, by means of the local governor control system of the turbine. This control is proportional to the system frequency deviation. The governor dead band is set at 0.15Hz.

Secondary frequency control – Regulating reserve

Secondary Frequency Control is mainly performed via automatic control of generator outputs to provide a balance between the supply and demand in a control area. Automatic control is performed by the Automatic Generation Control (AGC) system at the National Control Centre.

Dead band

With reference to Primary Frequency Control, dead band is the maximum frequency range over which there is no automatic adjustment of the generator output or governing response.

Unit Islanding

Unit Islanding is the ability of a generating unit to suddenly disconnect from the Transmission System by opening the High Voltage breaker and to control all the necessary critical parameters automatically to a sufficient degree to maintain the turbine generator at speed and excited and supplying its own auxiliary load.

Load Rejection

Load Rejection is the separation of a unit from the Transmission System by the opening of the generator breaker after which the turbine returns to nominal synchronous speed.

Permissive Interlocks

Logic intended to be fulfilled in order for a drive to accept a start of stop command. e.g Start and Stop Permissives.

Drive Protection

Logic utilised to initiate a trip of the related drive. e.g. Safety OFF.

Definition	Description
Approved by	The accountability of the Approver of the document is equivalent to the specified role of Functional Responsible/Owner as identified in 240-53114186 and 32-6 for Documents and Records Management.

2.3.1 Disclosure Classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
AGC	Automatic Generation Control
AXGC	Auxiliary Group Control
BOP	Balance Of Plant
CPP	Condensate Polishing Plant
FFFR	Fossil Fuel Firing Regulations
FGD	Flue-gas desulfurization
GC	Group Control
HMI	Human Machine Interface
IO	Input/Output
LCP	Local Control Panel
LCS	Local Control Station
LOA	Level of Automation
OEM	Original Equipment Manufacturer
SGC	Sub-Group Control
UC	Unit Co-ordinator

2.5 ROLES AND RESPONSIBILITIES

Group Technology Plant Engineering C&I Plant COE Governance will develop the requirements for the level of automation.

Group Technology Plant Engineering C&I Plant COE Design and Applications will implement the requirements for the level of automation on projects.

2.6 PROCESS FOR MONITORING

The Engineering Discipline Managers will ensure this guideline is implemented on all projects.

2.7 RELATED/SUPPORTING DOCUMENTS

Not applicable.

3. LEVEL OF AUTOMATION TECHNICAL DISCUSSION

3.1 CONTROL CONCEPT

The concept and main software design principle of the control system is that it is decentralised but has a logically hierarchical structure.

It is important to note that the configuration of the control system should not pose a multiple unit trip risk and care should be taken to follow the principles of control system IO functional distribution and system redundancy. The control system redundancy should mimic at least the process and electrical redundancy principles for the plant at hand.

A Control System is typically divided into several control levels, as shown in Figure 1 below:

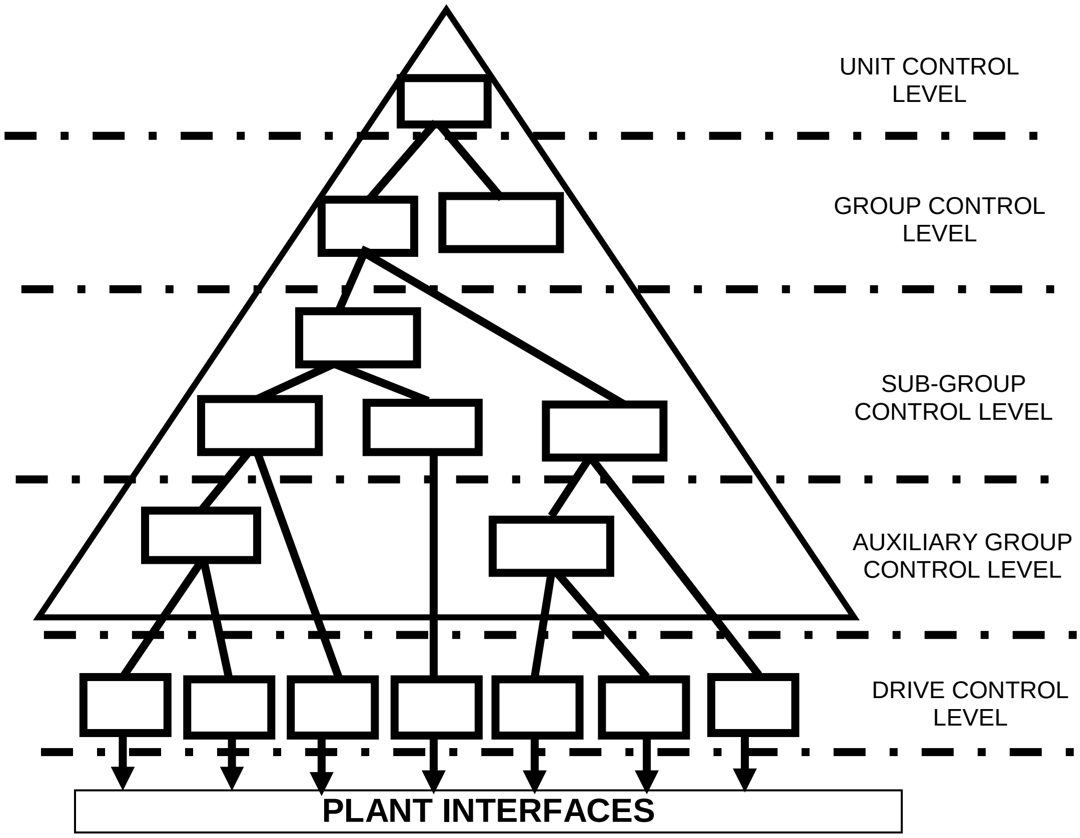

Figure 1: Hierarchical structure of a Control System

The control system is divided into several control levels or layers. The higher the control level, the higher the degree of automation, and the lesser the degree of manual control interventions will be necessary. A higher level of control introduces operational comfort and brings in a higher degree of controllability and safety to a complex process, as the system will react automatically in the specified manner, should any abnormal condition be detected.

Each hierarchical control level has its own specific tasks and always depends on the subordinated <u>lower</u> control levels. If a higher control level fails, the next lower control level will not be affected and will allow the levels to control the power plant with full controllability and safety, but this state will require additional supervision and/or manual interventions by the operator.

Hierarchical structures as shown in figure 1 ensure a higher level of operational flexibility. Manual interventions at all levels of control should be possible at any time, without any specific operations necessary on the superimposed levels, such as transfer from automatic to manual. This will eliminate the operational risk of operating a complex plant in full manual mode, when the operator only requires making a single or a limited number of operational interventions.

In the hierarchical structure the auxiliary group control level may or may not be required and will be used where necessary.

3.2 ANALOGUE (MODULATING) CONTROL

The task of the analogue control system is to control the process variables according to set point values and different parameters. The objective of analogue control higher up in the control hierarchy is to give set point values to the subordinate control levels, and ultimately, to the drive controllers in such a manner that the process requirements are fulfilled. Typically, such tasks are required for the start-up, shut-down, steady state, load variations, disturbances and severe plant transient conditions. During all these varying conditions, plant limitations should be adhered to.

The analogue control should be able to perform analogue and binary control actions for selection of set point values, control parameters, control structures and process orders from the binary control. For example, for automatic mode and set point selection during start-up or shut-down of the plant.

3.2.1 Hierarchical levels for analogue control

The hierarchical levels used for analogue controls are the:

- Unit control level (excluding BOP controls)
- Group control level
- Sub-group control level
- Drive control level

3.2.1.1 Unit Control Level

The Unit control level is the highest control level for the unit, comprising analogue control. The unit co-ordinator resides at this level and would for example perform the master load control (MWe).

Subordinate within this level, is the main control level, which unites all functions that govern the next subordinate group control level. The main boiler load controller (main fuel and main steam pressure controllers), turbine controller and HP Bypass controller reside at this main control level.

3.2.1.2 Group Control Level (GC) analogue controls

The Group control level of analogue controls control the main systems of the Unit and BOP. They are, for example:

Unit: The controllers for the Mill Loads, Combustion Air, Feed Water, Furnace Pressure, Primary Air Pressure, Superheater and Reheater temperature control.

BOP: Water Treatment plant and Compressor Plant & Auxiliaries

The Group control level may contain a sub-group control level.

3.2.1.3 Sub-group Control Level (SGC) analogue control.

The subordinate controls of group controls reside at the Sub-group control level. Stand alone controllers may also be found at this level.

They are for example:

Unit: Mill Primary Air flow and Mill outlet temperature controllers are subordinate controls for the Mill Load controllers at group control level (for each mill). Stand-alone controllers such as the auxiliary steam header pressure controller may be found here.

BOP: Water Treatment Plant: Demineralised water production trains, Individual Compressor and Dryers, Coal/Ash Conveyors streams

3.2.1.4 Drive Control Level (For Analogue and Binary control).

The drive control level is the lowest hierarchical level. Its task is to control and monitor a particular drive.

The drive control level forms the link between the control room (operator) and the upper level of control on the feedback and input side, with the switchgear installation and the process on the output side.

The drive control level contains the standard drive control function, the logic for the protection and permissive interlocks of the individual drives, to protect the drives against damage.

The analogue and binary drive control level fulfils the following additional functions:

- Stopping of electrically actuated valves and dampers if the torque switch responds.
- Selectable stop of electrically actuated valves and dampers at their travel end position either by torque or limit switch.
- Position and deviation from set point indication (analogue drives).
- Clear priority for manual, automatic, protective orders and for two commands given simultaneously. For process plants, manual orders take priority. The manual commands need to be within the process plant’s set operating limits. For such a scenario, the process plant’s operating interlocks remain in place and will prevent the plant in operating in an unsafe condition or envelope.
- Signalisation and annunciation of disturbed status of an individual modulating drive (position control).
- Holding of position set point during transfer from automatic to manual modes of operation.

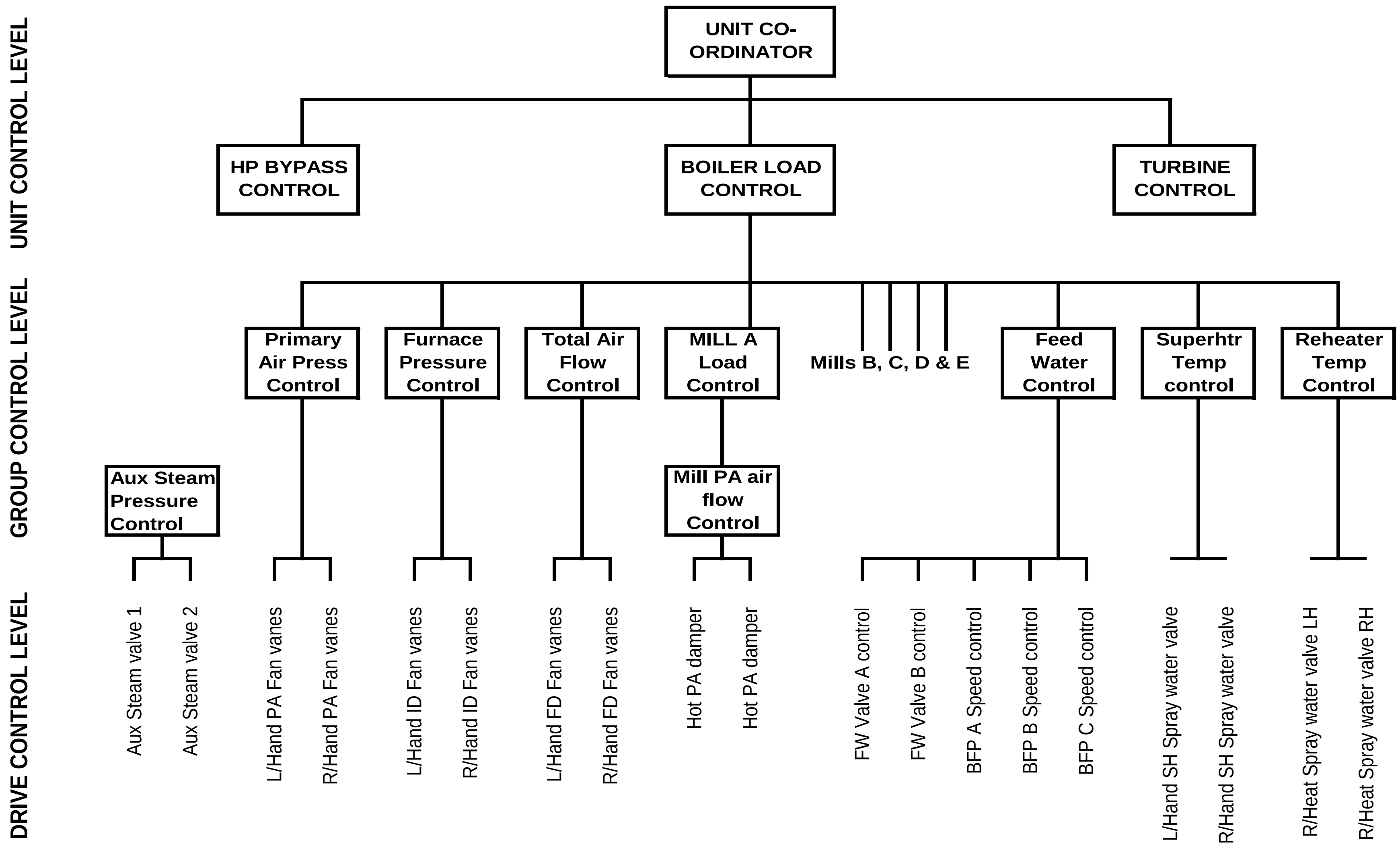

Figure 2: Example of an analogue hierarchical structure (Unit Control)

3.3 BINARY (SEQUENCE) CONTROL.

Sequence control is a control method in which the control process is divided into single steps that are processed one after another according to a pre-determined procedure. The operations to be performed when starting a system take place on a step-by-step basis, in a pre-set sequence and are monitored according to pre-set time intervals for execution of the commands to be performed at a given step by means of “stepping” criteria.

The active programme step and step criteria that are not fulfilled, which prevent the programme from advancing further, are displayed on the HMI.

The binary controls of any hierarchical level using sequential controls will always automatically synchronise with the actual state of the process when they are initiated.

Orders or commands which are not allowed to be issued during the synchronisation process of the sequence control, due to the process state, will be suppressed by “overrun” criteria.

The binary control system is configured such that:

- Start-up and shut-down of any process section is performed in a safe and reliable way and in the shortest possible time.
- The drive itself or other related components are protected against damage.
- The operator receives uniform and clear information about the process under control.
- The operator has the capability to provide other operating or maintenance personnel with detailed information about the nature and location of process plant faults when a step criterion has not been met and the sequence has paused.

3.3.1 Hierarchical levels for binary control

The hierarchical levels used for binary controls are the:

- Unit control level
- Group control level
- Sub-group control level
- Auxiliary group control level
- Drive control level

3.3.1.1 Unit Control level for binary control

The Unit Control level is the highest binary hierarchical level if a Supervised Fully Automatic (“single push button”) philosophy is adopted for start-up or shut-down of the unitised plant.

3.3.1.2 Group Control level (GC) for binary control

The Group Control level is the highest binary hierarchical level for BOP, and for the Unit if a Supervised Fully Automatic (single “push button”) philosophy for start-up or shut-down of the plant is not implemented. The GC controls a unique main group of drives in the plant or a group of main drives with identical function. In the case of main drives with identical functions (such as 3 x 50% pumps), the GC monitors the status of the Sub-Group Control functions below it, and it contains a selector for that main SGC group. The selected main group is started automatically or manually via a Sub-group control.

The Group control level may be divided into several sublevels such as:

- Sub-group control level (SGC) and
- Auxiliary group control (AXGC) level

3.3.1.3 Sub-group Control level (SGC) for binary control

The Sub-group Control level controls a unique group of drives in the plant which are important to get the main group started e.g. turbine oil supply.

The main characteristic of the Sub-group control level is the sequence control. It is the step-by-step control method of a pre-set sequence and is monitored according to pre-set time intervals for execution of the commands to be performed at a given step by means of “stepping” criteria.

The sequence steps can also stop in a pre-determined step, known as a “Hold Point”, awaiting an input action to be decided by the operator, after which the sequence will continue from where it stopped up to the last step of the SGC.

The SGC can also control a group of drives which are duplicated or threefold in the plant

For example, SGC can be found in :

Unit: Left hand or Right hand air/flue gas path, Boiler Feed Pump A, Boiler Feed Pump B, Boiler Feed Pump C.

BOP: Water Treatment Plant
Condensate Polishing Plant (CPP)

The Balance of Plant process plants in the above examples, in particular, have plant sections that reside in the units and that serve as a common plant:

The CPP plant consists of the CPP unit plant and the CPP regeneration plant in the Water Treatment Plant area that functions as a common plant for the unit CPPs. The sequence control of the CPP plant is however typically still fully controlled by the Water Treatment plant control system and supervised by the Water Treatment Plant operator. A similar methodology applies for the sample analysis plant, which also consists of unitised plant and common plant. The Water Treatment Plant control system, supervised by the WTP operator, makes control decisions, such as increasing or decreasing the chemical dosing set-points, based on the sample analysis measurements taken in the unitised plant.

3.3.1.4 Auxiliary Group Control Level (AXGC) for binary control

The Auxiliary Group Control level controls the auxiliary drives of a main drive. An AXGC is applied when this auxiliary drive consists of more than one aggregate, with which it must work in conjunction with, for example, two 100% duty L.P. Heater Drains pumps supplied where one is the duty pump and the other the standby pump or, if the auxiliary drive does not have to work continuously to fulfil its duty.

For example:

Unit: An emergency lube oil pump or a lube oil pump which has to maintain a certain pressure in a tank.

BOP: Demineralised, Potable and Raw water distribution systems.

3.3.1.5 Drive Control Level for Binary Control.

As in the case of analogue controls, the drive control level is also the lowest hierarchical level.

Refer to section 3.2.1.4.

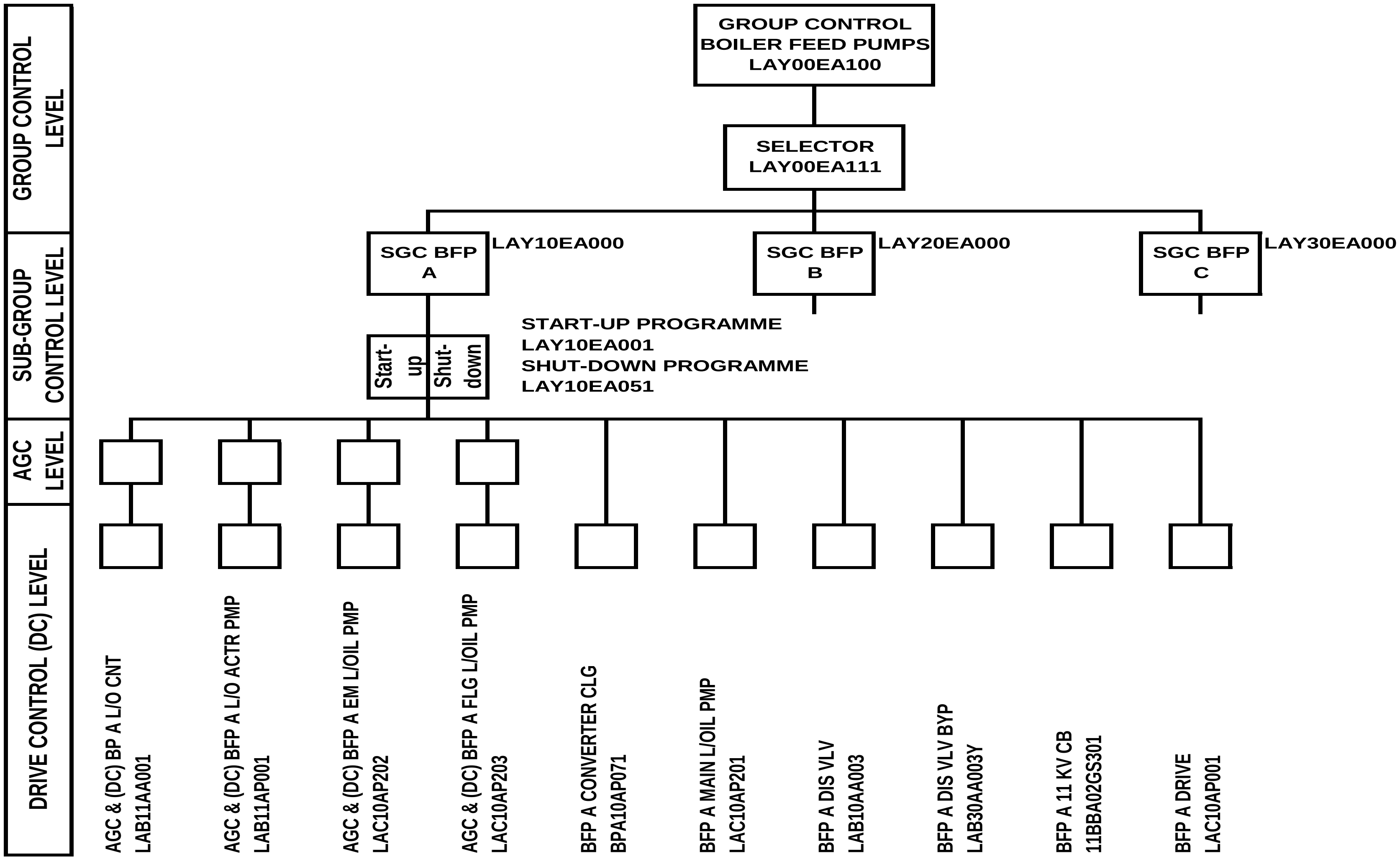

Figure 3: Example of a binary hierarchical structure (Unit Control)

3.4 LEVEL OF AUTOMATION – MINIMUM ESKOM OPERATIONAL REQUIREMENTS

3.4.1 Typical Unit Start-ups – Cold, Warm and Hot.

All unit start-ups shall have the ability of being started up Supervised Fully Automatic, from a Unit start-up sequencer, located at the highest hierarchical control level, being the Unit Control level.

Dedicated main systems which can be in operation independently from the unit operation (e. g. auxiliary steam system, cooling water system, fuel oil supply system, etc.) will be started by the operator from their respective group control levels, as per the overall start-up procedure. An initial fully automatic start-up of all the auxiliary systems of the unit is not foreseen.

The term "fully automatic", with respect to the automation of the boiler and turbine systems is understood to be as follows:

From a defined starting point, for example the collecting vessel being at normal starting level and the turbine on barring, the main control loops of the boiler and turbine will be co-ordinated from the unit control level in automatic mode.

All the main systems of the boiler, main turbine and water steam cycle, which are a sequential part of the start-up or shut-down sequence (e.g. flue gas – combustion air, primary air, feed water and turbine start-up) will be prepared by switching the group level control to automatic or stand by, whichever is requested by the unit sequencer.

The term "supervised fully automatic" means the operator monitors the sequence steps of the fully automatic start-up or shut-down sequence. The sequence steps will have hold points, where essential plant parameters to be aligned and checked or actions required by the operator, (with the possibility hold points being programmed) will be implemented in the start-up and shut-down sequences.

The start-up of the plant is performed by an operator in the Control Room.

3.4.1.1 Unit sequencer

The Unit start-up sequencer, when initiated by the operator, will start up the main systems in sequence or in parallel, as determined by an optimised start-up sequence. The main systems on the boiler, main turbine and water steam cycle, shall be started via dedicated sequence controls at Group/sub-group control level, when required in the overall start-up sequence:

Pre-programmed hold points are designed into the start-up sequence programme where the process conditions need to be supervised and confirmed, prior to the initiation of the next commands, e.g. the initiation of starting and shutting down of each of the oil burner levels, starting and stopping each of the mills.

The group and sub-group controls will start the various main systems fully automatic, by initiating and or starting subordinate auxiliary group controls and drives, without operator intervention.

Pre-selection of main plant to be started, for example whether the A, B or C feed pump is to be started first, is done at Group Control level, and is only altered via operator selection.

Should operator intervention be required or the sequence needs to be paused, the operator is able to temporarily halt the sequence of the affected system's Group/ sub-group control, via an Operator Guide function within the Group or sub-group sequencer.

During start-up, the analogue control loops will be switched from the Manual to the Automatic mode via their respective Group/sub group sequence controllers.

3.4.1.2 Unit Start-up sequences

Appendix 1 contains an example of a Unit co-ordinated cold start-up sequence with all the systems that need to be started.

Typical criteria to be fulfilled prior to a supervised fully automatic start-up are:

- Start up (collecting) vessel level is greater than minimum
- Three mills are ready for service
- All pre-start requirements, as laid down in the Fossil Fuel Firing Regulations, are fulfilled
- All other pre-start conditions in accordance with the boiler OEM operating manuals and instructions are fulfilled
- The main turbine alternator/generator (main machine set) is on barring with the main machine set condition monitoring system being healthy. All the main turbine auxiliary systems are in service and healthy
- The generator is pressurised with hydrogen with the Generator Care and Generator Condition Monitoring systems being healthy. All the generator auxiliary systems are in service and healthy.
- Auxiliary steam is available
- Demineralised water is available for make-up to the cycle. If the unit has a condensate reserve tank, the water level in this tank should be at a level equal to or greater than the normal working level
- The condenser hot well or air-cooled condenser condensate tank is at normal working level
- The feed water tank is at the starting level as recommended by the OEM
- The condensate and feed water system is primed and ready for service, including the auxiliary cooling system
- Redundant main plant is available and on standby; redundant condensate extraction pump and at least one boiler feed pump
- Condensate polishing plant, sampling and dosing systems are available
- All other pre-start conditions in accordance with the turbine, turbine auxiliaries OEM's operating manuals and instructions are fulfilled.

During start-up and shut-down, a supercritical boiler will be transiently operated below the Benson point. The sequences will be organised in a manner that a stop at a critical point is prohibited.

Within the stable load range from Benson point to full load, the boiler and turbine shall be capable of operating in the fully automatic mode, i.e. from the unit control level, while the further starting of oil burners and mills sequential controls is left to the unit sequencer, considering the defined hold points.

3.4.2 Typical BOP Plant Start-up operations

The Balance of Plant process plants should have the ability to start-up in Supervised Automatic mode, from GC or SGC level. Typically, once start-up at GC level is selected, the lower hierarchical level of SGC is placed in Automatic mode by default.

A start-up initiation of a main group via SGC will place the drives and lower level AXGC into operation through an automatic sequence. When the last sequence step is completed, the entire main group is deemed to be fully in operation.

Typically main groups may be in operation independently from other main groups and these can be started by the operator from the respective group control level, as per the plant area start-up procedure. The start-up of the Balance of Plant is performed by operators located in the Outside Plant and Water Treatment Control rooms. One operator is dedicated to control the Coal, Ash and Low Pressure Services plants in the Outside Control Room. The other operator is dedicated to control the Water Treatment Plant in the Water Treatment Plant Control Room. Power Stations equipped with Flue-gas desulfurization technology have a dedicated control room and FGD plant operator.

3.4.3 Unit: Normal Shut-Down

As in the case of start-ups, all unit shut-downs shall have the ability of being shut down Supervised Fully Automatic, from a unit shut-down sequencer, located at the highest hierarchical Unit Control level.

The shutdown of the plant is performed by an operator from the Control Room. Pre-programmed hold points are designed into the shut-down sequence programme, where the process conditions need to be supervised and confirmed, prior to the initiation of the next commands. For example, the initiation of each of the oil burner levels, stopping each of the mills, turbine steam cooling if required, the initiation of diverting steam flow from the turbine to the HP & LP Bypasses, changing over from Benson to Circulation, start of the turbine de-loading process and the shutting down of mills and oil burners.

Post boiler shut-down purge is typically initiated manually.

3.4.4 BOP: Normal Shut-Down

As in the case of start-ups, all plant shut-downs should have the ability of being shut down automatically via GC and SGC of the main groups.
The shut-down of the plant area is performed by the respective operator from the Control Room. Pre-programmed hold points are typically designed into the shut-down sequence programme, where the process conditions need to be supervised and confirmed, all prior to the initiation of the next command.

3.4.5 Unit: Emergency Shut-Down

The following scenarios will not require any sequencer.

3.4.5.1 Scenario 1 - Boiler trip (with Turbine Inter-trip) and auxiliary power available.

The automation system must automatically safeguard the plant without any operator intervention. Trips are usually initiated by a protection system such as the Boiler Protection System or Turbine Protection system independent of the Control System.

Boiler: the automation system must maintain the boiler secondary air flow at the value prior to the trip and then reduce or increase the total air flow to minimum as required by the FFFR. The Mills must automatically be shutdown per requirements as laid down by the Boiler OEM.

Status feedbacks are required in order to obtain the releases required to proceed with the Post Boiler Trip Purge. Under this scenario, Post Boiler Trip Purge is then manually initiated.

Turbine: Following a boiler trip, the turbine trip is immediately initiated automatically (turbine emergency stop valves trip close) and the generator breaker is opened when reverse power is detected. All turbine plant and auxiliaries are kept in service or automatically shut down, as required for safe plant shut-down.

If a restart is decided, the unit sequencer will be used to restart the unit.

3.4.5.2 Scenario 2 - Boiler trip (with Turbine Inter-trip) no auxiliary power except for essential power for critical drives.

Boiler and turbine essential plant as defined by the boiler and turbine OEM's will automatically be driven to the status that is safe for the unit. This operation must not require any operator initiation.

Auxiliaries required for the safe run-down of the plant, for example emergency lube oil pumps, will be started automatically.

3.4.5.3 Scenario 3 – When power is restored after a unit black-out

Full automation from Group Control level shall be available, so that the operator is able to initiate all the necessary operations to ensure safe status of the unit.

3.4.5.4 Scenario 4 - When power is restored after a Power Station black-out

Full automation from Group Control level on the units and BOP shall be available, so that the operators at the respective control stations are able to initiate all the necessary operations to ensure a safe status for the unit.

Auxiliary steam will have to be restored manually via the auxiliary boiler.

3.4.6 Redundant Plant on standby

Where redundant components are provided, automatic transfer to the standby equipment shall be provided should failure occur. This does not apply to mills and oil burners.

The level of automation for redundant plant is divided into a minimum of two categories - for main plant and for auxiliary plant.

3.4.6.1 Redundant Main Plant on standby

Main plant that contains redundancy is, for example, the feed water and condensate extraction pumps.

Level of automation for this plant is done at Group and Sub-Group level. As a minimum, the SGC's must cater for a sequence programme that ensures the pumps reach their standby status, prior to linking with their respective Group Controllers.

The Group Controllers must cater for fully automatic on-load (above Benson point) pump changeovers, upon the order being given by the operator.

The Group Controllers must also cater for the automatic start and immediate take-over of the standby plant in case of failure (trip) of the duty pumps.

3.4.6.2 Redundant Auxiliary Plant on standby

The level of automation for all plant, except main plant as described above, that contains redundancy e.g. redundant lube oil pumps, drain pumps, valves, fans and blowers, as a minimum, is achieved at Auxiliary Group Control level.

3.4.7 Modes of Unit Operation

The Units are able to be operated in two control modes; the Co-ordinated Boiler Follow mode of operation (turbine leads and the boiler follows) and in the Co-ordinated Turbine Follow mode of operation (boiler leads and the turbine follows).

3.4.7.1 Co-ordinated Boiler Follow mode

In Co-ordinated Boiler Follow mode, the turbine leads and controls the generated power, according to the unit load set point generated by the unit co-ordinator, at unit control level. The boiler load set point, generating the main fuel and boiler steam pressure set points, is also governed by the unit load set point. The boiler firing is controlled by the fuel set point and corrected by the boiler steam pressure controller.

3.4.7.2 Co-ordinated Turbine Follow mode

In Co-ordinated Turbine Follow mode, the boiler load set point is set according to the unit load set point generated by the unit co-ordinator, at unit control level. The turbine then controls the steam pressure according to the generated steam pressure set point. The boiler steam pressure controller, which normally adjusts the fuel, is rendered ineffective during this mode of operation.

3.4.7.3 Other Modes of Unit Operation

The units will also be required to supply essential ancillary services, namely Regulating Reserve (Automatic Generation Control/Secondary Frequency Control) and Instantaneous Reserve (Primary Frequency Control).

In order to be able to supply these reserves effectively, the units will have to operate in the Co-ordinated Boiler Follow mode of operation (turbine leads and the boiler follows).

Only during major plant trips (capability run-backs) will the units be expected to operate in the Co-ordinated Turbine Follow mode of operation. This mode of operation will also be possible during normal operation when initiated by the operator. Co-ordinated Turbine Follow mode of operation will not be used for System Operations Automatic Generation Control (secondary frequency control), due to the System Operators stringent requirement for rapid and accurate response to load set point changes.

For both modes of operation, the unit load set point will be adjustable at the Unit Control level by the operator. For Co-ordinated Boiler Follow mode of operation, the unit load set point will also be adjustable from the external load dispatching system of National Control (System Operator), for Automatic Generation Control (secondary frequency Control), from minimum to maximum load capacity. Preset limits, according to milling plant capability and safe boiler operation, will be defined. For more information on the Generation AGC Design Standard for Power Plants refer to [8].

The automation level for both modes of operation, Co-ordinated Boiler Follow and Co-ordinated Turbine Follow, will be at the Unit control level and accomplished by a Unit Co-ordinator.

3.4.8 Unit Co-ordinator

A Unit Co-ordinator contains the sophisticated control algorithms and logics to affect complete control co-ordination between the boiler and turbine. This co-ordination function is required for start-ups, load operation, shut downs and disturbances.

3.4.8.1 Unit Co-ordination during start-ups

During start-ups, the firing rate and the pressure set point are generated in a start-up controller. This controller will control until the boiler and turbine are ready for co-ordination i.e. when the boiler is in Benson operation and the HP Bypass valves have closed. Once the bypass valves have closed, the unit will be ready for Co-ordinated Boiler Follow mode of operation, provided the boiler firing and turbine load demands are matched.

3.4.8.2 Unit Co-ordination during load operation

During load operation, when the boiler is in Benson operation and the HP Bypass valves have closed, the unit must be able to operate in either the pre-selected Co-ordinated Boiler follow or Co-ordinated Turbine follow modes of operation.

Advanced control, using model based co-ordinated control for the boiler and turbine is recommended. Caution must be exercised in that the model based control does not unduly retard the turbine load demand during load set point changes, as there are stringent requirements from the System Operator in terms of load responses to changes in load set point.

3.4.8.3 Unit Co-ordination during shut-down operation

Unit co-ordination is required up to the point where the HP Bypass system is placed into operation during shut-down.

3.4.8.4 Loading and unloading gradients

Loading and unloading gradients of both the boiler and turbine during all stages of operation, start-ups, load operation and shut-downs, are automatically determined by the allowable thermal margins of the boiler and turbine.

3.4.8.5 Fixed versus Sliding Pressure

For supercritical boilers with sliding pressure control capability, the default mode of operation is the sliding pressure mode of operation (modified sliding pressure if applicable).

3.4.8.6 Capability computation and run-back control

The unit co-ordinator will contain the unit capability computation and all the run-back logics required for a successful unit run-back, in cases of major plant failure (e.g. loss of one of the boiler feed pumps and failure of the standby pump to start successfully). The automation level required is that the initiation, run-back and settling of the unit occurs automatically and without any operator intervention. The only operator intervention allowed is for the acceptance of transient alarms.

During run-back operation, the unit will switch from Co-ordinated Boiler Follow to Co-ordinated Turbine Follow automatically. The turbine will control the pressure, while the boiler will deload rapidly to the new and safe boiler load condition, which can be handled by the remaining plant in service.

3.4.8.7 Unit Co-ordinator features - summary

In summary, the unit co-ordinator will contain the following control loops and/or features:

- A Start-up fuel set point elaboration
- An on-load set point controller for unit load, adjustable from the superimposed load dispatcher (Automatic Generation Control/Secondary frequency control)
- The boiler fuel set point during both modes of operation (boiler follow and turbine follow)
- The load set point for the turbine during boiler follow mode of operation
- The steam pressure set point computation for the boiler, turbine and HP bypass controllers
- The acceptance of signals from the boiler and turbine stress evaluators, which will limit the boiler and turbine loading gradients if the allowable thermal margins of the boiler or turbine are consumed.
- The Run-back set point of fuel and automatic adjustment of the pressure set point during major plant disturbances
- Pre-selection for Automatic Generation Control On/Off
- Pre-selection for Primary Frequency Control On/Off
- Pre-selection for Co-ordinated Boiler or Turbine Follow modes

3.4.9 Unit Islanding/Load Rejection

The unit co-ordinator will also contain the capability computation and all the run-back logics required for a successful Unit Islanding and/or Load Rejection. The automation level required is that the run-back initiation to a pre-determined boiler load and settling of the unit occurs automatically, with operator supervision only and without any undue operator intervention.

During this severe transient, the only operator intervention expected is for the acceptance of transient alarms. Re-synchronisation to the grid after Islanding/Load Rejection and subsequent loading of the unit is accomplished by only one operator, at Group/sub-group control level.

Unit co-ordination is not required during Unit Islanding or load rejection as the boiler load is set to a pre-determined level and the turbine controller maintains the turbine at nominal speed with or without auxiliary generated load.

3.5 PLANT CONTROL MODES

Where local control facilities are required three distinct modes of operation are typically provided: Automatic, Remote Manual and Local Manual. Selections of modes of control will be available at group, sub group and drive level as indicated below.

3.5.1 Remote Manual Control Mode

In Remote Manual mode, the control room operator at the control room's HMI initiates control of the individual devices. Selection of this mode is from the Control Room HMI. All the safety and process interlocks remain active in this mode. This mode will be selectable from either group or sub group level where devices are reporting to the group or sub group.

3.5.2 Local Manual Control Mode

In local manual mode, the control of devices is initiated from the field mounted LCS or LCP. Control on the Unit and Balance of Plant is primarily centralized and to achieve this control mode, in normal operational circumstances, the control room operator selects the "Local" mode at the control room HMI, which provides a release signal to the LCS or LCP. The control functions are then activated so that the Local Plant Operator is allowed to initiate control of the individual devices. In this mode all the safety and process interlocks remain active. This mode will be selectable from group or sub group level where devices are reporting to the group or sub group.

3.5.3 Local Maintenance Control Mode

In local maintenance mode, the control of devices is initiated from the field mounted Local Control Station. To achieve this function the control room operator selects the "Maintenance" mode at the control room HMI, which provides a release signal to the Local Control Station. The control functions are then activated so that the Local Plant Operator is allowed to initiate control of the individual control devices in the field. In this mode all the process interlocks are inactive with the safety interlocks still active. This mode will be selectable from sub group level where devices are reporting to the sub group. Examples of plant areas with this mode include the Coal and Ash plant conveyors.

3.5.4 Local Control Station Equipment

Each LCS will be equipped with the following minimum functions, and these functions form an integrated part of the Control System:

- Local/Remote/Maintenance selector switch
- Emergency stop pushbutton
- Lamp test pushbutton
- Local indication lamp
- Open/Close (Stop/Start) pushbuttons
- Open/close (Stopped/Running) indicating lamps
- Fault acknowledge pushbutton
- Fault indication lamp

Plant areas that have exposed or moving machinery are required to include an Emergency Push button on the LCS. The Emergency Push button should be hardwired directly to the Electrical Switchgear of the affected drive(s) to trip the drive and a signal sent to the control system in parallel for information purposes.

3.5.5 Local Control Panel Equipment

The LCP includes the functions of the LCS, with the added benefit of providing the local operator much more process information of the plant that the operator is controlling. The LCP typically provides the operator information on process alarms, overall plant status, status of applicable interlocks, sequence control conditions and other information that is deemed necessary to control the local process plant. The LCP typically presents the information via a digital software MIMIC, although hardware MIMICs are also found in some plant areas.

3.5.6 Local Drive/Plant Control Level via LCS/LCP

For most Balance of Plant areas, the local operation via the LCS/LCP is intended primarily for the Maintenance mode. The exception to this is primarily the Water Treatment and CPP Plants where the Station Chemist conducts regular monitoring and the operator makes interventions via the LCP. However, all plants as a whole are normally run in fully automatic (remote) control mode.

There are Balance of Plant areas that do not have process storage or an operational buffer and are vital to the units operation, an examples is the Main Cooling Water plant. These plants are classified as critical and their unavailability could lead to a MUT, even if unavailable for only a short period of time. It is recommended, that for the critical Balance of Plant areas, the LCSs and LCPs are configured to have an automatic release to Local Mode should the control room HMI fail and allow the local operators to monitor and control the plant further with all process interlocks in place. As a further save guard, it is recommended that the LCSs and LCPs for the critical plants are tying into the process or automation layer of the control system and not at the application layer to minimize the risk of LCSs or LCPs becoming unavailable due to an application server failure.

4. AUTHORISATION

This document has been seen and accepted by:

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5. REVISIONS

Date	Rev.	Compiler	Remarks
November 2018	0.1	Z Y Moola	Initial draft as mandated through SCOT Charter. Medupi specific LOA (N. Baruffa) revised to fleetwide document and combined with BOP LOA and Plant Control Modes documents.
January 2020	0.2	Z Y Moola	Comments Update after Review Process
January 2020	1	Z Y Moola	Final Document for Authorisation and Publication

6. DEVELOPMENT TEAM

The following people were involved in the development of this document:

- Zubair Y Moola
- Nerino Baruffa
- Christoph Kohlmeyer

7. ACKNOWLEDGEMENTS

The following people were involved in the development of Medupi Level of Automation document which was used as the basis for this Fleetwide Guideline:

- Nerino Baruffa (PEI – C&I Engineering)
- Zubair Moola (GTD – C&I Engineering)
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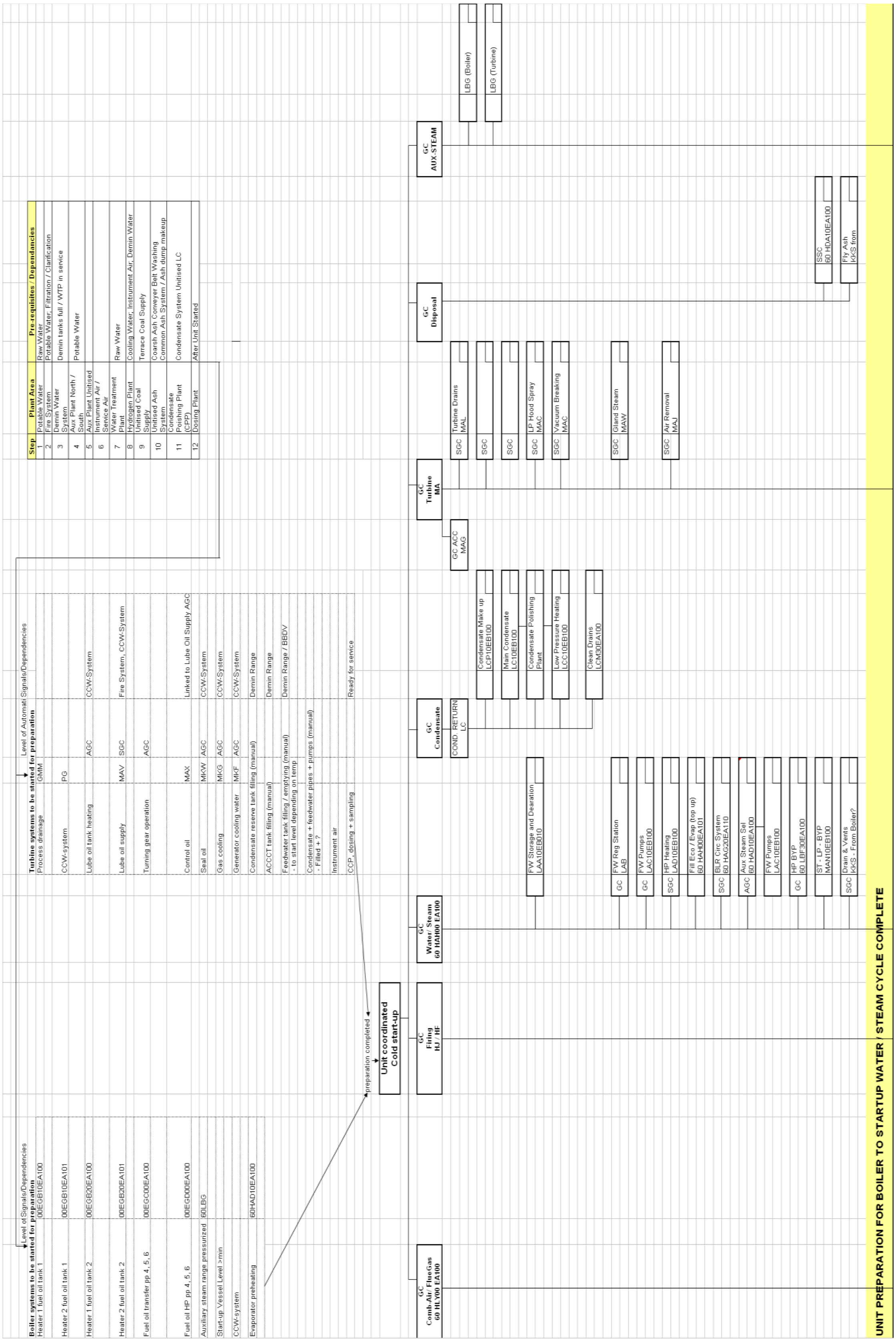
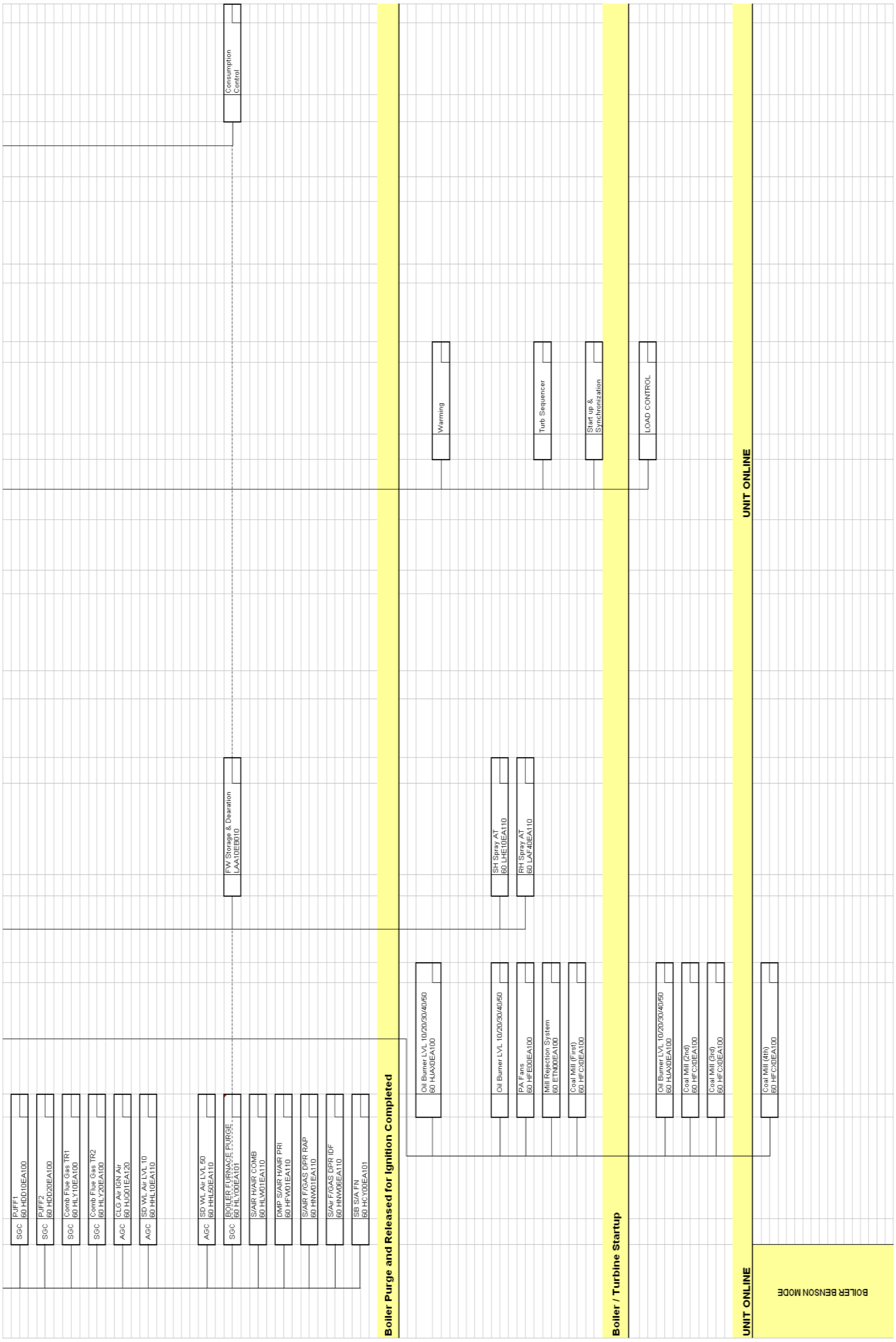
The following people were involved in the development of the BOP Level of Automation document which was combined with the Medupi specific document to produce this fleet wide guideline.

- Paul du Plessis (C&I PEI)
- Nerino Baruffa (C&I PEI)
- Jorge Nunes (C&I PEI)

APPENDIX A: UNIT CO-ORDINATED COLD START-UP SEQUENCE

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Warming
Turb Sequencer
Start up & Synchronization
LOAD CONTROL
UNIT ONLINE
FW Storage & Dearation
SH Spray AT
RH Spray AT
PA Fans
Boiler Purge and Released for Ignition Completed
Boiler / Turbine Startup
UNIT ONLINE
BOILER BENSON MODE