DEVELOPMENT OF THE CONTROL AND AUTOMATION SYSTEM FOR MINI HYDRO TURBINES

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Thesis submitted in fulfilment of the requirements for the Masters Degree in Technology to the Department of Electrical Engineering (Light Current) at the Cape Technikon.

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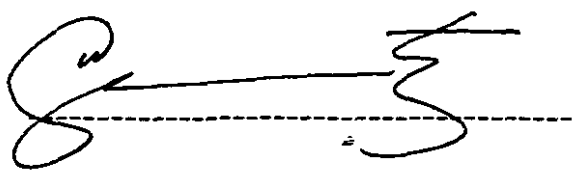
DECLARATION

I hereby declare that the contents of this thesis represent my own work and the opinions contained herein are my own. It has not been submitted before for any examination at this or any other institution.

W.F. Schmutz



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SUMMARY

This thesis describes the research, development and design of one of the most modern generic control and automation system for mini Hydro turbines available in the world.

Special emphasis is placed on the Man machine interface. A concept of total dynamic plant and data status representation was pursued. To achieve this, a large amount of graphical animation was incorporated into the design.

The end product was to be the most economical and cost effective implementable design available , yet providing the most modern functions and features available in the world market.

The system was developed and researched to be generic and applicable to any small Hydro plant. The design can thus be implemented on any suitable PLC and SCADA system and is not dependant on any specific manufactures hardware or software. The main emphasis is laid on functional capability of the design.

Utilising this design standard would virtually cut the cost of engineering associated with the design of a Hydro control system by 90%. The design and engineering costs related to a Hydro automation project could typically exceed R 100 000 a for small Hydro plant as this scheme.

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1. INTRODUCTION

The project revolves around the automation of a 800 kW mini Hydro Turbine generator situated at the Gariep Power station below the Gariep dam wall.

The main function of the Mini Hydro is to provide emergency power in the event that all external power is lost to the power station.

The power generated by the Mini Hydro (House Set) is used to start the auxiliary systems of the 4 main Hydro units of 90 MW each. Once the main units are started the power station can then supply the grid and itself with power.

It is important to note that this is a critical function, and without the effective operation of the House Set there is a real risk of not being able to supply the grid with 360 Mw of power under emergency conditions.

The House Set was installed in 1974 and was equipped with a electro-mechanical governor and control system. It became apparent that the electro-mechanical governor system was not able to effectively govern the speed or power generation of the House Set. This in itself meant that the machine was no longer able to perform the critical function of emergency power generation.

It was decided to replace the entire governor and associated systems with a modern digital electronic control system with the governor as an integrated part of the system.

This implied that the entire hydraulic system had to be redesigned and interfaced to the new electronic control equipment in order to achieve the required response from the system.

To achieve the above, cost estimates indicated that the entire project would cost in the region of R 800 000.00.

This led to the project to research, develop and design a generic automation and control system was initiated. This was also the first time that the entire automation and control system development of a mini Hydro generating set has been under taken in South Africa.

2. EXPLANATION OF TERMS

Below a brief explanation is given of the PLC and SCADA systems:

PLC - Programmable logic controller

These industry standard plant control devices typically consist of a CPU analogue inputs, analogue outputs, binary inputs and binary outputs.

The CPU can perform Boolean functions and have timer and counter functions. The status of the binary inputs and analogue inputs are scanned and according to the logical function plan the CPU will inturn switch and manipulate the binary and analogue outputs. The binary outputs can then for example be used to stop or start motors or manipulate other plant devices.

A simple example of a binary function would be performing a AND function on two binary inputs. If both the inputs are present a selected output can then be switched on or off. A typical application would be to start a motor, providing that two conditions are present simultaneously.

These systems can also perform analogue value processing. A typical example would be the generating of alarms, which is done by reading a analogue value from the plant in the form of a 4-20 mA signal. The signal is digitised into a 12 or 8 bit word and then compared to a word containing the Setpoint value in the software by the CPU. If the value from the plant exceeds the Setpoint value a selected binary output can be switched on or off.

Examples of PLC software can be see in the APPENDIX C: PLC LOGIC DIAGRAMS .

SCADA - Supervision Control And Data Acquisition

SCADA systems are software packages that are utilised for the purpose of control, supervision and data acquisition of plant. These systems are used to display plant representative graphics, plant variables, general operator information and perform animation.

These systems are also used to send operator commands to the plant via the PLC for the purposes of stopping and starting motors and altering other plant parameters. This is achieved by activating touch sensitive objects created on the PC screen with the mouse, so forming the Man Machine Interface with the plant.

The SCADA system reads the plant variables from the PLC by means of a software driver via a serial data link.

3. OBJECTIVES

The objective was to generate a generic functional design that would be one of the most modern in the world with regard to the Man-machine interface and general functionality.

The system was designed to be hardware independent, meaning that the design can be implemented on any suitable PLC and SCADA system. This would give great flexibility with regard to implementation by a varied number of automation and control system companies and or contractors.

It was also decided to do 95% of all the associated engineering and design work; this would cut the cost of implementation of the entire project by 10 to 15%.

Further it was envisaged that the design will serve as an invaluable expertise and knowledge base for the upgrading and refurbishment of the big Hydro units (set to commence in the next 5 years).

As Eskom has been totally reliant on overseas companies with regard to design of Hydro plant control systems,it will also serve in the generation of local expertise in the Hydro plant automation and control area.

The final objective was to fully automate the House Set so that it will perform the required function described in this thesis totally autonomously without any human intervention.

The new automation system would be required to operate in 3 different modes namely, ISOLATED, SYNCHRONISED operation and BLACK START operation.

ISOLATED operation is a mode where the House Set is the only power generator that supplies power to a load.

SYNCHRONISED operation is a mode where the House Set is connected to the common grid and supplies power to the grid as one of many participants.

BLACK START is a mode where the House Set monitors the grid for loss of total power. The House Set then starts up and performs the function of a emergency power generator.

These modes of operation cover all the possible modes of operation applicable to the mini Hydro power plant, with the exception of water level regulation.

The control system design also had to make provision for the mini Hydro to be used for training, giving the function of total automatic autonomous control, and on the other hand total local control by the operator.

The requirement with regard to speed and power regulation was set at less than 0,1%. This implies that if the machine is running at 750 rpm which generates a frequency of 50 Hz, a deviation of only + or - 0,3 Hz from 50 Hz will be allowed. This is important as damage to electrical motors supplied from the House Set, can be caused by excessive under or over frequency.

In order to meet this requirement the speed need to be regulated between 745 rpm and 755 rpm, giving a frequency output range of 49,67 Hz and 50,33 Hz.

It is important to note that when a load is applied to the generator the speed will tend to drop proportionally to the size of the load connected. It is essential that the governor will rapidly respond by opening the guide vanes to compensate for the drop in speed. This means that the system should be capable of correcting any deviation incurred due to load demand increases at a rate of 0,01 second per 1 kW.

This means that when a load of 100 kW is instantaneously applied to the House Set, the resulting dip in frequency should be rectified within 1 second.

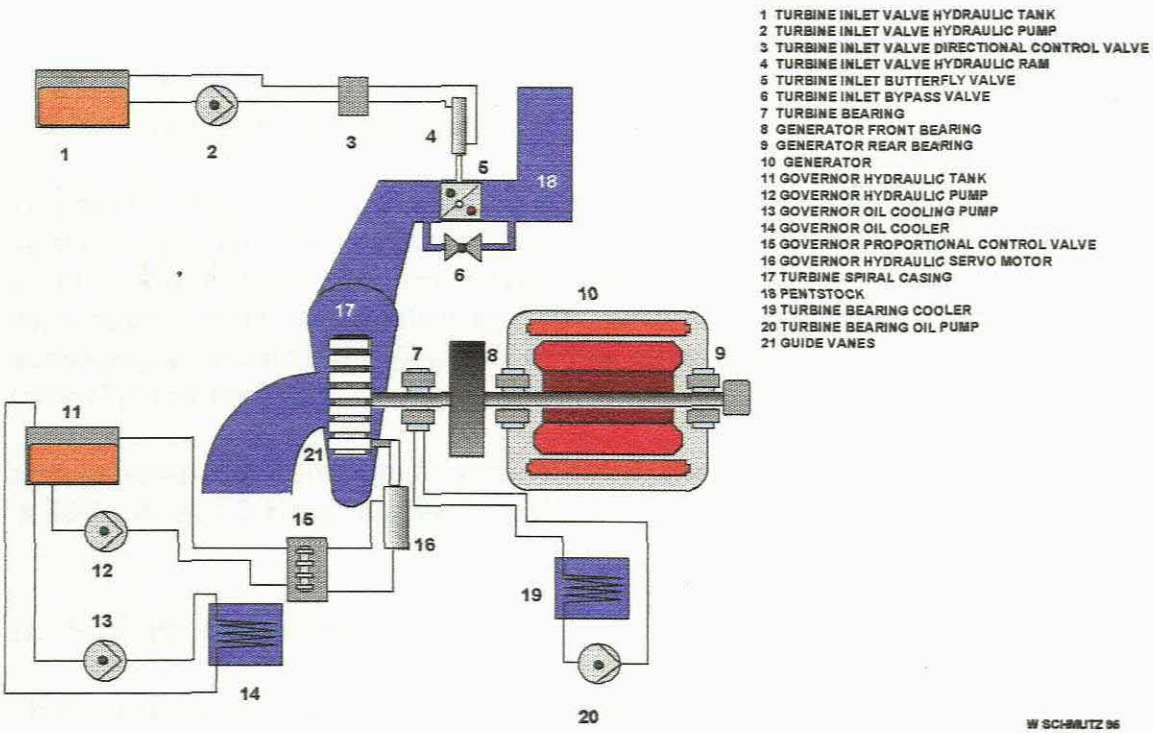
3.1 SUMMARY OF REQUIREMENTS

- One of the most modern and advanced automation and control system designs available in the world.
- Most cost effective and flexible design available.
- Full automatic start up and shut down without any operator assistance in the 3 modes of operation.
- Suitable to accommodate the training of operating personnel.
- Perform frequency regulation between 49,7 and 50,3 Hz from 0 kW to 750 kW load.

- Perform frequency deviation correction in less than 1 second for any additional 100 kW load instantaneously connected to the generator.

4. BASIC PRINCIPLES OF OPERATION

The sketch below shows a schematic representation of the House Set.



The main components are the:

- Penstock
- Turbine inlet valve system
- Turbine inlet valve bypass valve
- Guide vanes
- Turbine runner
- Governor hydraulic system
- Generator

The penstock feeds the turbine with water from the dam with a head of 50 meters. The energy from the water is used to turn the turbine runner, which then turns the generator.

The turbine inlet valve is situated in the pentstock just before the turbine, and has the main function of isolating the water flow to the turbine when the turbine is shutdown or under emergency conditions. The system is

designed with a static counter weight to ensure that the valve will close should the control of hydraulic systems fail.

The turbine inlet valve bypass valve is required to equalise the pressure across the main inlet valve before the inlet valve is opened. This is required to relieve the stress on the main valve during opening.

The guide vanes are placed in a ring formation around the spiral casing of the runner, and consist of 16 individual blades. The purpose of the guide vanes are to control the water flow through the turbine. By varying the position of the guide vanes the water flow is altered and the speed of the machine can then be controlled.

The guide vanes are controlled by a hydraulic servo motor connected to the guide vane ring. The position of the servo motor is controlled by a hydraulic proportional position control valve. The proportional control valve receives its setpoint from the control system, and then positions the servo motor accordingly, altering the position of the guide vanes and thus changing the speed of the machine.

The generator is connected to the turbine shaft and is designed to generate ±800 kW at 50 Hz at a speed of 750 Rpm with 100% guide vane opening.

5. SCOPE OF WORK

The scope of work included the following:

- Field investigations
- Overseas research
- Overall system control philosophy development
- Governor hydraulic system design
- Governor analog control system design
- Automation system sequence design
- Local control panel design
- Total system operational philosophy development
- SCADA system graphic and animation development

The field investigations covered areas such as the existing system performance evaluation and the establishment of shortcomings and deficiencies. The result of this investigation revealed that the entire control and governor system was not capable of performing the required functions.

Control system manufacturers overseas (Siemens, Voith and ABB) were visited and discussions were held on their control systems suitable for mini Hydro application. It was generally found that the level of automation and graphic representation envisaged for the House Set was only available on systems designed for large Hydro units. The cost of these systems would also be very high and could not be justified for use on a mini Hydro plant.

The system control philosophy was developed in conjunction with the plant requirements as set out further in this thesis; it must be emphasised that the operating philosophy has been altered radically from the original configuration. Not much external information was used for the development of the operating philosophy.

The development of the governor system was based on the performance requirements with regard to speed, safety and robustness. Several options such as regenerative, accumulator and straight hydraulic systems were evaluate and investigated. The emphasis of design was on speed compactness and minimal energy consumption. Other aspects taken into account were complexity and cost.

The analog design for the governor system was uniquely adapted to suit the various operational mode requirements of the system. The unique feature was the speed setpoint variation during synchronising in order to minimise synchronisation time. This will be discussed in detail under the relevant heading.

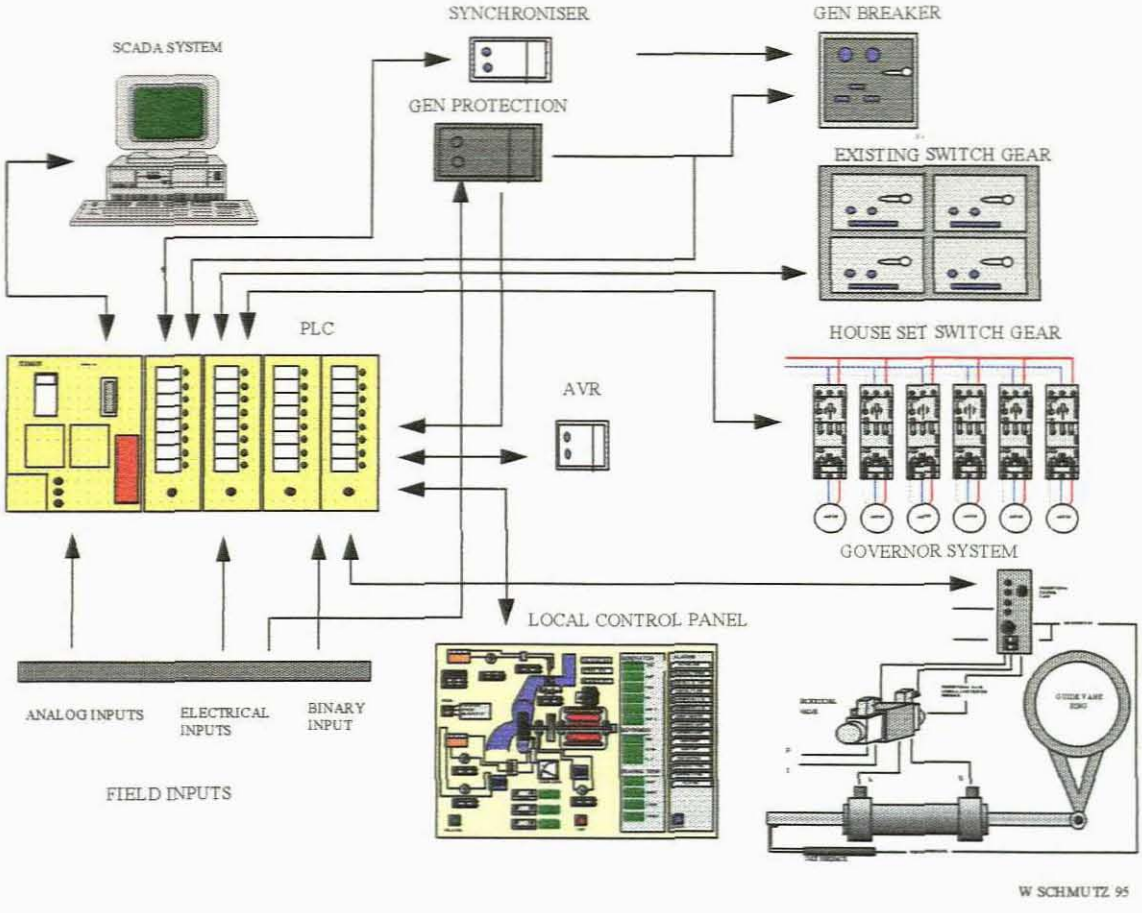
The sequence control was developed to give the fastest, safest and highest integrity to the system when performing start up and shut down operations in the automatic mode of operation. The sequence design will also be a integrated part of the graphic display and animation development of the operator system.

The local control panel was developed taking the following into account : logical graphical representation of the plant, ergonomic considerations, data representation and user friendliness.

The SCADA system graphical developments are one of the major aspects of this project, the aim being to bring the plant in all its aspects to the operator. The animation aim to represent the plant conditions and the internal functioning of the control system to the operator as realistically as possible.

6. AUTOMATION PHILOSOPHY

The control of the House Set will be done from two locations, namely the local control panel and the SCADA system. These and the main related control devices are briefly dealt with below. The diagram shows how these elements are interconnected to form the control system



LOCAL CONTROL PANEL

The local control panel provides the plant operator with a operating facility to locally start up and shut down the plant in the 3 different modes. It Indicates values of variables such as temperatures and pressures etc. All alarm indications and the display the status of valves and motors are provided on the local control panel in the form of a interactive mimic.

SUPERVISION CONTROL AND DATA ACQUISITION SYSTEM (SCADA)

The SCADA system forms the heart of the Man machine interface and provides the operator with the following facilities:

Remote control of the plant via the PC in the control room
Graphical representation of the entire plant
Status display of the various valves and motors
Display of the various analog values
Trends of the analog values
Visual representation of the various start up and shut down steps
Dynamic display of governor performance
On line help related to plant operation
Logging of events
Logging of alarms

HYDRAULIC GOVERNOR SYSTEM

The hydraulic governor system positions the guidvanes according to the setpoint that is provided by the PLC. This is accomplished by means of a hydraulic cylinder that is proportionally moved via a distributor control valve that receives a 4-20 mA signal from the PLC. The 4-20 mA signal corresponds to 0 to 100% of the guide vane opening.

PLC (Programmable logic controller)

The function of the PLC is to perform the total co-ordination of the entire plant from start-up to shut down in the 3 modes of operation. It also monitors the variables and generates alarms and protection signals accordingly. All the analog and binary information is sampled by the PLC and passed to the SCADA system for the purpose of displaying vital information to the operator.

The total governor electronic analog control is supervised by the PLC and forms the heart of the speed and power regulating process.

All start-up and shut down commands are received by the PLC and compared to the required criteria and executed accordingly.

SYNCHRONISER

The synchroniser provides the PLC with a signal indicating that the generator frequency is in phase with the grid frequency, and also ensures

that the main circuit breaker connecting the generator to the grid is only closed once the 2 system frequencies are in phase.

GENERATOR PROTECTION RELAY

This device gives a signal to the PLC when an electrical fault is detected in the generator. On the initiation of this signal the PLC will shut the plant down to avoid any damage to the plant or generator.

AUTOMATIC VOLTAGE REGULATOR (AVR)

This device continuously adjusts the excitation of the generator rotor to ensure that the voltage remains constant at 380 VAC.

GENERATOR BREAKER

This device connects the House Set generator to the grid. In the event of any protection system operating, the generator breaker is opened in order to immediately disconnect the House Set from the grid.

HOUSE SET SWITCH GEAR

The switch gear is controlled by PLC and in turn switches the auxiliaries of the House Set on or off. The switch gear also protects the motors against over current and thermal damage.

7. The SCADA system

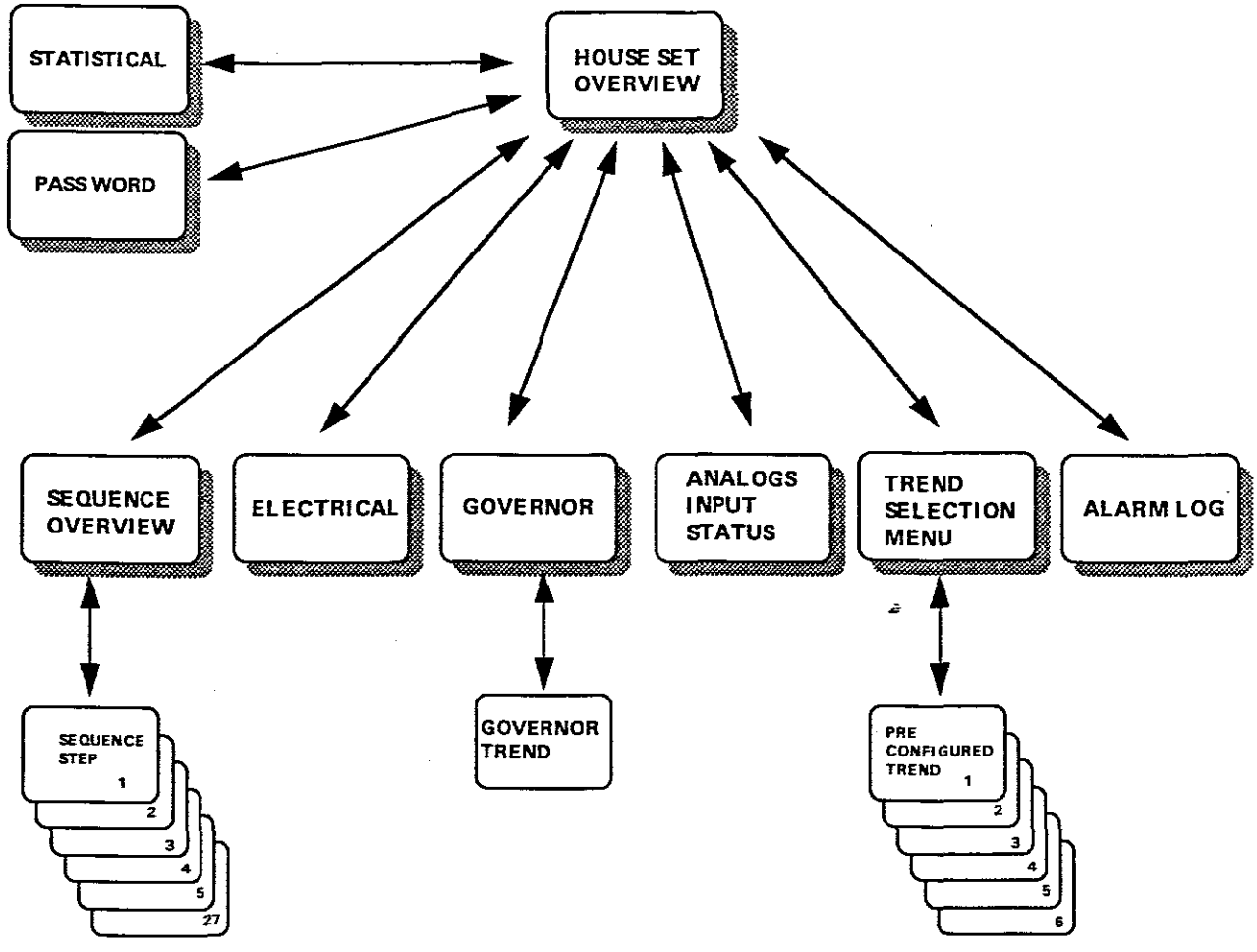
Data Logging and Handling

All inputs and outputs as listed in Section 8. and the sequencing data logged from the PLC will be archived in the database residing on the hard drive of the SCADA system PC. Archiving facilities for a minimum of 30 days will be provided. This provides a means for the access to long term data for the purpose of evaluation.

All events and alarms generated by the PLC system will also be archived. The Tag number, Description and Time/Date stamp will form part of the descriptive information in the historical database.

SCADA Windows

SCADA GRAPHIC SCREEN LINKING REQUIREMENTS



The graphics consist of the following 36 screens and the linking of the screens are shown above, these screens can be seen in APPENDIX B:SCADA SCREENS. The screens are namely;

- Overview screen
- Statistical screen
- Password and access control screen
- Sequence overview screen
- Screens showing the various steps of the sequence (27 screens)
- Electrical screen
- Governor screen
- Analog value and status screen
- Trend selection menu screen with one random select trend
- Alarm and event log screen

The entire plant will be operable from the screens displayed on the SCADA system PC by means of mouse driven active tiles.

The mode of operation ISOLATED, BLACK START and SYNCHRONISED will be selectable on the overview screen.

Procedure for automatic start up from the SCADA overview screen

The GROUP Control tile will be called and selected to AUTOMATIC.
On the activation of the START UP button the PLC will perform the start up steps in the selected mode of operation as specified. (Step 1 and onward as discussed later in this thesis).

To shut the plant down the GROUP CONTROL tile will be called and on the activation of the SHUT DOWN button the PLC will perform the shut down steps as specified. (Step 51 and onward). The above operations will not be possible if the group control module is selected to MANUAL.

Procedure for manual start up from the SCADA overview screen

The GROUP CONTROL tile will be called and selected to MANUAL. The drive to be stopped or started will selected by clicking on it. On selection the control tile for the drive will appear in the lower right corner of the OVERVIEW screen.

By activating the stop or start button the drive will be stopped or started by the PLC, providing the required releases criteria are present as can be seen in APPENDIX C: PLC LOGIC DIAGRAMS.

The actual feedback indicating that a drive has started will be taken from the switchgear contactor status auxiliary contact.

The Statistical screen will calculate and display the following data:

Running time in the ISOLATED mode of operation for the last operation and total running time in ISOLATED mode.

Running time in the SYNCHRONISED mode of operation for the last operation and total running time in SYNCHRONISED mode.

Running time in the BLACK START mode of operation for the last operation and total running time in BLACK START mode.

kW hours generated in the various modes and total kW hours generated.

Time to Start up from stand still to time when the generator breaker is closed - Synchronisation time.

This information is vital to asses the long term mode performance of the plant.

Password screen

When selected this screen will display a keyboard and the operator will have to enter a password to obtain access to the operation of the plant. Three levels of access will be provided namely; operator level, setpoint alteration level and configuration level. This function is essential to avoid unauthorised tampering with the system parameters

Sequence overview screen

This screen shows all the steps of the sequence, the status of every step is indicated namely; ACTIVE and COMPLETE. This screen will also indicate the mode of operation ISOLATED, BLACK START or SYNCHRONISED. The direction of operation will also be indicated e.g.

MODE	DIRECTION	STATUS
BLACK START	SHUTDOWN	COMPLETE
BLACK START	SHUTDOWN	IN PROGRESS

BLACK START	START UP	COMPLETE
BLACK START	START UP	IN PROGRESS

The above will also be done for the ISOLATED and SYNCHRONISED modes.

Step and criteria screens (27 off)

The philosophy is based on the fact that commands to the plant will not be issued unless the required feedback signals are not received within a determined monitoring time, the monitoring time being the time that the system will wait for the feedback signals to be received from the plant.

The step and criteria blocks also includes a Waiting time, this time being the time that the system will wait before issuing commands to the plant after the required feedback signals are received.

These screens will show the individual steps being executed with their related criteria. As a sequence progresses, the screens showing the individual steps at that point of time will be active .

The inputs to drive the sequential display windows will be taken from the PLC. The system will be such that the operator will be able at any stage to see in which step the plant is.

The step number criteria and elapsed time will be depicted on these windows. The status of the individual criteria will be indicated by a change in the text colour to give an indication if the criteria is present or not.

The remaining time for the step will be depicted in the form of a down counter; if the sub program is still in progress after the allocated time has elapsed the counter will flash.

On a start up or shut down the relevant sequencing step will automatically appear on the screen, as well as the remainder of the steps as processed by the PLC, providing that the SEQUENCE DISPLAY mode is selected.

The operating modes ISOLATED MODE, SYNCHRONISED MODE, BLACK START MODE and STANDSTILL will be displayed on this screen.

Electrical Screen

This screen will display the electrical reticulation and will indicate the breaker status and the following parameters:

- Grid frequency

- Generator frequency
- Difference between the above 2 frequencies
- kW output
- Vars (Reactive power)
- Generator voltage
- Grid voltage
- Power factor

On the activation of the "Manual synchronise" push button a vector scope graphic will be displayed indicating the difference and magnitude of phase angle between the House Set and the grid frequency. As soon as the phase angle is zero a tile "Breaker close" will be displayed and on activation the PLC will issue the command Breaker close. This will be true as long as the synchronisation check relay is active and a 0° phase difference is detected.

The breaker which is selected to synchronise across will then be closed.

Governor screen

This screen displays the entire governor system consisting of the following main components:

- Speed controller indicating setpoint, controller output, error and raise/lower buttons
- Power controller indicating setpoint, controller output error and raise/lower buttons
- Min. selector indicating minimum value
- Max. selector indicating minimum value
- Measured power
- Measured speed
- Measured guide vane position
- Speed, Power and Guide vane controller proportional and integral settings
- Graph showing guide vane position, power output, machine speed, Power setpoint, Speed setpoint.

Detailed can be seen on the associated graphic screen in the APPENDIX B: SCADA SCREENS.

Variable screen

This screen displays all the variables in the system, indicating the description, value and status of the signal. The status is an indication of the health of the measurement (either in range or out of range). For binary signals the on or off states will be indicated.

Trend selection menu screen

This will provide for the selection of historical and on-line trend displays.

This screen will provide for the random attachment of any variable to any one of the 4 recording pens in on-line and historical modes. This will be possible by selecting the pen, and by clicking on the desired variable shown on a menus screen.

The trend screen will have the following functions:

Zoom
Axis adjustment
Printing the screen
Rewind and fast forward in time.

The system will be capable of historical trend replay of all the analogue variables as listed under Section 8.

8. PLC system

The systems will be configured to automatically perform the following functions:

Sequential start up and shut down
Monitor all analog and binary inputs from the plant
Produce alarms
Produce trips
Govern turbine speed
Govern generator power output
Manual start up and shut down
Detecting analog signals that are out of range

The PLC will be interfaced to the SCADA system and local control panel to display plant representative graphics, alarms, trends, archived data and log variables as per attached information where applicable.

The PLC logical function can be seen in APPENDIX C: PLC LOGIC DIAGRAMS and will be discussed in detail later in this thesis.

All signals will be monitored in such a way that an alarm will be initiated should the signal fall out of the specified 4 - 20 mA range. An alarm on the SCADA system will uniquely identify the faulty field device.

The PLC will require the following features:

Distributed I/O facility or field bus
Have a modular structure
24 volt DC supply
8 bit resolution for analog input signals
12 bit resolution for Governor related analog input and output signals
Galvanically isolated inputs for analog and binary signals
Change over relay outputs for binary output signals

The software will be of modular type with every step of the sequence in a individual program software block.

The governor system will be in its own program software block and have the smallest possible cycle time. This block should be executed at least every 25 ms to ensure optimum governor response.

Protection signals will take highest priority and be executed on a interrupt basis to minimise machine cycle time.

An estimated PLC I/O count for a typical small Hydro is shown below.
(See end of table for ledgen)

	I/O COUNT		
	DRIVE TO CONTROL TILES		
1	DC GOVERNOR OIL PUMP	4	4
2	TIV DC OIL PUMP	4	4
3	TURBINE DC LUB OIL PUMP	4	4
4	TIV CONTROL SOLENOID	4	4
5	GOVERNOR OIL CIRC PUMP	4	4
6	TIV BYPASS VALVE	4	4
	GROUP CONTROL TILES		
1	GROUP CONTROL	5	13
	ALARMS		
1	DC FAILURE		1
2	REVERSE POWER		1
3	GOV OIL LEVEL TRIP		1
4	GOV OIL PRESS LOW		1
5	GEN BEARING OIL LVL LOW		1
6	OVER 1040 rpm		1
7	TURB BRG TEMP HIGH		1
8	GEN BRG TEMP HIGH		1
9	GEN TEMP HIGH		1
10	GEN TRIP		1
11	PROTECTION TRIP		1
12	AVR SUPPLY FAIL		1
13	GEN VOLTAGE FAIL		1
14	PLC FAIL		1
	PUSH BUTTONS		
1	RELEASE	1	
2	ALARM ACCEPT	1	
3	TRIP	1	
4	SELECT ISOLATED	1	
5	SELECT SYNCHRONISED	1	
6	SELECT BLACK START	1	
	INDICATIONS		
	GEN BREAKER OPEN/CLOSE		1

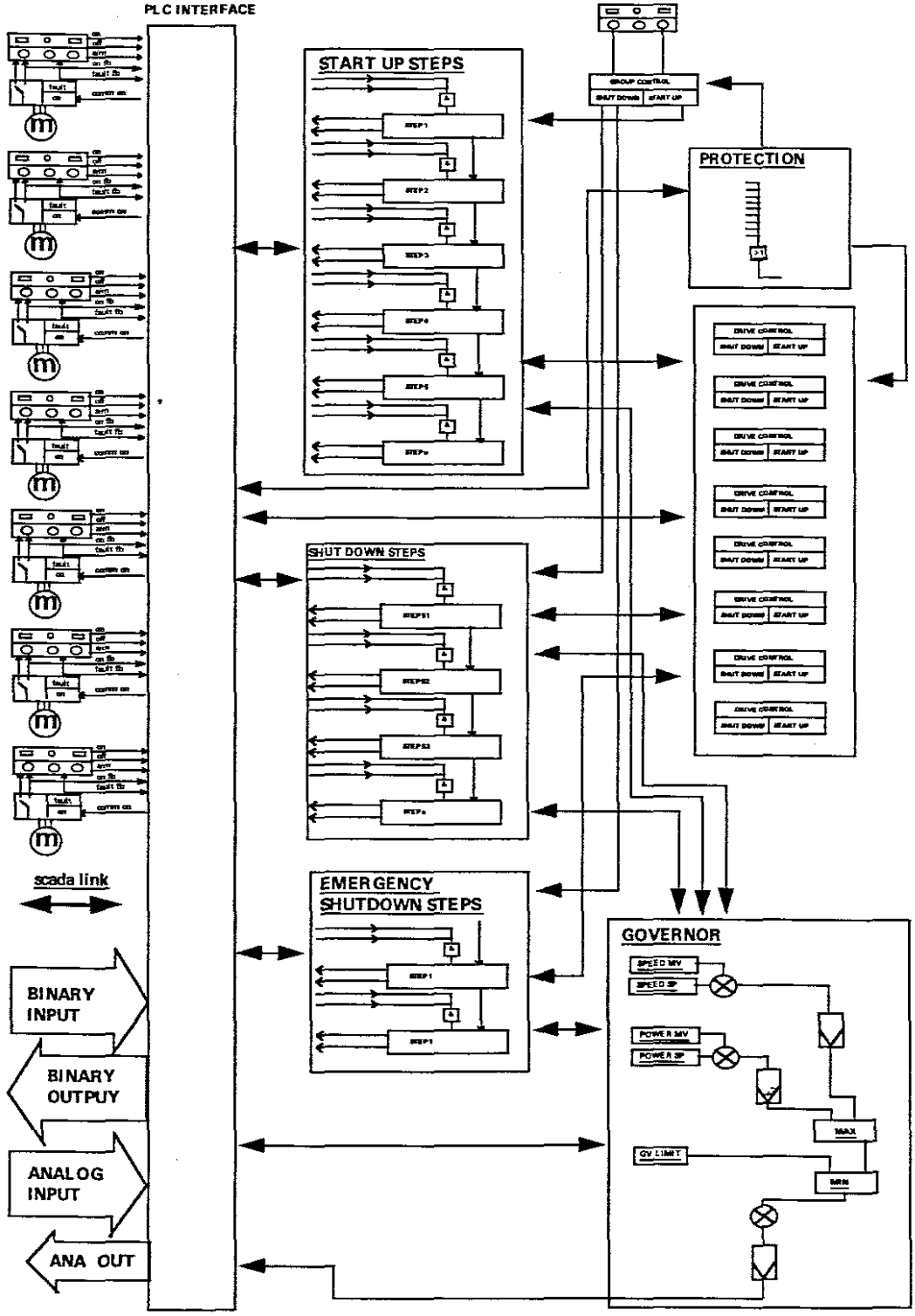
I/O COUNT				
	ANALOG OUTPUTS			
1	TURBINE SPEED SETPOINT			1
2	POWER SETPOINT			1
3	GUIDE VANE LIMITER			1
	FIELD I/O			
	BINARY INPUTS			
1	GOVERNOR OIL PRESSURE	1		
2	GOVERNOR OIL LEVEL	1		
3	TURBINE BRG OIL LEVEL	1		
4	TURBINE BRG OIL PRESSURE	1		
5	CLOSING SERVO CLOSED	1		
6	GUIDE VANE SERVO CLOSED	1		
7	TIV FULLY CLOSED	1		
8	TIV FULLY OPEN	1		
9	TIV > 90%	1		
10	MECH OVER SPEED DEVICE	1		
11	GEN BREAKER CLOSED	1		
12	UNDER VOLTAGE RELAYS	4		
13	BREAKER STATUS	8		
14	PROTECTION TRIP	1		
15	FIELD SWITCH STATUS	2		
	BINARY OUTPUTS			
1	SYNCHRONISER ON/OFF		1	
2	SYNCHRONISER AUTO		1	
3	PROTECTION TRIP		1	
4	PLC FAILURE		1	
5	EXCITATION ON/OFF		1	
6	BREAKER COMMANDS OPN/CLS		4	
7	EMERGENCY SOLENOID VALVE		1	
8	GOVERNOR EQUALISATION VLV		1	

I/O COUNT					
	ANALOG INPUTS				
1	GEN BEARING TEMP FRONT			1	
2	GEN BEARING TEMP REAR			1	
3	TURBINE BEARING TEMP			1	
4	GEN TEMP			1	
5	GEN TEMPERATURE * 6			6	
6	GOVERNOR OIL TEMP			1	
7	PENT STOCK METERS HEAD			1	
8	rpm			1	
9	GV POSITION TRANSDUCER			1	
10	kW			1	
11	KVar			1	
12	AMPS			1	
13	VOLTS			1	
14	COS Ø			1	
15	GRID FREQUENCY			1	
16	GRID VOLTAGE			1	
	ANALOG OUTPUTS				
1	PROPORTIONAL VLV CONTROL SIG.				1
		B/I	B/O	A/I	A/O
	TOTAL	61	49	21	4

Legend

I/O	Input output signals to the PLC
A/O	Analog output signal
A/I	Analog input signal
B/O	Binary output signal
B/I	Binary input signal
TIV	Turbine inlet valve
BRG	Bearing
LVL	Level
KVar	Kilo Var.
KW	Kilo watt
rpm	Revolutions per minute
Gen	Generator
Temp	Temperature
CosØ	Power factor
VLV	Valve

The PLC structure is shown below.



9. Modes of operation

A description of the function of the modes of operation as depicted by the PLC logic diagrams are given below. It is essential that the description below are read in conjunction with the PLC logic diagrams.

9.1 ISOLATED mode of operation start up

The start-up sequence will be initiated via the start up group control tile on the local control panel or on the SCADA system.

In this mode of operation the PLC will issue the following commands to the plant.

The following states (releases) must be present before progressing to step1:

Guide vanes fully closed
Turbine inlet valve (TIV) fully closed
Mechanical over speed centrifugal switch reset
Governor oil level larger than minimum
Bearing oil temperatures less than maximum permitted
Turbine bearing oil level larger than minimum

9.1.1 Step 1

Issue commands to plant:

Open the turbine inlet bypass valve
Set governor Speed setpoint to 0%
Set governor Power setpoint to 0%
Set governor guide vane limiter to 0%

Issue indication step complete

9.1.2 Step 2

Before issuing commands the following feedback signals will be present:

None

Issue commands to plant:

Start TIV pump set
Open TIV servo motor control solenoid valve
Issue indication step complete

9.1.3 Step 3

Before issuing commands the following feedback signals will be present:

- TIV fully open

Issue commands to plant:

- Start governor oil pump set
- Energise the emergency close solenoid valve in the governor system
- Issue indication step complete

9.1.4 Step 4

Before issuing commands the following feedback signals will be present:

- Governor oil pressure larger than minimum

Issue commands to plant:

- Set guide vane limiter to (Speed no load position ±3% of guide vane opening)
- Set the guide vanes to 5%
- Select the governor Speed setpoint to 750 rpm

Once the error between the Speed setpoint and the actual machine speed is less than 1%:

- Set the guide vane limiter to 95%
- Issue indication step complete activate the indication ISOLATED operation

An ISOLATED mode start up will be initiated by:

- Command from the SCADA system
- Command from the local control panel

- Automatic command from the PLC when the BLACK START mode is selected.

9.2 SYNCHRONISED operation

This mode will be selectable on the local control panel and on the SCADA screen.

In this mode of operation the PLC will issue the following commands to the plant:

Steps 1 to 4 as above but will progress to step 5

9.2.1 Step 5

Before issuing commands the following feedback signals will be present:

- Deviation between the Speed setpoint and the machine speed is less than 1%

Issue commands to plant:

- Synchroniser on
- Select grid frequency as Speed setpoint
- Multiply the Speed setpoint by 1,01
- Generator excitation on
- Activate the synchroniser

If the "breaker closed" feedback is not received within 40 seconds the synchroniser is enabled to raise or lower the Speed setpoint.

Once the breaker closed feedback is received the following actions will be executed:

- Multiply Speed setpoint by 1,00
- Synchroniser off
- Raise the power controller setpoint to pre-set Power setpoint at a rate of 20 kW per second
- Issue the indication SYNCHRONISED run up complete once the pre set power output is reached

The power controller setpoint is set to 0% on the following conditions:

- If GEN breaker is opened
- If GEN breaker is closed and Station transformer breaker 1 and Station transformer breaker 2 are open
- If the bus coupler is opened

A SYNCHRONISED mode start up command will be possible from:

- Command from the SCADA system
- Command from the local control panel

9.3 BLACK START operation

BLACK START mode is essentially the same as ISOLATED operation with the difference that the plant will stand idle until a BLACK START condition occurs.

A BLACK START condition is when all the main power boards in the station are dead. The PLC will continuously monitor the station boards and when no voltage is detected the plant will be started up as described below.

This mode will be selectable on the local control panel and on the SCADA screen.

Detecting a BLACK START

When this mode is selected the PLC will continuously monitor the Station transformer 1 and Station transformer 2 for under voltage. In the event of a under voltage being detected in either one of the boards the PLC will issue the following commands to the plant:

9.3.1 Step 1b

- Open Station transformer 1 breaker
- Open Station transformer 2 breaker
- Open bus coupler breaker

9.3.2 Step 2b

Before issuing commands the following feedback signals will be present

- Station transformer 1 breaker opened

- Station transformer 2 breaker opened
- Bus coupler breaker opened
- Perform start-up steps 1 to 4
- Issue command to close generator breaker

After 10 seconds issue command to close bus coupler breaker and disable the switch gear of the drives as per page 25 and 26 of the APPENDIX C: PLC LOGIC DIAGRAMS

If less than 60 % of the 750 kW is used additional drives can be started. As soon as more than 60% of the 750 kW is utilised no more drives will be permitted to start.

9.4 Normal Shutdown

The shut down sequence for all modes are the same:

9.4.1 Step 51

Issue commands to plant:

- Ramp Power setpoint to 0% at a rate of 10 kW per second
- Once the power output is less than 10 kW issue command to open the generator breaker
- Set Guide vane limiter 0%
- Set the Speed setpoint to 0%
- Excitation off
- TIV oil pump off

After 3 seconds:

- Governor emergency close solenoid de-energise
- Governor oil pump off
- Issue indication step complete

9.4.2 Step 52

Once 0% speed is present for 120 seconds:

- Turbine bearing oil pump off
- Under speed reset in the logic
- Issue indication step complete

A normal shutdown will be initiated by the following.

Command from the SCADA system
Command from the local control panel
Automatic command in the PLC BLACK START mode

9.5 Emergency shutdown

9.5.1 Step 55

- Set guide vane limiter to 0%
- Set Speed setpoint to 0%
- Set Power setpoint to 0%
- Command generator breaker to open
- TIV control solenoid valve close
- Excitation off

After 3 seconds:

- Governor pump set off
- Governor emergency solenoid de-energise

Once 0% speed is present for 120 seconds - turbine bearing oil pump set off.

9.5.2 Step 56

A emergency shutdown will be initiated under the following conditions:

- Electrical protection operated
- Speed larger than 1040 rpm
- A speed of less than 650 rpm is experienced for more than 4 seconds after the machine has reached 750 rpm
- Turbine bearing oil level less than minimum
- GEN bearing 1 temperature larger than maximum permitted
- GEN bearing 2 temperature larger than maximum permitted
- Turbine bearing 1 temperature larger than maximum permitted
- Turbine bearing 2 temperature larger than maximum permitted

- Governor oil pressure less than minimum
- PLC failure
- Guide vane controller failure

10. Alarms

Section 8 contains a list of all analog variables that will be alarmed. All alarm outputs will have a 2 second delay to avoid spurious alarm generation caused by spikes and noise. All alarms will be generated in the PLC and not in the SCADA system, and logged on the SCADA alarm screen and historical database.

Switchgear faults for all the drives will be logged and alarmed in the SCADA.

Analog field devices falling out of range will be logged and alarmed in the SCADA.

Alarms.will be indicated on the local control panel as per panel layout diagram.

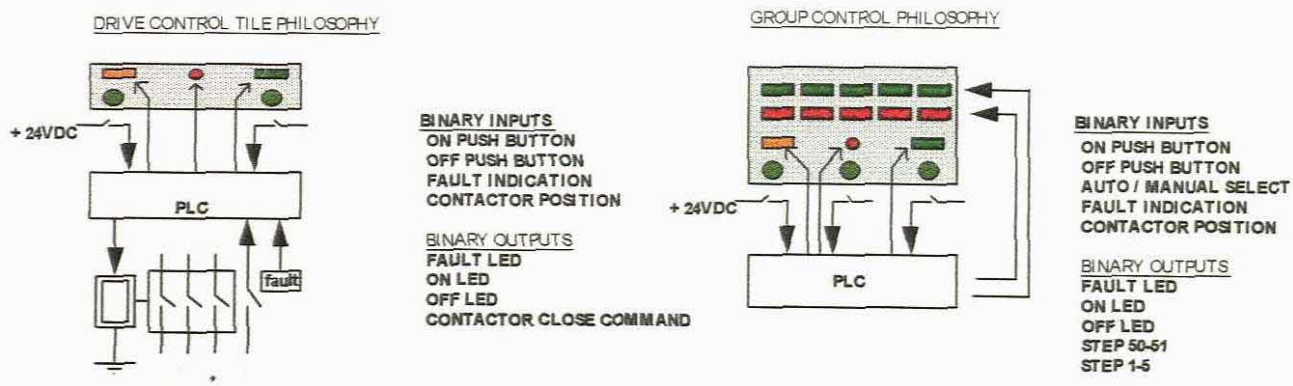
On initiation of a alarm the relevant alarm tile will flash at 2 Hz. Alarm status will be indicated on the SCADA system in different colours for; accepted alarms, new alarms and alarm conditions that have cleared.

Alarms will have a re-flash facility. An accepted alarm will be illuminated constantly, if the alarm reoccurs it will flash at 2 Hz. Alarms will be audible to draw operator attention.

The acknowledging of alarms will be time stamped and logged in the database.

11. Local control panel

The local control panel can be seen in APPENDIX A:LOCAL CONTROL PANEL.



The drive control tiles on the local panel will have the following functions:

On push-button
Off push-button
On status indication
Off status indication
Drive fault indication

The sequence control tile will have the following functions:

Start sequence push-button
Stop sequence push-button
Auto / Manual selection push-button
Step status indication for every individual step
Step fault indication for every individual step
Sequence fault indication

Automatic group control

In this mode the group control module is selected to Auto. On pushing the start-up push-button the system will automatically progress through the start up steps depending on the mode that is selected ISOLATED, BLACK START or SYNCHRONISED as previously described in the modes of operation.

As the system completes the various start-up steps this will be indicated on the relevant LEDs on the Group control tile.

On pushing the shutdown push-button the system will automatically progress through the shutdown steps depending on the mode that was selected.

As the system completes the various shut down steps this will be indicated on the relevant LEDs on the control tile.

The status of the various drives will be displayed on the drive control tiles as they are switched on and off by the sequence.

Auto/manual control

By selecting the Auto push-button on the group control tile none of the drives will be able to be operated by means of the stop/start push buttons on the tiles.

By selecting the Manual mode on the group control tile by depressing the manual push button, operation of the various drives will be possible via the stop/start push buttons on the tiles, providing that it is allowed by the relevant interlocks as indicated on the PLC logic diagrams.

In Auto mode only the altering of the Power setpoint will be possible.

All operation in manual mode will require that the release push button is pressed simultaneously with the relevant command push button. If a command push button is pressed without the release push button the command will not be executed.

The turbine bearing lubrication oil pump will not be able to be switched off manually unless the machine speed is 0 rpm for 120 seconds, to ensure adequate lubrication to the turbine bearings.

In the event of the fault signal being received from the drive switch gear, the centre LED on the tile will flash and a grouped alarm will be initiated.

Local Control Panel

The following variables will be displayed on the local panel with digital indicators :

- Generator Kilo watts
- Generator amps
- Generator volts
- Generator Vars
- Generator temp 1
- Generator temp 2
- Machine rpm
- Guide vane position
- Governor oil pressure
- Generator bearing temp 1
- Generator bearing temp 2
- Turbine bearing temp 1
- Turbine bearing temp 2

The following alarms will be indicated:

- Reverse power detected
- Governor oil level low
- Governor oil pressure low
- Generator bearing oil level low
- Turbine bearing oil level low
- Speed over 1040 rpm
- Turbine bearing temp high
- Generator bearing temp high
- Generator temp high
- Generator trip
- Generator protection operated
- AVR supply failure
- Generator voltage failure
- PLC failure

A raise and lower push-button will be provided for Speed setpoint, Power setpoint and Guide vane limiter. These analog values will also have digital indicators.

A selection facility for the 3 modes will be provided with indicators. This function will be limited by key switch.

The local control panel will also incorporate a electrical section with the following functions:

- Graphical display of the electrical reticulation
- Indication of breaker status
- Synchroscope
- Breaker close push button
- Manual synchronising on / off selection
- Grid voltage analog display
- House Set generator voltage analog display
- Grid frequency analog display
- House Set generator frequency analog display
- Breaker synchronisation selection facility

A lamp test facility will be provided to indicate any failed LEDs on the display.

The panel dimensions will be 500 mm by 600 mm and located at eye level for ergonomic ease of operation.

12. Valve and drive status

When a drive is running or a valve is in the open position the LED on the symbol will be illuminated green. If not the LED will be red. Dual colour LEDs will be utilised for this purpose. The drive status will be indicated on the SCADA screens by a change of colour as for the local control panel.

13. Emergency trip push button

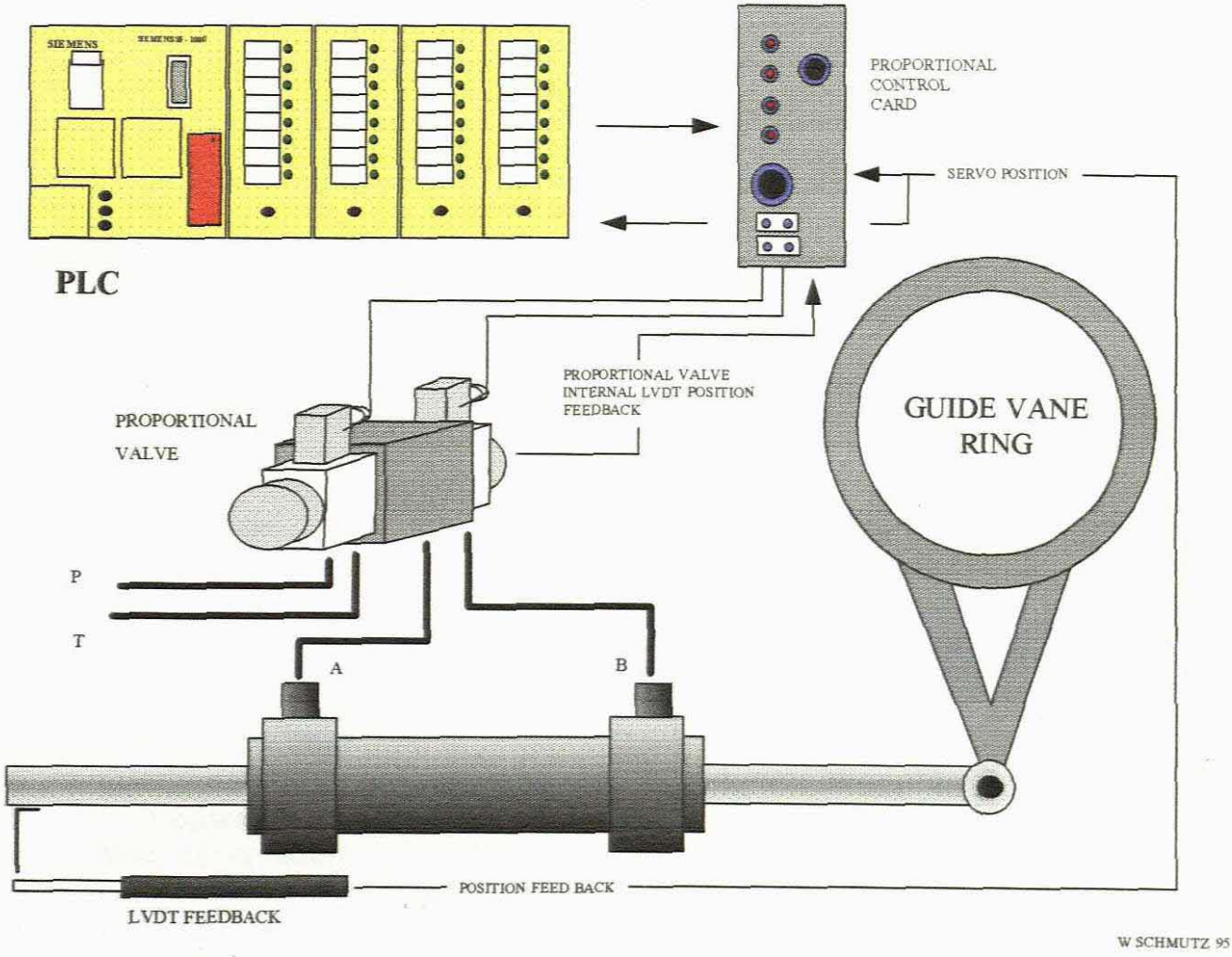
The activation of the trip push button will also require the simultaneous pressing of the release push button. The system will execute the emergency shut down sequence on activation of the trip push button.

14. Interface to the hydraulic system

The interface to the hydraulic system will be by means of a 4-20 mA signal to a electronic Proportional control card from a PLC analog output.

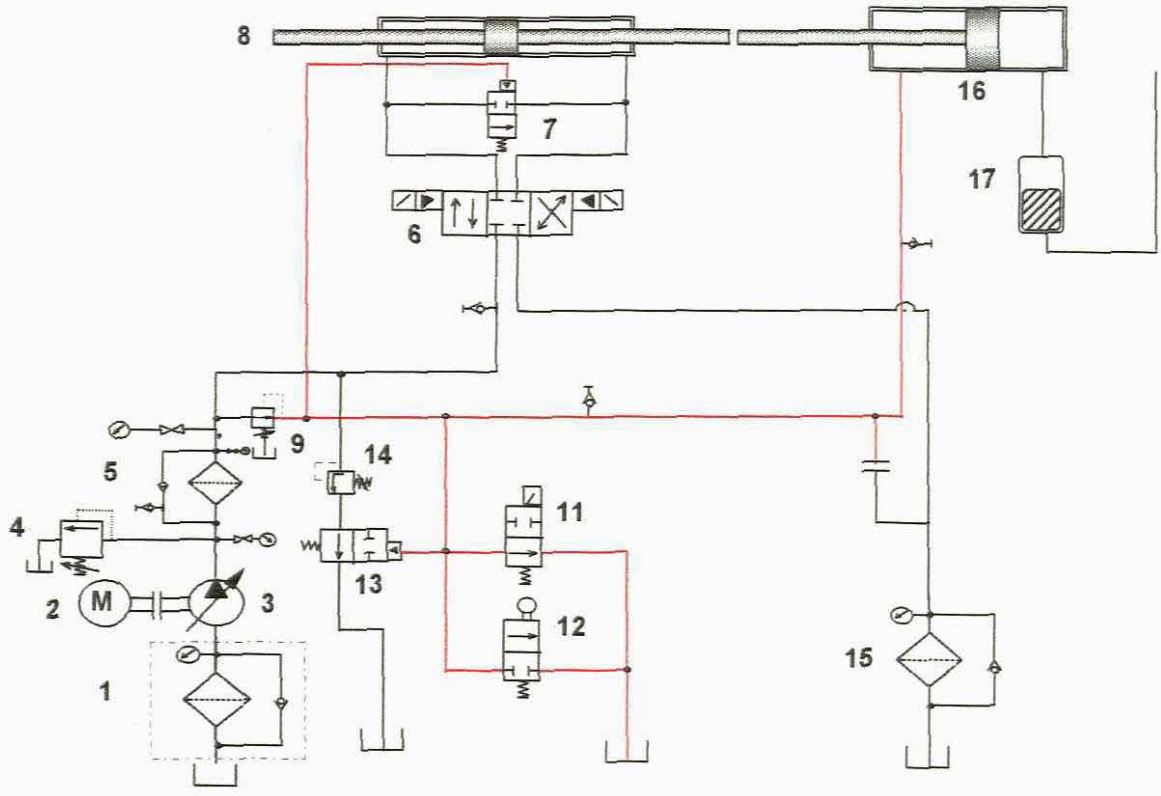
The guide vane position signal generated by the governor software block in the PLC will supply the proportional control card with the guide vane setpoint. The proportional control card will position the main servo motor to setpoint by means of the Proportional control valve. The proportional control card contains all the required PID control elements including acceleration control.

INTERFACE CONCEPT



The governor concept is shown above with the electronic interface to the proportional control valve and the connection of the servo motor to the guide vane ring.

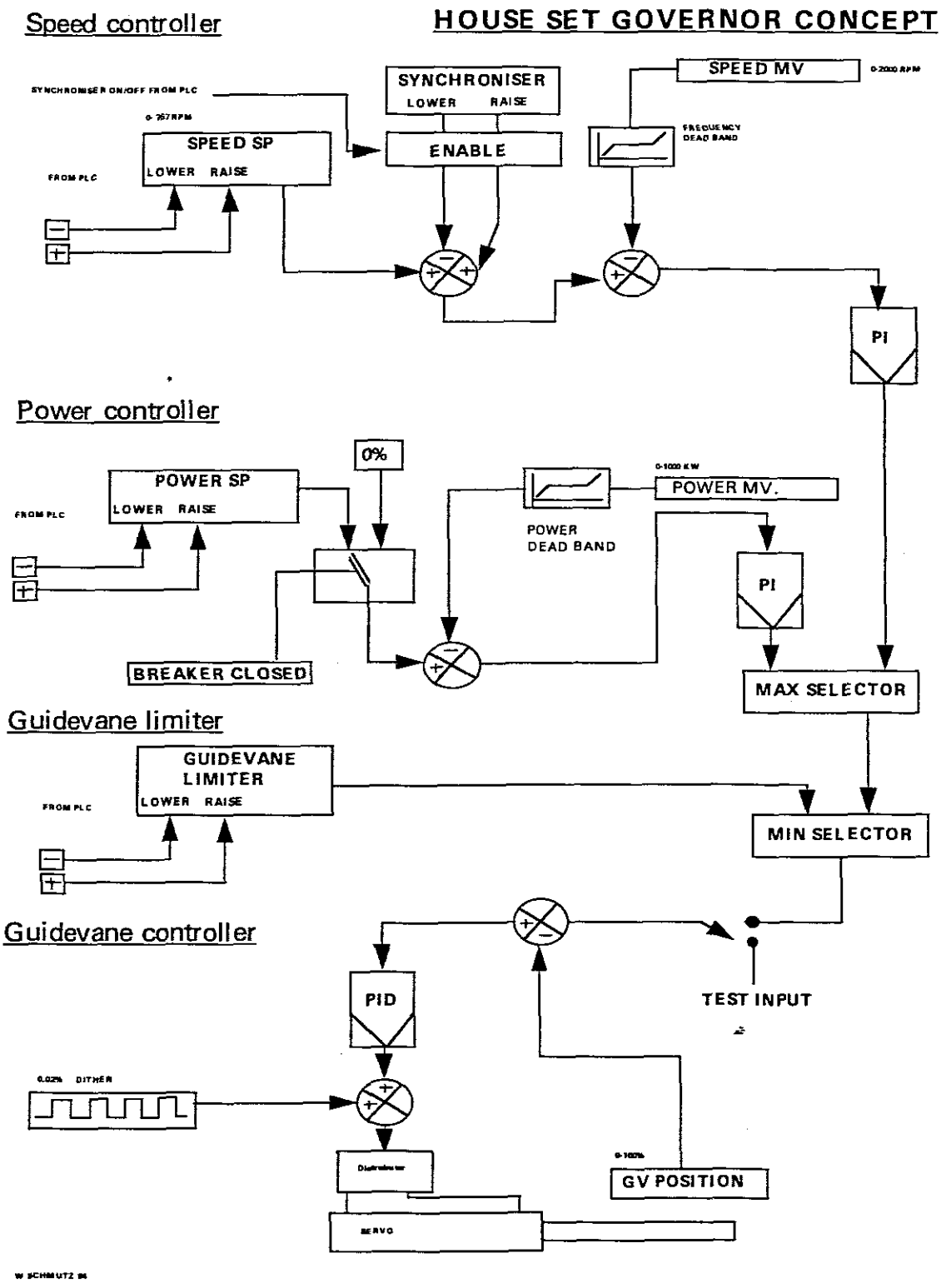
The detail hydraulic system design is shown below



Component legend

1 Suction filter
2 Electric motor
3 Pump
4 Pressure relief valve
5 Pressure line filter
6 Main Proportional control valve
7 Pilot operated balance control valve
8 Main servo motor
9 Pilot system pressure reducing valve
10 Rupture disk
11 Electrically operated shutdown valve
12 Mechanical overspeed shutdown valve
13 Main system dump valve
14 System dump sequence valve
15 Return line filter
16 Water servo
17 Water oil separator

15. GOVERNOR CONCEPT



The governor system will be realised in a software block in the PLC and will be structured as above. APPENDIX C: PLC LOGIC DIAGRAMS should be read in conjunction with the description below.

The system consists of 3 control loops integrated into one main functional control loop namely:

- Speed controller
- Power controller
- Guide vane controller

The only controller that is not part of the PLC governor software block is the guide vane controller.

Speed controller

The function of this loop is to control the speed of the machine at 750 rpm by means of altering the guide vane position.

A feedback signal will be in the form of pulses received from a pulse generator installed on the end of the generator shaft with a 4-20mA output signal. The speed feedback loop will have a accuracy and linearity of better than 0,2% of full range.

The controller will include the following:

Speed setpoint 0%-100% (0-800 rpm) in the form of a 4-20mA signal manipulated by the PLC.

Raise lower influence from the synchroniser in the form of pulses. For every pulse 1% will be added or subtracted from the speed setpoint.

An enable signal from the PLC for the synchroniser raise and lower pulses to be processed.

A speed feedback signal 4-20mA (0 - 2000 rpm) with a dead band element of 4 rpm, meaning that the signal has to fall out of the 748 to 752 rpm to be passed to the output.

A PI controller (Proportional Integral control functions)

Power controller

The function of this controller is to control the power output of the machine to the power setpoint, by means of altering the guide vane position once the machine is synchronised with the grid.

The following explinations should be read in conjunction with the governor concept drawing.

A setpoint signal of 0%-100% (0-800 kW) in the form of a 4-20mA signal is manipulated by the PLC.

A selection element to select between 0% and the actual setpoint depending on the Generator breaker status.

If the Generator breaker is open 0% setpoint is selected.
If the Generator breaker is closed actual setpoint is selected.

A power feedback signal 4-20mA (0-1000 kW) with dead band element of 5 kW, meaning that the signal has to change more than 5 kW before the output will change.

The PI controller then adjusts the output in order to regulate the power at the setpoint level.

Guide vane limiter

The function of this element is to limit the movement of the guide vane (during start up) to the opening corresponding to no load speed. By doing this the initial speed overshoot is avoided and the run up time shortened.
This signal of 0%-100% guide vane opening is manipulated via the PLC.

Guide vane controller

The function of this controller is to control the position of the guide vane to a setpoint generated by the combined function of the Speed controller, Power controller and the Guide vane limiter.

This will be a integrated function of the power control card for the Proportional control valve. The setpoint input to this card will be a 4-20 mA signal from the PLC.

Feedback of the actual guide vane position 0%-100% will be from a LVDT (Linear variable differential transformer) type device, in the form of a 4-20 mA signal.

A dither signal to eliminate friction sticking in the hydraulic system will be incorporated. This is a small square wave signal superimposed on the DC control signal.

The electronic control card will include the following functions:

- Test facility to adjust the setpoint of the guide vane between 0% and 100%.
- Self monitoring function.
- In the event of a failure the card will drive the guide vanes to the closed position via the Proportional control valve and hydraulic system.
- Electronic adjustment of hysteresis, linearity, opening speed, closing speed, damping and acceleration.
- Volt DC supply.
- Input and output signals of 4-20mA.
- Integrated PID controller.
- Matched to the Proportional control valve selected.
- A input signal for the internal LVDT position feedback of the proportional control valve.

The selection of equipment must be such to ensure a total loop accuracy of better than 0,5% for the positioning system, meaning that if a setpoint of any value between 0-100% is selected the loop will position the guide vanes at the selected position to +/-0,5%.

If a setpoint of 50 % is selected, the guide vane will be positioned between 49.75 and 50,25%.

Maximum selector

This element will select the maximum between the speed controller output and the power controller output. Whichever signal is the biggest will be passed to the output of this element.

Minimum selector

This element will select the minimum between the maximum selector output and the Guide vane limiter. Whichever signal is the smallest will be passed to the output of this element.

16. Interface to the electrical system

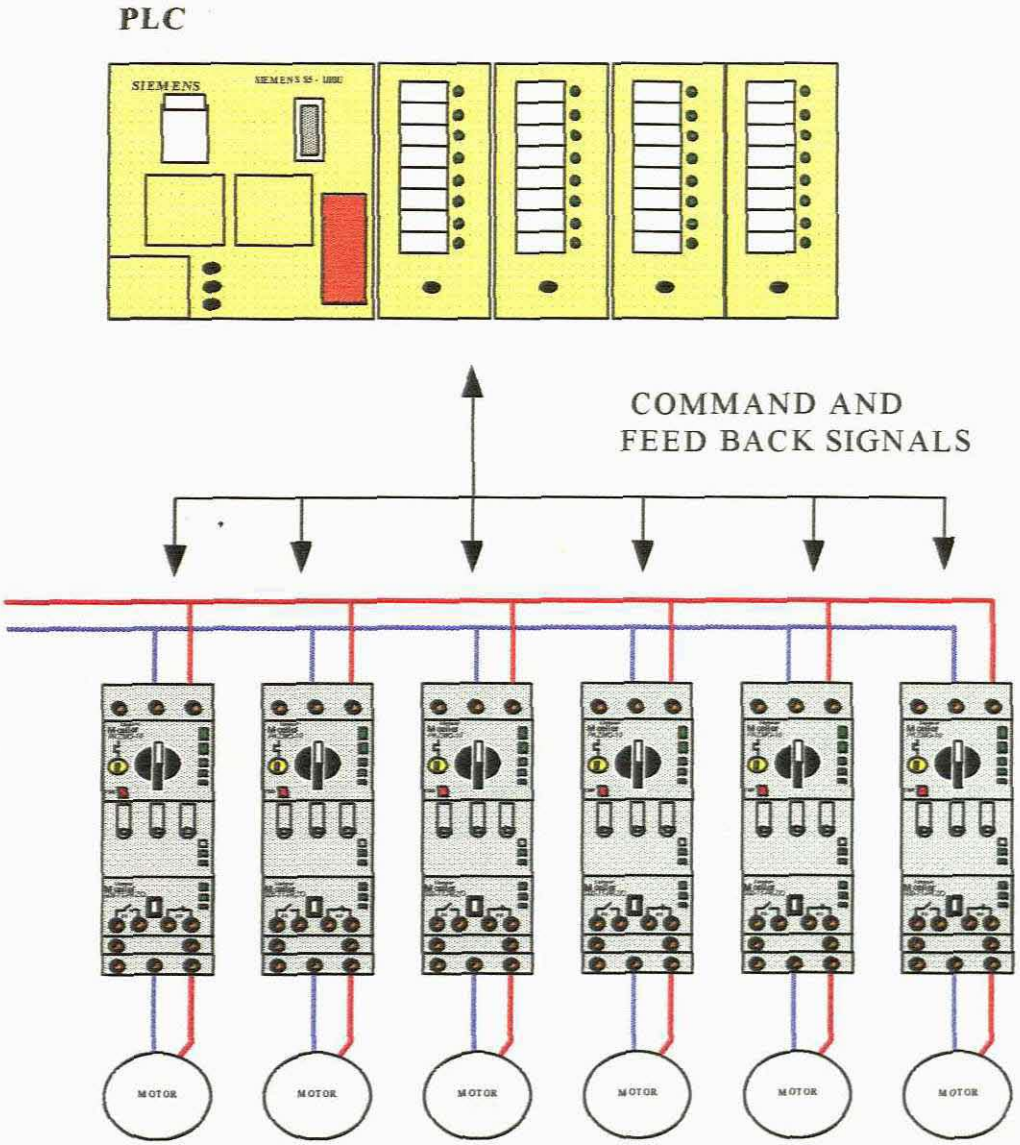
The binary signal interface between the electrical system and the PLC control system will be by means of potential free changeover contacts.

The analog signal interface between the electrical system and the PLC control system will be by means of galvanically isolated 4-20mA signals.

All electrical plant variables monitored by the Electrical protection and metering system will be incorporated as PLC inputs and displayed on the appropriate SCADA screens and local panel as shown on the relevant graphics.

The interface between the PLC system AVR and synchroniser will be in accordance with the logical diagrams and descriptions. Refer to APPENDIX C: PLC LOGIC DIAGRAMS.

17. Switch gear interface



Above the links from the PLC to the compact motor starters(switch gear) can be seen. The interface to the switch gear will be by means of potential free contacts.

The switch gear supplied for drives will be of the non-latching type, so that when the control signal from the PLC is lost the contactor will open as a safety function.

The switch gear supplied for the Turbine bearing oil pump will be of the latching type, so that if the control signal from the PLC is lost the contactor will remain closed. The contactor will require a pulse to unlatch the circuitry and open the contactor. This will ensure that sufficient lubrication is supplied to the turbine bearings during rundown.

The switch gear will be of compact DIN rail mount type with the following functions.

- Adjustable over current and thermal protection
- Isolator switch
- Local ON, OFF and REMOTE selection
- Fault indication with potential free change over contact to signal PLC
- Contactor status indication with potential free change over contact to signal PLC
- 24 VDC interposing relay to energise contactor coil
- Pad locking facility

All switch gear will be suited for their application and will be sized according to the drive requirements with 10% over capacity.

17.1 Switch gear disabling

For the function of controlled starting of drives in BLACK START mode depicted on pages 25 and 26 of the APPENDIX C: PLC LOGIC DIAGRAMS , the switch gear of the relevant drives will be modified, by introducing a interposing relay that will disable the starting of the drive when the interposing relay is energised by a signal from the PLC.

When the PLC is off or non operational the contact of the relay will be closed allowing for the drives to be started.

Once a drive is running the start disabling relay will be inhibited, which will ensure that drives which are running are not switched off when the PLC issues the start disabling command.

Listed below are the essential pumps and compressors that will need to be started in sequence.

- Drain pump 1
- Drain pump 2
- Drain pump 3
- Auxiliary sump pump A1
- Auxiliary sump pump A2
- Auxiliary sump pump B1
- Auxiliary sump pump B2
- Sewerage pump 1
- Sewerage pump 2
- SCO compressor 1

- SCO compressor 2

The above is required to avoid the condition where the House Set can be overloaded to a point where the required regulation can not be achieved.

18. FINDINGS

To verify and prove the new philosophies of the control system structure, it would be ideal to simulate the most important aspects such as the man machine interface, and the logical functions.

To do this, all the graphics windows that will be displayed to form the man-machine interface were created. This consisted of over 36 graphical screens that incorporated in excess of 500 dynamically linked and animated objects.

The graphical screens were generated by utilising the In Touch SCADA system software. These screens can be seen in Appendix B: SCADA SCREENS and are described under previous sections of this thesis.

In order to make this simulation as true to life as possible the essence of the predicted plant response had to be captured.

The objective was to simulate the entire function of the plant in real time to prove the functionality of the entire man-machine interface including all mouse operations, dynamic graphics, animation and logic control aspects of the design.

The starting and stopping of motors in the manual mode of operation, using the mouse to activate dynamic points on the screen, was the first part of the system to be simulated. The result achieved was correct and on activation of the motor stop/start button, the corresponding colour change was an effective indication of the status of the motor. It was also observed that all animation aspects of the design were achieved.

The condition of the motors and valves was then linked to the logic diagram and it was observed that the graphical logic representational diagrams reflected the corresponding motor and valve status.

The next step was to simulate the start up sequence. To achieve this, all the drives had to be linked into the sequence as dictated by the logic diagrams previously discussed. The sequence was simulated on a time base with times to open and close valves taken from real plant data.

The sequence diagrams also had to be displayed if selected, indicating the steps and status of motors and valves in real time as the sequence progressed through the various steps. See APPENDIX B: SCADA SCREENS.

This also incorporated 3 different start up sequences for the 3 modes of operation, which required the simulation and interlocking of hundreds of events. The modes were individually selected and the start up initiated. The appropriate motors and valves were activated and de-activated in accordance with the logic specifications for each mode. After several alterations and many hours of redesign, the simulation achieved a 100% correctness with regard to automatically starting up and shutting down the plant, including motor and valve status display on the logic diagrams.

The most difficult part of the plant to simulate was the response of the governor and the guide vanes. This was achieved by utilising plant related transfer functions with regard to the speed feedback response time of the system and the time delays of the hydraulic system. To achieve this, many hours were spent on the tuning and adapting of the simulation to give a suitable response comparable to the real plant. It should also be borne in mind that the governing system was also incorporated as part of the shutdown and start up procedures.

Another aspect that complicated matters was the required function of manual operation of the governor system, which had to be interlocked to the status of the relevant motors and valves. Finally the governor was incorporated into the automatic sequence control simulation and the simulation functioned correct in all modes of operation. The governor system also includes a large amount of animation of the guide vane position, hydraulic cylinder motion and turbine rotation.

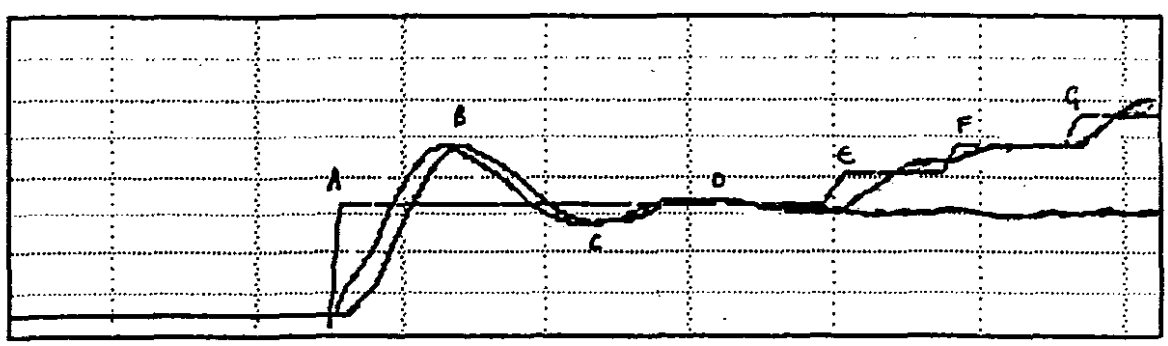
The final part of the simulation included the linking of variables and parameter to the electrical and alarm screens.

Finally a total simulation of the plant in its 3 various modes of operation was achieved correctly. After all the simulations were concluded, it was found that the simulation on its own can be used for training.

Below a response during a start-up can be seen. It should be noted how close the guide vane position and speed of the machine is related in this simulation. It can also be noted that the guide vane leads the speed response by ±0,7 second. Synchronisation occurred just after point D on the trend.

The legend to the graph is as follows.

A. Setpoint change from 0% speed to 100% speed.
B. First speed overshoot.
C. Second oscillation.
D. Steady state.
E. Increase of Power setpoint after synchronisation.
F. Further increase of Power setpoint as the machine ramps up.
G. Further increase of Power setpoint as the machine ramps up to 100% load.



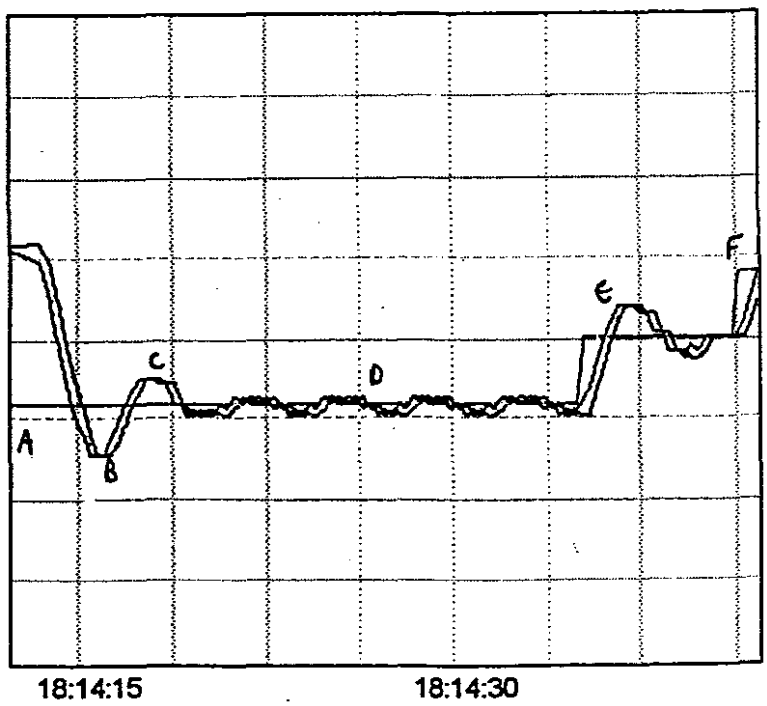
X Scale = 10 Seconds per division
Y Scale = 33% per division for speed
Y Scale = 10% per division for guidevane position

Graph 1: Simulation response from Start-up to synchronisation and loading.

Below a response to a rapid changing speed setpoint can be seen. It can be noted that the system P parameters were set in order to demonstrate the response of a under damped system.

The legend to the graph is as follows.

A. Setpoint change from 100% speed to 45% speed.
B. First speed overshoot.
C. Second oscillation.
D. Steady state with oscillations cause by under damping.
E. Increase of Speed setpoint with first speed overshoot.
F. Further increase of Speed setpoint.



X Scale = 5 Seconds per division
Y Scale = 20% per division

Graph 2: Simulation response to rapid changing speed set point.

19. FUTURE WORK AND DEVELOPMENT

Linked to this project, the development of a real time governor optimisation system is envisaged. The objective will be to develop a low cost optimisation package that can be included into the SCADA system or PLC software. This system will essentially manipulate the parameters of the governor system to find the optimum response parameters during transient and stable conditions.

The philosophy will be that of altering parameters in the direction where efficiency improves until an optimum point of operation is established. The system would then memorise the ultimate parameter settings for the various conditions. Such a system would save vast amounts of money if a mere 1% improvement in efficiency can be achieved.

Furthermore, the simulation basis of this development could be developed to such a extent that it can be utilised to develop a generic Hydro training simulator.

20. CONCLUSION

To conclude, a totally locally designed automation system for mini Hydro was developed over the period of 2 years. The system covered in this thesis is 100% implementable as confirmed and verified by the various simulations performed as discussed in the previous section.

The amount of animation, realistic plant graphical representation, functionality and philosophies with regard to the SCADA system developed, is superior to control systems for mini Hydros that were observed in Europe and Scandinavia. It can be stated that this development is probably one of the most advanced of its kind in the world.

The system is truly unique as it brings the total dynamic functioning of the internal components of the control system to the operator. This gives the operator the ability to perceive why and how the plant is functioning in a certain manner, and will greatly assist him in fault finding. This is also a new concept of live GLOBAL information for the human operator.

The system can be utilised for training, as it is a full working simulation of a functional plant giving the possibility to simulate fault conditions that will not be practical on a real plant

The system developed is generic and sets a local control philosophy and design standard that can be implemented on any mini Hydro turbine including a functional hydraulic system with only slight modifications.

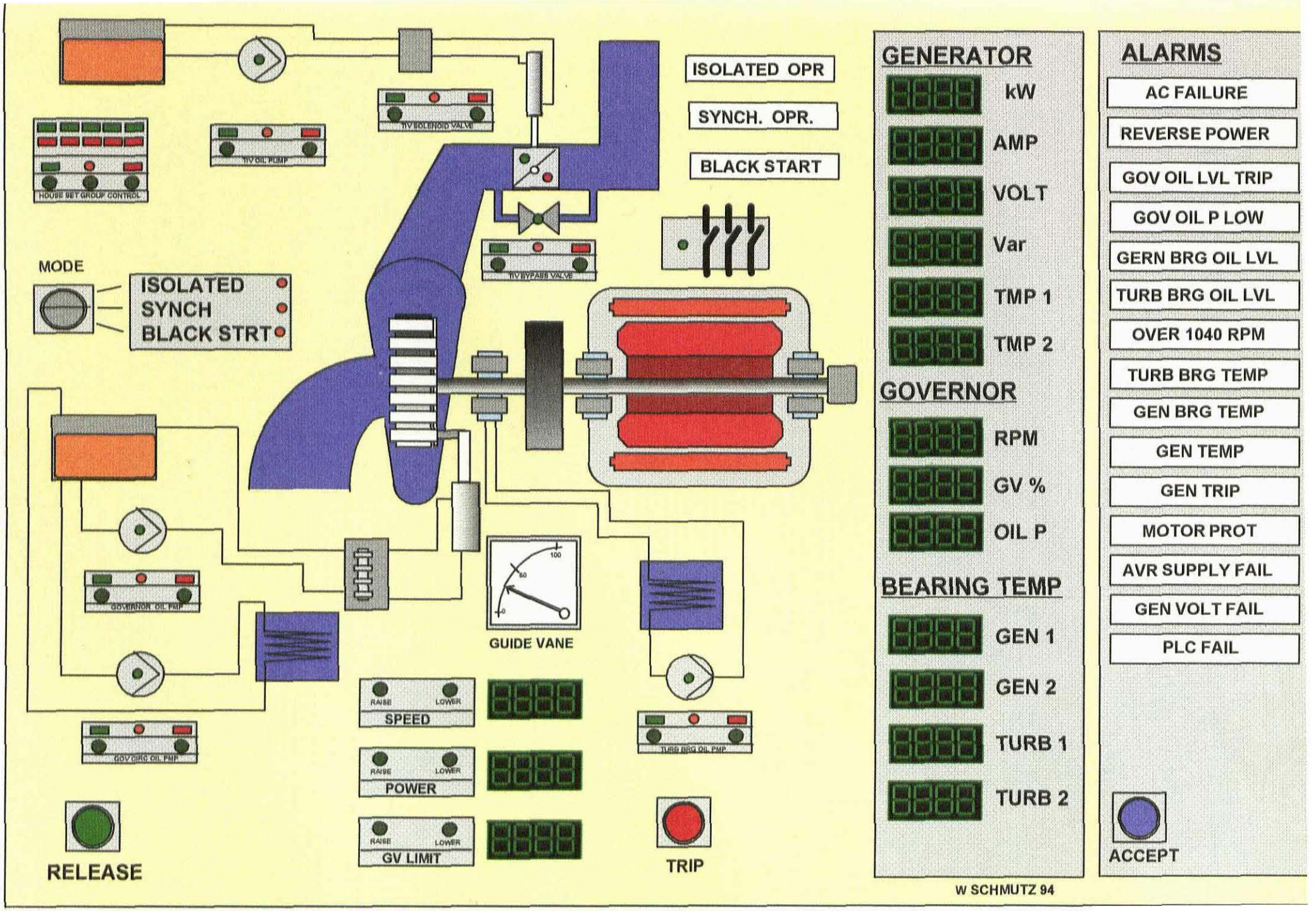
The development is ideal for the refurbishment of old mini Hydro turbine generating systems as it provides a tested automation standard and philosophy which will eliminate ± 95% of engineering work, cutting total project costs by 15 to 20%.

Invaluable local expertise and knowledge was obtained with regard to the automation of Hydro turbines, which to a large extent, will make ESKOM less dependent on overseas expertise.

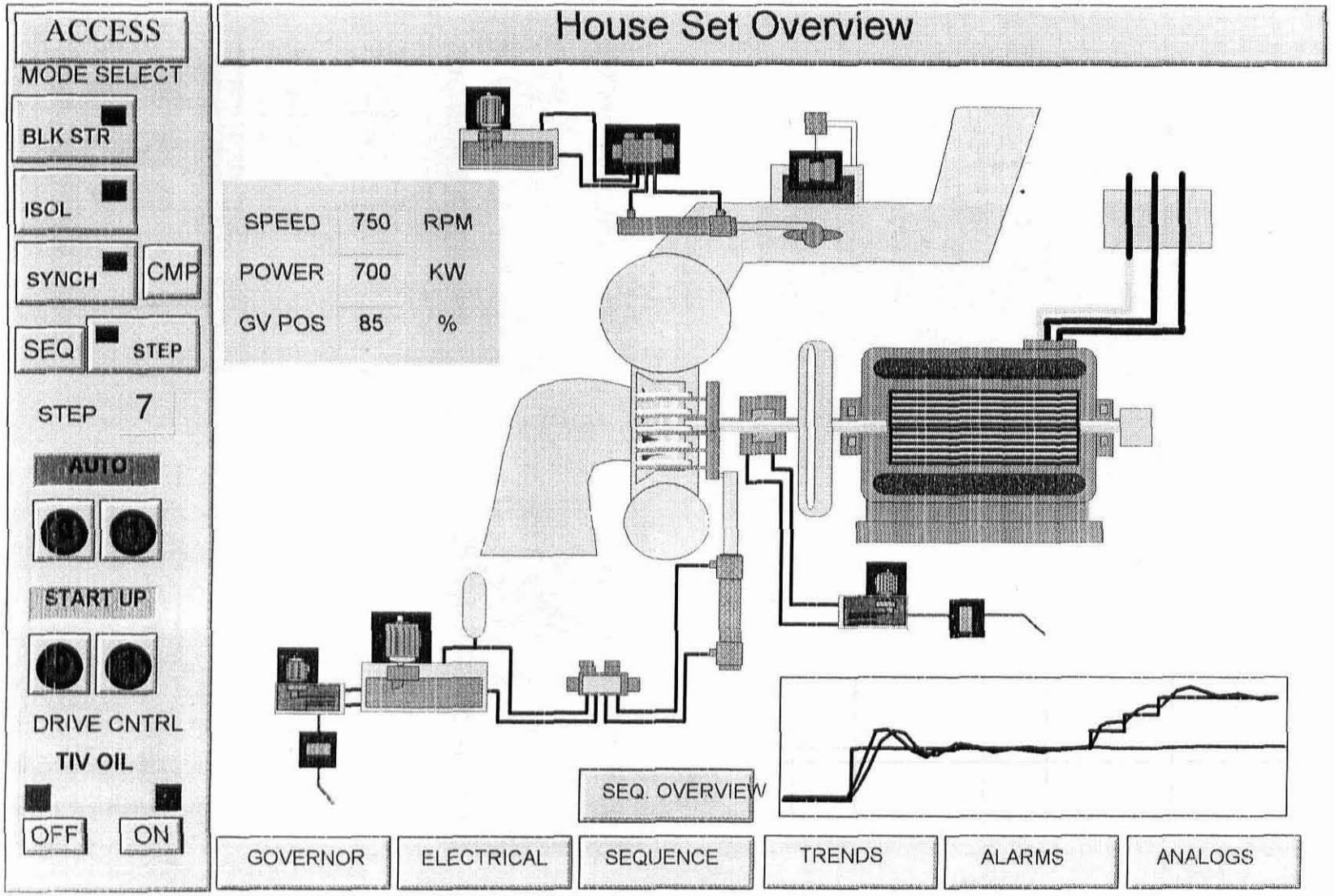
The final objective of a fully functioning automated mini Hydro, performing all functions described in this thesis will be realised by 15 November 1995 when the Gariep Power station House Set's automation will be completed utilising this development.

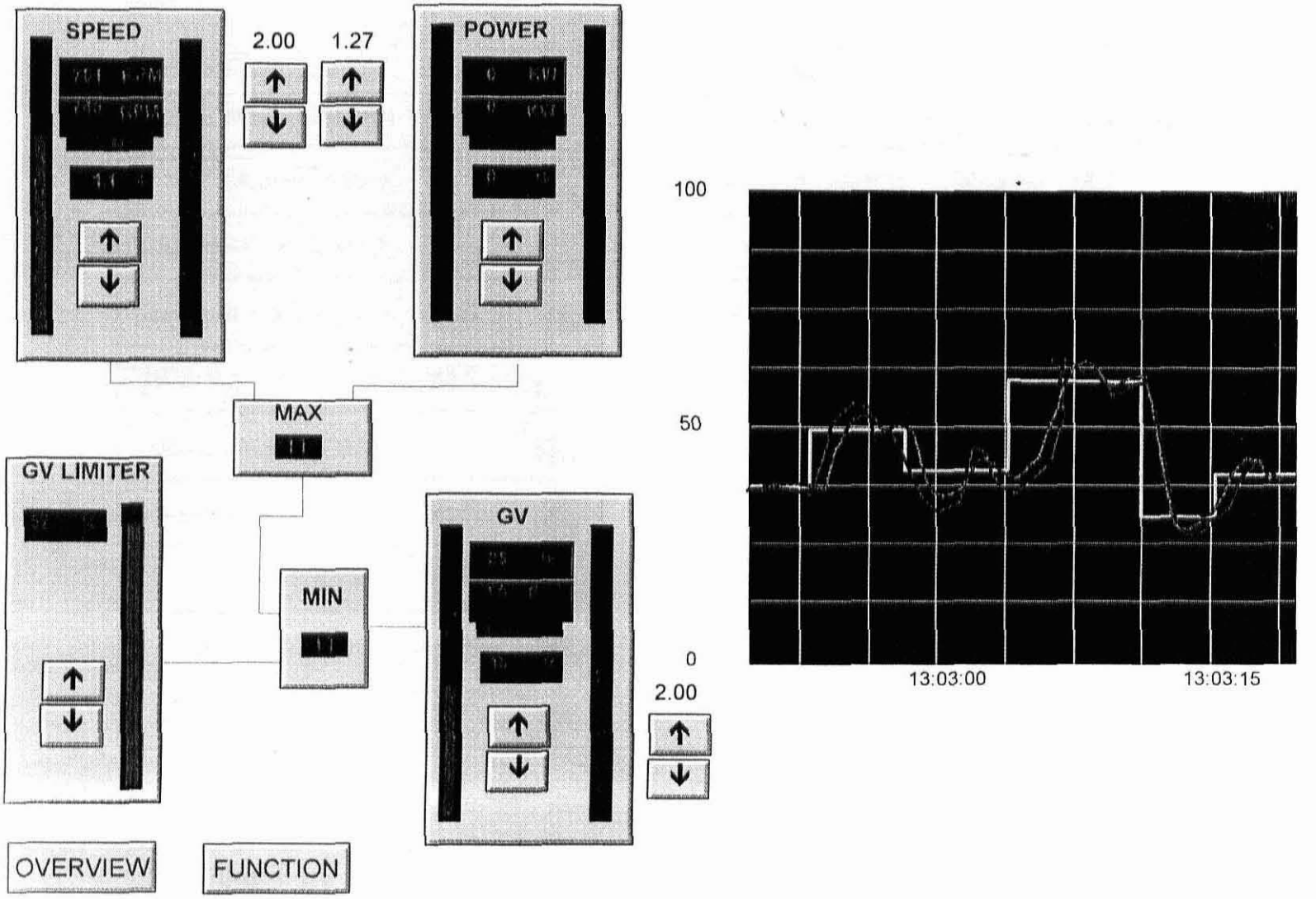
ooOOOoo

APPENDIX A:
LOCAL CONTROL PANEL


ISOLATED OPR
SYNCH. OPR.
BLACK START
HOUSE SET GROUP CONTROL
HV OIL PUMP
HV SOLENOID VALVE
HV BYPASS VALVE
MODE
ISOLATED
SYNCH
BLACK STRT
GOVERNOR OIL PMP
GOV BRG OIL PMP
TURB BRG OIL PMP
GUIDE VANE
RAISE
LOWER
SPEED
POWER
GV LIMIT
RELEASE
TRIP
GENERATOR
kW
AMP
VOLT
Var
TMP 1
TMP 2
GOVERNOR
RPM
GV %
OIL P
BEARING TEMP
GEN 1
GEN 2
TURB 1
TURB 2
ALARMS
AC FAILURE
REVERSE POWER
GOV OIL LVL TRIP
GOV OIL P LOW
GERN BRG OIL LVL
TURB BRG OIL LVL
OVER 1040 RPM
TURB BRG TEMP
GEN BRG TEMP
GEN TEMP
GEN TRIP
MOTOR PROT
AVR SUPPLY FAIL
GEN VOLT FAIL
PLC FAIL
ACCEPT
W SCHMUTZ 94

APPENDIX B:
SCADA SCREENS

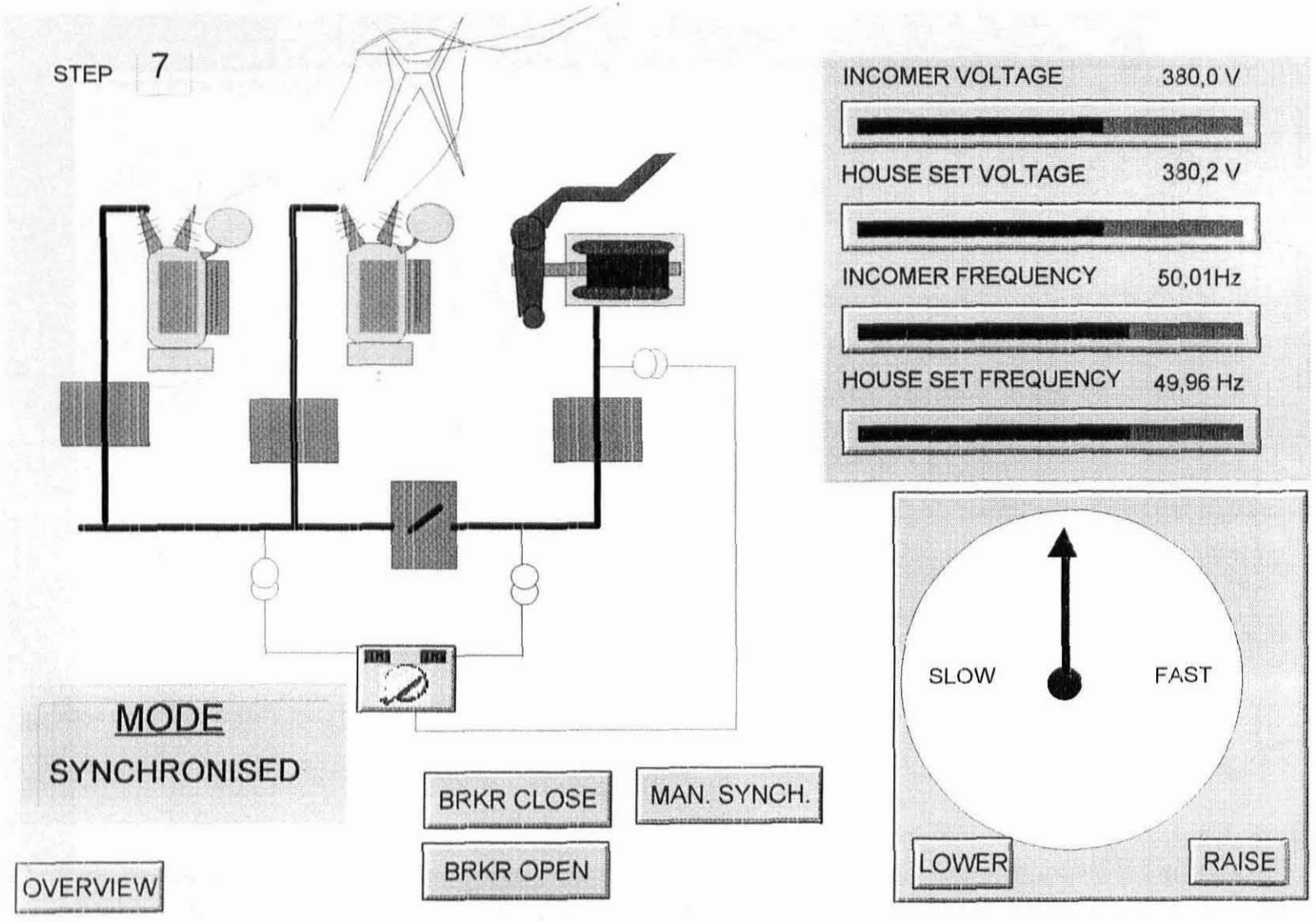

ACCESS
MODE SELECT
BLK STR
ISOL
SYNCH
CMP
SEQ
STEP
STEP 7
AUTO
START UP
DRIVE CNTRL
TIV OIL
OFF
ON
House Set Overview
SPEED 750 RPM
POWER 700 KW
GV POS 85 %
SEQ. OVERVIEW
GOVERNOR
ELECTRICAL
SEQUENCE
TRENDS
ALARMS
ANALOGS

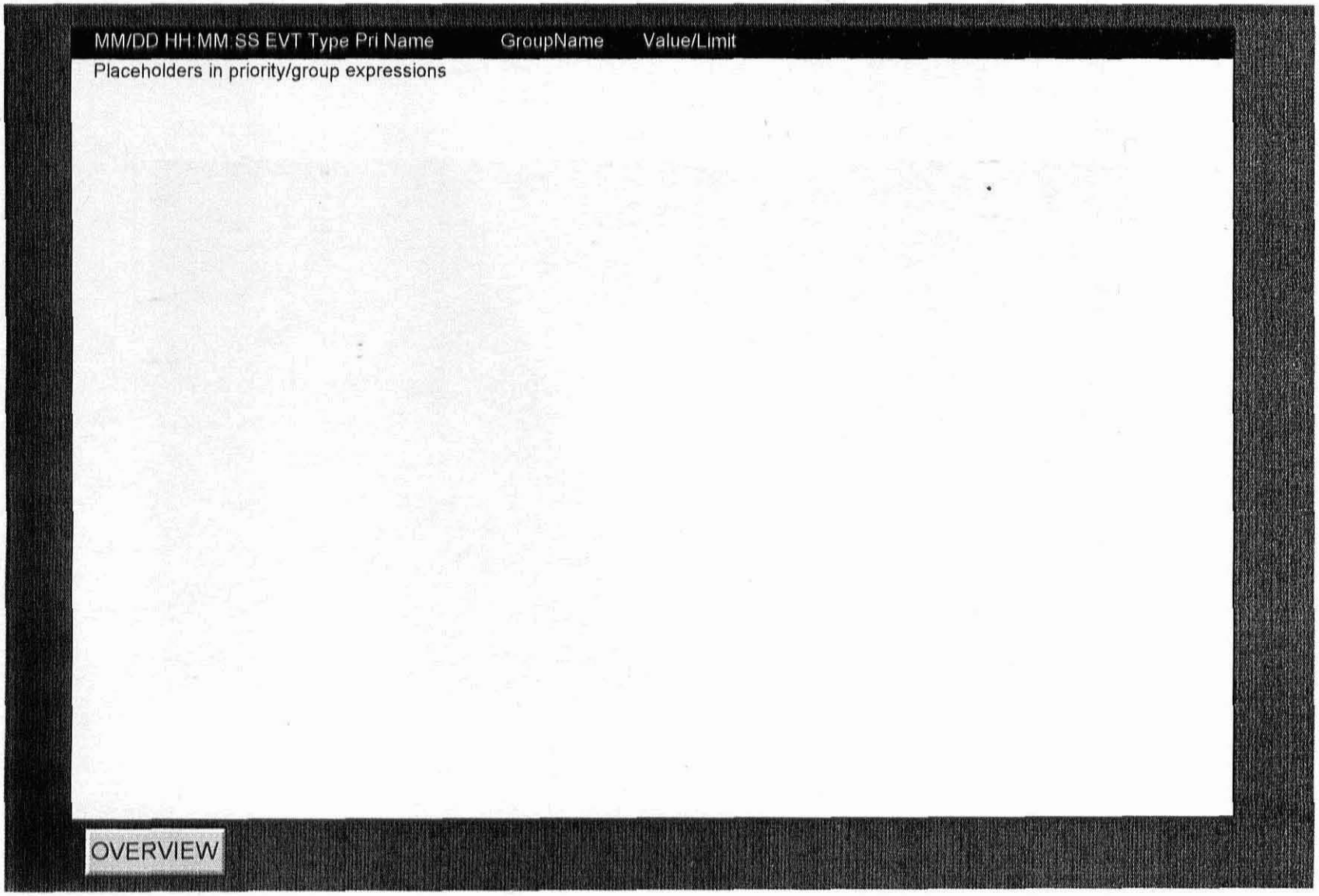

SPEED
2.00
1.27
POWER
MAX
GV LIMITER
MIN
GV
OVERVIEW
FUNCTION
100
50
0
2.00
13:03:00
13:03:15

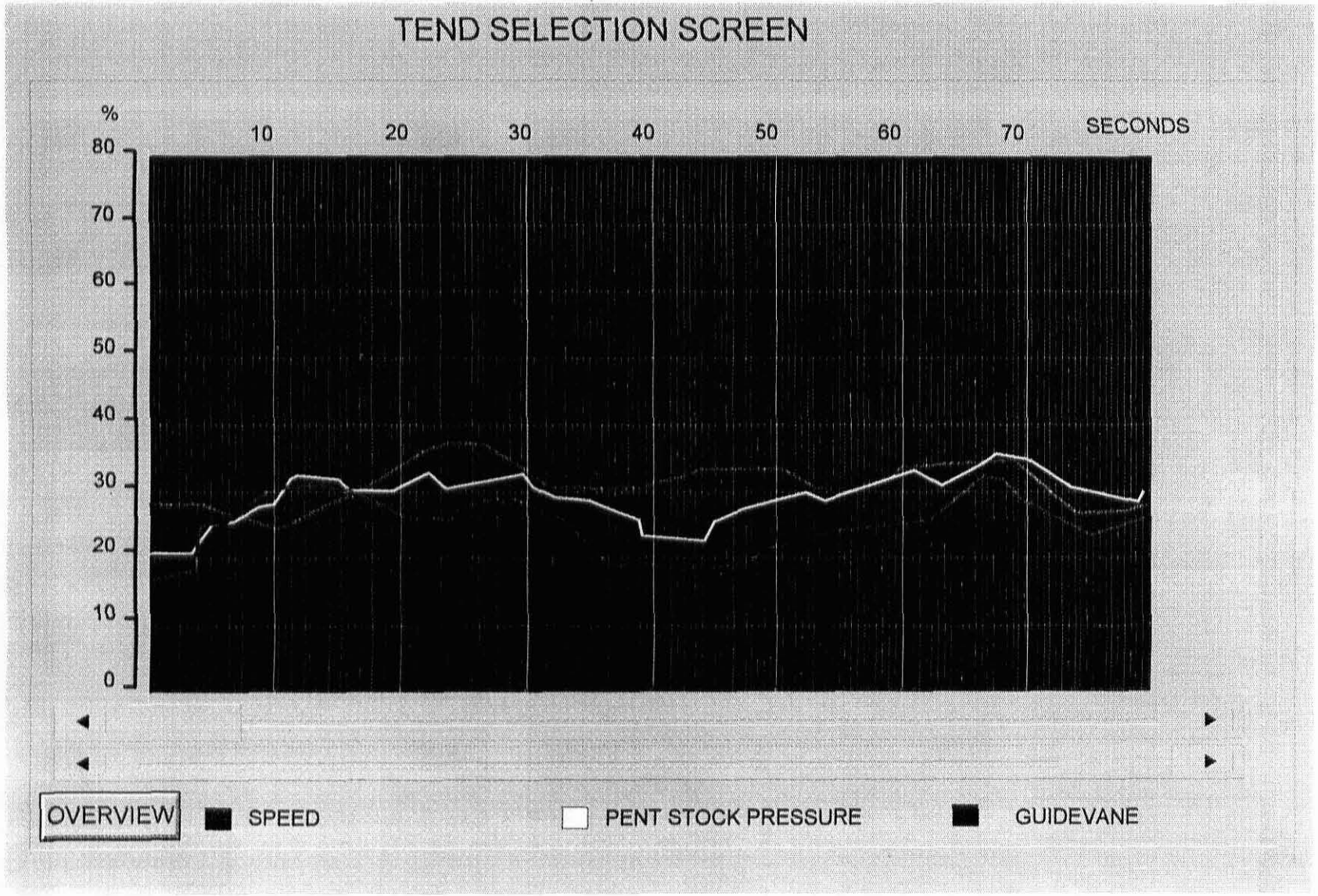
ANALOG INPUT VALUES

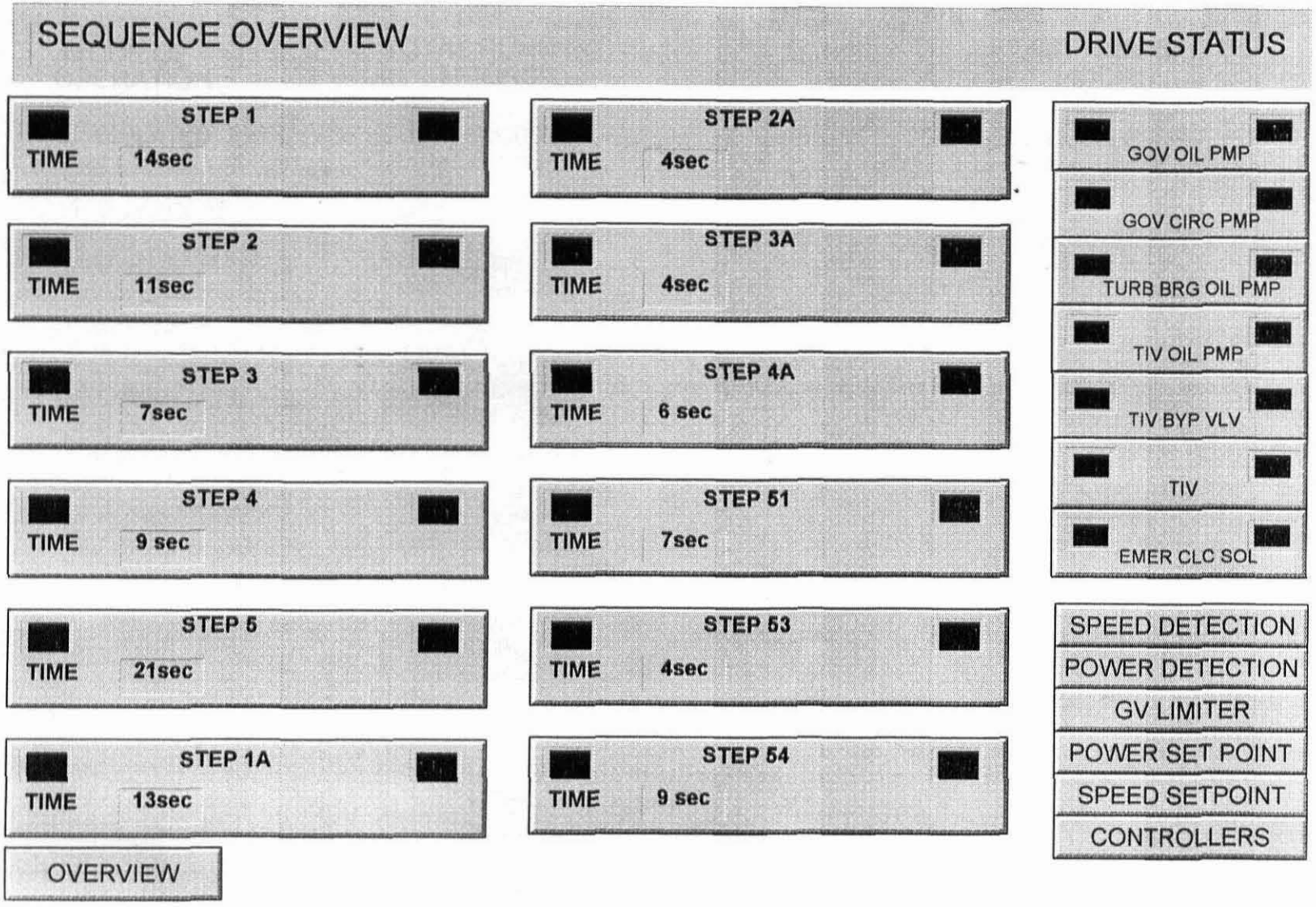
GUIDE VANE POSITION	64%		POWER FACTOR	1,2	
GEN BEARING TEMP F	55 'C		GRID FREQUENCY	50,02 Hz	
GEN BEARING TEMP R	55 'C		GRID VOLTAGE	44 KV	
TURB BERING TEMP F	55 'C		GENERATOR FREQUENCY	50,02 Hz	
TURB BERING TEMP R	55 'C		SPEED SET POINT	64%	
GOVERNOR OIL TEMP	43'C		POWER SET POINT	64%	
PENTSTOCK PRESS	5,1 Bar		GUIDE VANE LIMITER	64%	
MACHINE SPEED	748 RPM		GENERATOR KVar	6,7 KVar	
GENERATOR KW	544 KW		GENERATOR AMPS	332 A	
GENERATOR VOLTS	377 V				

OVERVIEW


STEP 7
INCOMER VOLTAGE 380,0 V
HOUSE SET VOLTAGE 380,2 V
INCOMER FREQUENCY 50,01Hz
HOUSE SET FREQUENCY 49,96 Hz
SLOW
FAST
LOWER
RAISE
MODE
SYNCHRONISED
BRKR CLOSE
MAN. SYNCH.
BRKR OPEN
OVERVIEW


MM/DD HH:MM:SS EVT Type Pri Name GroupName Value/Limit
Placeholders in priority/group expressions
OVERVIEW

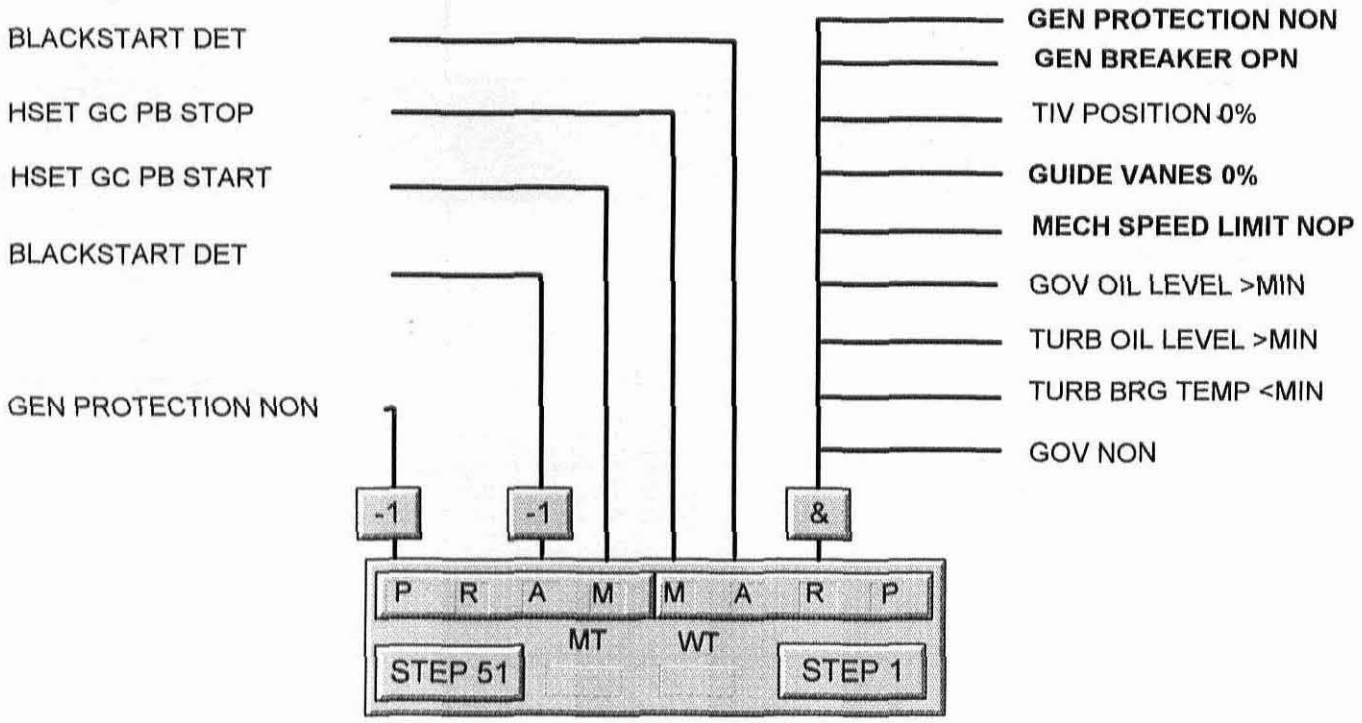

TEND SELECTION SCREEN
%
10
20
30
40
50
60
70
SECONDS
80
70
60
50
40
30
20
10
0
OVERVIEW
SPEED
PENT STOCK PRESSURE
GUIDEVANE


SEQUENCE OVERVIEW
DRIVE STATUS
STEP 1
TIME 14sec
STEP 2
TIME 11sec
STEP 3
TIME 7sec
STEP 4
TIME 9 sec
STEP 5
TIME 21sec
STEP 1A
TIME 13sec
OVERVIEW
STEP 2A
TIME 4sec
STEP 3A
TIME 4sec
STEP 4A
TIME 6 sec
STEP 51
TIME 7sec
STEP 53
TIME 4sec
STEP 54
TIME 9 sec
GOV OIL PMP
GOV CIRC PMP
TURB BRG OIL PMP
TIV OIL PMP
TIV BYP VLV
TIV
EMER CLC SOL
SPEED DETECTION
POWER DETECTION
GV LIMITER
POWER SET POINT
SPEED SETPOINT
CONTROLLERS

STATISTICAL INFORMATION

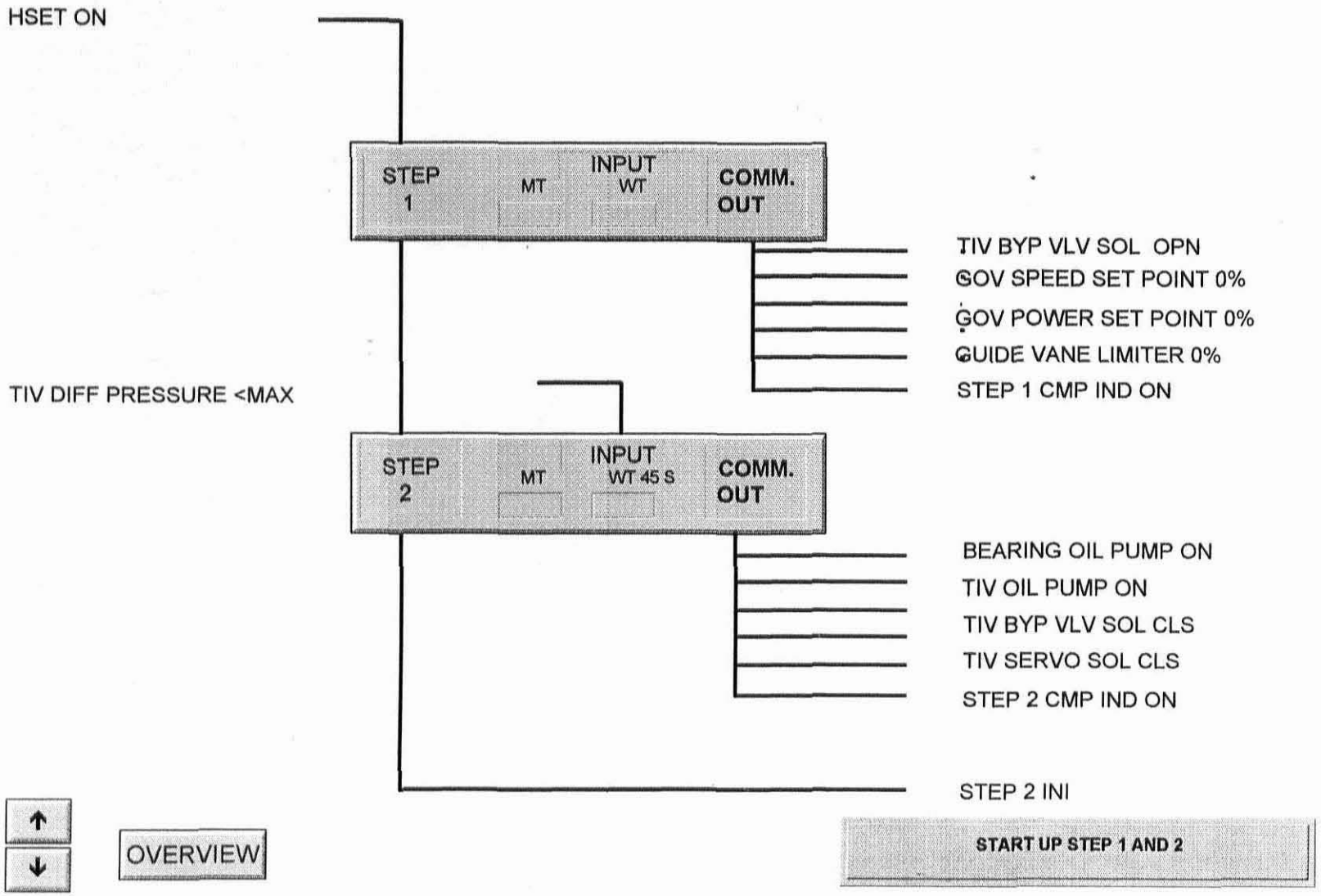
OVERVIEW

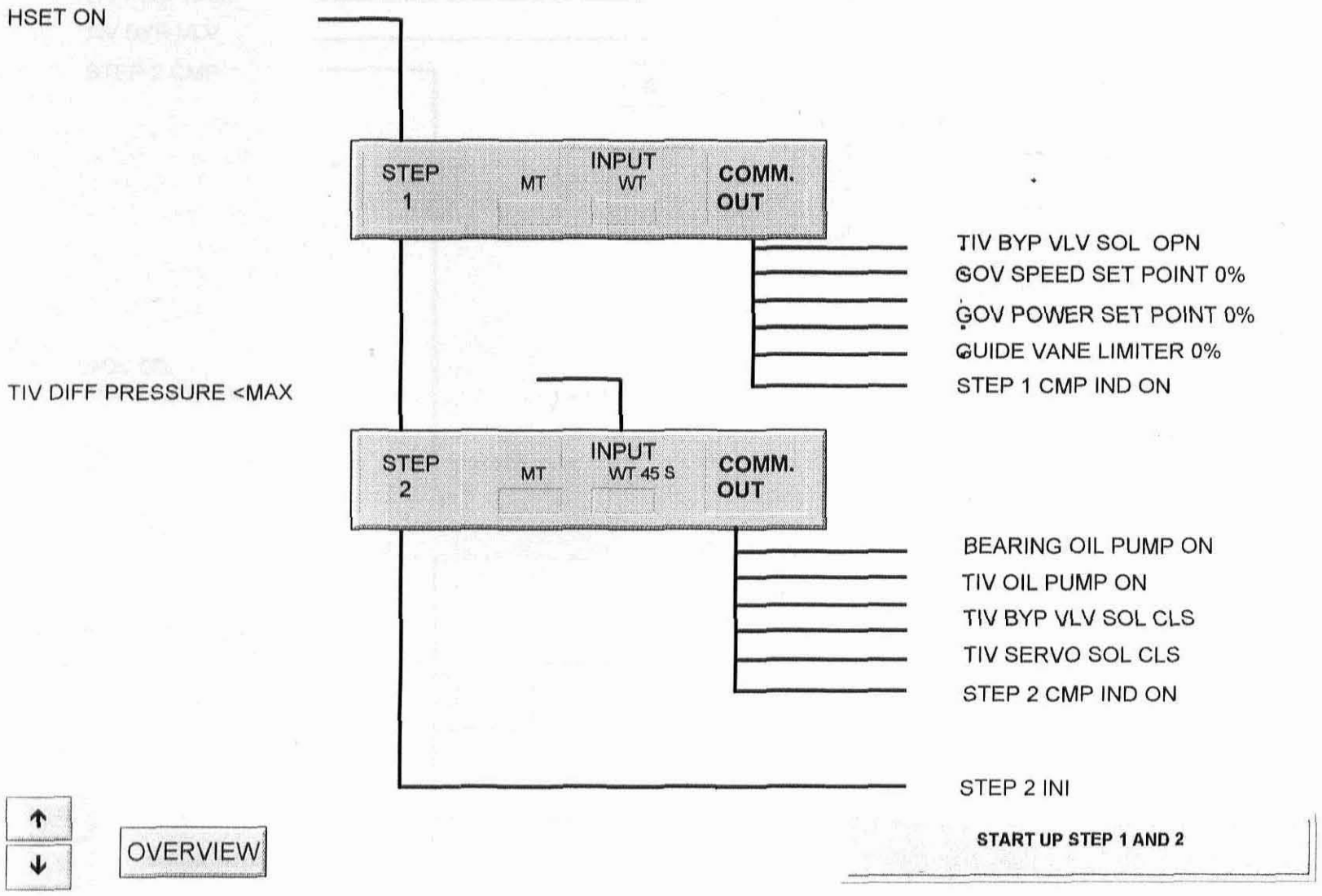
MODE OF OPERATION	TOTAL RUNNING HOURS		LAST RUNNING HOURS
ISOLATED	230 HOURS		23 HOURS
BLACK START	30 HOURS		13 HOURS
SYNCHRONISED	23 HOURS		3 HOURS
K.W.H. GENERATED	283 HOURS		82 HOURS
STARTUP TIME	134 SEC	SHUT DOWN TIME	32 SEC

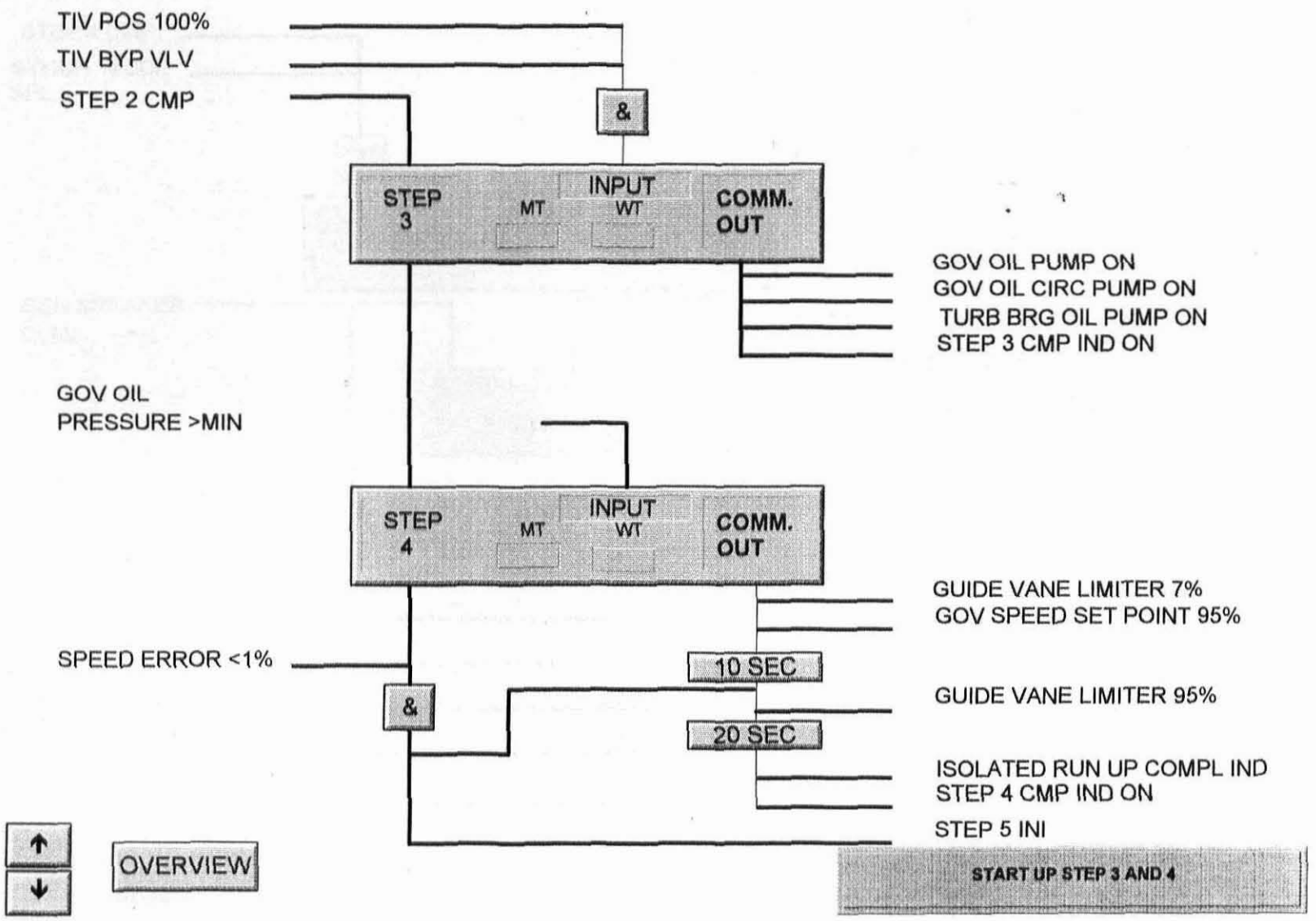


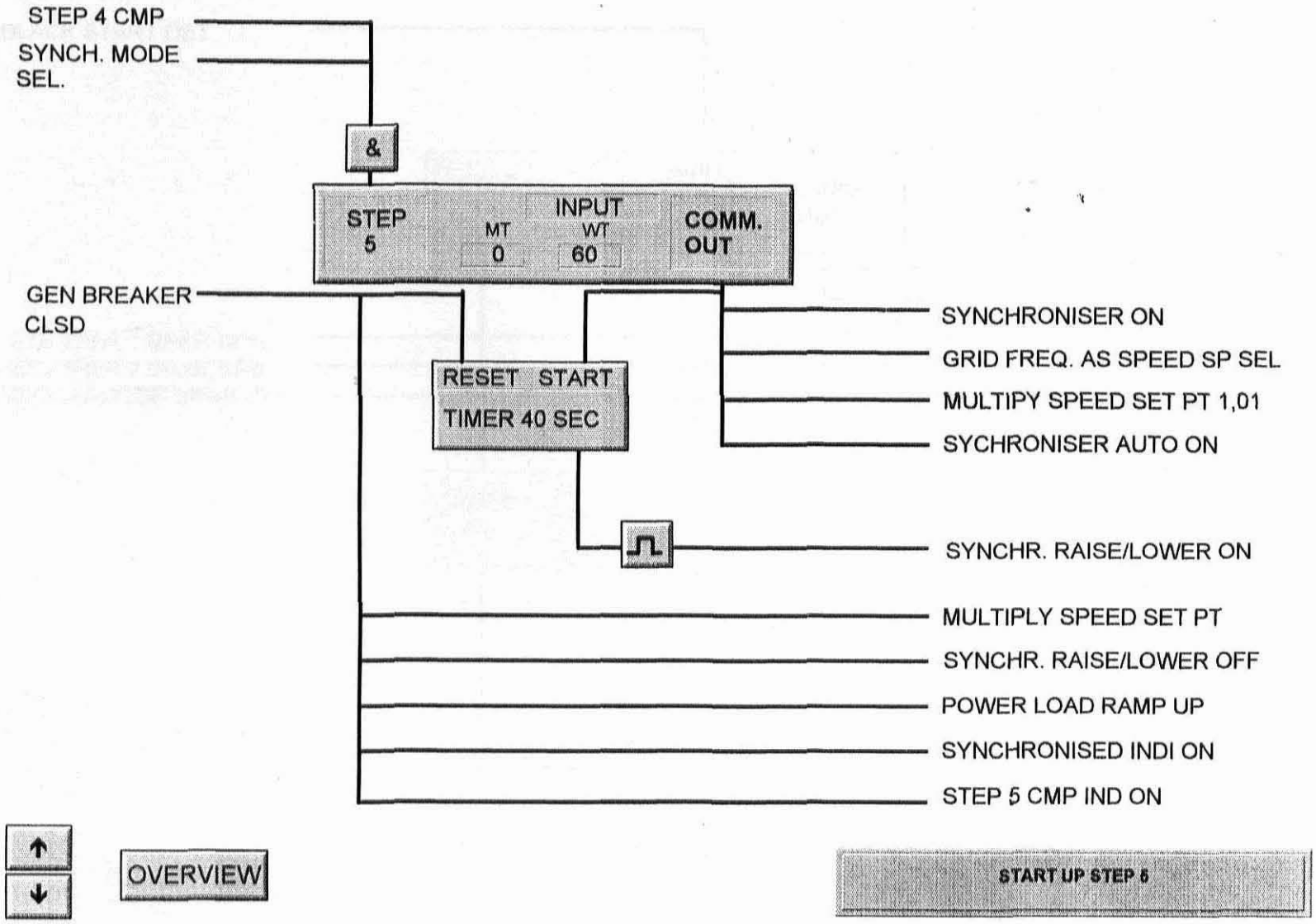
↓ OVERVIEW

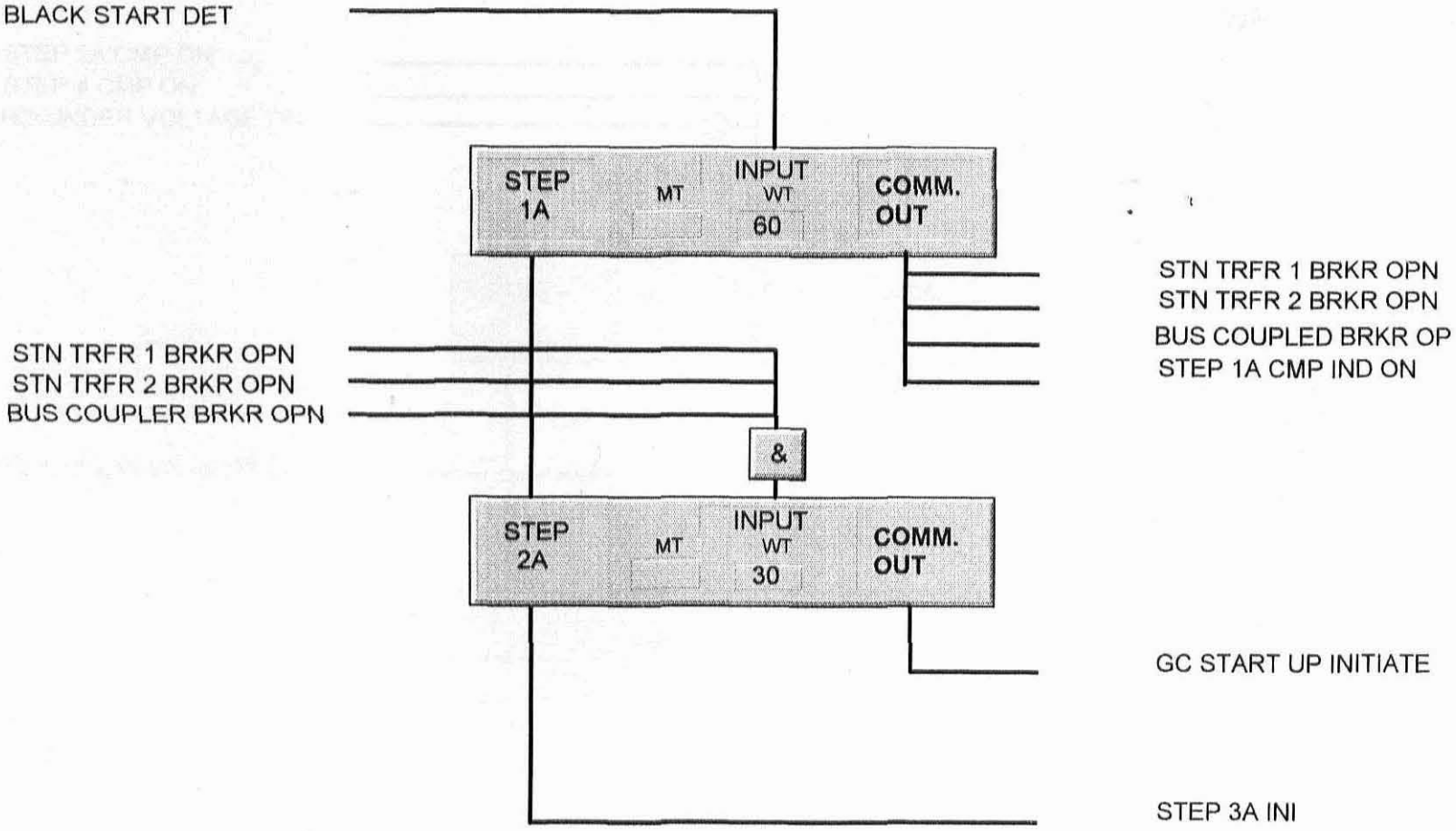
HOUSE SET GROUP CONTROL


HSET ON
STEP 1
MT
INPUT WT
COMM. OUT
TIV BYP VLV SOL OPN
GOV SPEED SET POINT 0%
GOV POWER SET POINT 0%
GUIDE VANE LIMITER 0%
STEP 1 CMP IND ON
TIV DIFF PRESSURE <MAX
STEP 2
MT
INPUT WT 45 S
COMM. OUT
BEARING OIL PUMP ON
TIV OIL PUMP ON
TIV BYP VLV SOL CLS
TIV SERVO SOL CLS
STEP 2 CMP IND ON
STEP 2 INI
OVERVIEW
START UP STEP 1 AND 2


HSET ON
STEP 1
MT
INPUT WT
COMM. OUT
TIV BYP VLV SOL OPN
GOV SPEED SET POINT 0%
GOV POWER SET POINT 0%
GUIDE VANE LIMITER 0%
STEP 1 CMP IND ON
TIV DIFF PRESSURE <MAX
STEP 2
MT
INPUT WT 45 S
COMM. OUT
BEARING OIL PUMP ON
TIV OIL PUMP ON
TIV BYP VLV SOL CLS
TIV SERVO SOL CLS
STEP 2 CMP IND ON
STEP 2 INI
OVERVIEW
START UP STEP 1 AND 2


TIV POS 100%
TIV BYP VLV
STEP 2 CMP
&
STEP 3
MT
INPUT WT
COMM. OUT
GOV OIL PUMP ON
GOV OIL CIRC PUMP ON
TURB BRG OIL PUMP ON
STEP 3 CMP IND ON
GOV OIL PRESSURE >MIN
STEP 4
MT
INPUT WT
COMM. OUT
GUIDE VANE LIMITER 7%
GOV SPEED SET POINT 95%
SPEED ERROR <1%
10 SEC
&
GUIDE VANE LIMITER 95%
20 SEC
ISOLATED RUN UP COMPL IND
STEP 4 CMP IND ON
STEP 5 INI
OVERVIEW
START UP STEP 3 AND 4

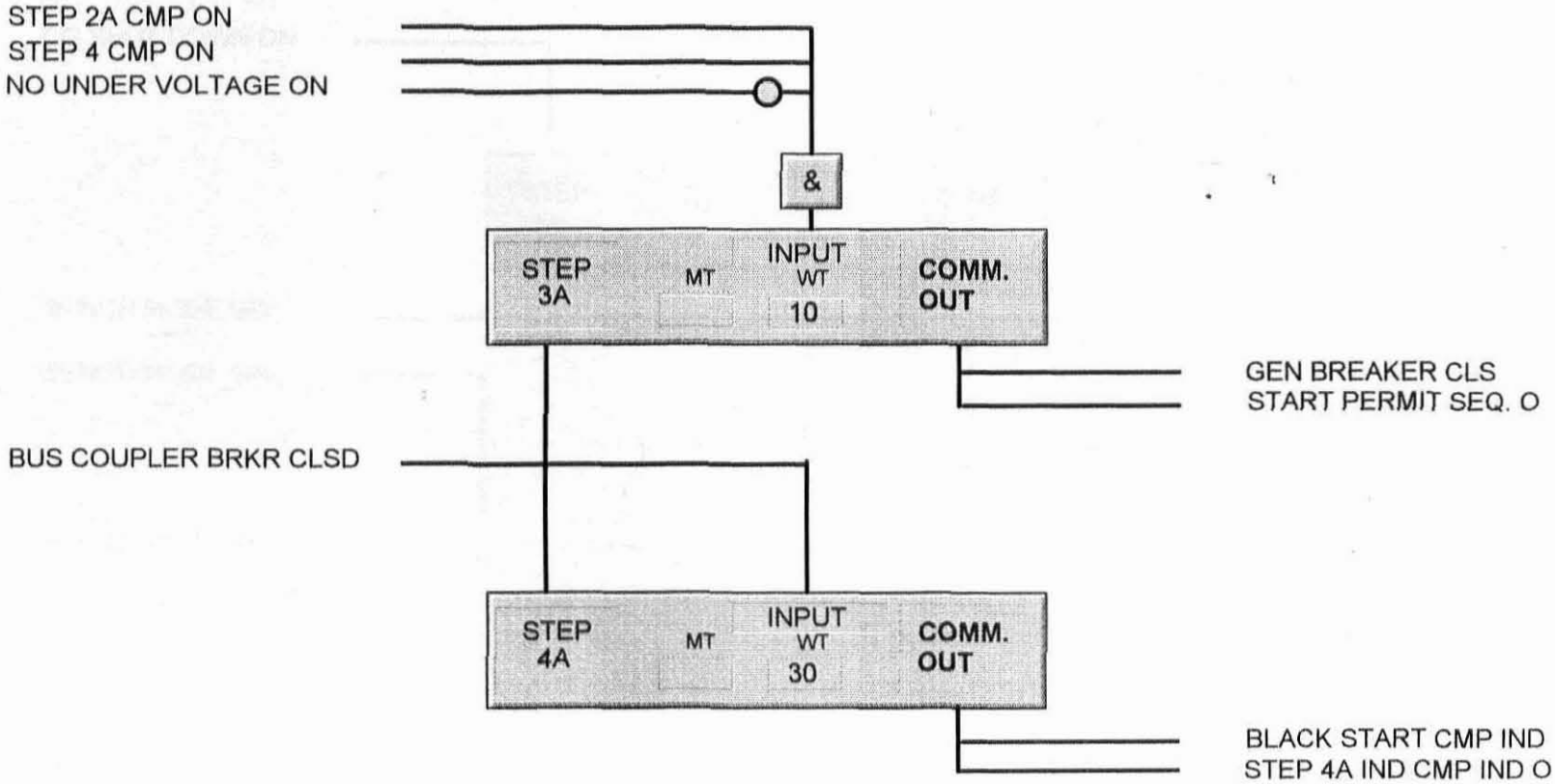

STEP 4 CMP
SYNCH. MODE SEL.
&
STEP 5
INPUT
MT 0
WT 60
COMM. OUT
GEN BREAKER CLSD
RESET START
TIMER 40 SEC
SYNCHRONISER ON
GRID FREQ. AS SPEED SP SEL
MULTIPY SPEED SET PT 1,01
SYCHRONISER AUTO ON
SYNCHR. RAISE/LOWER ON
MULTIPLY SPEED SET PT
SYNCHR. RAISE/LOWER OFF
POWER LOAD RAMP UP
SYNCHRONISED INDI ON
STEP 5 CMP IND ON
OVERVIEW
START UP STEP 5



OVERVIEW

START UP STEP 1A AND 2A

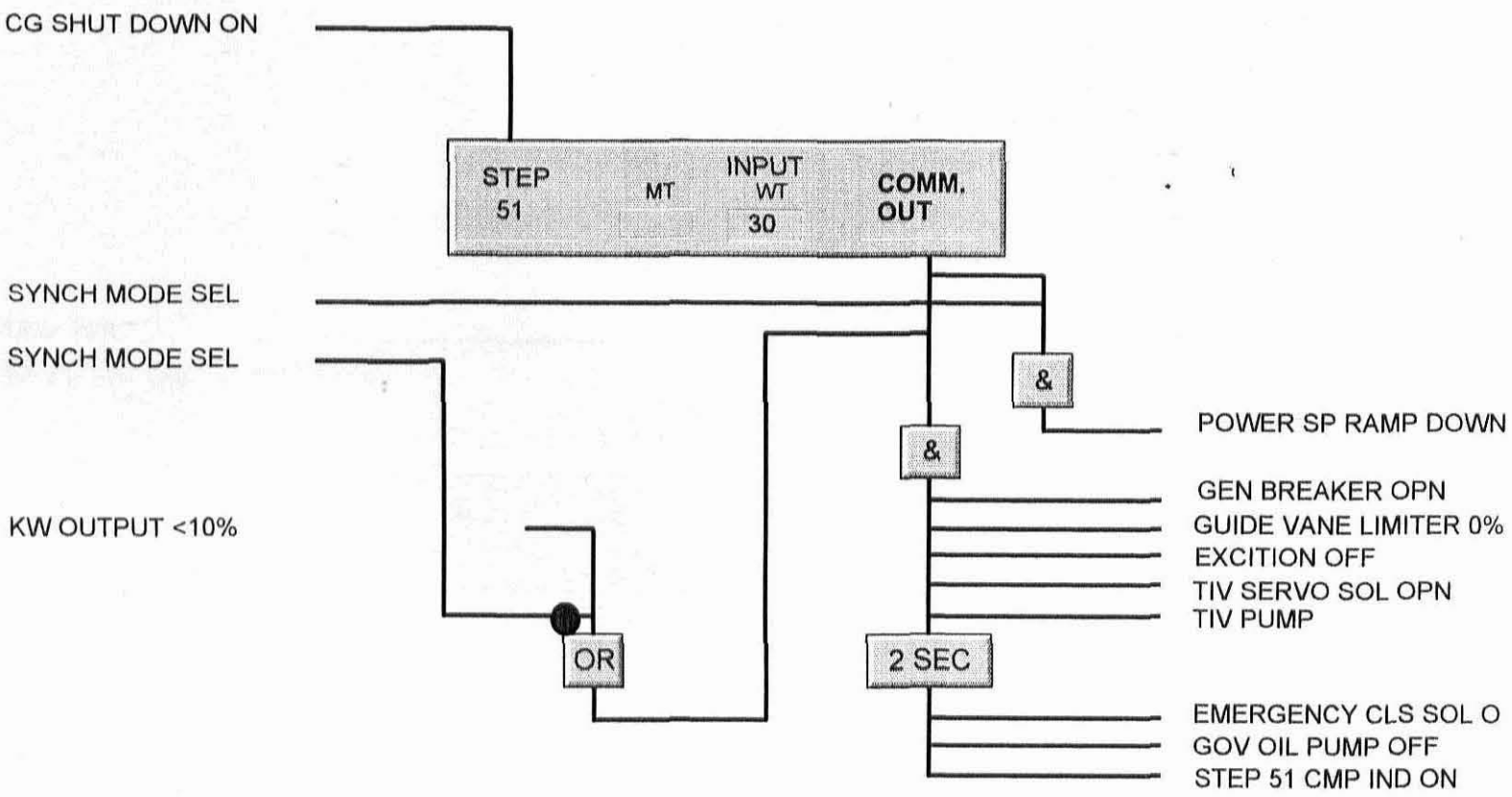
WF SCHMUTZ 95



↑ ↓ OVERVIEW

STATUP STEP 3A AND 4A

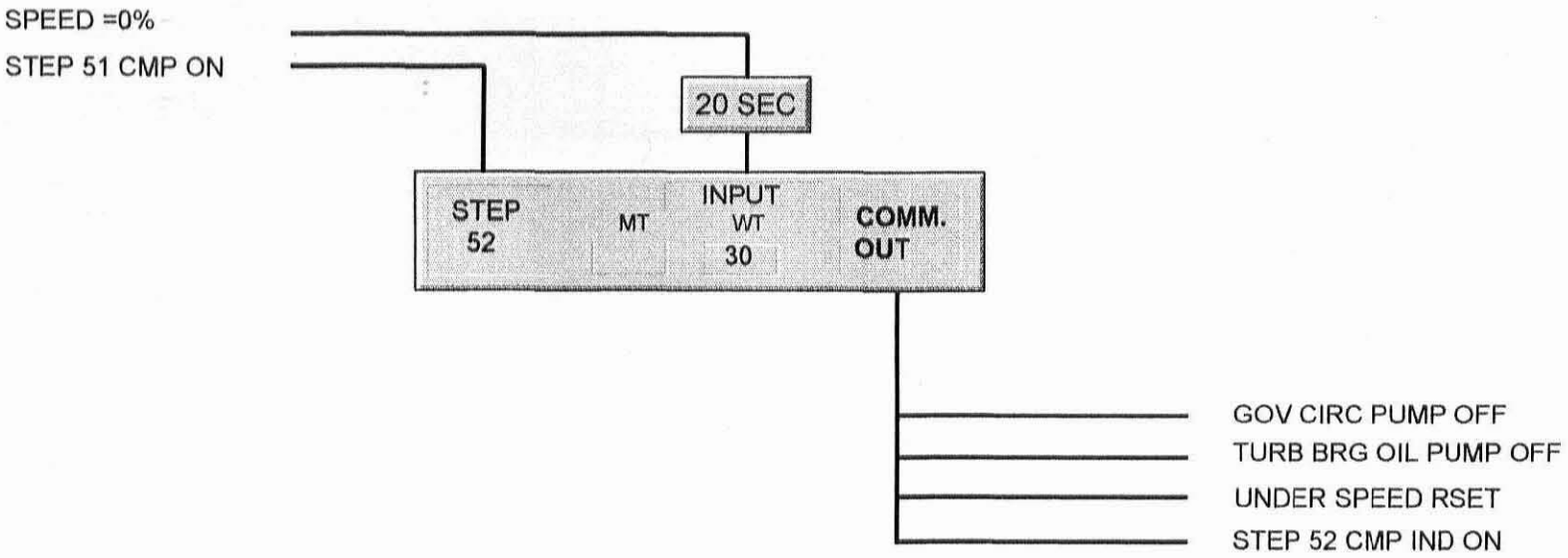
WF SCHMUTZ 95



OVERVIEW

SHUT DOWN STEP 51

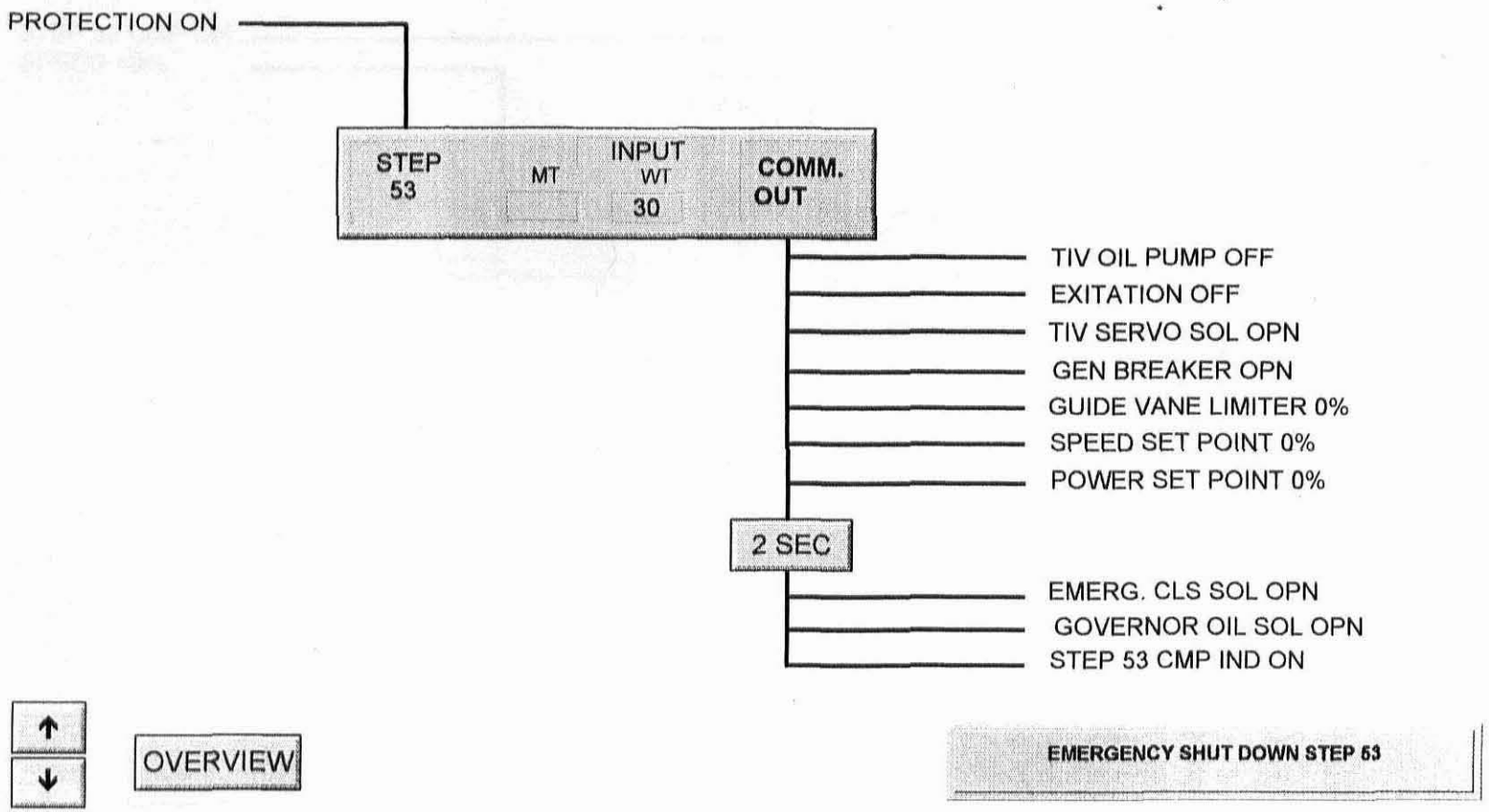
WF SCHMUTZ 95

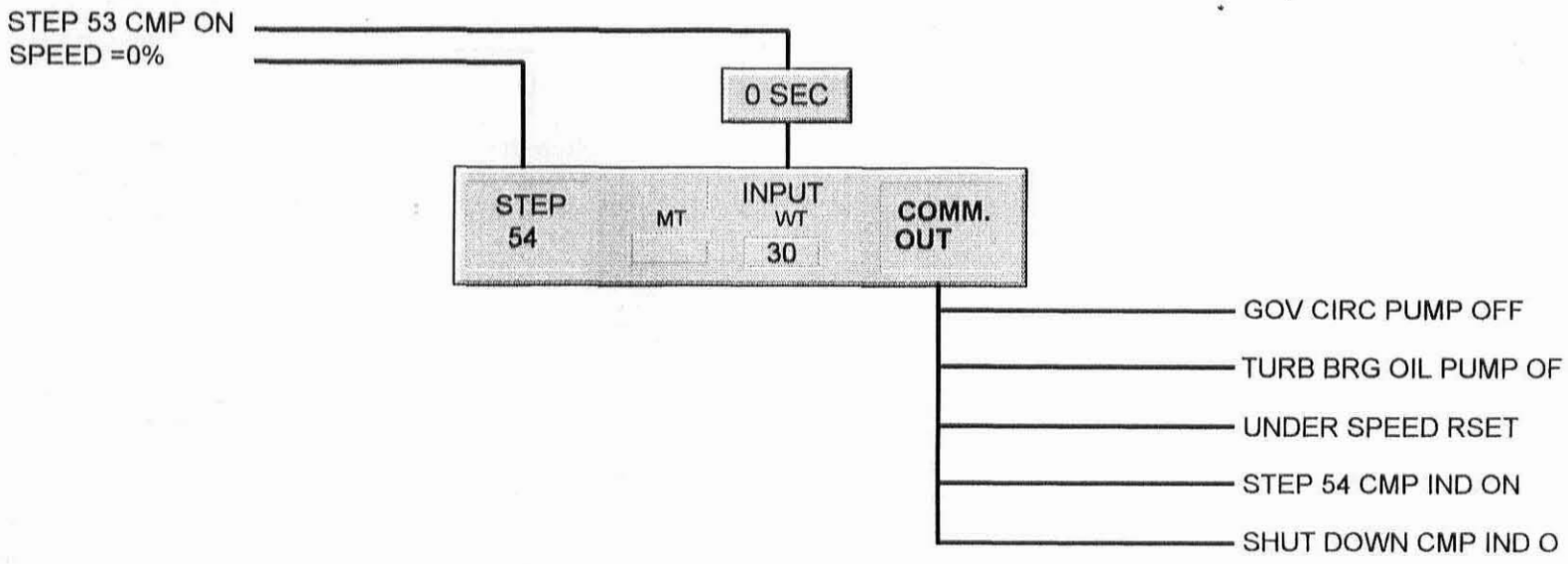


↑
↓

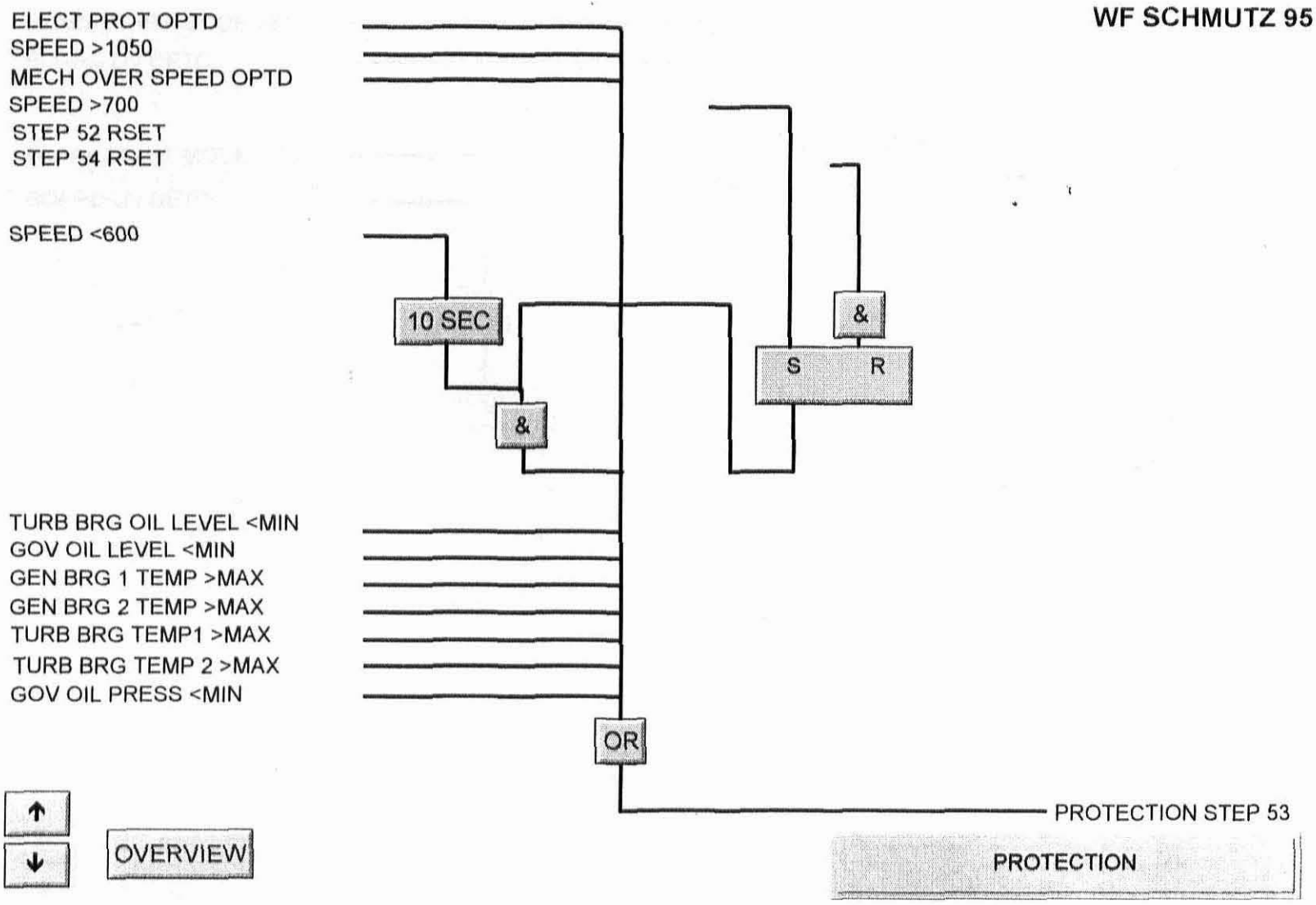
OVERVIEW

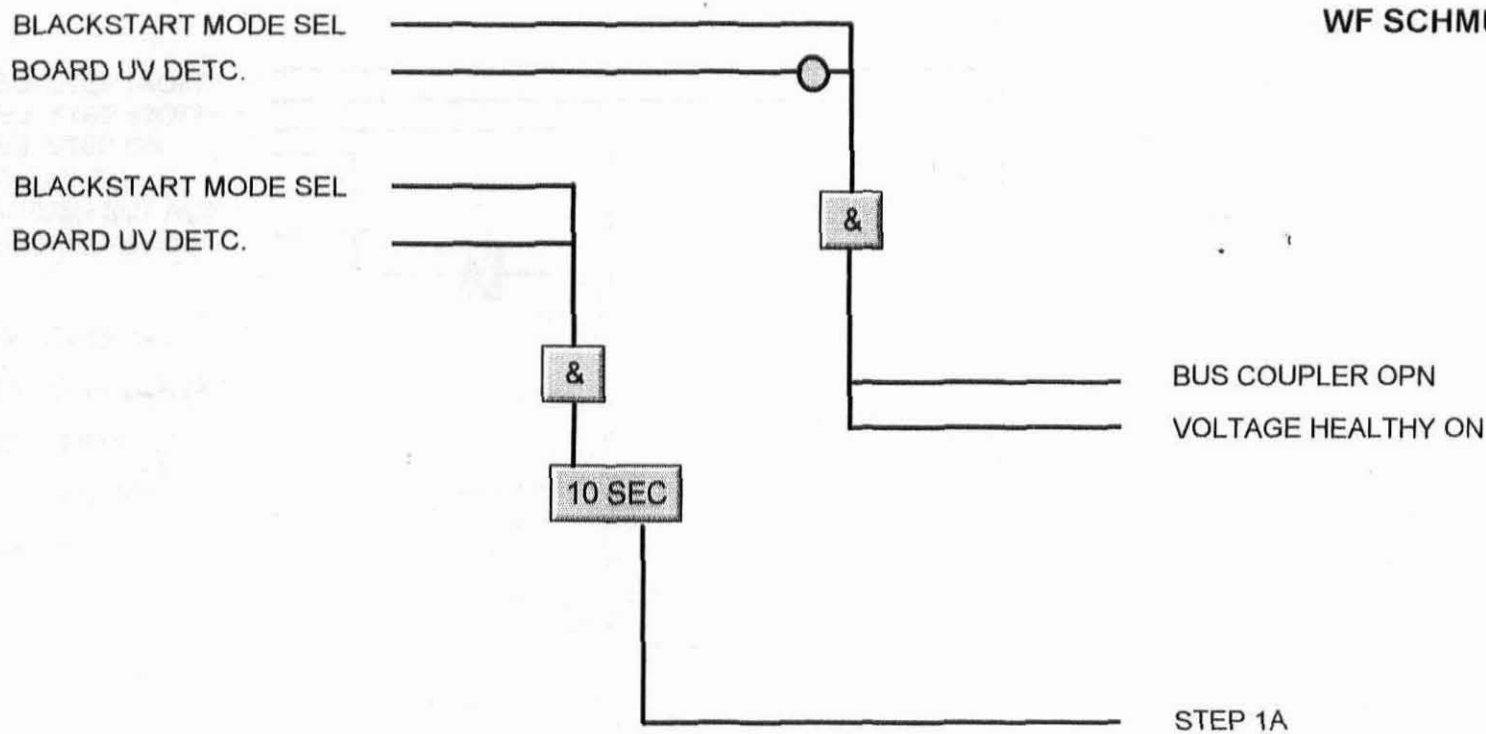
SHUT DOWN STEP 52


PROTECTION ON
STEP 53
MT
INPUT WT 30
COMM. OUT
TIV OIL PUMP OFF
EXITATION OFF
TIV SERVO SOL OPN
GEN BREAKER OPN
GUIDE VANE LIMITER 0%
SPEED SET POINT 0%
POWER SET POINT 0%
2 SEC
EMERG. CLS SOL OPN
GOVERNOR OIL SOL OPN
STEP 53 CMP IND ON
OVERVIEW
EMERGENCY SHUT DOWN STEP 53

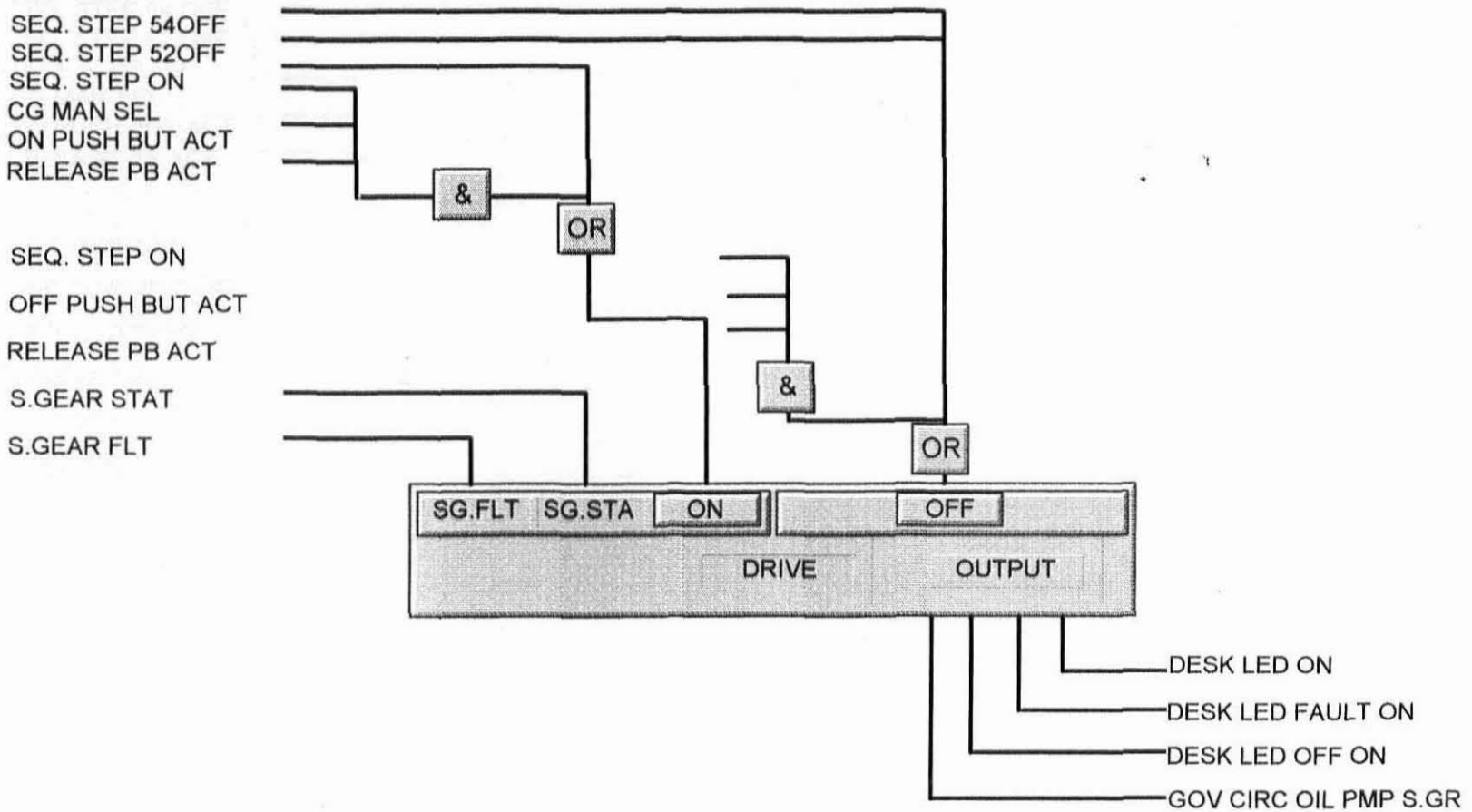

STEP 53 CMP ON
SPEED =0%
0 SEC
STEP
54
MT
INPUT
WT
30
COMM.
OUT
GOV CIRC PUMP OFF
TURB BRG OIL PUMP OF
UNDER SPEED RSET
STEP 54 CMP IND ON
SHUT DOWN CMP IND O

WF SCHMUTZ 95




BLACKSTART MODE SEL
BOARD UV DETC.
BLACKSTART MODE SEL
BOARD UV DETC.
&
&
10 SEC
BUS COUPLER OPN
VOLTAGE HEALTHY ON
STEP 1A

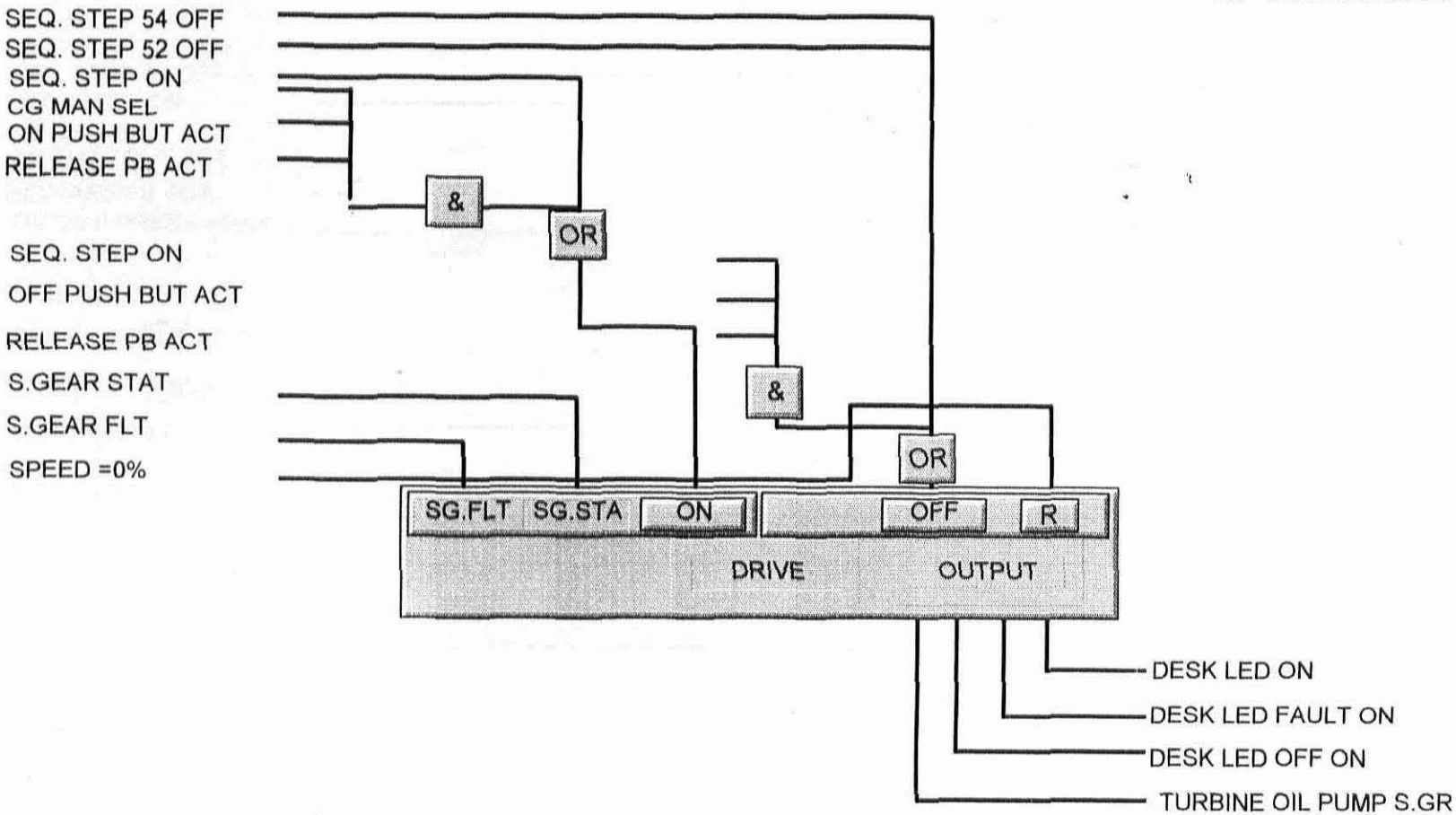
WF SCHMUTZ 95



OVERVIEW

GOVERNOR CIRC OIL PUMP

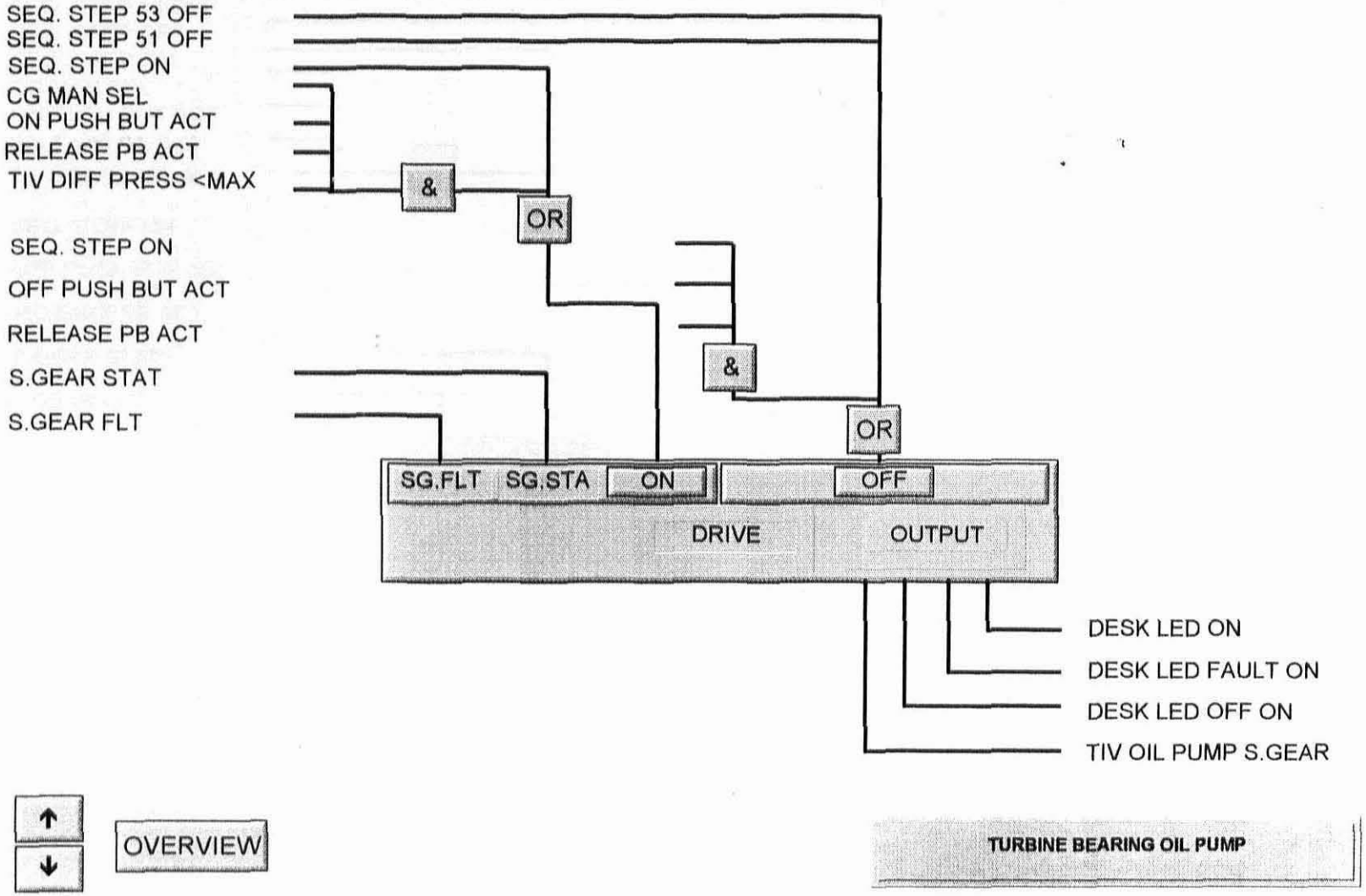
WF SCHMUTZ 95



OVERVIEW

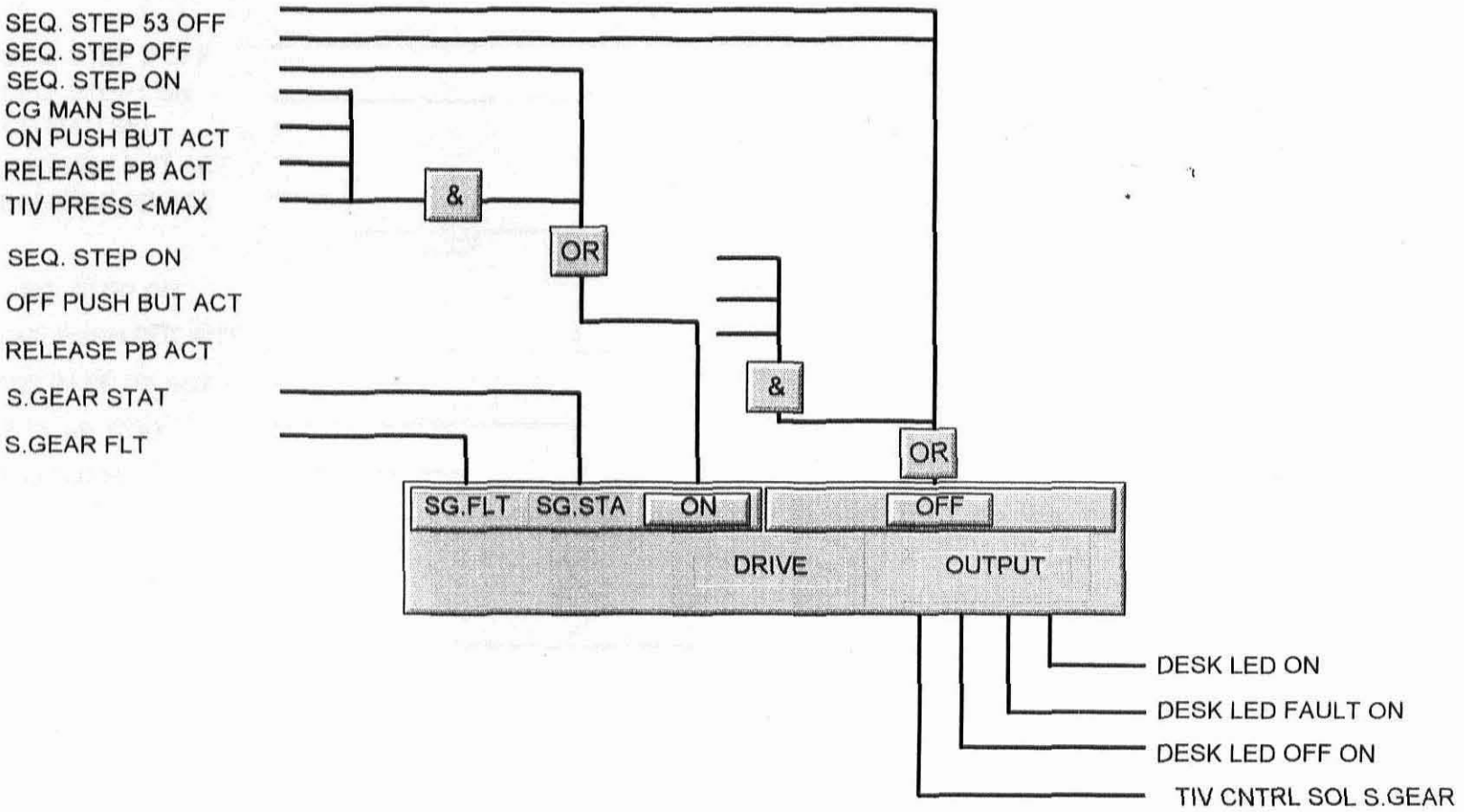
TIV OIL PUMP

WF SCHMUTZ 95



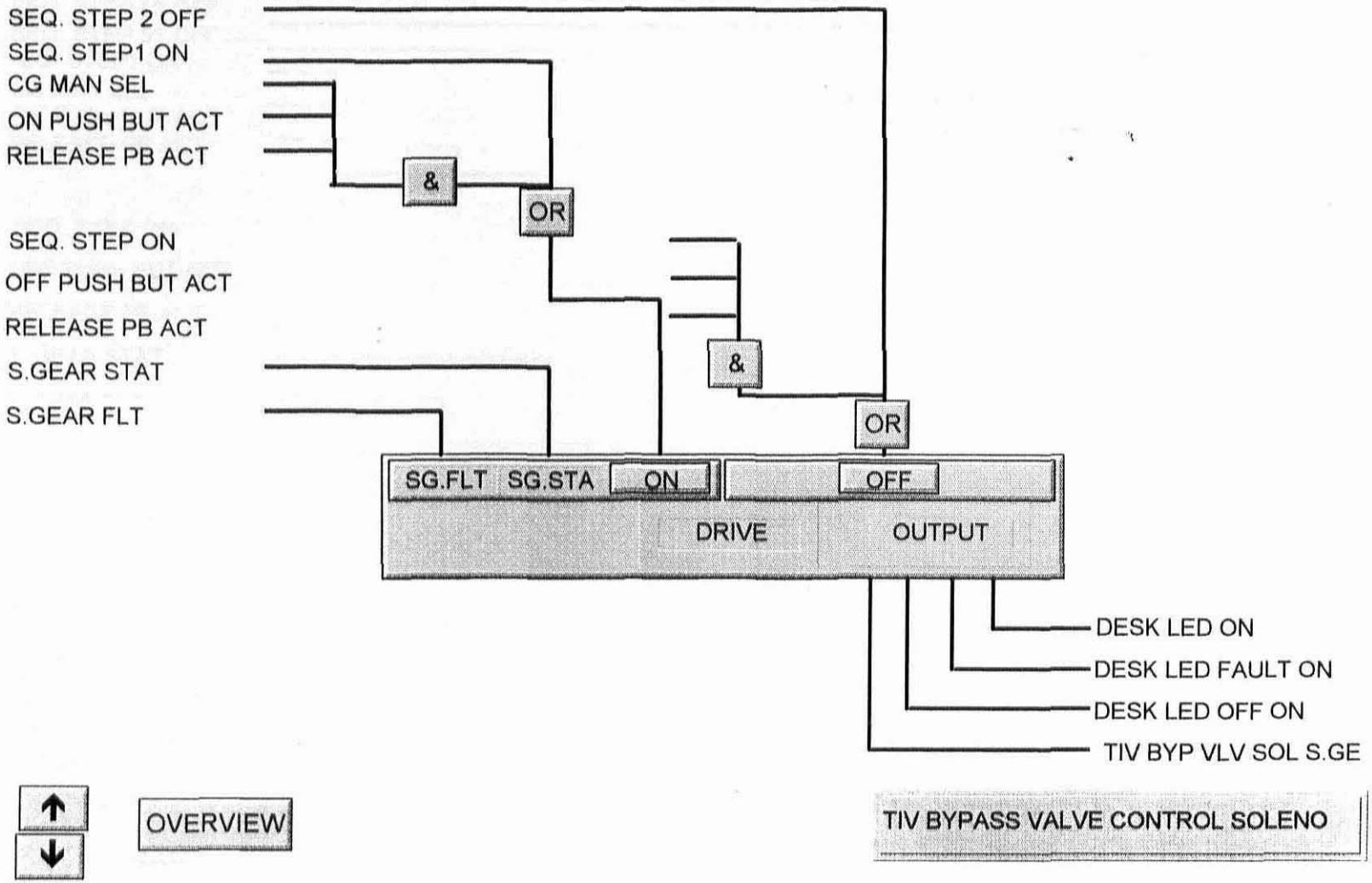
OVERVIEW

TURBINE BEARING OIL PUMP

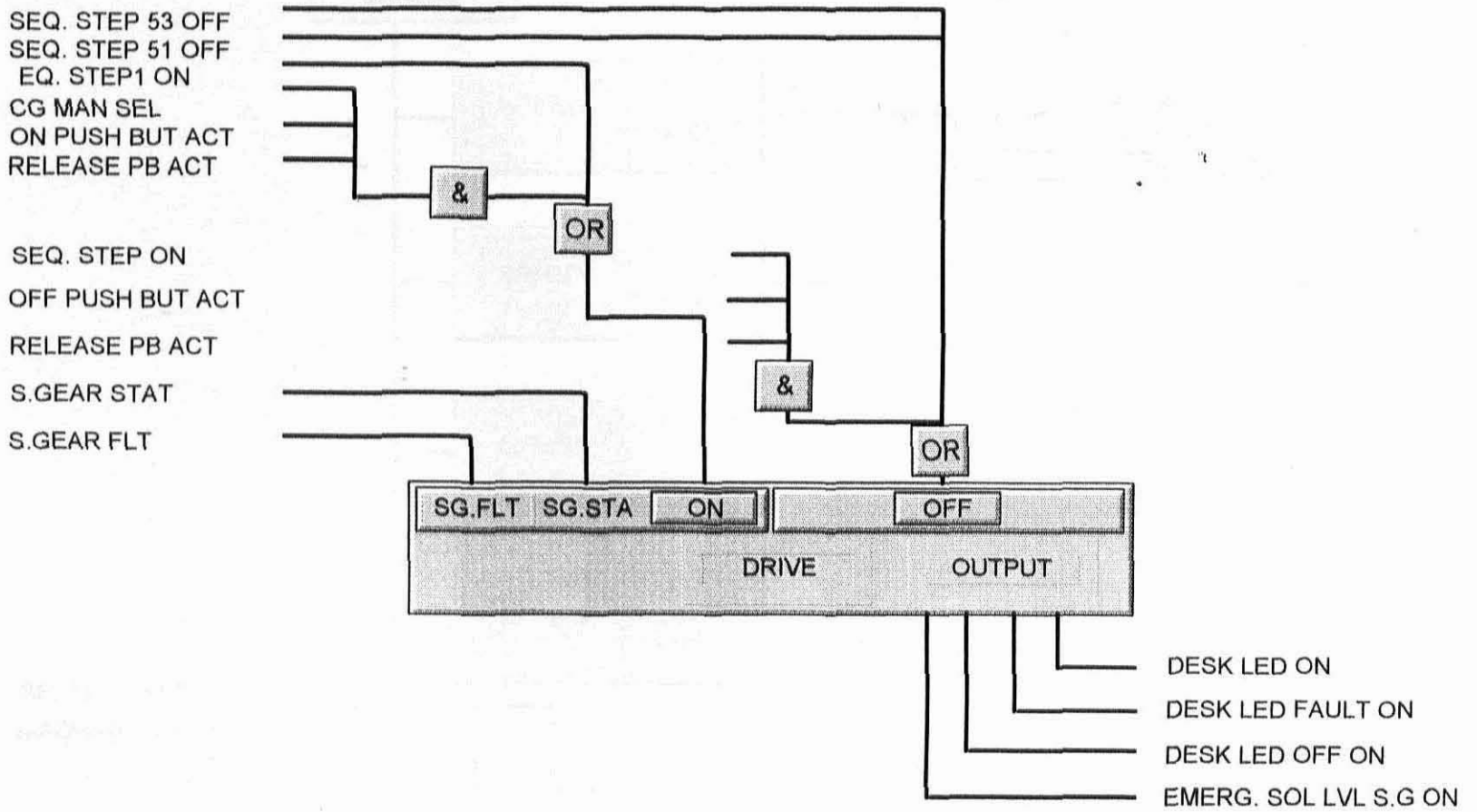

SEQ. STEP 53 OFF
SEQ. STEP OFF
SEQ. STEP ON
CG MAN SEL
ON PUSH BUT ACT
RELEASE PB ACT
TIV PRESS <MAX
&
OR
SEQ. STEP ON
OFF PUSH BUT ACT
RELEASE PB ACT
&
S.GEAR STAT
S.GEAR FLT
OR
SG.FLT
SG.STA
ON
OFF
DRIVE
OUTPUT
DESK LED ON
DESK LED FAULT ON
DESK LED OFF ON
TIV CNTRL SOL S.GEAR


OVERVIEW


TIV OIL PUMP


SEQ. STEP 2 OFF
SEQ. STEP1 ON
CG MAN SEL
ON PUSH BUT ACT
RELEASE PB ACT
&
OR
SEQ. STEP ON
OFF PUSH BUT ACT
RELEASE PB ACT
S.GEAR STAT
S.GEAR FLT
&
OR
SG.FLT
SG.STA
ON
OFF
DRIVE
OUTPUT
DESK LED ON
DESK LED FAULT ON
DESK LED OFF ON
TIV BYP VLV SOL S.GE
OVERVIEW
TIV BYPASS VALVE CONTROL SOLENO

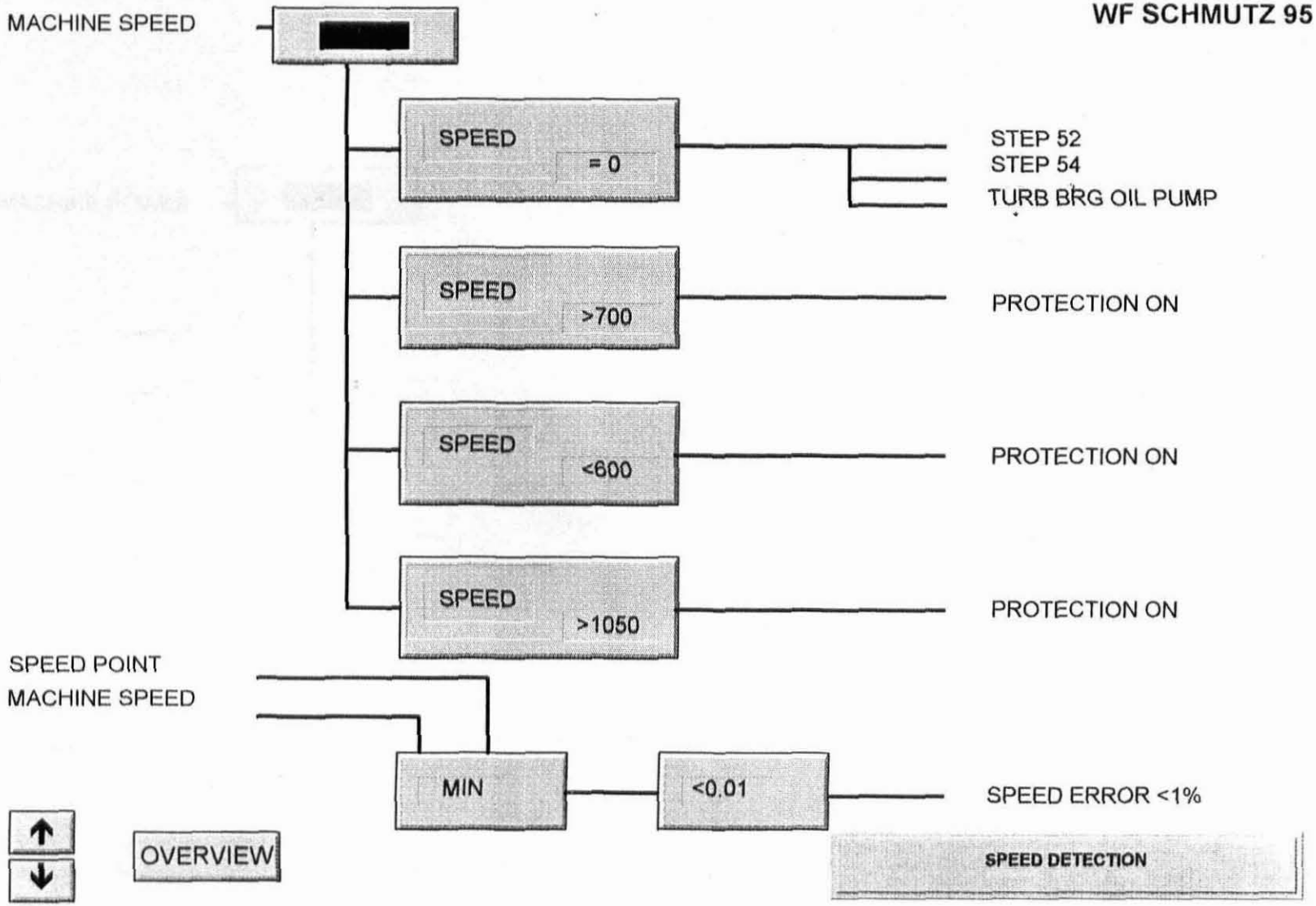
WF SCHMUTZ 95

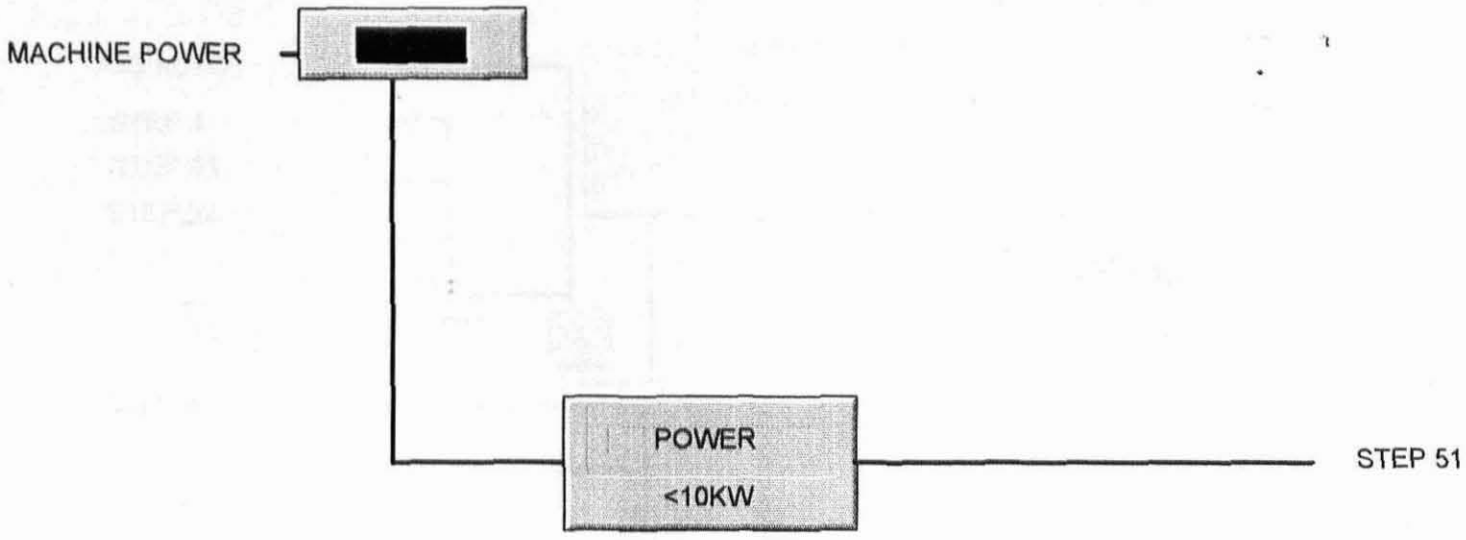


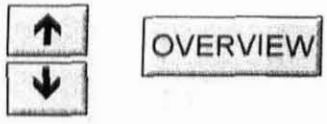
OVERVIEW

EMERGENCY CLOSE SOLENOID VALV

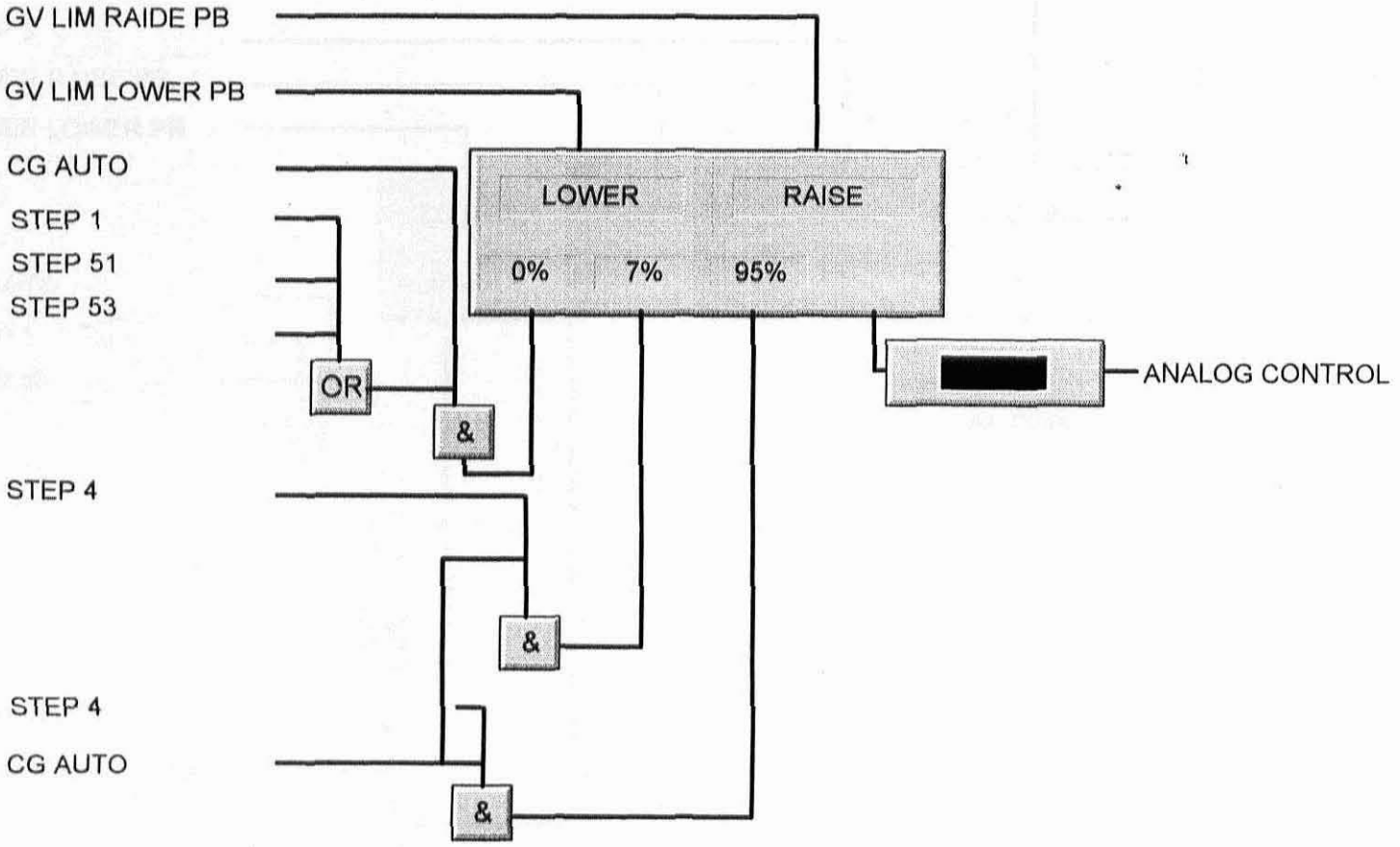
WF SCHMUTZ 95




MACHINE POWER
[redacted]
POWER
<10KW
STEP 51


OVERVIEW

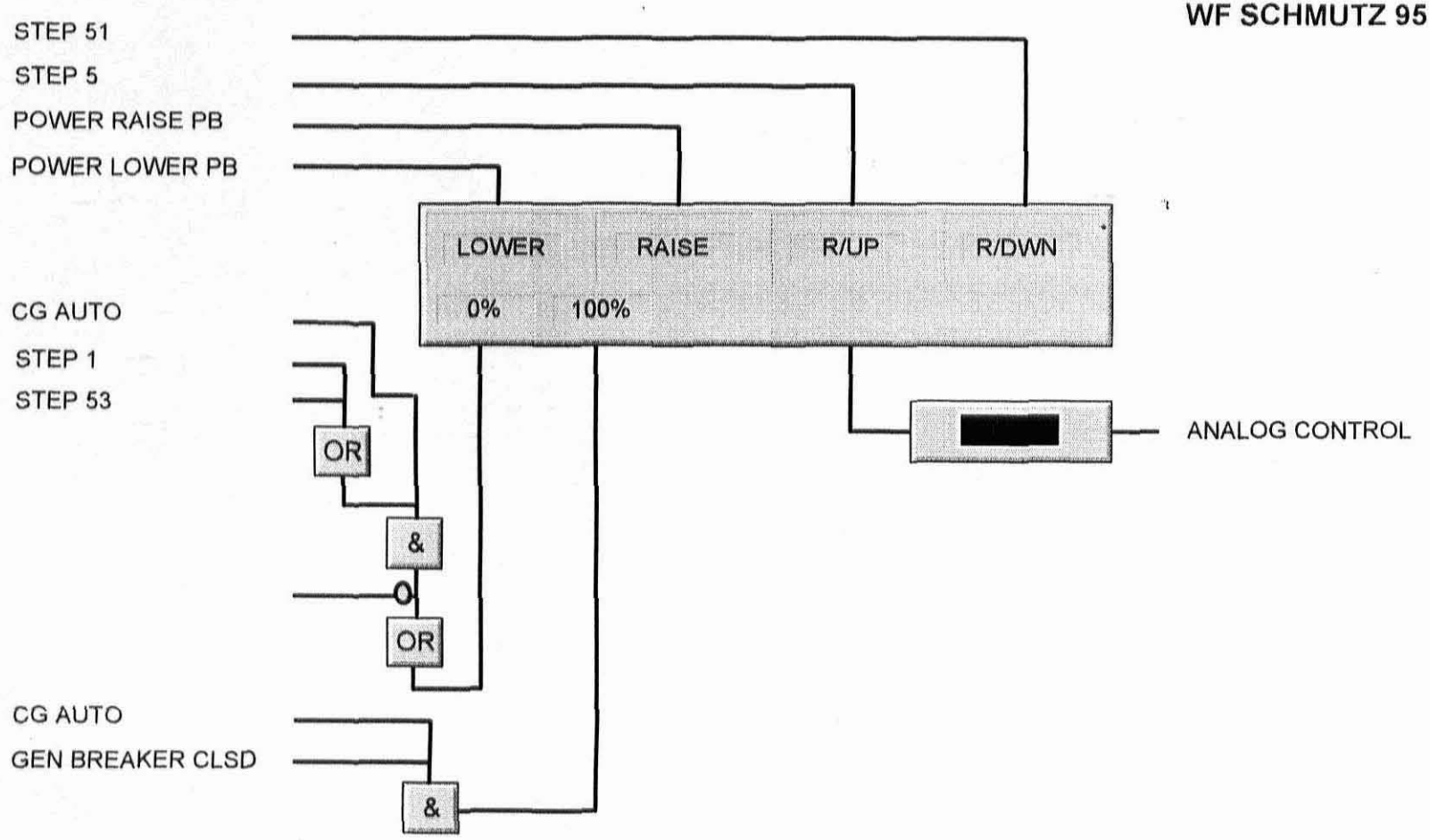
WF SCHMUTZ 95



OVERVIEW

GUIDE VANE LIMITER SET POIN FORMATIO

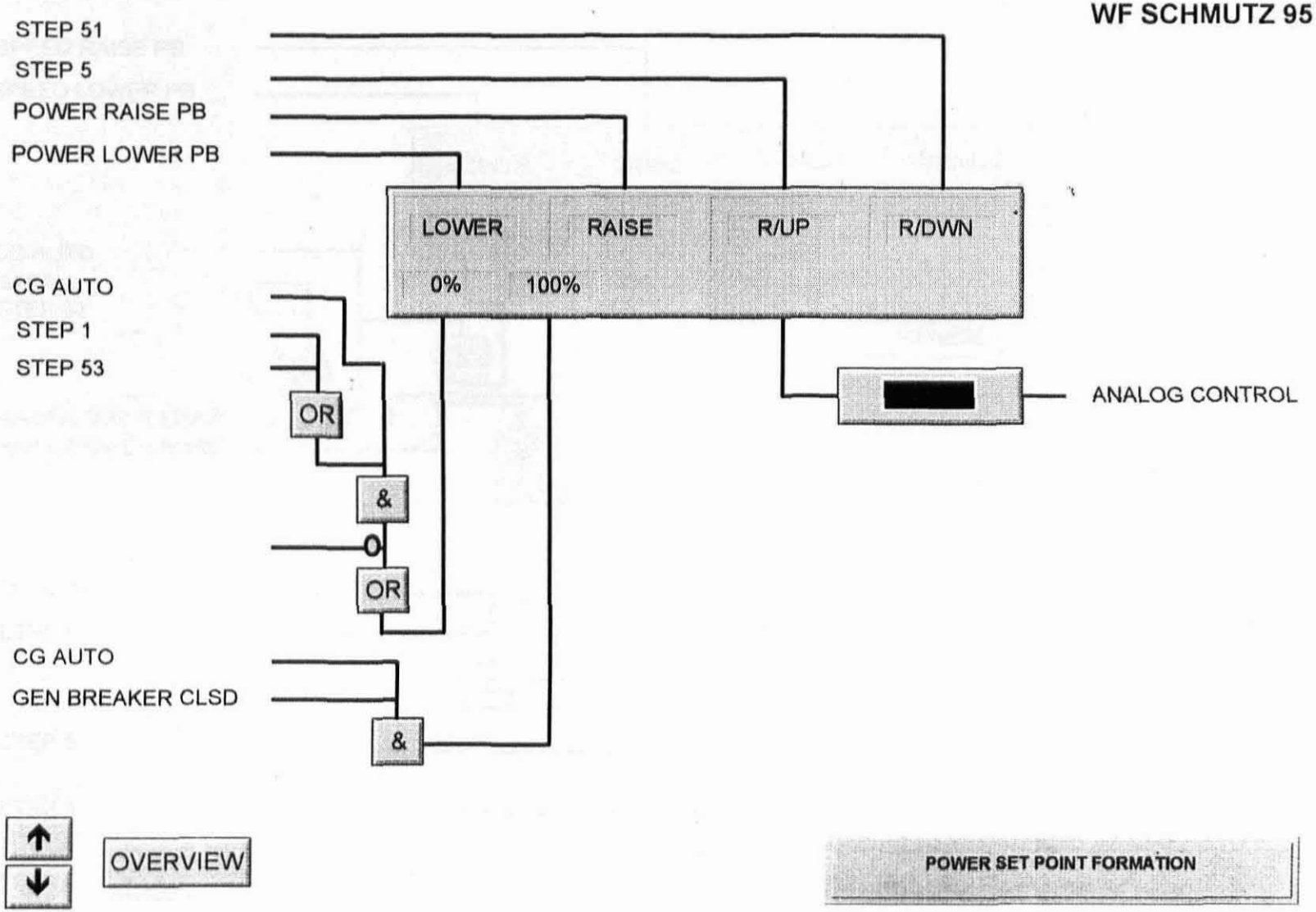
WF SCHMUTZ 95



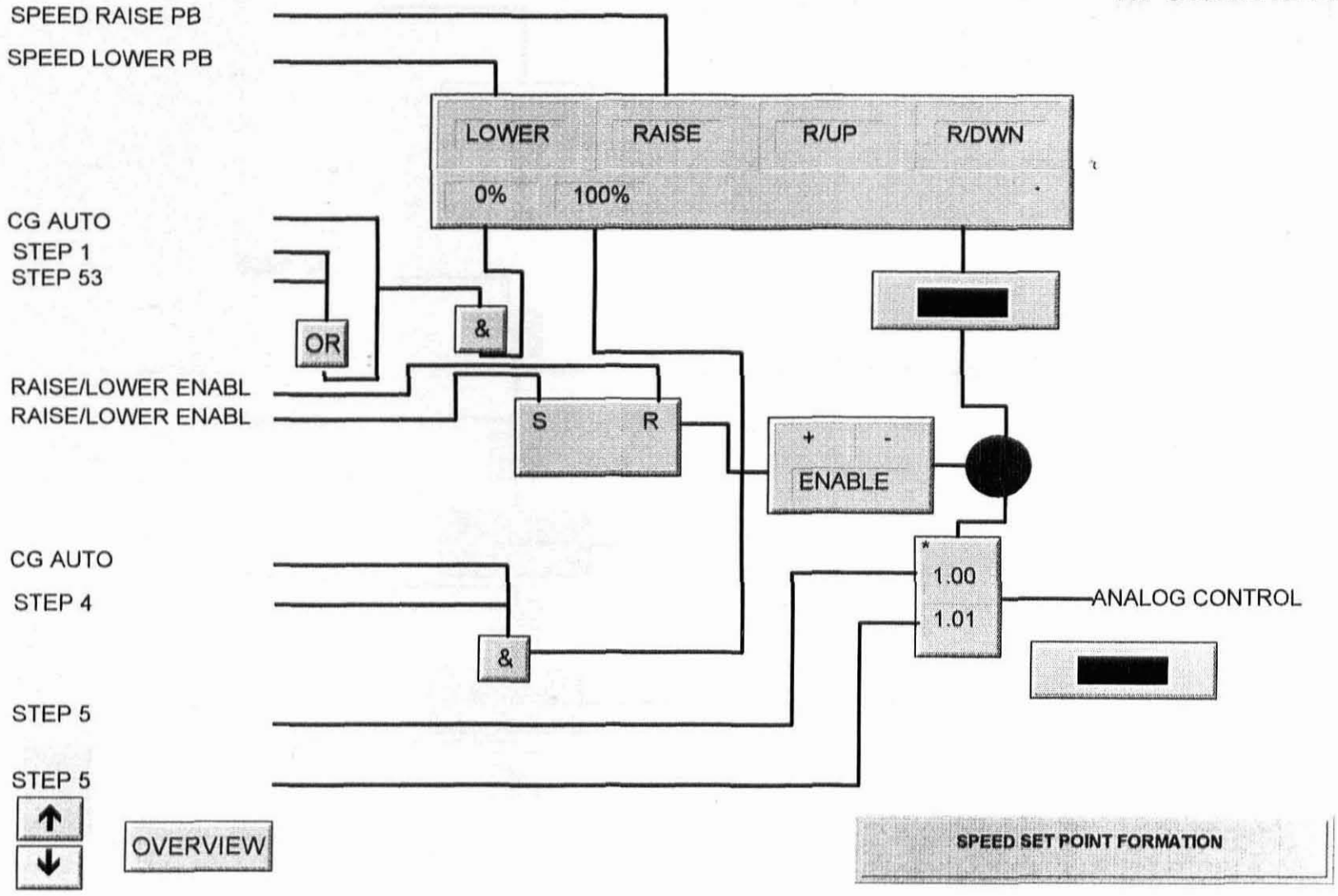
OVERVIEW

POWER SET POINT FORMATION

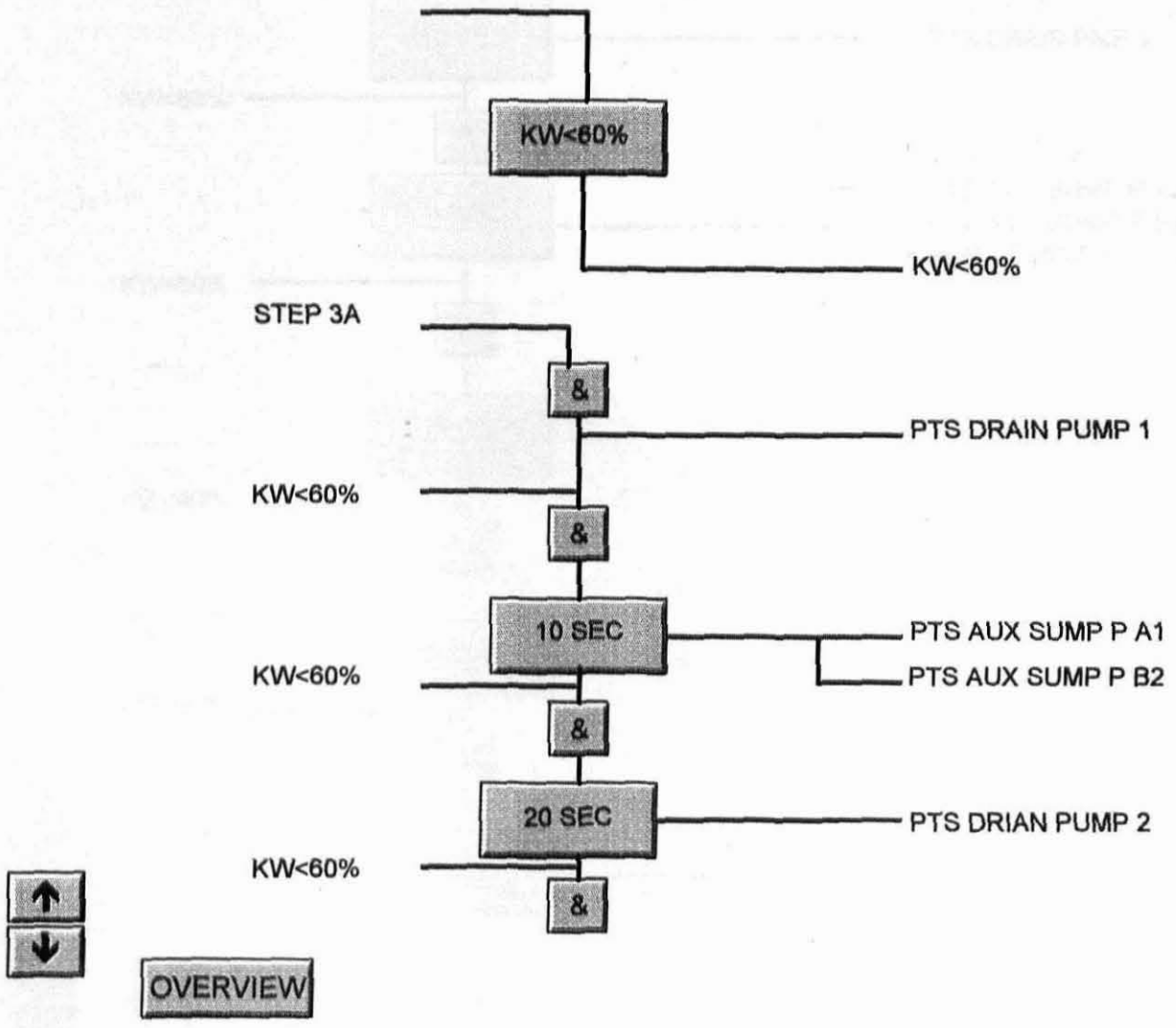
WF SCHMUTZ 95



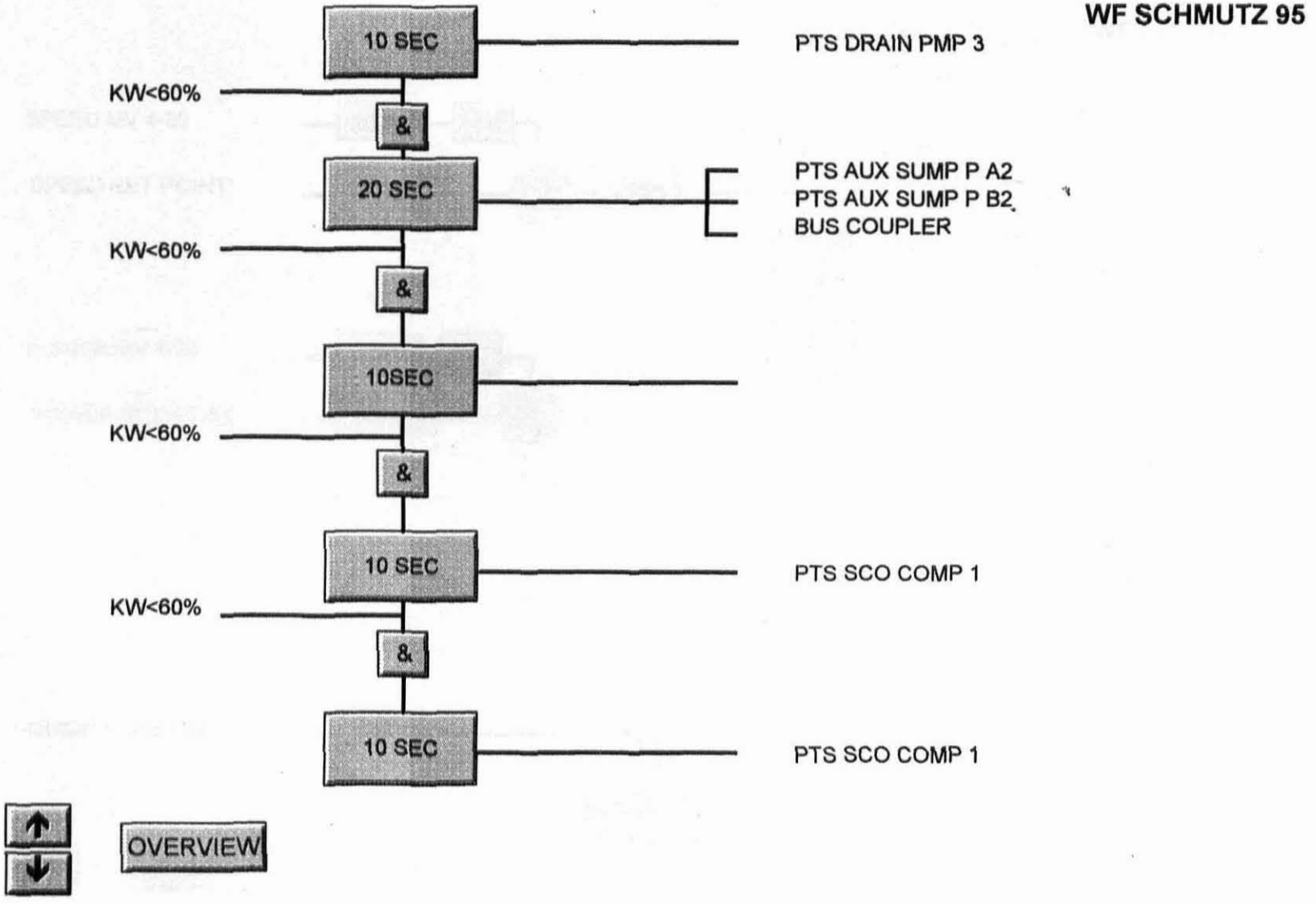
WF SCHMUTZ 95



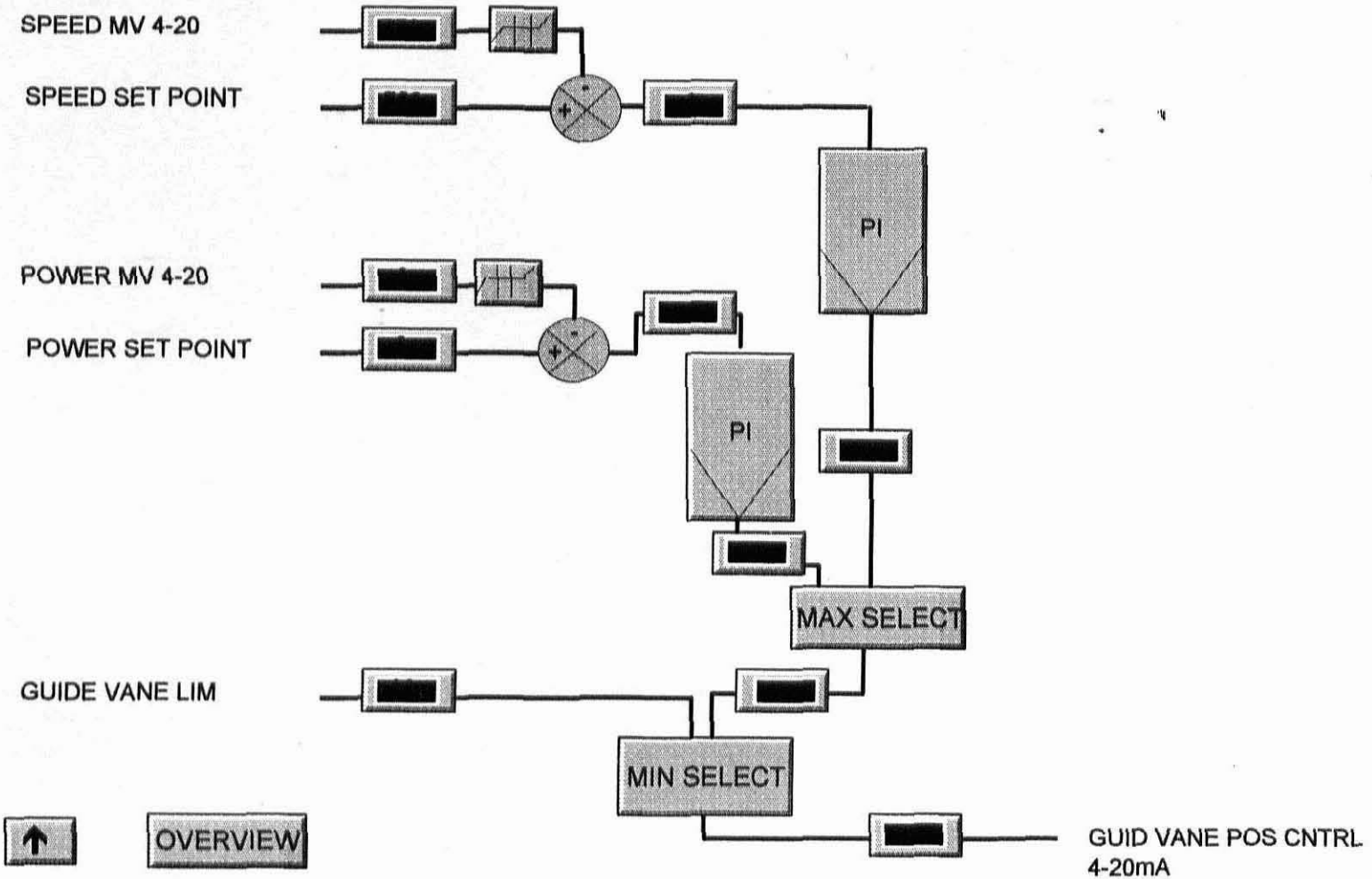
WF SCHMUTZ 95



WF SCHMUTZ 95

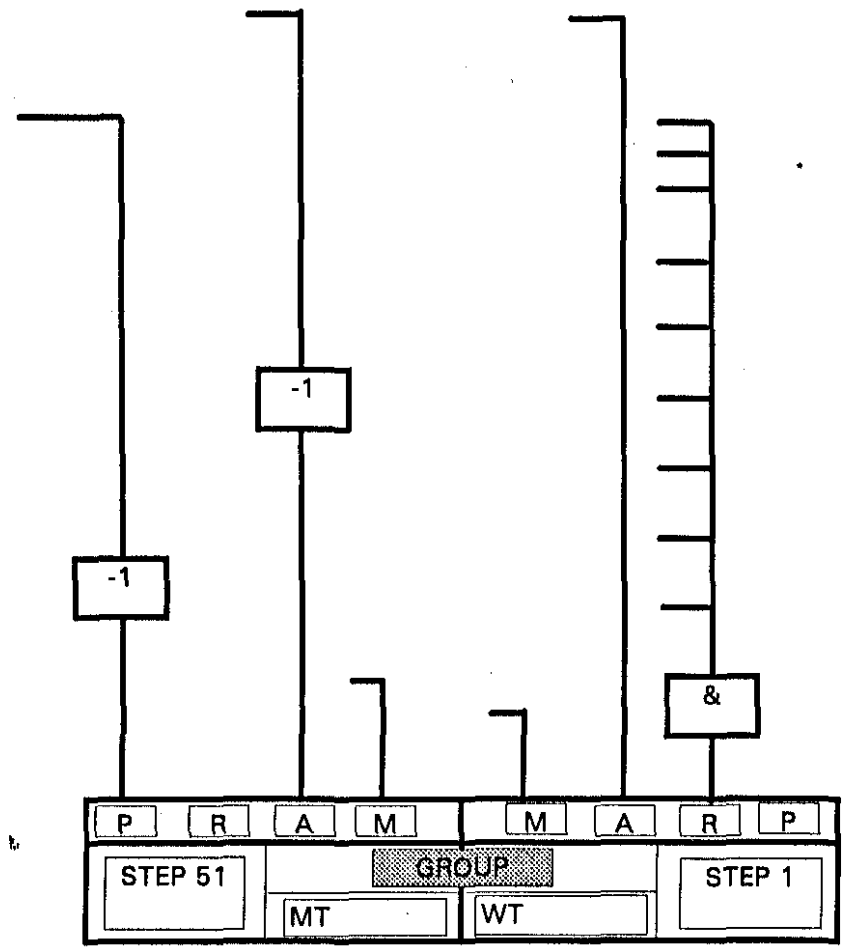


WF SCHMUTZ 95



APPENDIX C:
PLC LOGIC DIAGRAMS

Dest	Input	Set	Adr
1			
2			
3	BLACKSTART	DET	5-24
4			
5			
6	GEN PROTECTION	NON	FIELD
7	GEN BREAKER	OPN	
8	TIV POSITION	0%	FIELD
9			
10	GUIDE VANES	0%	FIELD
11			
12	MECH SPEED LIMIT	NOP	FIELD
13			
14	GOV OIL LEVEL	>MIN	FIELD
15			
16	TURB OIL LEVEL	>MIN	FIELD
17			
18	TURB BRG TEMP	<MAX	FIELD
19			
20	GOV	NON	
21			
22	HSET GC PB	STOP	DESK
23	HSET GC PB	STRT	DESK
24			
25			
26			
27			
28			
29			
30			
31			
32			
	page 1		



HOUSE SET GROUP CONTROL

Adr	Dest	Set

Dest	Input	Set	Adr
1			
2	HSET CG	ON	1
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15	TIV DIFF PRESSURE	<MAX	FIELD
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
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28			
29			
30			
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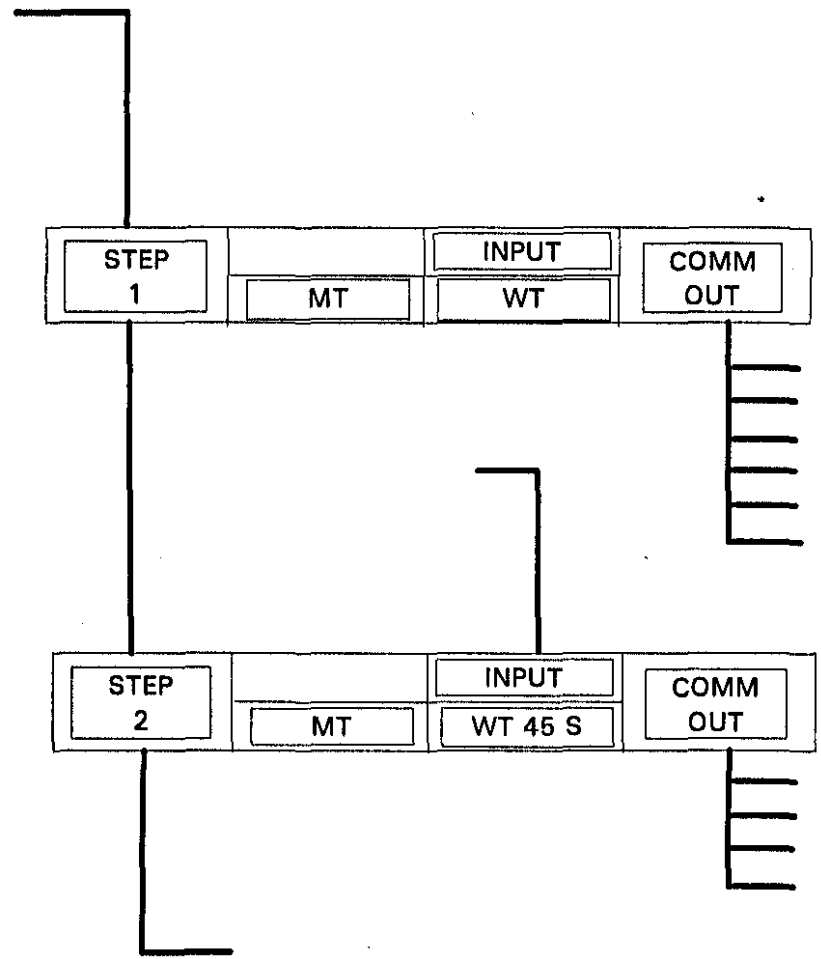
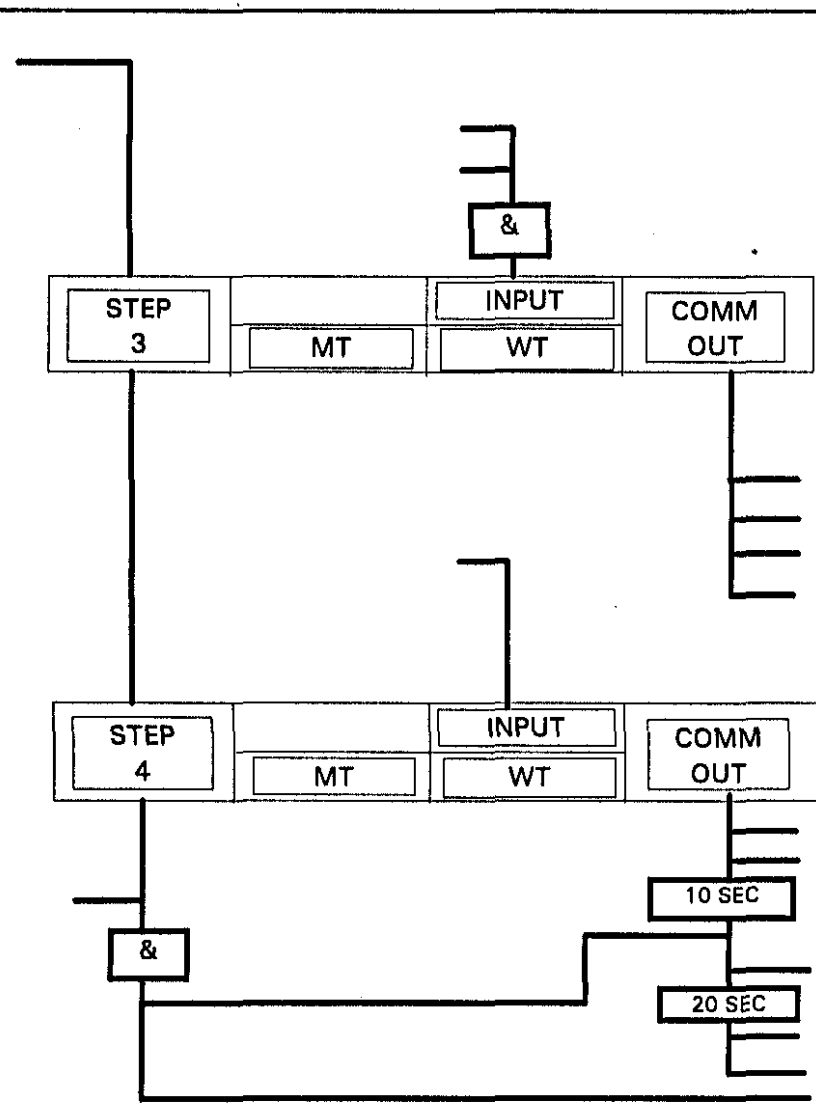


START UP STEP 1 AND 2

Adr	Dest	Set
18-3	TIV BYP VLV SOL	OPN
24-10	GOV SPEED SET POINT	0%
23-10	GOV POWER SET POINT	0%
22-10	GUIDE VANE LIMITER	0%
DESK	STEP 1 CMP IND	ON
16-3	TIV OIL PUMP	ON
18-11	TIV BYP VLV SOL	CLS
17-3	TIV SERVO SOL	CLS
DESK	STEP 2 CMP IND	ON
	STEP 3 INI	ON

Dest	Input	Set	Adr
1			
2	STEP 2	CMP	2
3			
4	TIV POS	100%	FIELD
5	TIV BYP VLV	0%	FIELD
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16	GOV OIL PRESSURE	>MIN	FIELD
17			
18			
19			
20			
21			
22			
23			
24			
25			
26	SPEED ERROR	<1%	20-29
27			
28			
29			
30			
31			
32			
	page 3		



START UP STEP 3 AND 4

Adr	Dest	Set
13-3	GOV OIL PUMP	ON
14-3	GOV OIL CIRC PUMP	ON
15-3	TURB BRG OIL PUMP	ON
19-3	EMER CLS SOL VLV	CLS
DESK	STEP 3 CMP IND	ON
22-16	GUIDE VANE LIMITER	7%
24-20	GOV SPEED SET POINT	95%
22-20	GUIDE VANE LIMITER	95%
GBCF	GEN BREAKER	CLS
DESK	ISOLATED RUN UP COMPL	IND
DESK	STEP 4 CMP IND	ON
	STEP 5	INI

Dest	Input	Set	Adr
1			
2	STEP 4	CMP	3
3	SYNCH MODE	SEL.	DESK
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14	GEN BREAKER	CLSD	GBFC
15			
16			
17			
18			
19			
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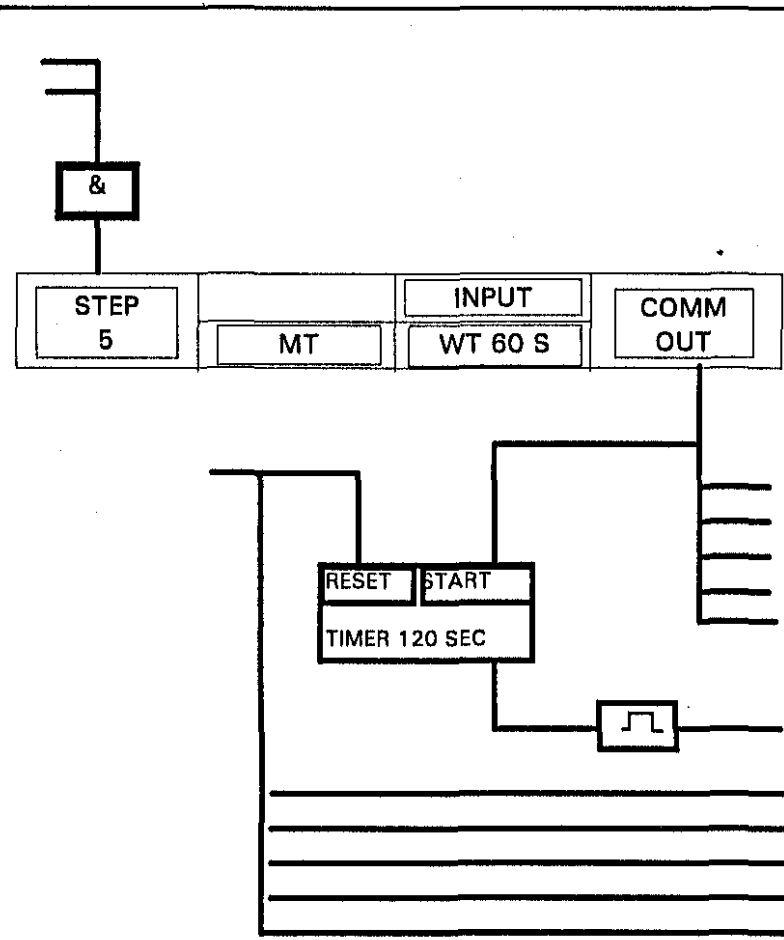

START UP STEP 5

Adr	Dest	Set
SYON	SYNCHRONISER	ON
GSSP1	GRID FREQ. AS SPEED SP	SEL
24-24	MULTIPY SPEED SET PT	1,01
EXON	GENRATOR EXITATION	ON
SYAU	SYCHRONISER AUTO	ON
24-17	SYNCHR. RAISE/LOWER	ON
24-23	MULTIPY SPEED SET PT	1,00
24-18	SYNCHR. RAISE/LOWER	OFF
23-2	POWER LOAD RAMP	UP
DESK	SYNCHRONISED INDI	ON
DESK	STEP 5 CMP IND	ON

Dest	Input	Set	Adr
1			
2			
3	BLACK START	DET	12-18
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15	STN TRFR 1 BRKR	OPN	ST2FO
16	STN TRFR 2 BRKR	OPN	ST1FO
17	BUS COUPLER BRKR	OPN	BC1FO
18			
19			
20			
21			
22			
23			
24			
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26			
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32			
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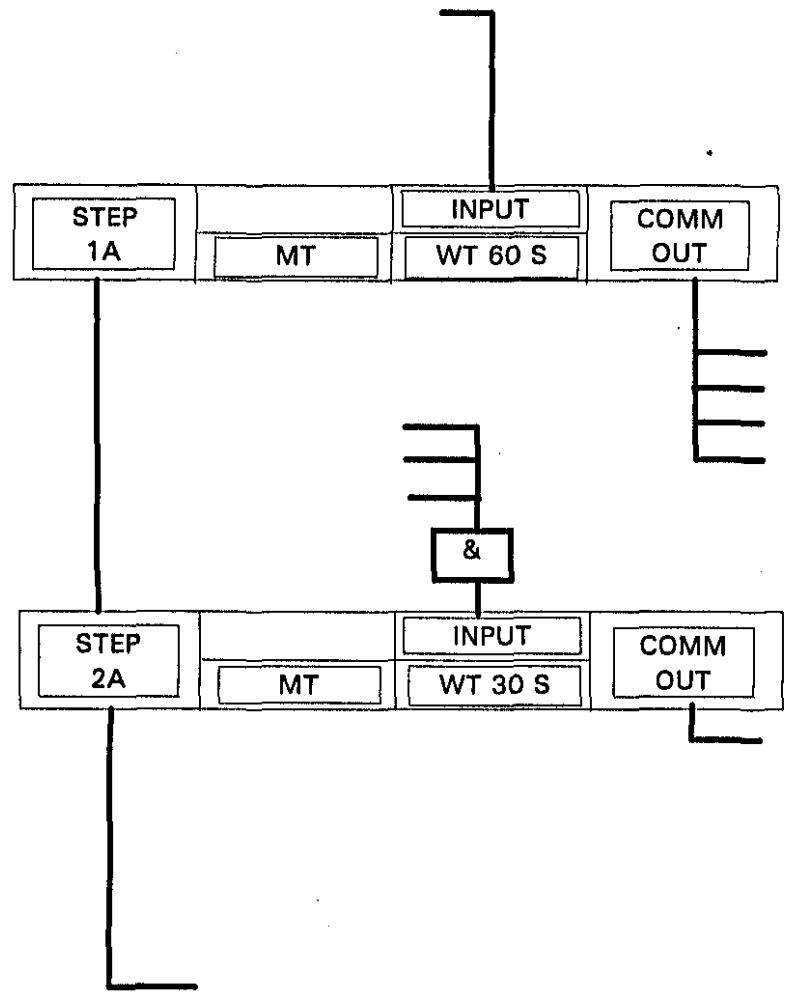
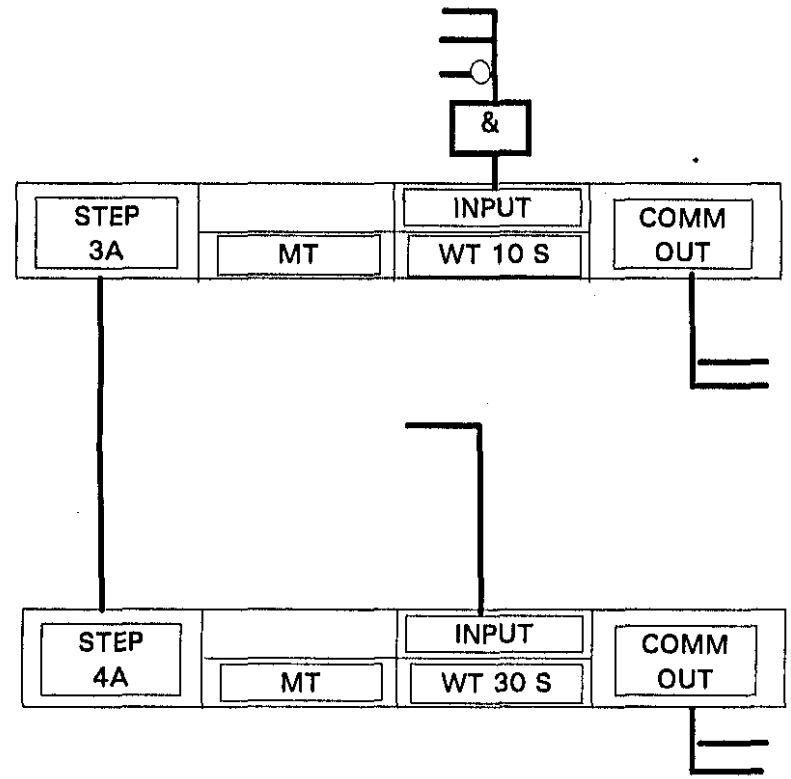


START UP STEP 1A AND 2A

Adr	Dest	Set
ST1CO	STN TRFR 1 BRKR	OPN
ST2CC	STN TRFR 2 BRKR	OPN
BC1CC	BUS COUPLER BRKR	OPN
DESK	STEP 1A CMP IND	ON
1-3	GC START UP INITIATE	ON
6-3	STEP 3A	INI

Dest	Input	Set	Adr		Adr	Dest	Set
1							
2							
3	STEP 2A CMP	ON	5-31				
4	STEP 4 CMP	ON	3-31				
5	NO UNDER VOLTAGE	ON	12-12				
6							
7							
8							
9							
10							
11							
12							
13					GBCC	GEN BREAKER	CLS
14					25-7	START PERMIT SEQ.	ON
15	BUS COUPLER BRKR	CLSD	BC1FC				
16							
17							
18							
19							
20							
21							
22							
23							
24					DESK	BLACK START CMP IND	ON
25					DESK	STEP 4A IND CMP IND	ON
26							
27							
28							
29							
30							
31							
32							
	page 6			START UP STEP 3A AND 4A			



Dest	Input	Set	Adr
1			
2			
3			
4			
5	CG SHUT DOWN	ON	GC
6			
7			
8			
9			
10			
11			
12			
13			
14	SYNCH MODE	SEL	DESK
15			
16			
17			
18			
19	KW OUTPUT	<10%	21-18
20			
21			
22			
23			
24			
25			
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27			
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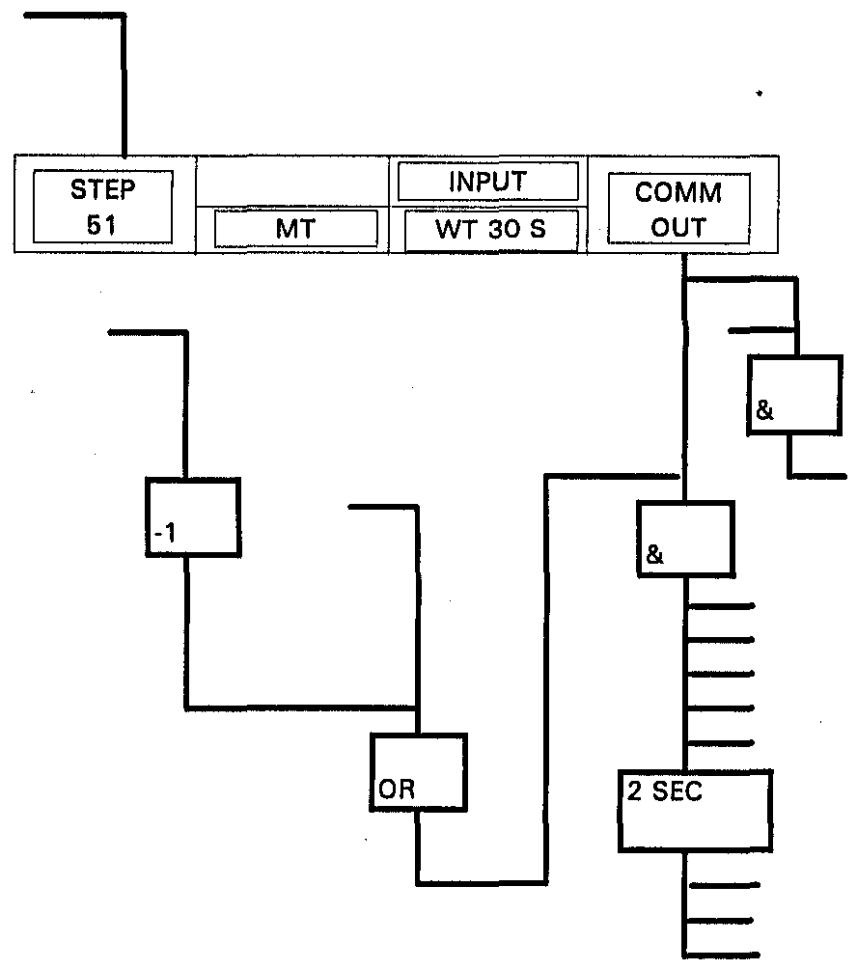
32			
	page 7		



Adr	Dest	Set
23-1	POWER SP RAMP	DOWN
GBCO	GEN BREAKER	OPN
22-10	GUIDE VANE LIMITER	0%
EXOFF	EXITATION	OFF
17-11	TIV SERVO SOL	OPN
16-11	TIV PUMP	OFF
19-11	EMERGENCY CLS SOL	OPN
13-11	GOV OIL PUMP	OFF
DESK	STEP 51 CMP IND	ON

SHUT DOWN STEP 51

Dest	Input	Set	Adr
1			
2			
3			
4			
5	STEP 51 CMP	ON	7-32
6			
7			
8	SPEED	= 0%	20-6
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
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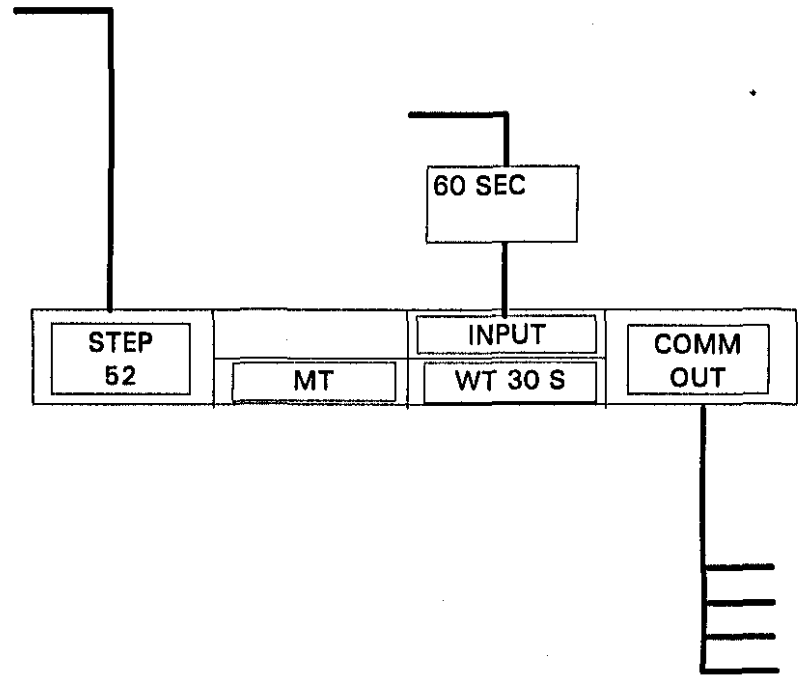

SHUT DOWN STEP 52

Adr	Dest	Set
14-11	GOV CIRC PUMP	OFF
15-11	TURB BRG OIL PUMP	OFF
11-6	UNDER SPEED	RSET
DESK	STEP 52 CMP IND	ON

Dest	Input	Set	Adr
1			
2			
3			
4			
5	PROTECTION	ON	11-28
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
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30			
31			
32			
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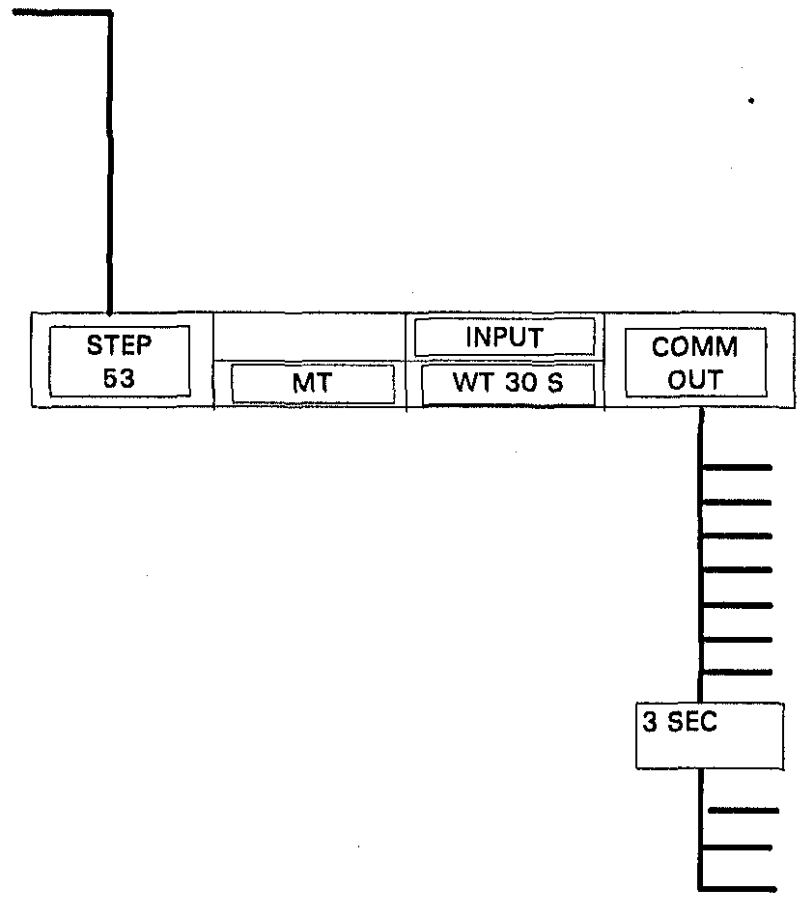

Adr	Dest	Set
16-10	TIV OIL PUMP	OFF
EXOFF	EXITATION	OFF
17-10	TIV SERVO SOL	OPN
GBCO	GEN BREAKER	OPN
22-12	GUIDE VANE LIMITER	0%
24-18	SPEED SET POINT	0%
23-11	POWER SET POINT	0%
19-10	EMERG. CLS SOL	OPN
13-10	GOVERNOR OIL PUMP	OFF
DESK	STEP 53 CMP IND	ON

EMERGENCY SHUT DOWN STEP 53

Dest	Input	Set	Adr
1			
2			
3			
4			
5	STEP 53 CMP	ON	9-30
6			
7			
8	SPEED	=0%	20-8
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
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22			
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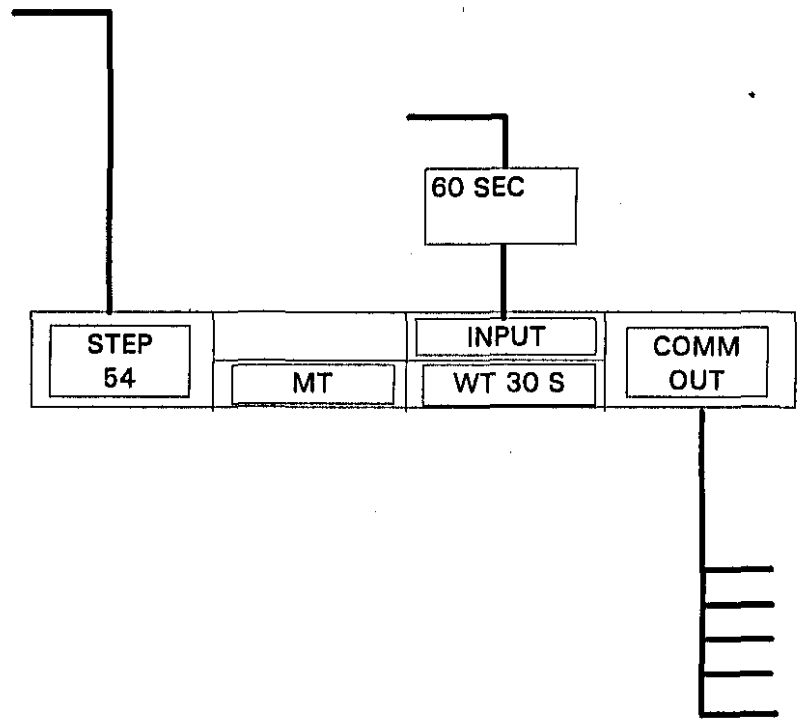

Adr	Dest	Set
14-19	GOV CIRC PUMP	OFF
15-10	TURB BRG OIL PUMP	OFF
11-6	UNDER SPEED	RSET
DESK	STEP 54 CMP IND	ON
DESK	SHUT DOWN CMP IND	ON

EMERGENCY SHUTDOWN STEP 54

Dest	Input	Set	Adr
1			
2	ELECT PROT	OPTD	EPO
3	SPEED	>1050	20-18
4	MECH OVER SPEED	OPTD	FIELD
5	SPEED	>700	20-10
6	STEP 52	RSET	8-23
7	STEP 54	RSET	10-23
8			
9	SPEED	<600	20-14
10			
11			
12			
13			
14			
15			
16			
17	TURB BRG OIL LEVEL	<MIN	FIELD
18	GOV OIL LEVEL	<MIN	FIELD
19	GEN BRG 1 TEMP	>MAX	FIELD
20	GEN BRG2 TEMP	>MAX	FIELD
21	TURB BRG TEMP 1	>MAX	FIELD
22	TURB BRG TEMP 2	>MAX	FIELD
23	GOV OIL PRESS	<MIN	FIELD
24			
25			
26			
27			
28			
29			
30			
31			
32			
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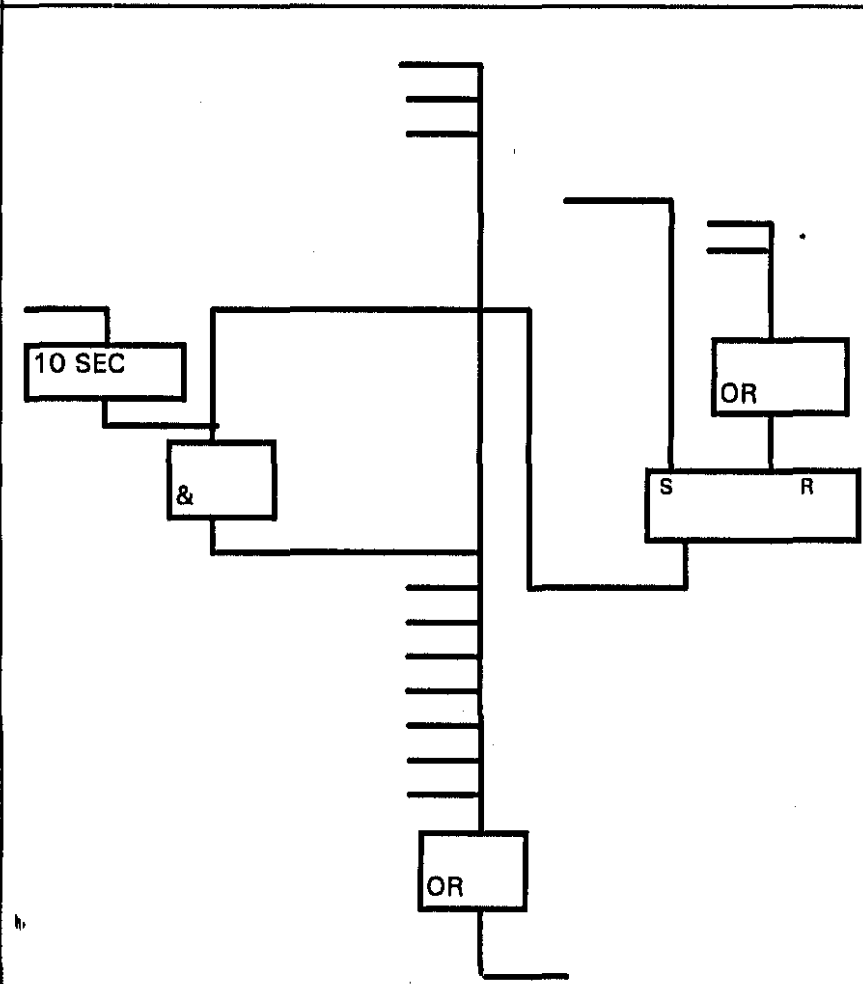
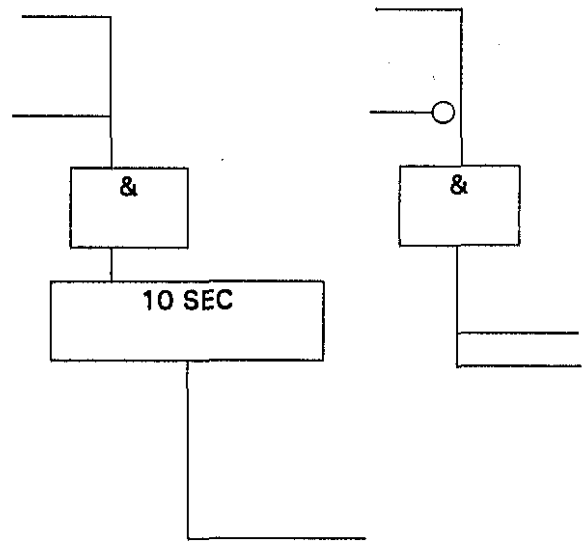


PROTECTION

Adr	Dest	Set
9-5	PROTECTION STEP 53	ON
	PROTECTION OPERATED	

Dest	Input	Set	Adr		Adr	Dest	Set
1							
2							
3	BLACKSTART MODE	SEL	DESK				
4							
5							
6	BOARD UV	DETC.	FIELD				
7							
8							
9							
10							
11							
12					BCCO	BUS COUPLER	OPN
13					6-5	VOLTAGE HEALTHY	ON
14							
15							
16							
17							
18					5-3	STEP 1A	ON
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							
33	page 12			BLACK START DETECT			



Dest	Input	Set	Adr
1			
2			
3	SEQ. STEP	ON	3-14
4	CG MAN	SEL	DESK
5	ON PUSH BUT	ACT	DESK
6	RELEASE PB	ACT	DESK
7			
8			
9	SEQ. STEP 53	OFF	9-29
10	SEQ. STEP 51	OFF	7-31
11	OFF PUSH BUT	ACT	DESK
12	RELEASE PB	ACT	DESK
13			
14			
15			
16			
17	S.GEAR	STAT.	SG
18	S.GEAR	FLT	SG
19			
20			
21			
22			
23			
24			
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27			
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29			
30			
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32			
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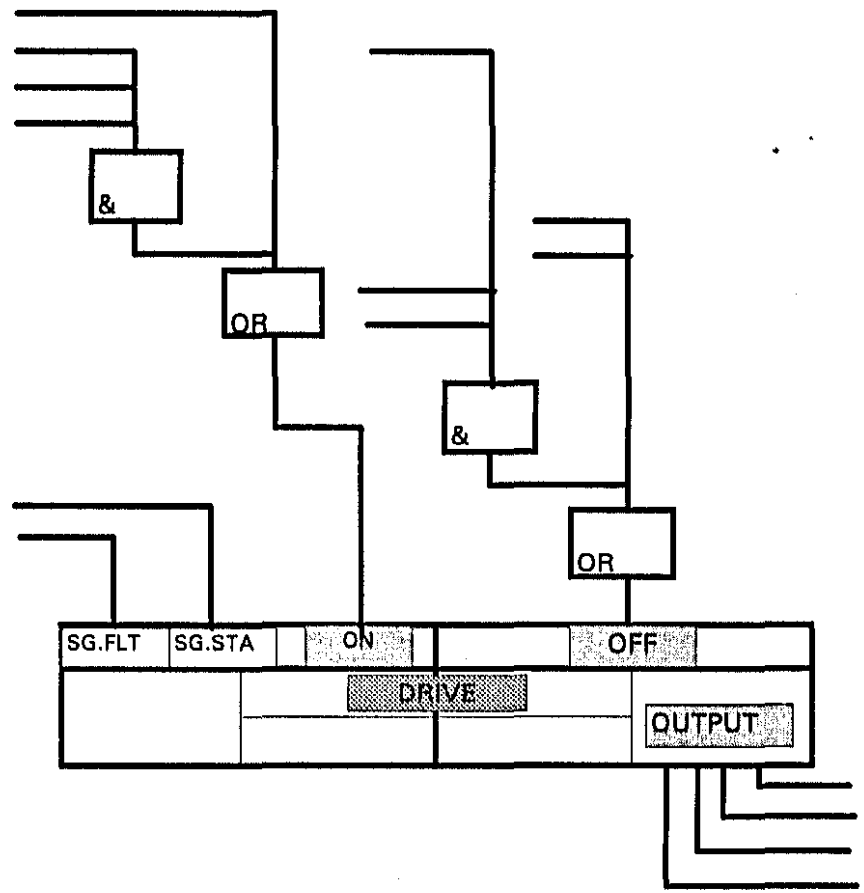

GOVERNOR OIL PUMP

Adr	Dest	Set
DESK	DESK LED ON	ON
DESK	DESK LED FAULT	ON
DESK	DESK LED OFF	ON
SG	GOV OIL PUMP S.GEAR	ON

Dest	Input	Set	Adr
1			
2			
3	SEQ. STEP	ON	3-15
4	CG MAN	SEL	DESK
5	ON PUSH BUT	ACT	DESK
6	RELEASE PB	ACT	DESK
7			
8			
9			
10	SEQ. STEP 54	OFF	10-21
11	SEQ. STEP 52	OFF	8-21
12	OFF PUSH BUT	ACT	DESK
13	RELEASE PB	ACT	DESK
14			
15			
16			
17	S.GEAR	STAT.	SG
18	S.GEAR	FLT	SG
19			
20			
21			
22			
23			
24			
25			
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31			
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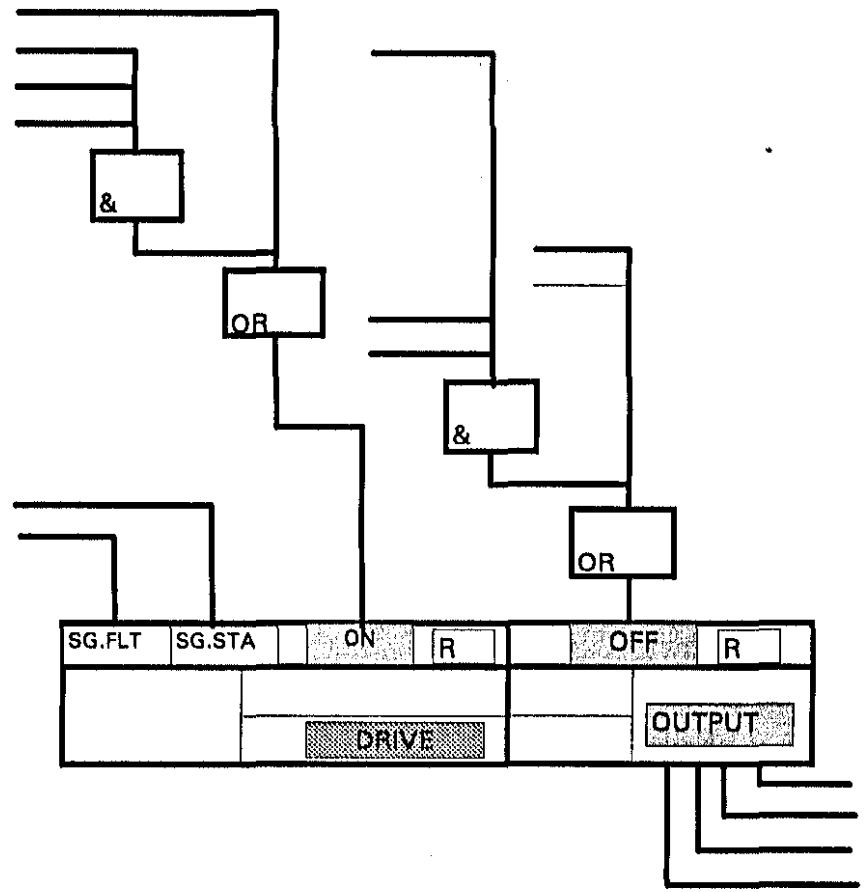

GOVERNOR CIRC OIL PUMP

Adr	Dest	Set
DESK	DESK LED ON	ON
DESK	DESK LED FAULT	ON
DESK	DESK LED OFF	ON
SG	GOV CIRC OIL PMP S.GR	ON

Dest	Input	Set	Adr
1			
2			
3	SEQ. STEP	ON	3-16
4	CG MAN	SEL	DESK
5	ON PUSH BUT	ACT	DESK
6	RELEASE PB	ACT	DESK
7			
8			
9			
10	SEQ. STEP 54	OFF	10-22
11	SEQ. STEP 52	OFF	8-22
12	OFF PUSH BUT	ACT	DESK
13	RELEASE PB	ACT	DESK
14			
15	SPEED	=0%	20-6
16			
17	S.GEAR	STAT.	SG
18	S.GEAR	FLT	SG
19			
20			
21			
22			
23			
24			
25			
26			
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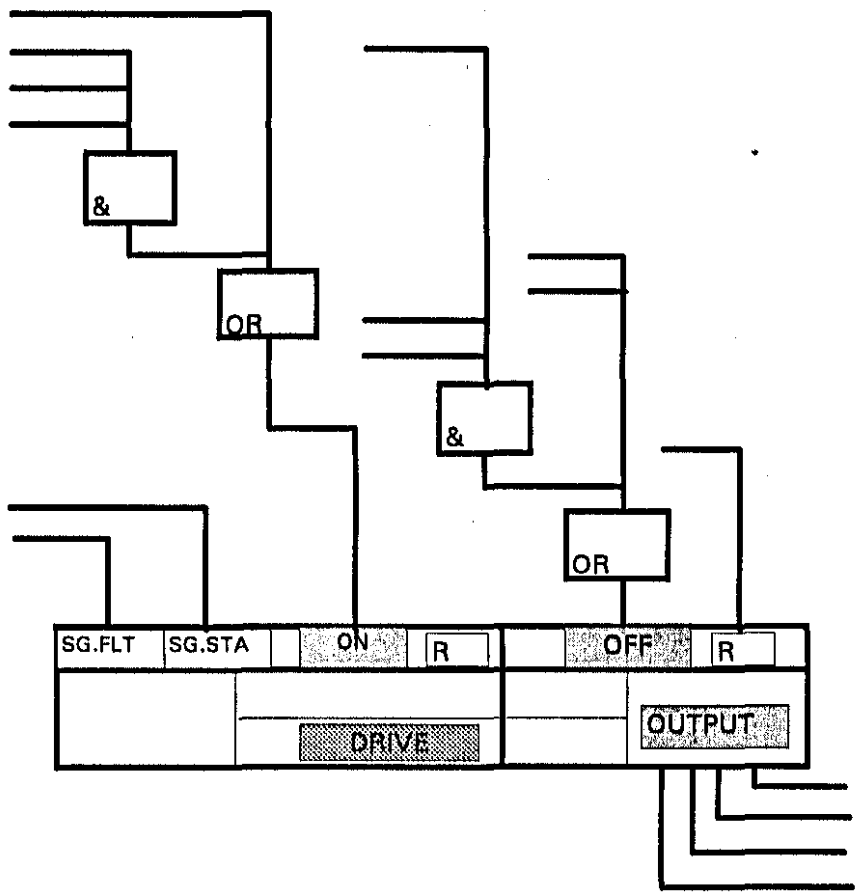

Adr	Dest	Set
DESK	DESK LED ON	ON
DESK	DESK LED FAULT	ON
DESK	DESK LED OFF	ON
SG	TURBINE OIL PUMP S.GR	ON

TURBINE BEARING OIL PUMP

Dest	Input	Set	Adr
1			
2			
3	SEQ. STEP	ON	2-24
4	CG MAN	SEL	DESK
5	ON PUSH BUT	ACT	DESK
6	RELEASE PB	ACT	DESK
7			
8			
9			
10	SEQ. STEP 53	OFF	9-18
11	SEQ. STEP 51	OFF	7-26
12	OFF PUSH BUT	ACT	DESK
13	RELEASE PB	ACT	DESK
14			
15	TIV POSITION	<=90%	
16	TIV POSITION	>=100%	
17	S.GEAR	STAT.	SG
18	S.GEAR	FLT	SG
19			
20			
21			
22			
23			
24			
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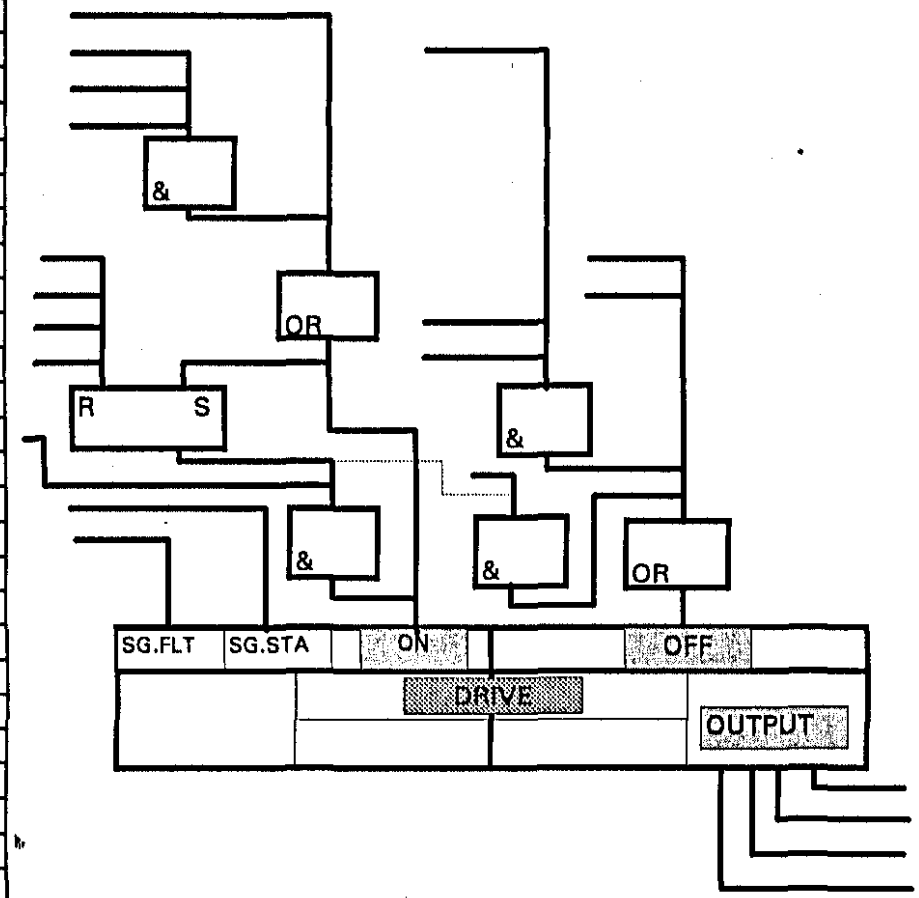

TIV OIL PUMP

Adr	Dest	Set
DESK	DESK LED ON	ON
DESK	DESK LED FAULT	ON
DESK	DESK LED OFF	ON
SG	TIV OIL PUMP S.GEAR	ON

Dest	Input	Set	Adr
1			
2			
3	SEQ. STEP	ON	2-26
4	CG MAN	SEL	DESK
5	ON PUSH BUT	ACT	DESK
6	RELEASE PB	ACT	DESK
7			
8			
9			
10	SEQ. STEP 53	OFF	9-20
11	SEQ. STEP	OFF	7-25
12	OFF PUSH BUT	ACT	DESK
13	RELEASE PB	ACT	DESK
14			
15			
16			
17	S.GEAR	STAT.	SG
18	S.GEAR	FLT	SG
19			
20			
21			
22			
23			
24			
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30			
31			
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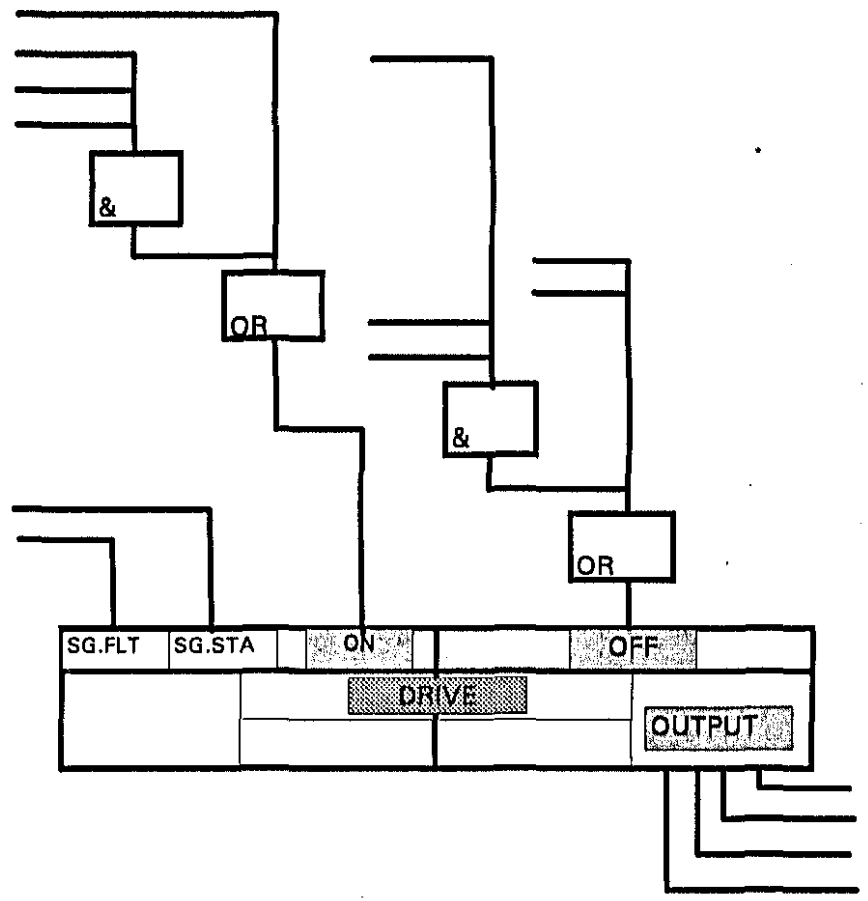
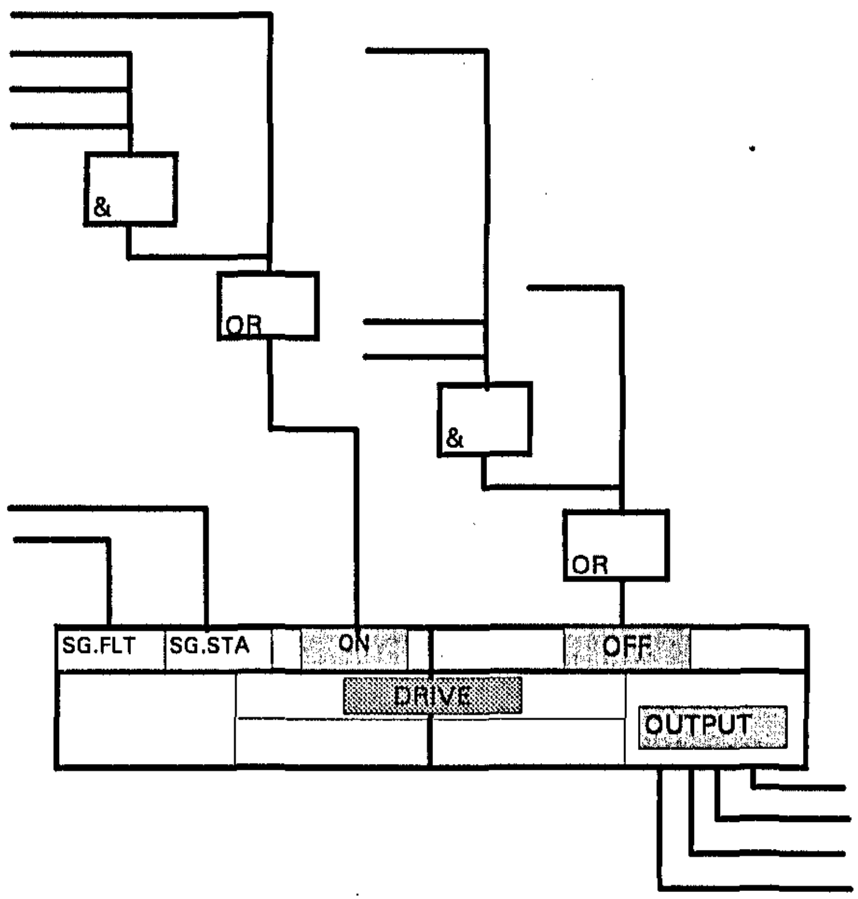


TIV CONTROL SOLENOID

Adr	Dest	Set
DESK	DESK LED ON	ON
DESK	DESK LED FAULT	ON
DESK	DESK LED OFF	ON
SG	TIV CNTRL SOL S.GEAR	ON

TIV BYPASS VALVE CONTROL SOLENOID



Dest	Input	Set	Adr	Adr	Dest	Set
1						
2						
3	SEQ. STEP 1	ON	2-25			
4	CG MAN	SEL	DESK			
5	ON PUSH BUT	ACT	DESK			
6	RELEASE PB	ACT	DESK			
7						
8						
9						
10						
11	SEQ. STEP 2	OFF	2-25			
12	OFF PUSH BUT	ACT	DESK			
13	RELEASE PB	ACT	DESK			
14						
15						
16						
17	S.GEAR	STAT.	SG			
18	S.GEAR	FLT	SG			
19						
20						
21						
22						
23						
24						
25				DESK	DESK LED ON	ON
26				DESK	DESK LED FAULT	ON
27				DESK	DESK LED OFF	ON
28				SG	TIV BYP VLV SOL S.GEAR	ON
29						
30						
31						
32						

Dest	Input	Set	Adr
1			
2			
3	SEQ. STEP 3	ON	3-17
4	CG MAN	SEL	DESK
5	ON PUSH BUT	ACT	DESK
6	RELEASE PB	ACT	DESK
7			
8			
9			
10	SEQ. STEP 63	OFF	9-28
11	SEQ. STEP 61	OFF	7-30
12	OFF PUSH BUT	ACT	DESK
13	RELEASE PB	ACT	DESK
14			
15			
16			
17	S.GEAR	STAT.	SG
18	S.GEAR	FLT	SG
19			
20			
21			
22			
23			
24			
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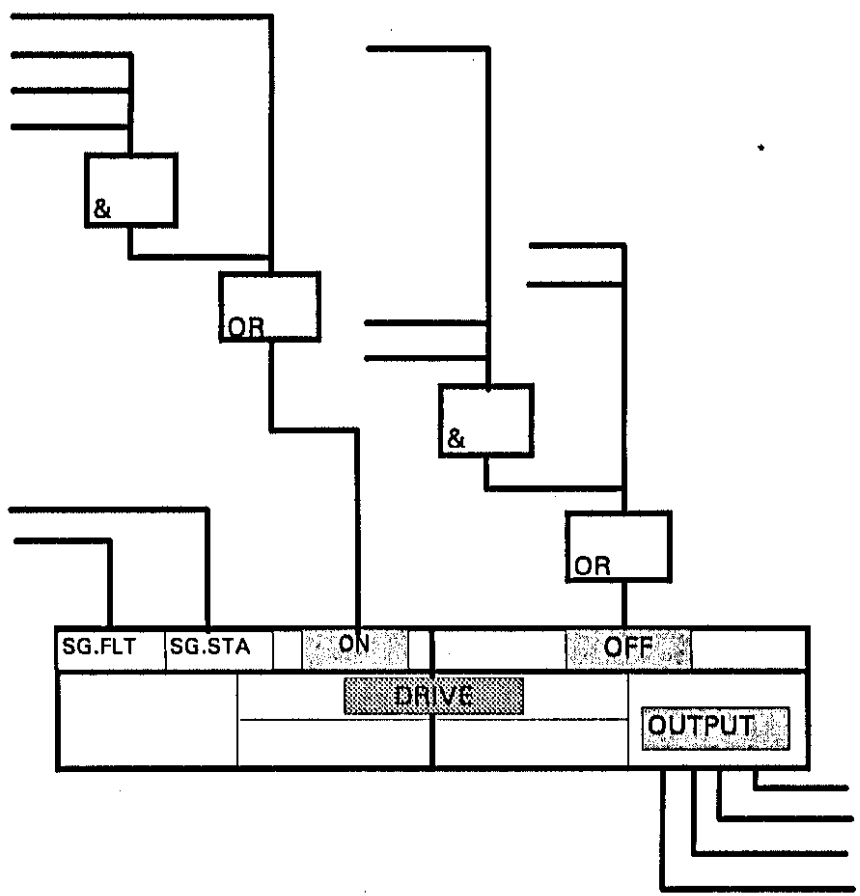

EMERGENCY CLOSE SOLENOID VALVE

Adr	Dest	Set
DESK	DESK LED ON	ON
DESK	DESK LED FAULT	ON
DESK	DESK LED OFF	ON
SG	EMERG. SOL VLV S.G	ON

Dest	Input	Set	Adr
1			
2	MACHINE SPEED		FIELD
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23	SPEED SET POINT		24-24
24			
25			
26	MACHINE SPEED		FIELD
27			
28			
29			
30			
31			
32			
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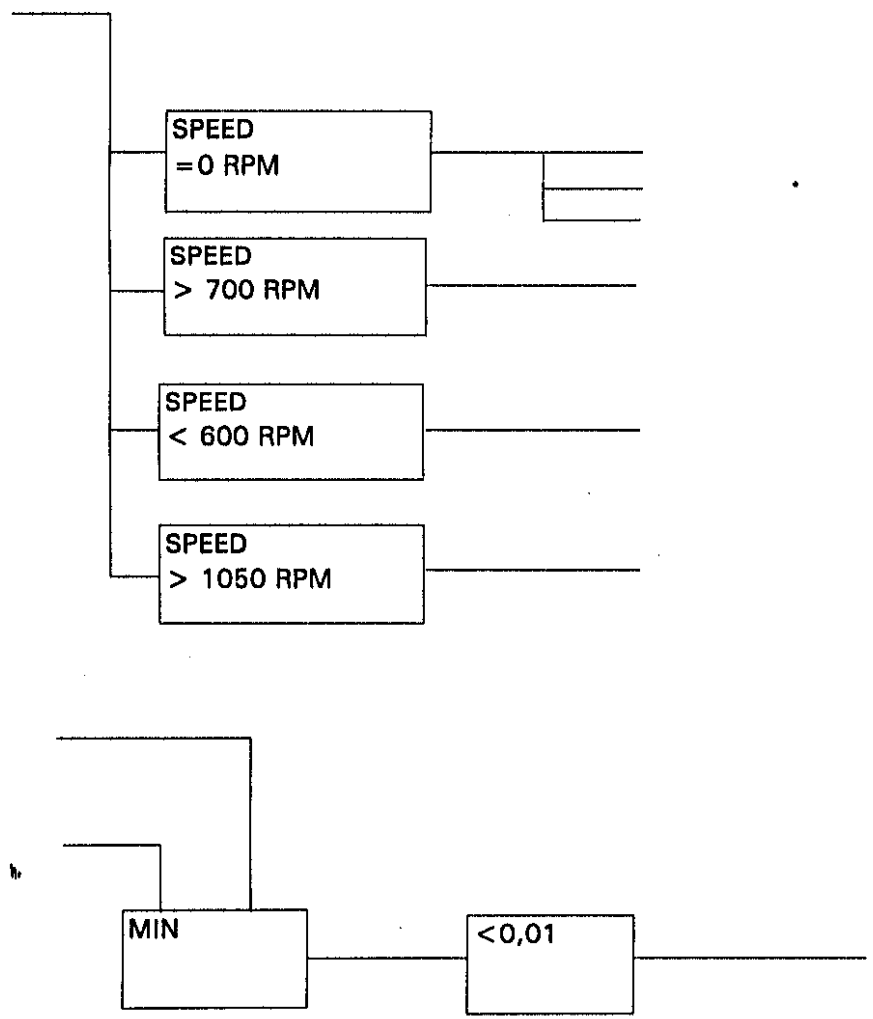
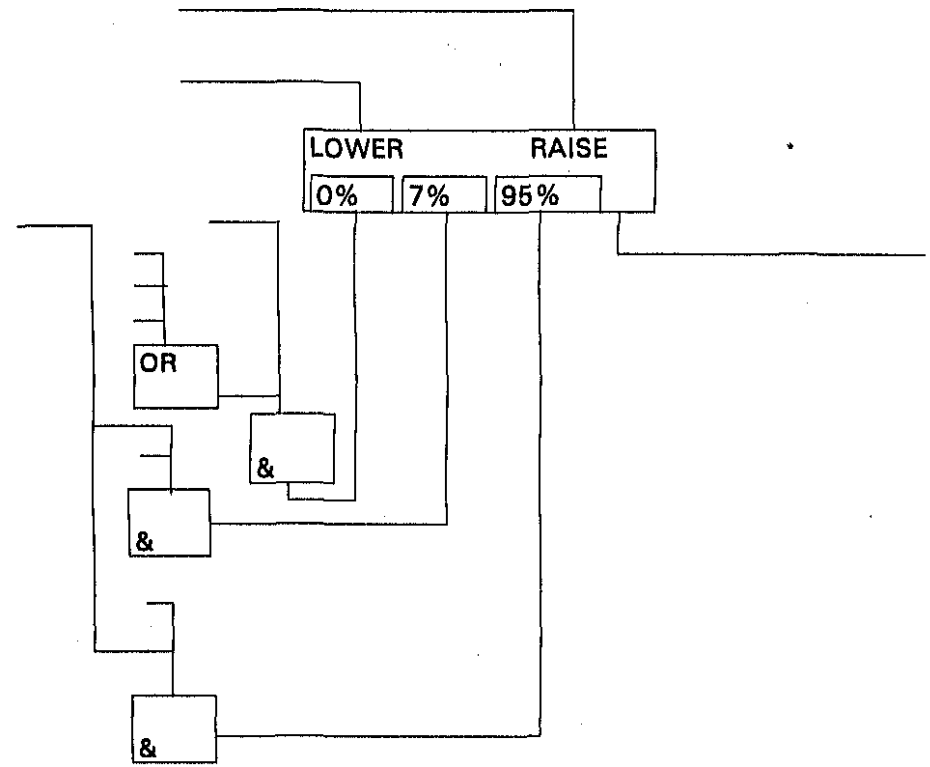


SPEED DETECTION

Adr	Dest	Set
8-8	STEP 52	
10-8	STEP 54	
15-15	TURB BRG OIL PUMP	
11-5	PROTECTION ON	
11-19	PROTECTION ON	
11-3	PROTECTION ON	
3-26	SPEED ERROR <1%	

Dest	Input	Set	Adr		Adr	Dest	Set
1							
2							
3	MACHINE POWER						
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18				POWER <10 KW	7-19	STEP 51	
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							
33	page 21			POWER DETECTION			

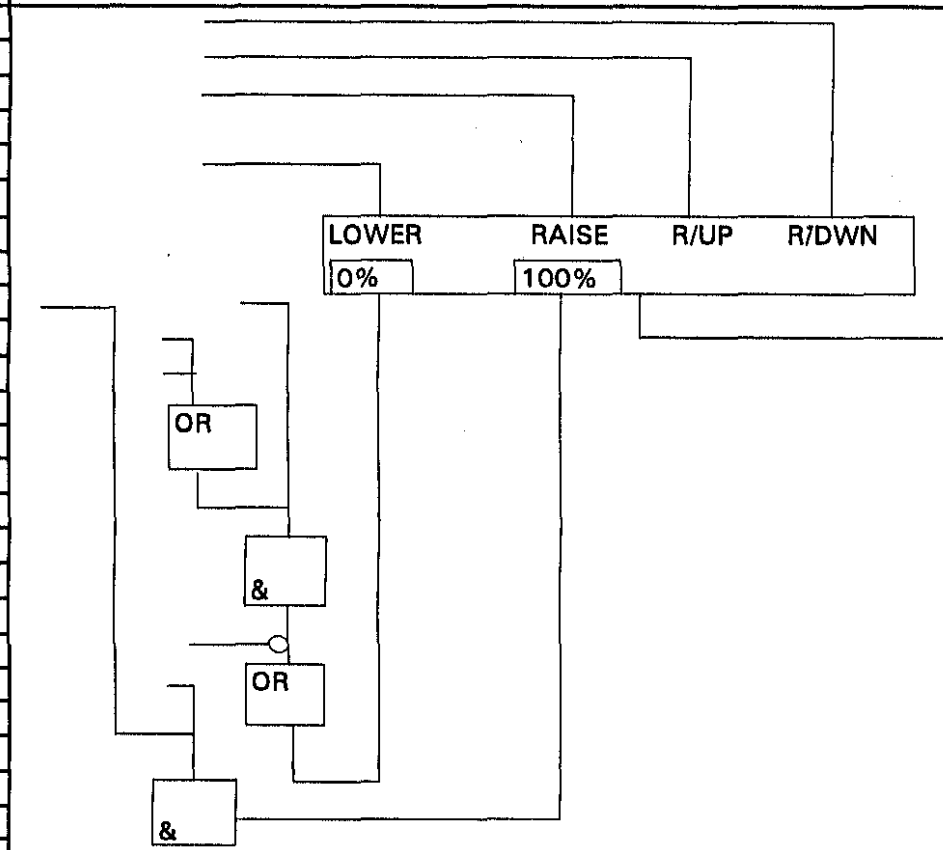
Dest	Input	Set	Adr
1			
2			
3	GV LIM RAISE PB		DESK
4			
5	GV LIM LOWER PB		DESK
6			
7			
8			
9	CG	AUTO	DESK
10	STEP 1		2-16
11	STEP 51		7-23
12	STEP 53		9-5
13			
14			
15			
16	STEP 4		3-24
17			
18			
19			
20	STEP 4		3-28
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33	page 22		



GUIDE VANE LIMITER SET POIN FORMATION

Adr	Dest	Set
27-27	ANALOG CONTROL	

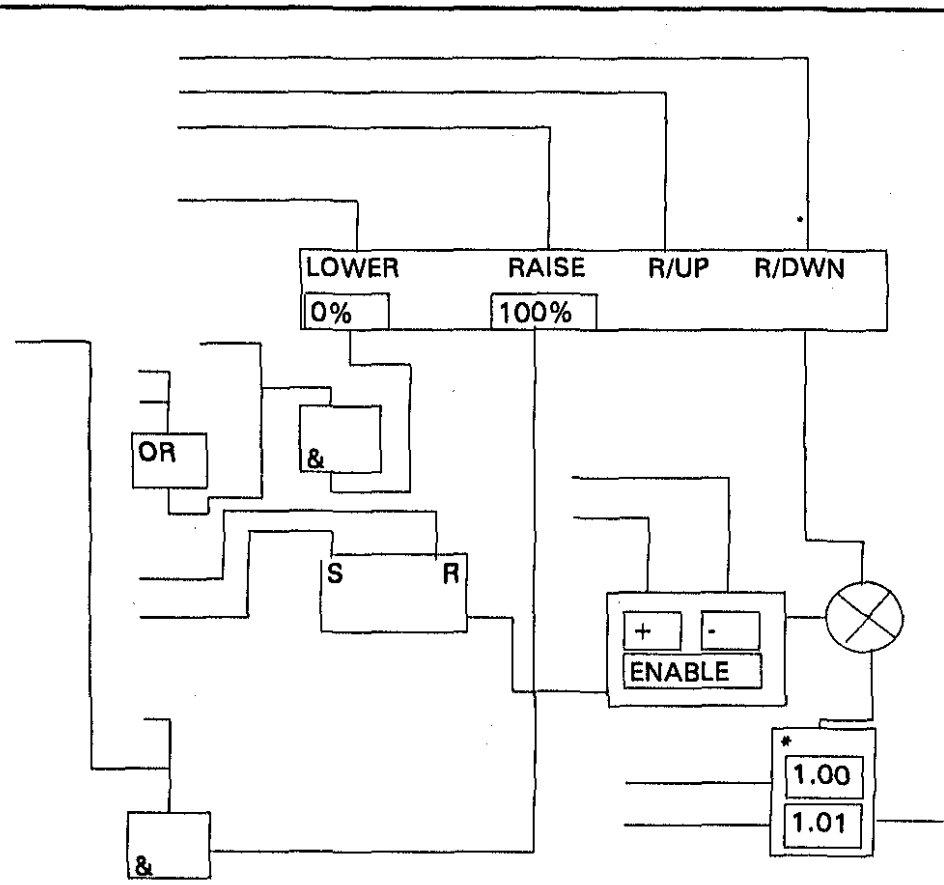
Dest	Input	Set	Adr
1	STEP 51		7-18
2	STEP 5		4-25
3	POWER RAISE PB		
4			
5	POWER LOWER PB		
6			
7			
8			
9	CG	AUTO	
10	STEP 1		2-15
11	STEP 53		9-24
12			
13			
14			
15			
16			
17			
18			
19	GEN BREAKER	CLSD	GBFC
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33	page 23		



Adr	Dest	Set
27-15	ANALOG CONTROL	

POWER SET POINT FORMATION

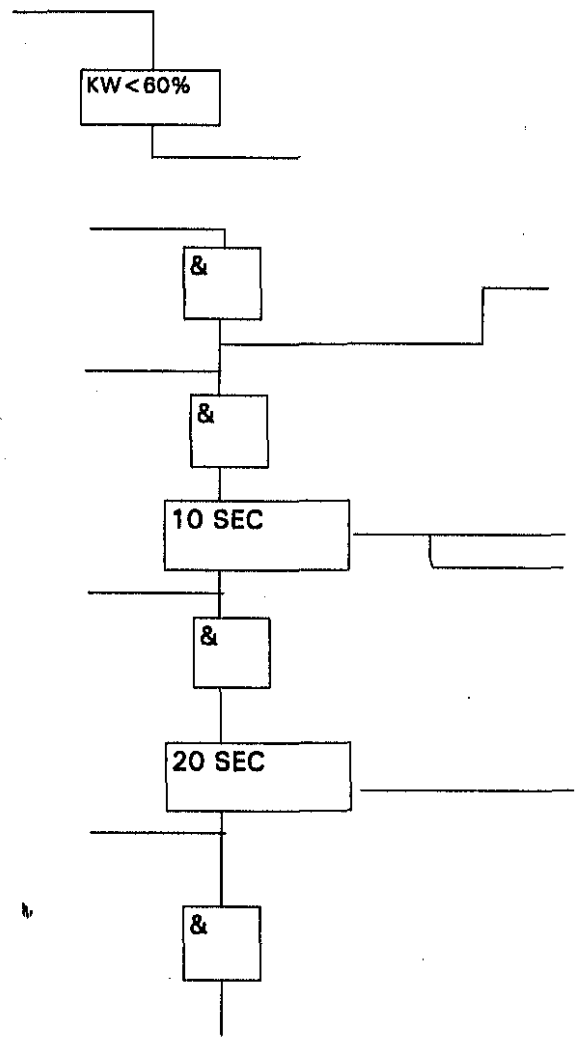
Dest	Input	Set	Adr
1			
2			
3			
4	SPEED RAISE PB		DESK
5			DESK
6	SPEED LOWER PB		
7			
8			
9			
10	CG	AUTO	
11	STEP 1		2-14
12	STEP 53		9-23
13			
14	SYNCH RAISE		
15	SYNCH LOWER		
16			
17	RAISE/LOWER ENABL.	ON	4-21
18	RAISE/LOWER ENABL.	OFF	4-24
19			
20			
21	STEP 4		3-26
22			
23	STEP 5		4-16
24	STEP 5		4-23
25			
26			
27			
28			
29			
30			
31			
32			
33	page 24		



Adr	Dest	Set
27-7	ANALOG CONTROL	

SPEED SET POINT FORMATION

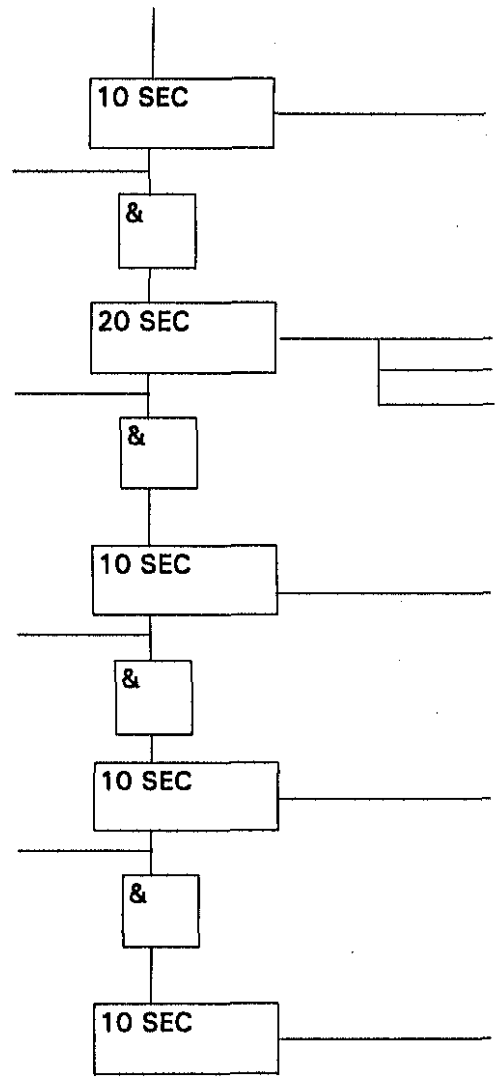
Dest	Input	Set	Adr
1			
2			
3			
4			
5			
6			
7	STEP 3A		6-15
8			
9			
10			
11	KW<60%		25-4
12			
13			
14			
15			
16			
17	KW<60%		25-4
18			
19			
20			
21			
22			
23			
24	KW<60%		25-4
25			
26			
27			
28			
29			
30			
31			
32			
	page 25		



SEQUENCED STARTING

Adr	Dest	Set
	KW<60%	
DP1PTS	PTS DRAIN PUMP1	
ASPA1PTS	PTS AUX SUMP P A1	
ASPA2PTS	PTS AUX SUMP P B2	
DP2PTS	PTS DRAIN PUMP 2	

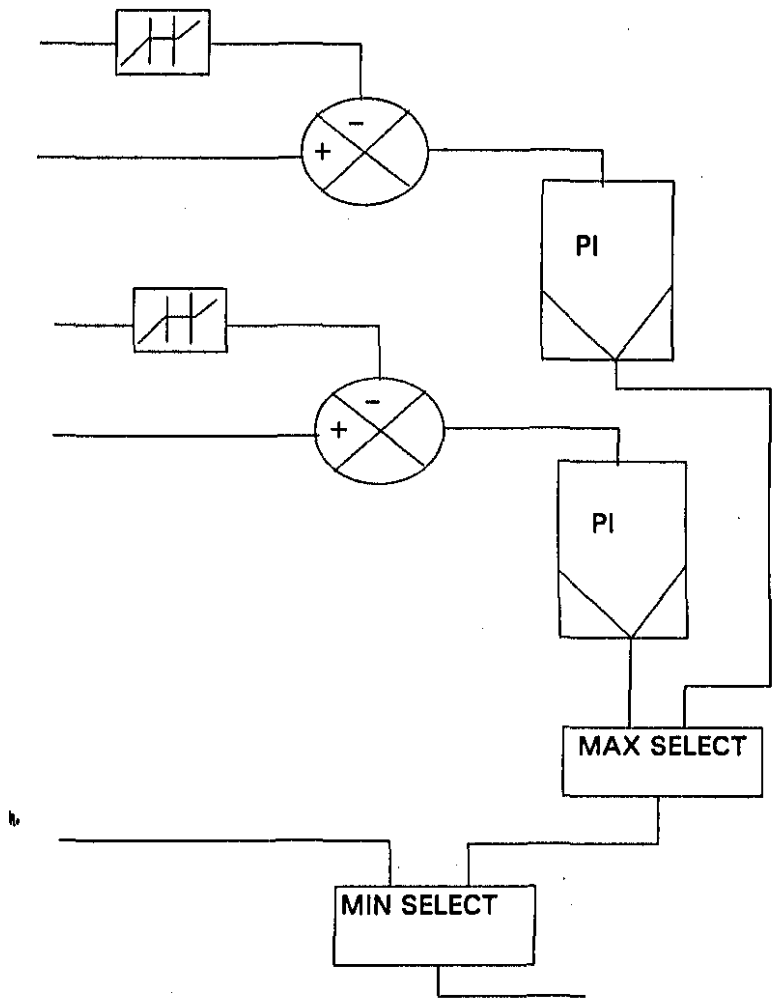
Dest	Input	Set	Adr
1			
2			
3			
4			
5	KW < 60%		25-4
6			
7			
8			
9			
10			
11			
12	KW < 60%		25-4
13			
14			
15			
16			
17			
18			
19	KW < 60%		25-4
20			
21			
22			
23			
24			
25	KW < 60%		25-4
26			
27			
28			
29			
30			
31			
32			
	page 26		



SEQUENCED STARTING

Adr	Dest	Set
DP3PTS	PTS DRAIN PMP 3	ON
ASPB2PTS	PTS AUX SUMP P A2	ON
ASPA2PTS	PTS AUX SUMP P B2	ON
BCCC	BUS COUPLER	CLS
SP2PTS	PTS SEWRAGE PMP 1	ON
SP1PTS	PTS SEWRAGE PMP 2	ON
SCO1PTS	PTS SCO COMP 1	ON
SCOPTS	PTS SCO COMP 2	ON

Dest	Input	Set	Adr
1			
2			
3			
4	SPEED MV	4-20	FIELD
5			
6			
7	SPEED SET POINT		24-24
8			
9			
10			
11			
12	POWER MV	4-20	FIELD
13			
14			
15	POWER SET POINT		23-10
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27	GUIDE VANE LIM		22-9
28			
29			
30			
31			
32			
	page 27		



ANALOG CONTROL

Adr	Dest	
AGVPS	GUIDE VANE POS CNTRL	
	4-20mA	