# Introduction to Nuclear Plant Steam Turbine Control Systems

**WARNING:**
**Please read the Export Control Agreement on the back cover.**

*Technical Report*

# Preface

*Since Nuclear Power Plants produce their power through the use of Steam Turbine Generators, any problems associated with the Turbine Control System has a direct effect on power generation. Although considerable effort has been expended in improving control system reliability, failures resulting in lost generation and high maintenance cost still plague the industry. On an individual basis, improvements have been made through maintenance techniques, modifications and upgrades. Unfortunately this information is not always readily available to plants experiencing similar failures so the tendency is to correct problems on a reactive rather than proactive basis.*

*This Tech Note reviews system failures using information from INPO's Nuclear Plant Reliability Data System (NPRDS) and Nuclear Network, the Operating Plant Experience Code (OPEC), the Nuclear Operations & Maintenance Information Service (NOMIS), and the Nuclear Maintenance Applications Center (NMAC) surveys and summarizes the corrective actions that have proven beneficial. This information can be used by utilities to evaluate maintenance programs. This Tech Note is a prelude to future NMAC guides which will cover in more detail hydraulic fluids, hydraulic components and electrical/ electronic control svstems.*

**Acknowledgments**

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## Table of Contents

# 1.0 Introduction

This Tech Note consists of four sections. Section 2 describes fundamentals of turbine control and provides some details on both Mechanical Hydraulic Control (MHC) and Electrohydraulic Control (EHC) systems. Specific parts of this section are devoted primarily to Westinghouse and General Electric systems with brief descriptions of systems provided by some of the other suppliers (i.e., Siemens, ABB, NEI Parsons, and GEC). The descriptions are not all inclusive and are presented for the purpose of assisting utility personnel in evaluating industry failure reports. Fire retardant hydraulic fluid is also discussed in this section.

Section 3 contains a list of nuclear plants, switchboard telephone numbers, and type of turbine control system. Again, the list is not all inclusive but is provided to assist in the communication between plants with similar systems.

Section 4 is a compilation of turbine control system problems. It highlights hydraulic fluid, fluid leaks, electronic and electrical controls, field devices, hydraulic components and maintenance.

# 2.0 Turbine Control Systems

## 2.1 Introduction

The function of the turbine control and protection system is to regulate turbine speed, maintain set load, control rate of load increases, and provide protection for the turbine and generator. For Boiling Water Reactors, an additional function of the control system is to control reactor pressure. The turbine control and protection system can be divided into five major parts:

- The hydraulic fluid system
- The emergency trip system
- The valve controllers
- The control system
- The trip and monitoring system
- Mechanical hydraulic control (MHC) systems use a complex arrangement of mechanical devices which normally utilize the turbine lubrication oil system as the source of hydraulic fluid. This results in a reliable source of hydraulic pressure but it is susceptible to water and particulate contamination from bearings, steam seals and corrosion. MHC systems typically are composed of relays, switches, synchros, and motors that provide a limited control capability. The majority of nuclear turbines are equipped with electrohydraulic control (EHC) systems which utilize a dedicated high pressure hydraulic fluid system independent of the turbine lubrication system. EHC systems utilize electronic controls which offer a wider range of control options.
- Compared to MHC systems, the high pressure EHC systems (typically 1600-2000 PSI) provide faster response, more precise control, fewer mechanical components, redundant electronic controls, flexible control schemes, and improved fire safety through use of fire resistant hydraulic fluid. However, EHC systems require dedicated high pressure hydraulic power units, close attention to hydraulic fluid cleanliness and chemistry, and complex electronic control systems.
- In contrast to the electronic control systems, hydraulic technology was relatively mature when EHC systems were introduced. Although improvements in materials and components have been made, essentially, modern EHC systems use the same hydraulic concepts as the original MHC designs.

## 2.2 Turbine Control System Fundamentals

### 2.2.1 Steam Path

Nuclear steam turbines are generally divided into two sections: high pressure and low pressure. The steam leaving the reactor (BWR) or steam generator (PWR) enters the High Pressure Turbine after passing through the Main Stop and Governor

Valves. After passing through the High Pressure Turbine the steam is directed through the Moisture Separator or Moisture Separator Reheater and then to the Low Pressure Turbine(s) by way of the Reheat Stop and Intercept Valves. The function of the turbine control system is to regulate the flow of the steam through these valves to maintain turbine speed or load. Figure 2-1 shows a basic system.

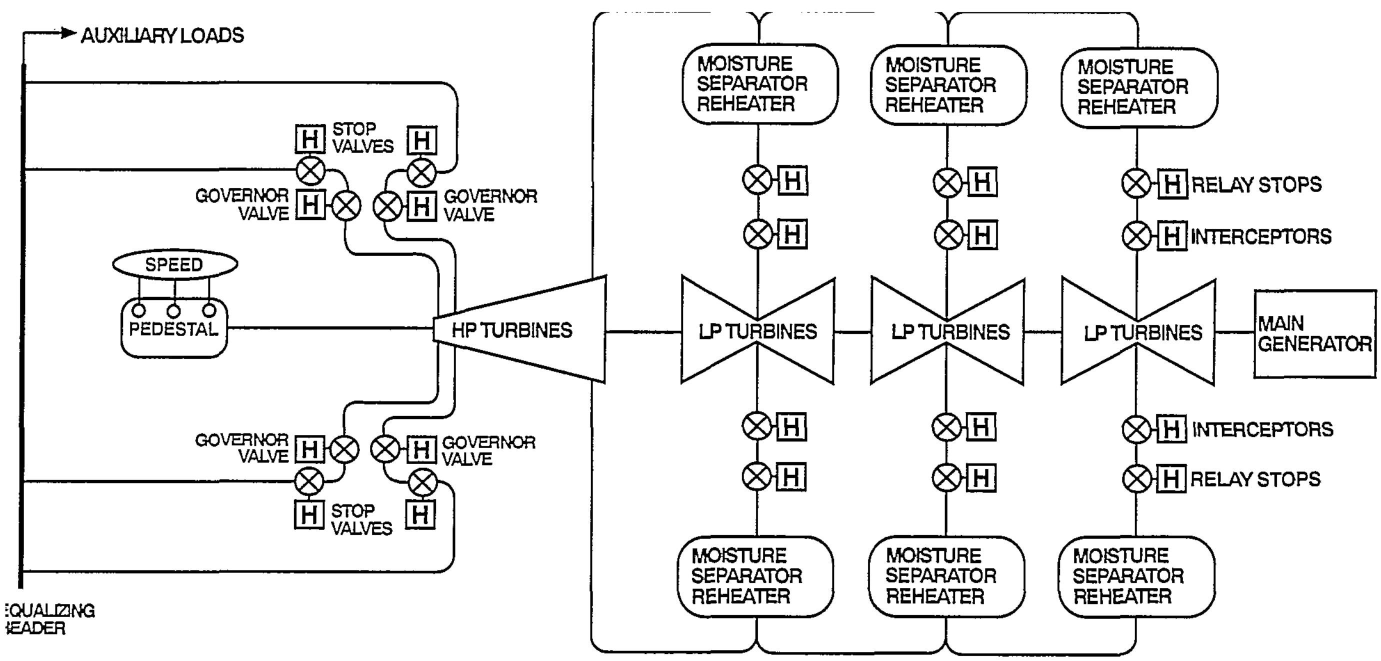


**Figure 2-1- Typical System Diagram**

### 2.2.2 Valve Functions and Terminology

Valve configurations and operation vary widely depending on the turbine manufacturer and model. Valve terminology for a particular function also varies between manufacturers and model. Table 2-1 gives a comparison of the valve names used for each function by the major U. S. manufacturers and indicates the name to be used in this discussion. Individual manufacturer discussions will conform to their terminology.

The stop valves are normally used to rapidly shut off steam flow to the turbine and are kept fully open during normal operation. On some units, an internal bypass valve is included in at least one of the stop valves and depending on the turbine design can perform several functions. The internal bypass valve is used on some units to equalize the pressure across the stop valves to allow them to open. On some units the bypass is used for warming the turbine and control during low speed or low load operation. On other units, the stop valves (and their bypasses) are non modulating and all speed/load control is done by the control valves.

| Table 2-1<br>Valve Terminology Comparison | | | |
|---|---|---|---|
| **Valve Function** | **General Electric** | **Westinghouse** | **Standard for Discussion** |
| Controls the steam flow rate to the turbine | Control Valve | Governor Valve | Governor Valve |
| Controls steam supply to the turbine | Main Stop Valve | Throttle valve or Main Stop Valve | Main Stop Valve |
| Controls steam flow to the low pressure turbine | Intercept Valve | Intercept Valve or I Interceptor | Intercept Valve |
| Controls steam supply to the low pressure stages of the turbine | Intercept Stop Valve or Intermediate Stop Valve or Reheat Stop Valve | Stop Valve or Reheat Stop Valve | Reheat Stop Valve |

The steam is admitted to the turbine blade sections through a series of openings, each controlled using Governor Valves. On large turbines, multiple valves are used because a single valve cannot provide adequate control throughout the steam flow range. The valves may be modulated by the turbine control system using individual valve actuators or by a single valve actuator operating a camshaft or lift bar.

Steam flow into the Low Pressure Turbine is controlled by one or more Intercept Valves. In some turbine designs these valves are modulated during startup and overspeed conditions. In others, the valves are either full open or shut.

Most turbine designs contain a valve in series with the Intercept Valve(s) commonly known as the "Reheat Stop" Valve. The Reheat Stop Valve serves only as a means to shut off steam to the Low Pressure Turbine in an emergency. It is appropriate to note that the Intercept and Stop Valves are sometimes combined in a single valve body (called combined intermediate valves) and are operated by separate valve actuators.

### 2.2.3 Governor Valve Control Modes

From a control and efficiency point of view it would be best to operate the Governor Valves sequentially, each valve opening at the upper end of the control range of the previous valve. The point at which each valve first cracks open is typically called a "Valve Point" or "Cracking Point". Because these points are mechanically defined, they are used to establish repeatable test conditions. A graph showing the valve travel versus the load range is usually known as the "Valve Curves" for the unit. An example of a set of valve curves for a nuclear plant steam turbine is shown in Figure 2-2.

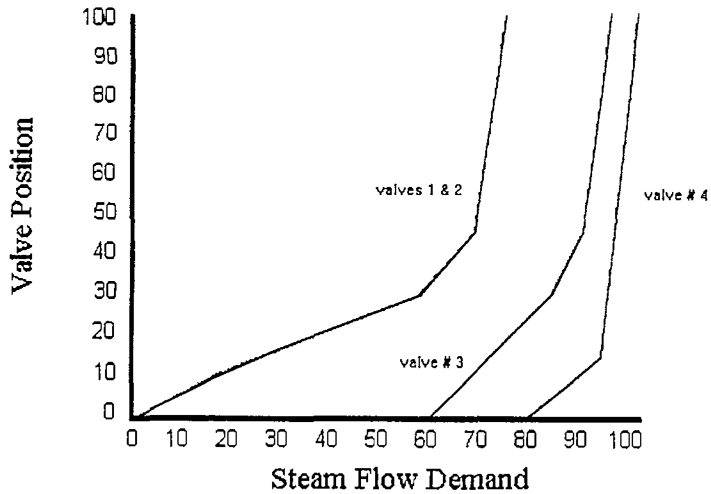


**Figure 2-2: Valve Curve Example**

The manufacturer develops the original valve curves for the unit based on theoretical design information and experience with similar designs. These curves may require adjustment over the life of the turbine to compensate for changes in turbine characteristics. The ability to modify the curves depends on the capabilities of the turbine control system. Some systems allow for full on-line programming of the curve and others require that the plant be shut down. Some turbines require disassembly of the steam chest to mechanically adjust the lifting mechanisms.

Sequential operation of the Governor Valves (called "Partial Arc" or "Sequential" control) during turbine startup and at low loads requires most of the valves to be shut. This results in uneven stage loading of the turbine causing excessive thermal stresses. Therefore, under these conditions it is preferable to operate all of the valves together, thus admitting steam equally to all sections of the turbine (called "Full Arc" or "Single Valve" control). The increase in throttling losses is accepted to prolong turbine life. Most turbines use both control modes: Full Arc for startup and low load operation then shifting to Partial Arc at higher loads. The type of control and ability to automatically shift between modes depends on the capabilities of the turbine control system.

Multiple Governor Valves can be operated using either a single valve actuator or a dedicated valve actuator for each Governor Valve. Most nuclear systems use dedicated actuators. Use of separate actuators allows for more flexibility because each valve can be independently controlled. This allows for operation of the valves in either Full Arc or Partial Arc control and provides for changes in the valve curves through the control system rather than mechanical means.

### 2.2.4 Main Stop Valve Control Modes

On some units, Stop Valve Internal Bypass Valves can be used to control the turbine during startup in lieu of the Governor Valves. This is necessary to allow for full arc steam admission when the Governor Valves cannot be operated in Single

Valve Mode. It may also be used when the Governor Valves cannot effectively modulate steam in Single Valve control during very low steam demand situations. When the turbine is started up, the Governor Valves are fully opened and the Stop Valve Bypass Valve is used to modulate steam to the turbine. When control is shifted to the Governor Valves the differential pressure across the Stop Valve must be reduced because the main valve plug is unbalanced. This is accomplished by throttling the Governor Valves until they control the turbine. This is seen by the operator (or turbine control system) as a reduction in speed or load. The parameter observed depends on the turbine manufacturer's startup instructions because some designs shift prior to synchronization, while others shift afterwards. When the Governor Valves are controlling, backpressure build up is sufficient to allow the Stop Valve to fully open. The transfer between Governor Valve and Stop Valve control may be performed manually or automatically depending on the capabilities of the turbine control system.

## 2.3 Mechanical Hydraulic Control (MHC) Systems

### 2.3.1 Westinghouse

A typical nuclear plant Westinghouse MHC system is shown in Figure 2-3. The system uses oil supplied by the turbine lubrication oil system for hydraulic fluid.

Fundamentally, all controls are operated hydraulically utilizing the oil supplied by the shaft mounted main oil pump. The discharge pressure is used to obtain the necessary force to actuate the servomotor pistons. This same high pressure oil is orificed and regulated by various controllers to obtain the lower pressure required to position the servomotors and monitor various trip devices, by means of auto stop and control oil systems. The control oil pressure is a function of the governor impeller and the controllers provided on the control block.

The primary function of the stop valves is to shut off the flow of steam to the turbine. Figure 2-3 shows the stop valve in the same body as the control valve. The valve is opened or closed in response to the position of the servomotor piston.

The piston is positioned by oil from the high pressure oil system. During normal operation the high pressure oil enters the servomotor through an orifice, passes around the relay piston and enters below the servomotor piston, forcing it open. Auto stop oil is directed to the top of the relay piston and holds it down by over-coming the spring force. Upon operation of the overspeed trip valve, the auto-stop oil pressure decays causing the spring to lift the relay piston, dumping the high pressure oil to drain. The stop valve will then close. Loss of auto-stop oil pressure will also cause the trip pilot valve piston to move to the right. This action moves an attached rod allowing the steam pressure acting on the inner end of the shaft to be relieved. When the auto-stop oil pressure is re-established, by "latching up" the overspeed trip lever, each trip pilot valve will close, and steam bypass valve will open. Once the steam pressure across the stop valves is equalized, they will open and the bypass valves will re-close.

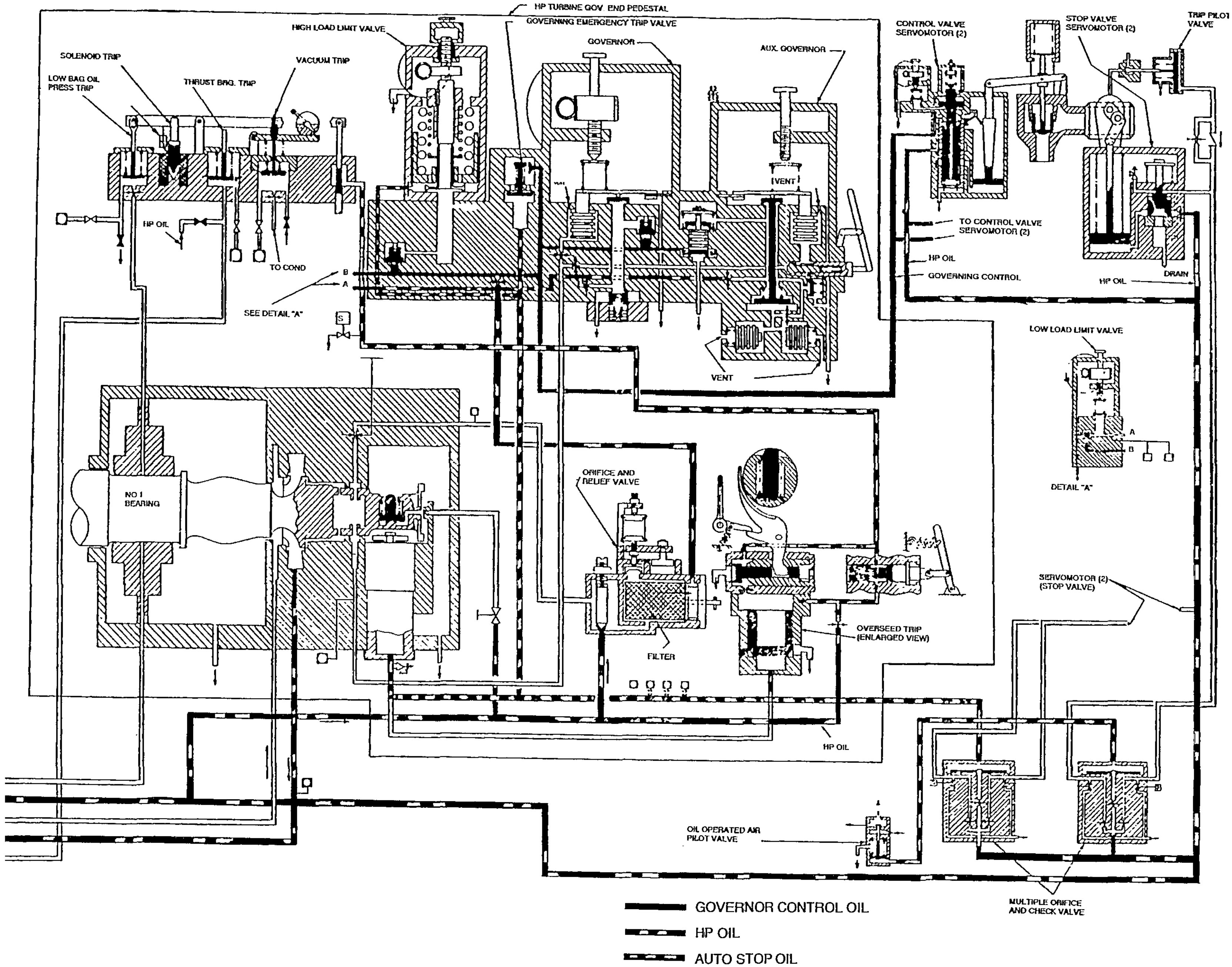


Figure 2-3: Typical Nuclear Plant Westinghouse MHC System

The control valves are used to regulate steam to the turbine during normal operation. Valve positioning is provided by the control valve servomotor. As with the stop valve servomotor, high pressure oil is used to move the servomotor and is allowed to enter, dependent on the relay piston position.

The control oil pressure acting on the relay pistons can originate from any of the following controllers:

a. Load limit valves (2)

b. Main governor

c. Auxiliary governor

The device maintaining the lowest control pressure will determine the position of the control valve servomotors and consequently the load carried by the turbine.

Oil for the control system is provided by the high pressure oil system. The oil is passed through a filter, orifice and relief valve before passing through another orifice into the control oil system. High pressure oil from this device is also supplied to the governor impeller.

When the turbine speed increases, the governor impeller discharge pressure increases, and when it decreases, pressure also decreases. The impeller discharge pressure is applied to the bellows in the main and auxiliary governors. The main governor and speed changer mechanism magnifies the relatively small governor impeller discharge pressure changes sufficiently to operate the relays of the control valve servomotors.

The auxiliary governor functions in essentially the same manner as the main governor. It is designed to control the turbine speed when the turbine load is completely lost or when an acceleration of more than 3% per second is detected.

Two load limit valves have been provided to control the maximum opening of the control valves. When the governing control oil pressure rises above the load limit control pressures, the check valve opens permitting the load limit control pressure to replace the governing control pressure, thereby preventing the governor from further opening the control valves.

The main governor (speed changer) and both load limits are normally remotely operated with selector switches in the control room. All four hydraulic control mechanisms, including the auxiliary governor, can be adjusted manually with hand wheels provided on the control block.

The overspeed trip mechanism consists of an eccentric weight mounted in the end of the turbine shaft. This mechanism is balanced in position by a spring until the speed reaches the point at which the trip is set to operate. When centrifugal force overcomes the spring, the weight flies out striking a trigger which trips the overspend trip valve. Movement of the trip valve off its seal allows the oil around it to go to drain. Loss of this oil pressure allows the piston to rise, releasing the auto-stop oil below it to drain. Upon loss of auto-stop oil the following will occur:

a. Governing emergency trip valve will operate dumping governor control oil.

b. Multiple orifice and check valve assembly will operate dumping the high pressure oil supplied to the stop and control valves.

c. Trip pilot valves will operate.

d. An oil-operated, air-pilot valve will operate, shutting off the air supply to the extraction steam non-return check valves allowing them to close.

Besides the overspeed trip mechanism, the following protective trip devices mounted in the trip block will cause the auto-stop oil to drain:

a. Low Bearing Oil Pressure Trip

b. Low Vacuum Trip

c. Solenoid Trips

d. Thrust bearing trip device

The Thrust Bearing trip device detects excessive rotor movement in the axial direction and shuts down the unit if the axial movement increases to the point where it may cause serious damage to the turbine.

Two solenoids are provided, one of which (20/AST) is mounted in the trip block and when energized raises the protective trip dump relay causing the autostop oil to be released to drain. The other solenoid (20/ASB) will directly release the autostop oil to drain. These solenoids can be energized by various protective trips such as:

- Reactor Trip Breakers Opening
- Redundant Overspeed Trip System
- Turbo-generator Primary Lock-Out Relay
- Turbo-generator Back-Up Relay
- Manual Turbine Trip Pushbutton
- High Vibration
- MSIV Closure

The overspeed trip, low vacuum trip, low bearing oil pressure trip, and thrust bearing trip can all be tested from the governor pedestal while the turbine is operating.

### 2.3.2 General Electric

A simplified diagram of a GE MHC system for a BWR is shown in Figure 2-4. The system is normally referred to as the Compound Control Mechanism.

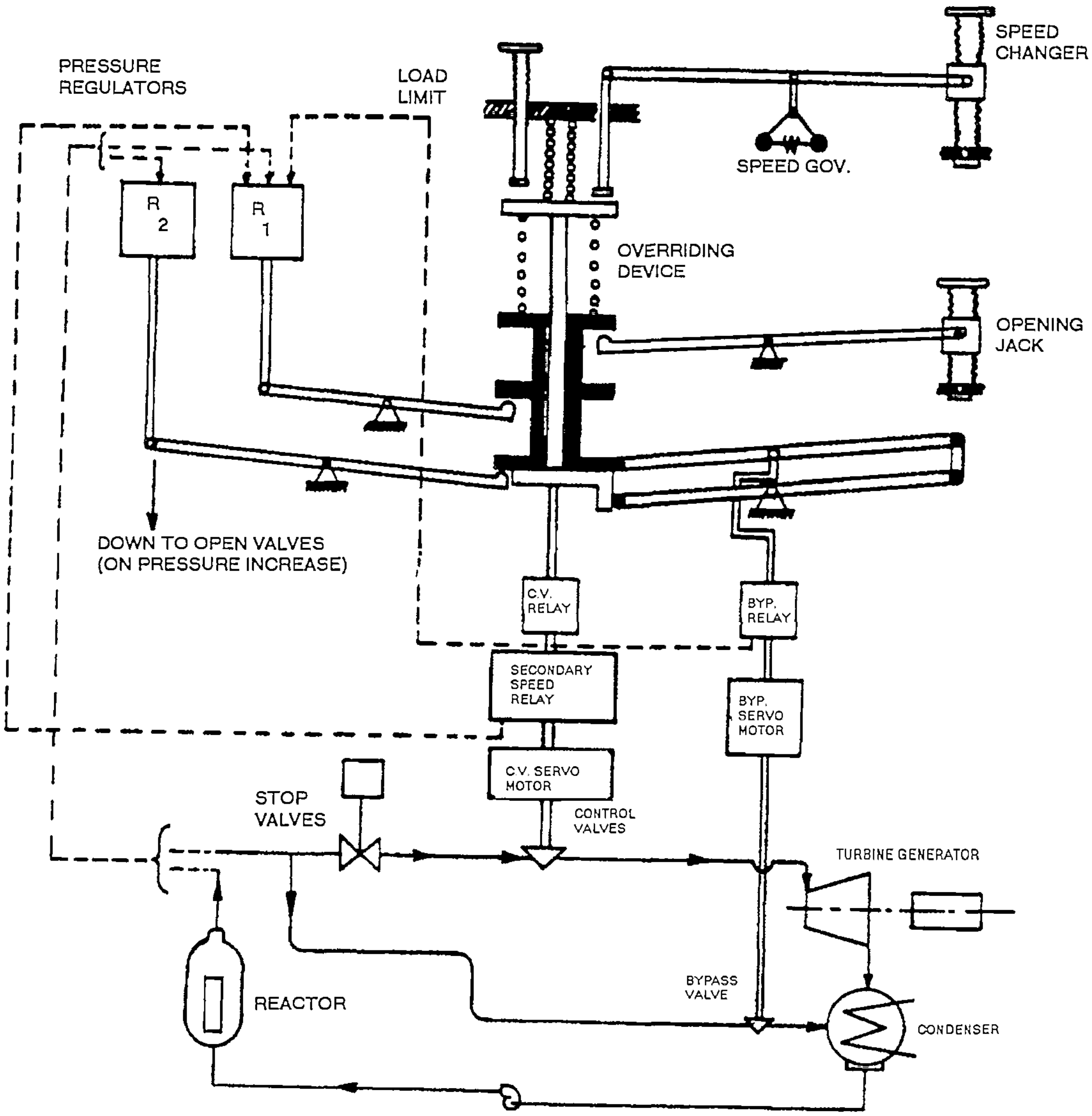


**Figure 2-4: GE Compound Control Mechanism**

### *Normal governing devices*

The normal governing devices function through hydraulic relays to operate the control, bypass, and intercept valves to control the reactor pressure and turbine load requirements.

The normal governing devices are:

1. Two parallel steam pressure regulators
2. The speed governor (rotating pilot valve type) with a motor-operated synchro- nizing device
3. Over-riding devices

The motor-operated main load limit and the motor-operated bypass valve opening jack over-ride normal governing devices in a direction which is safe for the reactor and turbine. They may be used for startup or whenever special operating requirements must be met.

### *Emergency devices*

Emergency devices will trip the turbine control system in order to protect the turbine and the plant under emergency conditions. These devices and their functions are:

1. The overspeed governor closes the main stop, intermediate stop, control and intercept valves, and extraction relay dump valve as a result of a turbine overspeed.
2. The backup overspeed trip closes the main stop, intermediate stop, control and intercept valves and extraction relay dump valve as a result of a turbine overspeed.
3. The turbine master trip closes the main stop, intermediate stop, control and intercept valves and extraction relay dump valve as a result of a manual trip signal or as a result of protective circuitry initiation.
4. The No. 1 vacuum trip closes the main stop, intermediate stop, control and intercept valves, and extraction relay dump valve as a result of low vacuum, actuation of the backup overspeed trip or by an electrical signal initiated by an operator or automatic protective circuitry.
5. The No. 2 vacuum trip closes the bypass valves on low vacuum or with an electronic signal initiated by an operator.
6. The generator motoring protection circuit trips the generator circuit breaker if the steam supply to the turbine is interrupted by any combination of closed turbine valves.
7. The hydraulic thrust bearing wear detector, which with excessive wear of the thrust plates, will energize the turbine lockout relay, which in turn will energize the trip solenoid on the No. 1 vacuum trip.

### *Special control devices*

In addition to the normal governing devices, this control system contains a number of special devices designed to perform specific functions for the control of a turbine in conjunction with a boiling water reactor. These special devices are:

1. A control valve relay to produce signals for the required opening of the control and bypass valves.
2. A bypass relay to produce an output for positioning the hydraulic servos of the bypass valves.
3. A secondary control valve relay to amplify the signal from the control valve relay to position the pilot valves of the control valve servos.

4 A hydraulic signal transmission system to position the intercept valves.

5. A reactor flow limit which is a mechanical stop in the control linkage system to limit the maximum opening of the control and/or bypass valves.

6. A control valve limit stop (hand-operated) to permit restriction of the opening of the control valves to a position lower than called for by the compound control mechanism.

### 2.3.3 ABB

The control system of the turbine is functionally divided into two systems; the control system proper and the safety and emergency system. Figure 2-5 is a basic block diagram of the control system. It classifies the subsystems and indicates how they are related in order to control the operation of the turbine valves.

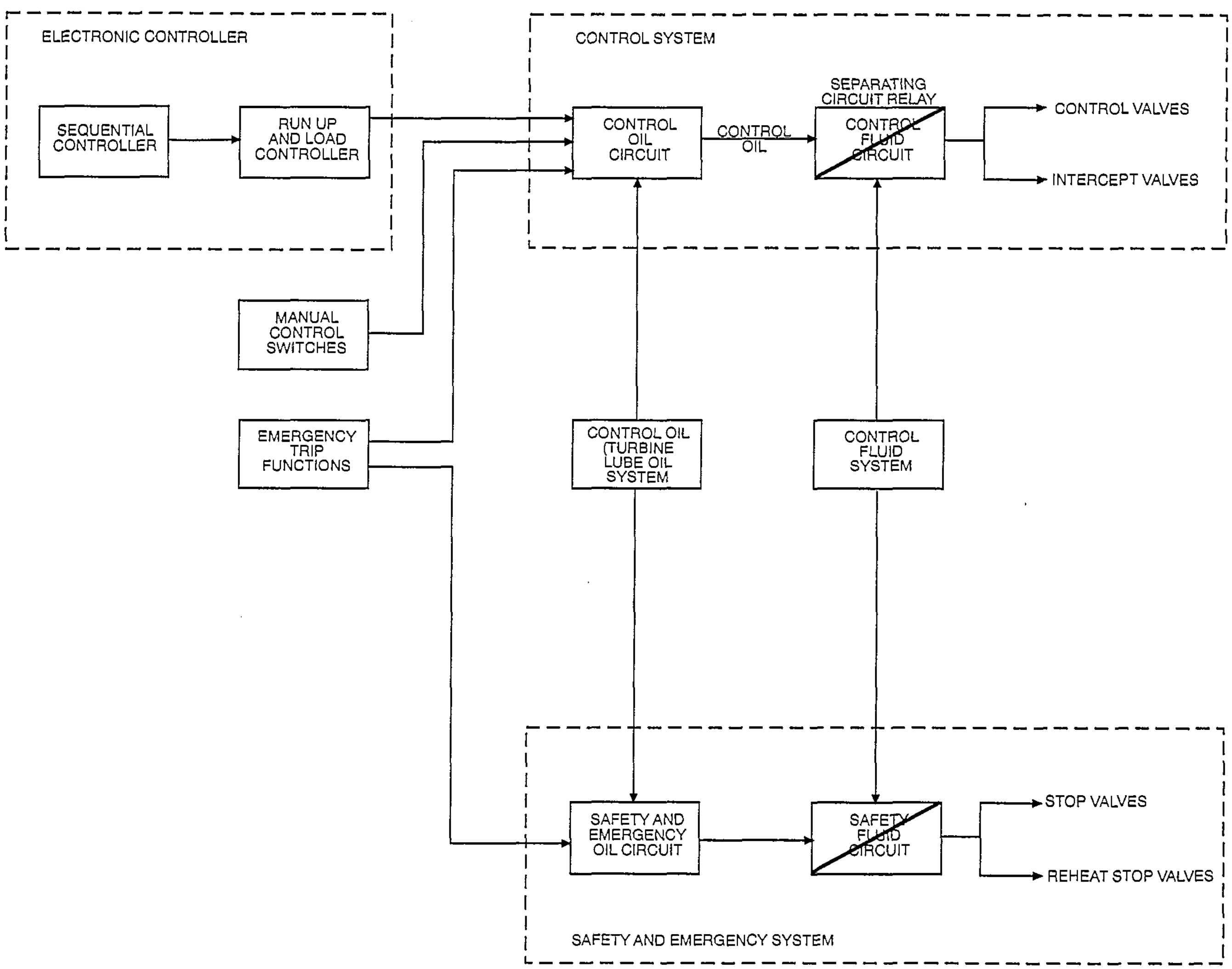


**Figure 2-5: ABB MHC Block Diagram**

The main functions of both systems operate hydraulically. Certain subfunctions operate pneumatically or electrically. The turbine shaft driven oil pump supplies the bearings with lube oil and the control oil for the devices located in the front bearing pedestal.

Both control and stop valves are operated by hydraulic servomotors which use a fire resistant control fluid. The valves are provided with pilot valves to limit the required positioning forces. All of the valve positioning elements can be tested during normal operation without load fluctuation.

The Operating Device is the controlling unit for operation of the system. It is a hydraulic controller providing a variable output, which is used as the speed or load setpoint of the system. This device responds to demands from the electronic controller or manual control from the control room or front standard.

A Speed Governor is provided to maintain the speed of the turbine at a preset value during start up and normal operation. The reference value for the speed governor is given by the operating device assembly. Additionally the turbine generator is provided with a run-up and load controller. This controller allows the unit to be automatically run up to normal speed and to operate the unit at a minimum load.

Further loading of the unit is done manually. The control oil pressure is determined by the drain opening of the speed governor. This opening is a function of the forces of the flyweight and the setpoint pressure which act on the speed governor piston. The governor is gear-driven by the turbine shaft and operates according to the balanced force principle.

If the speed increases, the force from the flyweight increases. At a constant setpoint pressure the drain opens and the pressure in the control oil circuit drops, closing the control valves. The static equilibrium of forces is re-established as soon as the force from the control oil circuit is reduced to an amount equal to force increase from the flyweight.

In order to limit the loading rate of the turbine, a pressure gradient relay is provided. It limits the rate of pressure increase in the control circuit. The maximum sudden rise in pressure is limited by adjusting a spring in the assembly. For instance, if the generator circuit breaker is opened, the shaft speed accelerates rapidly and will reach tripping speed if no special precautions are taken. In order to prevent this, and to assist the speed governor, an acceleration limiter is provided. In case the acceleration exceeds a certain adjustable value, the pressure in the speed setpoint circuit is temporarily lowered by the action of the acceleration limiter.

A steam pressure limiter lowers the pressure in the control oil circuit if it senses a decrease of the live steam pressure. This prevents the speed governor from opening the control valves. The limiter is provided with an adjustable setpoint. This enables operation with variable live steam pressures.

A load limiter functions as a constant pressure valve in the control oil circuit. The setpoint can be manually adjusted locally or remotely from the control room. Limiting the control oil pressure limits the control valve position, which limits the load.

The safety and emergency system provides damage protection to the turbine and turbine auxiliary equipment by closing the main stop valves and intercept stop valves during emergencies. These emergency systems are completely independent from the control portion of the system and do not rely on it to perform the tripping functions. However, since the emergency system also depressurizes the control circuit on a trip initiation, the control and intercept valves will also close.

The safety and emergency system is divided into three subsystems, or circuits; the emergency oil circuit, the safety oil circuit, and the safety fluid circuit. The emergency oil circuit is the primary protective circuit for the turbine, since it is depressurized directly by the protective devices for the turbine. The emergency oil circuit then depressurizes the safety oil and safety fluid circuits to trip the turbine. The safety fluid circuit drains oil to allow the stop valves and intercept stop valves to close by spring pressure. The safety oil circuit removes control oil circuit pressure to close the control and intercept valves, isolates the extraction line check valves from the air supply, and provides the Reactor Protection System with a turbine trip signal.

## 2.4 EHC Systems

### 2.4.1 Westinghouse

#### 2.4.1.1 Introduction

Westinghouse turbine controls installed in the late 1960's and early 1970's were called Analog Electrohydraulic (AEH) control systems which are exclusively analog in design. The AEH was replaced by the DEH Mod I digital turbine control system which was installed up until the late 1980's. The DEH Mod II was an upgrade version of the Mod I and was supplied during the 1970's and 80's. Westinghouse introduced the Mod III (WDPF) Distributed Process Family control system in the early 1980's. This system replaced the MOD I and II systems and had the additional advantage of being flexible enough to use as a plant wide control system thereby integrating the turbine control system with the other plant controls. This reduces the costs of spare parts as well as operator and technician training.

#### 2.4.1.2 Hydraulic Power Unit

The Hydraulic Power Unit (HPU) supplies and conditions 2000 PSI hydraulic fluid for use by the steam valve actuators and emergency trip devices. The major components are:

- hydraulic fluid pumps
- fluid reservoir
- heat exchangers
- fuller's earth filter
- accumulators

*Hydraulic Fluid Pumps.* Until recently, the HPU used constant volume positive displacement pumps. An unloader valve at the discharge of each pump controls the hydraulic fluid circuit pressure by alternately allowing full pump pressure to charge the system and accumulators to approximately 2000-2150 PSI, then diverting pump discharge into the reservoir at low pressure. The high pressure accumulators then supply the system pressure requirements for both normal and instantaneous demands. When the header pressure diminishes to approximately 1800 PSI the unloader valve again directs the pump discharge to the high pressure header. Therefore, the system continually cycles between 2150 and 1800 PSI. Because of a history of problems associated with the unloader system, Westinghouse has recommended changing to pressure compensated variable volume pumps.

A pressure switch may be provided to sense low fluid pressure and sound an alarm on decreasing pressure. Each pump has independent and parallel delivery systems with individual suction strainers, discharge filters, pressure relief valves, air bleed valves, pressure switches, and local pressure gages. Both pumps are capable of 100% system capacity. Normally one pump is in operation with the other in standby. The standby pump starts if pressure in the common discharge header decreases to approximately 1500 PSI.

Three pressure switches monitor the combined discharge header. If pressure drops below 1100 PSI (sensed using 2-out-of-3 logic) the turbine is tripped.

*Hydraulic Fluid Reservoir.* The fluid reservoir is a stainless steel tank with internal baffling to ensure EKE fluid adequate residence time for any entrained air to escape before passing on to the pump suction. The reservoir contains fluid level sensors for high and low level alarming. The reservoir is also equipped with an emergency fluid level gauge and high/low temperature alarms.

A desiccant air filter removes moisture and particulate from the air entering the fluid reservoir. The element changes color to indicate when replacement is required.

*Heat Exchangers.* Two water cooled heat exchangers are used to cool hydraulic fluid returning from the valve actuators and trip devices. Temperature in the reservoir is maintained by automatic temperature control valves in the cooling water discharge line from each cooler. Normally only one cooler is in service during operation. The valves and piping allow one cooler to be removed during turbine operation for maintenance. A spring loaded bypass relief valve prevents excessive pressure buildup in the hydraulic fluid drain lines due to transient conditions, heat exchanger clogging, or valve malfunctions. When hydraulic fluid pressure in the fluid drain line exceeds 50 PSI the relief valve opens to bypass the coolers and direct returning hydraulic fluid to the reservoir.

*Fuller as Earth Filter* A fuller's earth filtration system is permanently installed for hydraulic fluid conditioning. The neutralization filtering system receives hydraulic fluid from the EHC pump discharge through an orifice. When the main pumps are shut down there is no flow through the neutralization filter.

*Accumulators.* Piston accumulators are supplied to provide hydraulic fluid in the event of a momentary loss of the EHC pumps and to improve regulation of the hydraulic fluid pressure. The accumulators are closed-end cylinders containing a free-floating piston precharged with nitrogen. They are connected to the hydraulic fluid supply header downstream of the common discharge of the EHC pumps. Isolation valves permit two of the six accumulators to be isolated and serviced with the turbine in operation. These valves also permit the nitrogen precharge pressure to be checked by isolating the associated accumulator and bleeding the hydraulic fluid back to the fluid reservoir.

#### 2.4.1.3 Valve Actuators

An actuator consists of a hydraulic cylinder and piston that uses fluid pressure to open and spring pressure to close the steam valve, plus a control block. The control block contains isolation, check, and dump valves, orifices, and additional components based on the actuator type such as, solenoids, servos, and filters. Examples of controlling and non controlling actuators are shown in Figures 2.6 and 2.7.

Each valve actuator is connected to three hydraulic lines:

*High Pressure Supply:* The primary source of working fluid to the actuator used to move the hydraulic piston.

*Emergency Trip (ET) Header:* Used to hold the dump valve shut. Loss of pressure releases the dump valve and removes the fluid from the hydraulic cylinder.

*Drain:* This is a pressurized drain from the valve actuator back to the fluid reservoir. It is typically pressurized to maintain it full of oil to minimize air entrainment in the fluid.

To open the steam valve, a servo or solenoid valve directs high pressure oil to the bottom of the hydraulic cylinder. When closing the valve the servo or solenoid valve controls the drainage of the fluid. The return spring is sized with the valve spring and forces on the steam valve to assure minimum fluid pressure in the cylinder. This results in satisfactory response and positioning accuracy for stroke in either direction.

The dump valve is used to trip the steam valve. The plug is normally held in place by pressure from the trip header. When the trip header is depressurized, the hydraulic pressure is released from the cylinder allowing the springs to shut the valve.

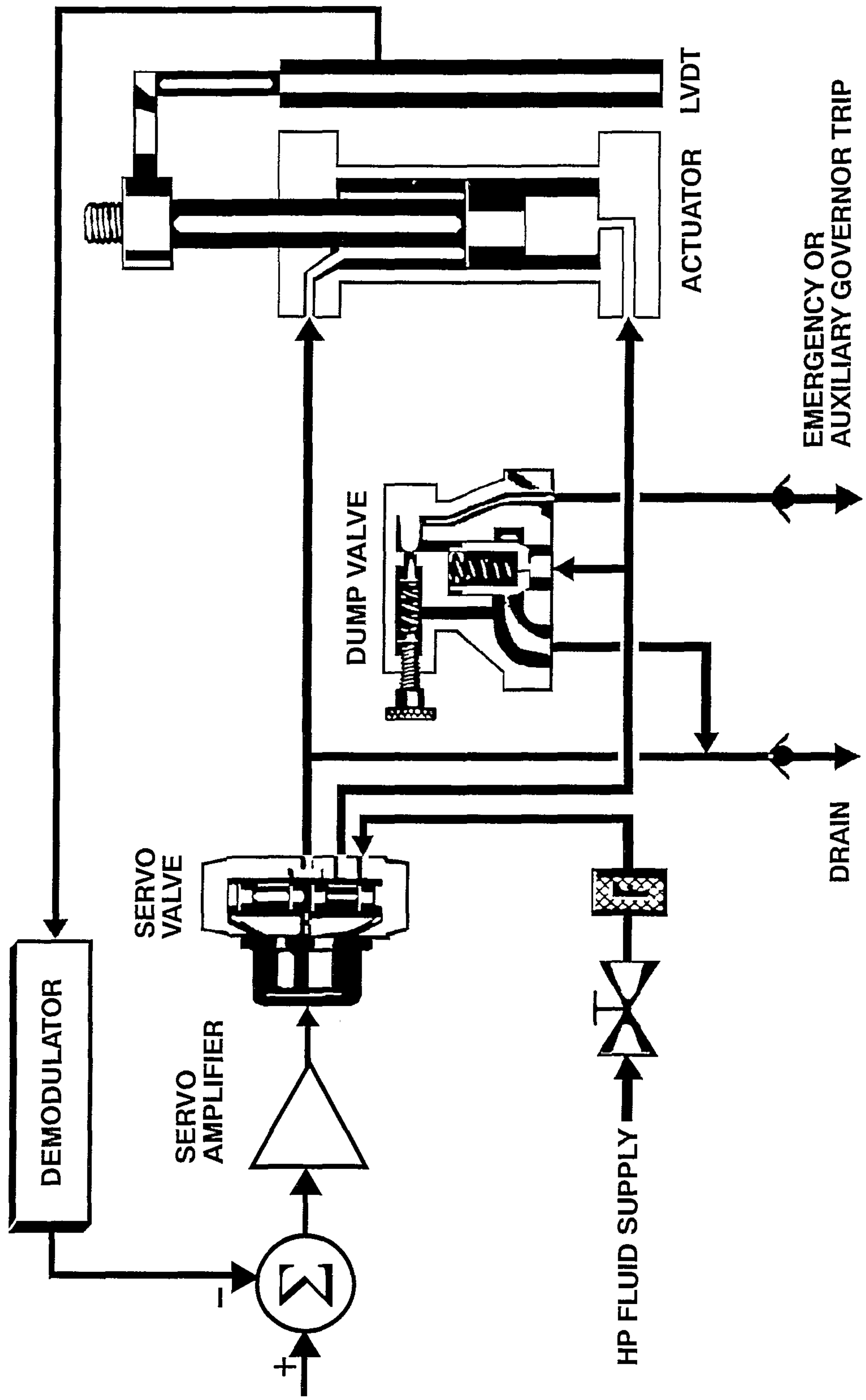


Figure 2-6: Westinghouse Controlling Actuator

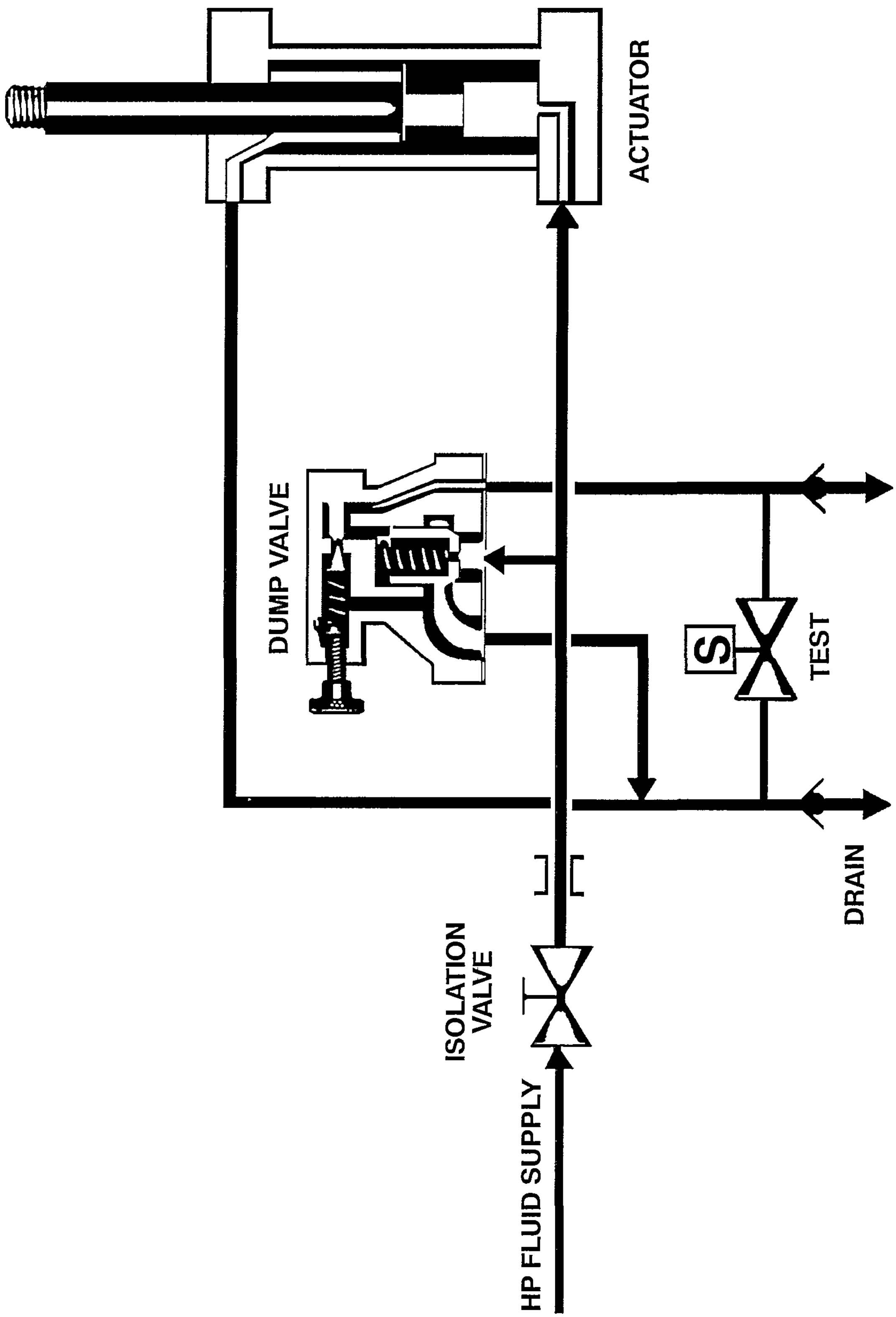


**Figure 2-7: Westinghouse Non-controlling Actuator**

### *2.4.1.4 Emergency Trip System*

The trip system on Westinghouse turbines consists of two high pressure trip headers which are usually referred to as the Overspeed Protection Controller (OPC) header and the Emergency Trip header, plus the Auto Stop oil system. Refer to Figure 2-8 for an example of a typical Westinghouse Emergency Trip System. Note the similarity between this Auto Stop system and that of the Westinghouse MHC system described earlier.

Loss of pressure in the OPC header will result in closure of the Intercept and Governor Valves only. The OPC header can be depressurized by either of two electrical trip solenoids controlled by the electronic control system. This partial trip allows for a more rapid recovery from a minor overspeed condition. It is considered to be an operational feature by itself and not a safety function.

Loss of pressure in the Emergency Trip header will result in closure of the stop valves, governor valves, intercept valves, and reheat and stop valves. The OPC and Emergency Trip headers are connected by a check valve in such a manner that loss of pressure in the Emergency Trip header will also depressurize the OPC header, thereby shutting all of the turbine steam valves.

The Emergency Trip (ET) header is depressurized by opening the Diaphragm Interface Valve. In most systems electrical solenoid valves are also used to depressurize the ET header as a backup to the Diaphragm Interface Valve. The Diaphragm Interface Valve is held shut by the low pressure Auto Stop oil system.

Auto Stop Oil is supplied from the turbine lubrication oil system through an orifice. Loss of the Auto Stop Oil System pressure on the diaphragm of the Diaphragm Interface Valve allows the valve to open using the actuator spring. This dumps the ET and OPC headers to the reservoir resulting in a turbine trip. An Auto Stop Oil System trip may be initiated by the mechanical overspeed device, the manual operator trip handle, or by electrical trip solenoids.

Note that the turbine is considered "tripped" when the Auto Stop Oil System is depressurzied and "latched" when the Auto Stop Oil System is pressurized. When the turbine is tripped all turbine valves should be shut. However, the shutting of all turbine valves does not necessarily indicate that the turbine is tripped. This statement is important because it is the driving philosophy in the trip system design. Although the high pressure OPC and ET trip headers are physically responsible for shutting the valve actuators, the entire trip system revolves around the low pressure Auto Stop Oil System trip header. Solenoid trip valves in the Overspeed Protection Controller and ET headers are considered backup devices to the Auto Stop Oil System trip devices.

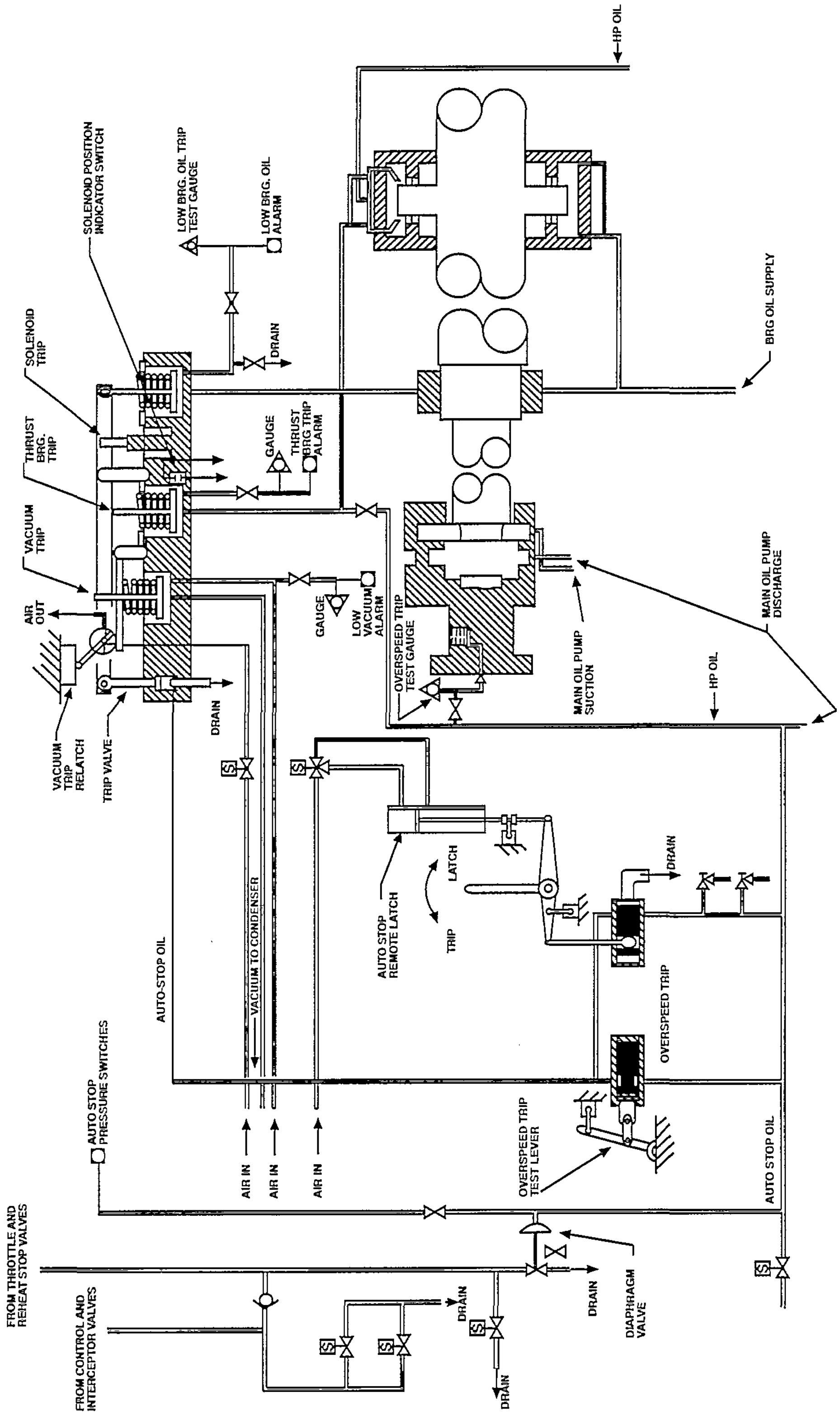


**Figure 2-8: Westinghouse Emergency Trip System**

### *2.4.1.5 DEH Control System*

The DEH control system is used in both PWR and BWR applications. In PWR applications the control system manages steam flow to satisfy the requested demand. In BWR applications the system controls steam flow to maintain a constant reactor pressure. Pressure control in BWR's is extremely important because changes in reactor pressure have a dramatic effect on reactor power. DEH control systems incorporate additional circuitry into their design for pressure control. For the purpose of this discussion only the operation of the DEH will be described. The AEH differs from the DEH in the electronic technology employed. The AEH electronics are entirely discreet components and all functions are hard wired. The DEH on the other hand uses digital components. Tables 2-2 thru 2-8 illustrate the major characteristics of the two systems.

**Table 2-2**
**Speed Control**

| Feature | AEH | DEH |
|---|---|---|
| Speed Reference | Variable from 0-1800 RPM | Same as AEH |
| Startup Mode | Starts in Throttle Valve control in either single or sequential mode. | Same as AEH |
| Synchronizing | Accepts contact input from remote synchronizer to change speed reference in 1 RPM steps. | Same as AEH |
| Redundancy | Two control speed channels and one overspeed channel. | Turbine trips if reference differs from actual speed by more than 200 RPM |

**Table 2-3**
**Load Control**

| Feature | AEH | DEH |
|---|---|---|
| FA to PA Transfer | Can be performed at any load. | Same as AEH. |
| Loading Rates | Six fixed load change rates. | Variable change rates. |
| 1st Stage Pressure Control (Impulse Loop) | Single loop to linearize steady state load response. | Same as AEH but control loop parameters (gain and integral action) are fully adjustable. |
| Throttle Pressure Control | Single setpoint set by operator using manual potentiometer. | Same as AEH but also allows remote and fixed setpoints. |

**Table 2-4**
**Speed Control**

| Feature | AEH | DEH |
|---|---|---|
| Overspeed Protection Control (OPC) | Initiated when speed exceeds 103% of rated value. Closes GV's and IV's until speed < 100% of rated. | Same as AEH |
| Close Intercept Valves CIV | Anticipates overspeed after partial load rejection. Initiated if MW less than Reheat Pressure by more than setpoint. Closes IV's for set amount of time. | Same as AEH |
| Load Drop Anticipator (LDA) | Anticipates overspeed after full load rejection. Initiated if generator breaker opens without a turbine trip. Closes GV's and IV's for set amount of time. | Same as AEH |
| Turbine Runback | Designed to reduce excessive steam demand. Initiated by external contact input. Ramps GV's closed until external contact opens or minimum threshold is reached. Three adjustable runbacks, each with different threshold but at same rate. | Same as AEH but each runback has individual rate setpoint. |

**Table 2-5**
**Testing Features**

| Feature | AEH | DEH |
|---|---|---|
| OPC Solenoids | Must be in Speed Control (Generator Breaker open). Initiated by a keyswitch,, closes GV's and IV's until keyswitch returned to normal. | Same as AEH. |
| Mechanical Overspeed Trip | Initiated by a keyswitch, defeats the overspeed protection feature to allow speeds greater than 103% of rated. | Same as AEH. |
| Valve Tests | Individual Throttle Valve testing with no load reduction. Governor Valve testing at reduced loads. Reheat Stops and Interceptors tested in pairs. | Same as AEH. |
| Maintenance Test Mode | Keyswitch initiated to allow operator to test portions of automatic controls while on-line. | Same as AEH. |

**Table 2-6**
**Miscellaneous Control**

| Feature | AEH | DEH |
|---|---|---|
| Manual Control | Available. Overspeed protection is maintained. | Same as AEH. |
| Valve Demand Characterization | Accomplished in servo card using one of two slopes. | "Valve Management" in servo card uses a seven segment curve to characterize the output demand signal. |
| Flow Limiter | Valve position limiter based on flow demand. | Same as AEH but must be in AUTO control to use. |

**Table 2-7**
**Electrical Power Supplies**

| Feature | AEH | DEH |
|---|---|---|
| 1 15 VAC Supply | Uses external 60 Hz power source for startup and a PMG above 1200 RPM. | Same as AEH. |
| LVDT Excitation | Each LVDT has an individual oscillator circuit. | Same as AEH. |

**Table 2-8**
**Cabinets**

| Feature | AEH | DEH |
|---|---|---|
| Cabinet Size | Housed in 3 small cabinets | Housed in 3 large cabinets approximately twice the size of AEH. |
| Expandability | Wired for all features. Options added by plugging in additional modules | Same as AEH but also requires software modifications when options are added. |

The DEH electronic controller is a hybrid system, consisting of a Digital System and an Analog System. A typical DEH system diagram is shown in Figure 2-9. The Digital System operates through the Analog System to position the turbine valves as follows:

*Digital System:*

- DEH Application Programs
- Reference Runback
- Automatic Synchronizer Interface
- Automatic Dispatch Interface
- Automatic Turbine Control (ATC)
- CRT Display
- Valve Management

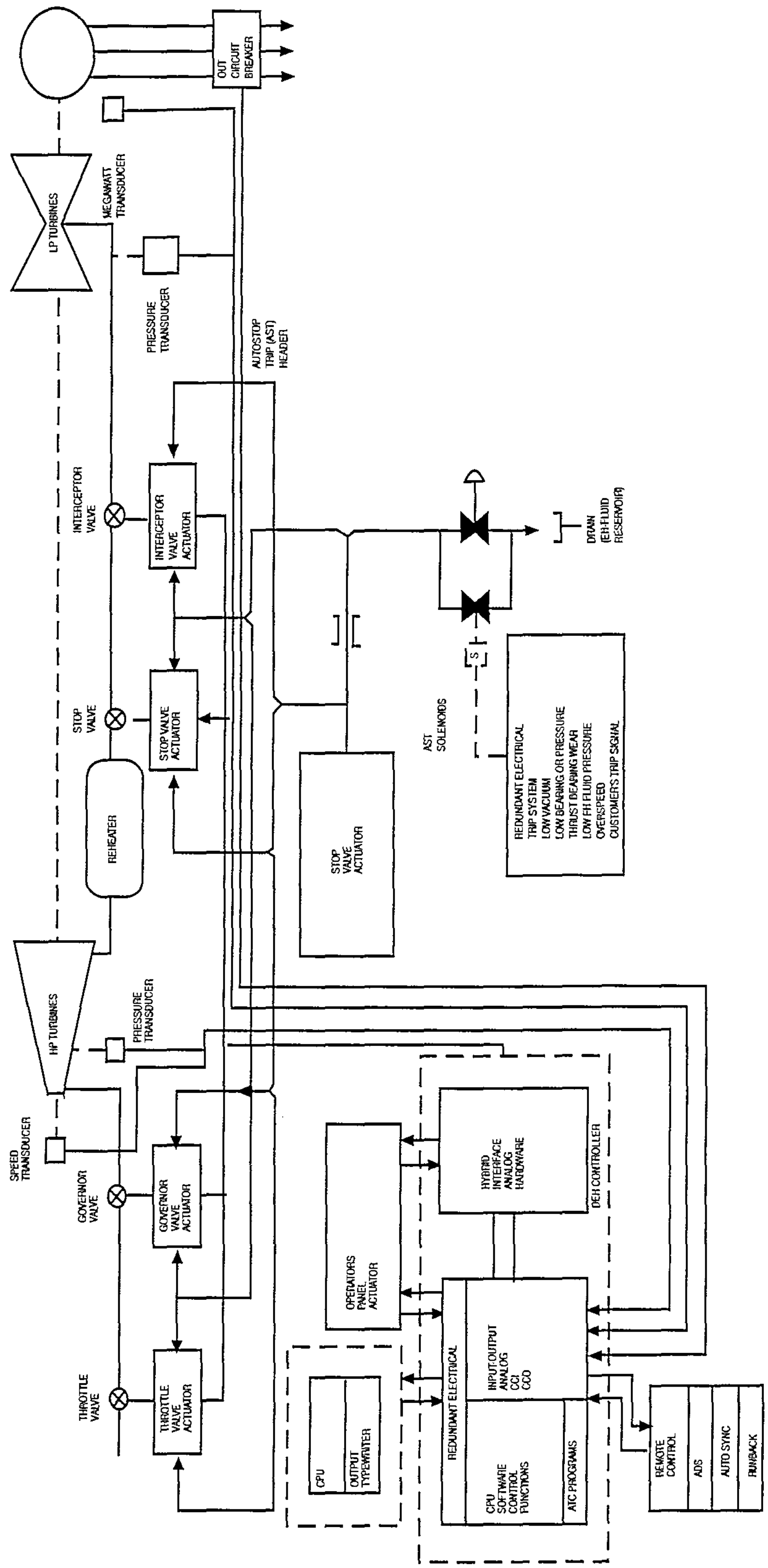


**Figure 2-9: DEH System Block Diagram**

*Analog System:*

- Valve Positioning Servo Loops
- Overspeed Protection Controller
- Manual Backup Control System
- Digital-To-Analog Converter

### 2.4.1.6 Digital System

The Digital Electrohydraulic (DEH) System consists of the central processor unit (CPU), input and output (I/O) hardware, and a software package. The CPU consists of the Westinghouse W2500 random access controller, a small, high-speed, integrated circuit machine. The W2500 features a flexible I/O system, with one common I/O bus providing interfacing capabilities for any direct I/O device, buffered I/O device, or a high-speed direct memory access I/O device.

In DEH application programs, three functions must be accomplished:

- A setpoint must be established.
- The setpoint must be compared with the turbine-generator feedbacks.
- The result of the comparison must result in valve position demand.

Westinghouse uses the term "Reference" for an adjustable speed or load setpoint. In speed control, the Reference is the turbine/generator speed setpoint. In load control, the Reference is the turbine load setpoint with the load or flow feedbacks in service, or the desired valve position with the load feedbacks out of service. When the Turbine/generator is producing megawatts, the reference is scaled to desired megawatts no matter which loops are in service.

The Reference is calculated in the CPU based on the logic for the system. A throttle pressure controller action or external runback over-rides any other control mode. If the DEH system is in MANUAL, the reference tracks the Manual System. If the DEH is in Operator Automatic (AUTO control), the operator sets a target and rate of change. When the operator presses a "GO" pushbutton the Reference moves to the target at the preselected rate. If the DEH is being controlled by either the Automatic Turbine Control program, a plant computer, or a data link, the controlling system sets a target and rate of change. As long as the Reference differs from the Demand, the reference changes at the selected rate. If the DEH is in Automatic Synchronizer or Automatic Dispatch System control, the Reference is changed by a contact closure input or an analog input. The demand tracks the reference.

The DEH Control System has the capability of controlling in either sequential valve operation (partial arc admission) or single valve operation (full arc admission). The transfer of operation is accomplished by a valve management program.

#### 2.4.1.7 Analog System Valve Positioning Servo Loops

High pressure hydraulic fluid enters the valve actuator block through an isolation valve and a filter to the servo valve. An electronic signal modulates the servo valve spools to change the actuator piston position. Positional feedback information is transmitted by a linear variable differential transformer (LVDT) located on the actuator block. As valve position changes the LVDT signal is conditioned and fed into a summing junction at the servo amplifier. Any resulting error continues to drive the valve further until the demand and actual position signals negate one another.

The servos are mechanically biased such that if electrical power is lost the servo valve drains the fluid from the actuator. The steam valve then closes due to spring force.

Since the Reheat Stop and Interceptor Valves are either open or closed, servo amplifiers, LVDTs and modulators are not needed. Open rates are accomplished by orificing the high pressure supply header at the actuators.

Dump valves are positioned ahead of the actuators on the assemblies to provide emergency or auxiliary governor tripping.

#### 2.4.1.8 Analog System Digital-To-Analog Converter

The DEH CPU provides the valve position in digital form. Since the valve actuator servo loop requires an analog signal, a signal converter is provided to convert the valve position signal from digital to analog.

#### 2.4.1.9 Analog System Manual Backup Control System

The Manual system is simply an up and down counter with a digital-to-analog converter. The operator accesses the counter using UP and DOWN pushbuttons on the Operator Panel. The throttle pressure controller and runback operation have access in the down direction only. The output of the counter is fed through a digital-to-analog converter to the servo loops.

A separate Operator Panel is provided for manual control. This allows other DEH panels to be removed for on-line maintenance while turbine operation continues.

#### 2.4.1.10 Analog System Overspeed Protection Controller

The primary objective of the Overspeed Protection Controller (OPC) is to prevent excessive turbine overspeed and turbine trips. The overspeed function of the OPC employs two-out-of-three logic to detect a speed channel failure. If the digital speed channel is unreliable, the OPC uses the analog speed channel. Above 103% of rated speed the OPC closes both the governor valves and interceptor valves. The reference is reset to rated speed. In auto control the governor valves stay closed due to speed error until speed has decreased to synchronous speed. At this point the Digital System takes over and maintains synchronous speed. In manual control the governor valves stay closed until the operator takes speed control by adjusting the appropriate governor valve position. The OPC function can be tested using a keyswitch on the Operator Panel.

The Close Intercept Valves (CIV) function compares turbine pressure with the generated electrical power. When they differ by an adjustable amount, the Interceptor Valves are shut in approximately 0.15 seconds. Closing the Interceptor Valves provides a momentary reduction in generator output and aids in maintaining power system stability. After a time delay the Interceptor Valves are reopened.

The Load Drop Anticipator (LDA) function initiates actions on a complete loss of load (generator breaker opens with turbine pressure greater than 30%) to minimize the increase in turbine speed following a load rejection. The DEH Reference is set to rated speed and OPC action is initiated. The LDA is reset when turbine speed is less than 103% for greater than 5 seconds.

### 2.4.2 General Electric

#### 2.4.2.1 Introduction

The Mark I model was used on nuclear plant turbines supplied in the early 1970's. From the mid 1970's the Mark II system was supplied. Both the Mark I and II models use analog electronic technology. Units installed in the future will have the digital triple redundant Mark V system. Because of their installation dates, virtually all nuclear turbine control systems are either the Mark I or II; therefore, only the Mark I and II systems are discussed in this document.

#### 2.4.2.2 Hydraulic Power Unit and Main Turbine Control Oil System

The Hydraulic Power Unit (HPU) supplies and conditions 1600 PSI hydraulic fluid for use by the steam valve actuators and emergency trip devices. The major components of the HPU are:

- hydraulic fluid pumps
- fluid reservoir
- heat exchangers
- fuller's earth filter
- accumulators

*Hydraulic Fluid Pumps*. The HPU uses variable volume pressure compensated pumps. These pumps vary the discharge flow capacity based on system demand. When there is zero demand the pump strokes to zero volume. This reduces the system power consumption and provides a more stable discharge pressure. Each pump has independent and parallel delivery systems with individual suction strainers, discharge filters, pressure relief valves, air bleed valves, pressure switches, and local pressure gages. Both pumps are capable of 100% system capacity. Normally one pump is in operation with the other in standby. The standby pump starts on low pressure in the common discharge header.

*Fluid Reservoir*. Depending on turbine rating, the fluid reservoir is either a 400 or 800 gallon stainless steel tank with internal baffling to ensure adequate residence time for any entrained air in the fluid to escape before passing on to the pump suction. The reservoir contains fluid level sensors for high and low level alarming. The reservoir also is equipped with an emergency fluid level gauge and high/low temperature alarms.

An air drier removes moisture and particulate from the air entering the fluid reservoir. Air passing through the dryer is treated by layers of desiccant to remove any moisture. Before entering the reservoir the air is filtered by a 5.0 micron filter. A glass window moisture indicator on the dryer shows the condition of the color indicating desiccant.

Two electrical heater-fan units keep the fluid reservoir, accumulators, and piping of the standby pumping system warm. The space heaters are operated automatically by a thermostatic controller which senses temperature in the fluid reservoir and operates the heater to control the hydraulic fluid temperature.

*Heat Exchangers.* Two water cooled heat exchangers on top of the reservoir are used to cool hydraulic fluid returning from the valve actuators and trip devices. Temperature in the reservoir is maintained by automatic temperature control valves in the cooling water discharge line from each cooler. Normally only one cooler is used during plant operation. The valves and piping allow one cooler to be removed during turbine operation for maintenance. A spring-loaded by-pass relief valve prevents excessive pressure buildup in the hydraulic fluid drain lines due to transient conditions, heat exchanger clogging, or valve malfunctions. When hydraulic fluid pressure in the fluid drain line exceeds 50 PSI the relief valve opens to bypass the coolers and direct returning hydraulic fluid directly to the reservoir.

*Fullers Earth Filter.* A fuller's earth filtration system is permanently installed for hydraulic fluid conditioning. During normal operation, filter flow (2.5-3 gpm) is supplied by the operating hydraulic pump through a pressure reducing flow control valve. When the hydraulic pumps are shut down, a dedicated low pressure transfer pump draws the hydraulic fluid from the reservoir and recirculates it through the filter and back to the reservoir. This method allows for continuous operation of the filter, even with the turbine shut down. The filter system contains a relief valve and a 0.5 micron backup filter after the fuller's earth filter. The reservoir can also be filled and drained using the transfer pump.

*Accumulators.* Piston accumulators are supplied to provide hydraulic fluid in the event of a momentary loss of the EHC pumps and to improve regulation of the hydraulic fluid pressure. The accumulators are closed-end cylinders containing a free-floating piston precharged with nitrogen. They are connected to the hydraulic fluid supply header downstream of the common discharge of the EHC pumps. Isolation valves permit two of the six accumulators to be isolated and serviced with the turbine in operation. These valves also permit the nitrogen precharge pressure to be checked by isolating the associated accumulator and bleeding the hydraulic fluid back to the fluid reservoir.

#### 2.4.2.3 Valve actuators

Each valve actuator, referred to as a "Control Pac", consists of:

- A cylinder and piston assembly to position the steam valve
- A disk dump valve
- Various servo valves, solenoid valves, and pressure controlled shutoff valves arranged depending on the valve application

Examples of controlling and non controlling control packs are shown in Figures 2.10 & 2.11.

Each control pack is connected to three hydraulic fluid lines:

- Fluid Actuator Supply (FAS): The primary source of working fluid to the actuator used to move the hydraulic piston.
- Emergency Trip System (ETS): Used to hold the disk dump valve shut. Loss of pressure releases the dump valve and removes the fluid from the hydraulic cylinder.
- Fluid Cooler Drain (FCD): This is a pressurized drain from the valve actuator back to the fluid reservoir. It is typically pressurized to maintain it full of oil to minimize air entrainment in the fluid.
- The system servo valves uses jet style and the fluid jet supply (FJS) oil is derived from the FAS internally in the Control Pac. This fluid is used in the jet pipe of the servo valve.

To open the steam valve, the servo or solenoid valve admits FAS oil to the bottom of the hydraulic cylinder; when closing the valve, the servo valve or solenoid valve controls the drainage of the fluid. The return spring is sized with the valve spring and steam forces on the valve to assure minimum fluid pressure in the cylinder. This results in satisfactory response and positioning accuracy is obtained for stroke in either direction.

The disk dump valve is used to trip the steam valve. The disk is normally held in place by pressure from the ETS trip header. When the ETS trip header is depressurized the disk is forced down by the hydraulic pressure in the hydraulic cylinder. This ports the hydraulic fluid in the cylinder to drain allowing the springs to shut the valve. This also relieves pressure from a pilot operated shut-off valve which supplies FAS oil to the servo or solenoid valve. This valve cannot reset and allow FAS oil to the Control Pac until ETS trip header pressure is restored. When the fluid pressure in the cylinder is essentially zero, a spring in the disk dump valve reseats the valve allowing operation of the cylinder when FAS fluid is restored.

On BWR units, steam by-pass valves are used to control reactor pressure during startup and shut-down of the main turbine. Hydraulic actuators for the by-pass valves do not use a disk dump valve.

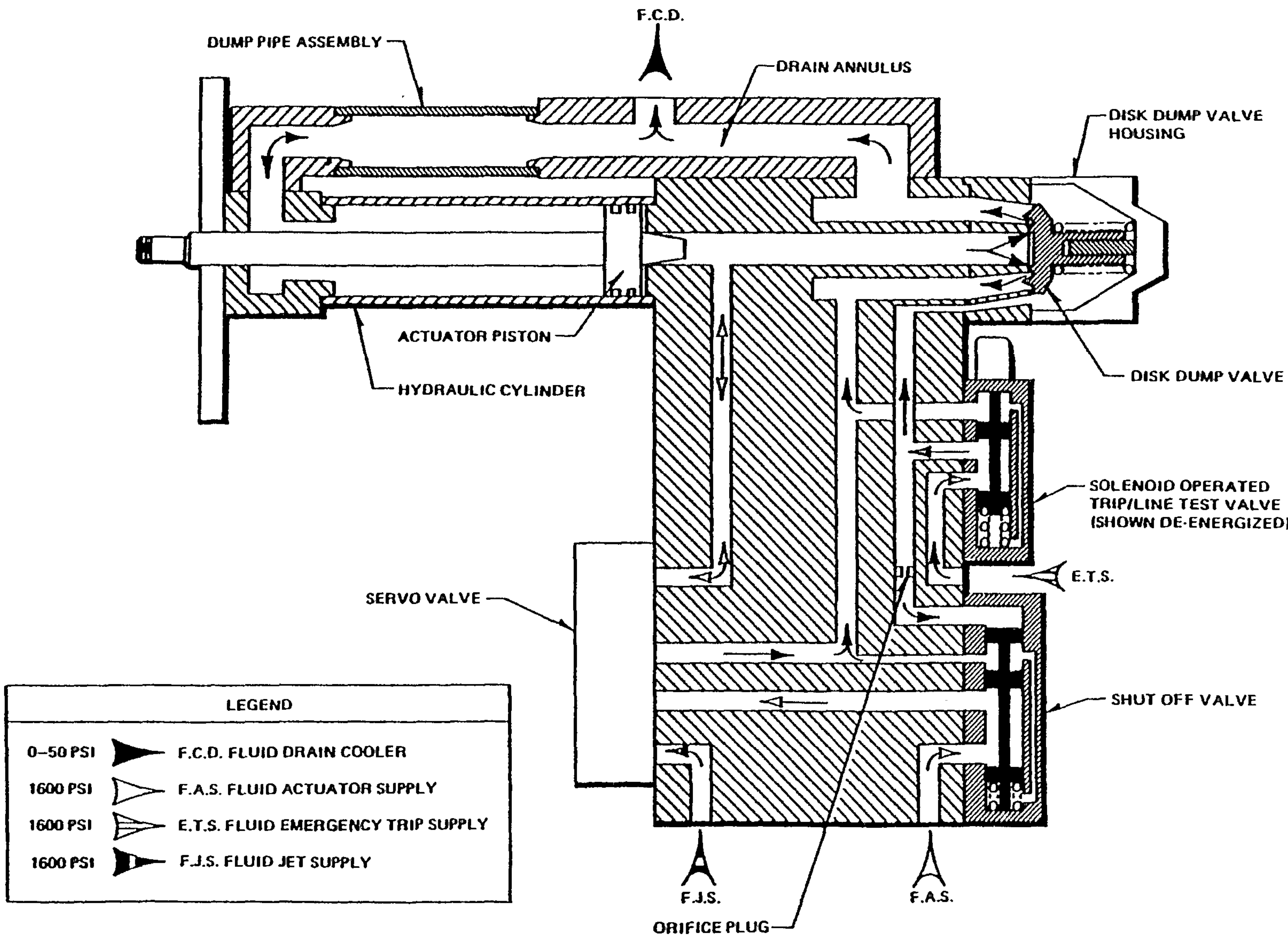


Figure 2-10: GE Controlling Control Pack

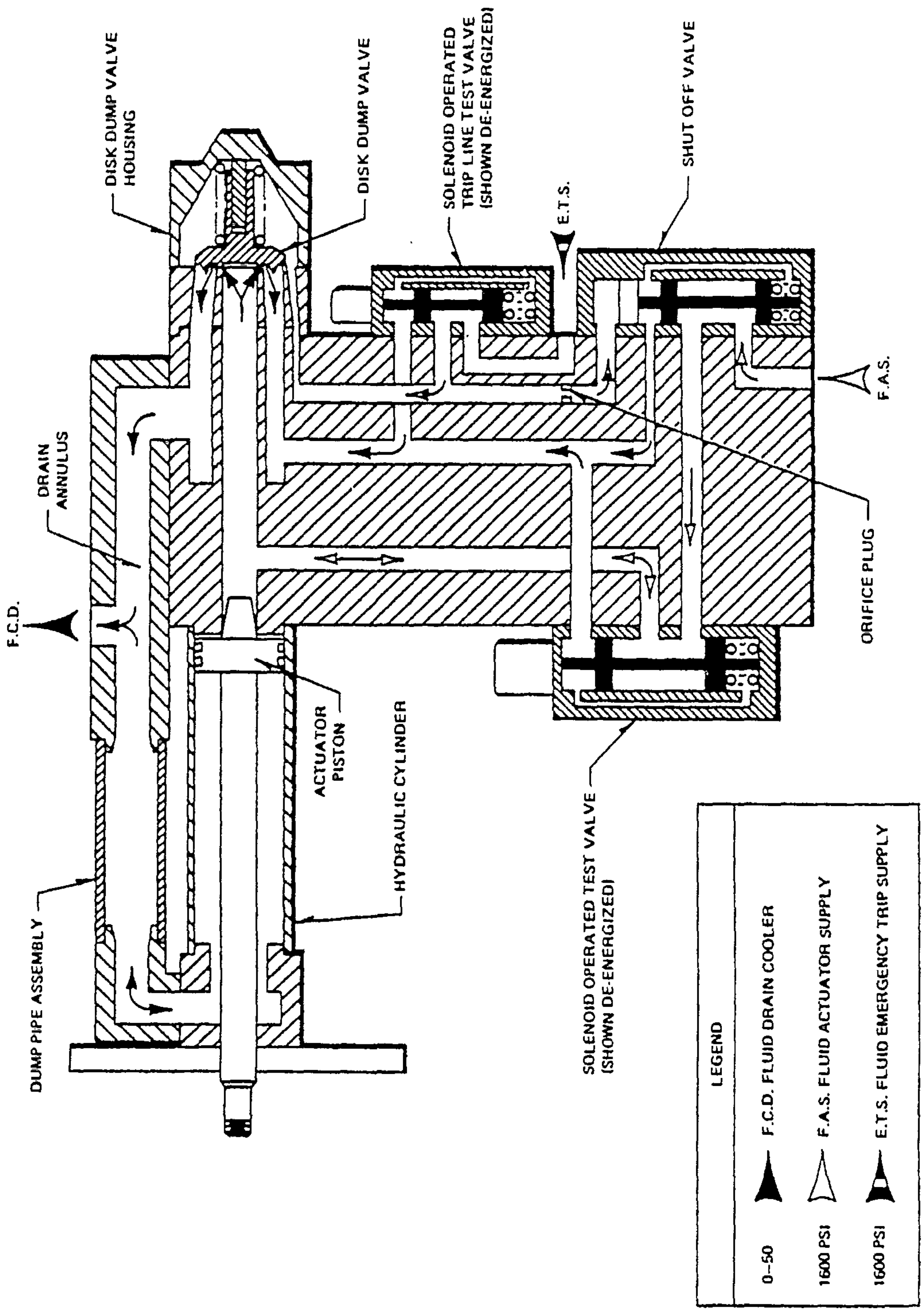


**Figure 2-11: GE Non-Controlling Control Pack**

### 2.4.2.4 Emergency Trip System

*Mark I.* The GE Mark I trip system consists of a single high pressure trip header referred to as the Emergency Trip System (ETS) (See Figure 2.12).

EHC fluid (FAS) is supplied to the trip system through the mechanical trip valve, the lockout valve, and the master trip solenoid valve. Once past the master trip solenoid valve, the FAS fluid is designated (ETS) fluid. The ETS fluid is routed to the disk dump valves of the turbine steam valves.

The hydraulic trip system removes ETS pressure upon actuation of either the mechanical trip valve or the master trip solenoid valve. The mechanical trip valve is actuated by:

1. Turbine Mechanical Overspeed
2. Manual Trip at the Front Standard
3. Any additional turbine trip signals are sent to a master trip relay which energizes the mechanical trip solenoid.

When Energized (125VDC), the mechanical trip solenoid actuates the trip mechanism to reposition the mechanical trip valve. FAS fluid is blocked and ETS header fluid is directed to the fluid cooler drains which return to EHC reservoir.

The master trip solenoid valve has two normally energized 24 VDC solenoids. Both solenoids must de-energize to block the EHC fluid supply and de-energize to block the EHC fluid supply and depressurize the ETS header. The dual solenoid arrangement allows on line testing of the solenoids and prevents spurious turbine trips with single solenoid failure conditions. With the exception of turbine mechanical overspeed and front standard trip lever manual actuation, all turbine trip signals provide an input into the master trip relay. If a trip signal is present, the master trip relay deenergizes both solenoids on the master trip solenoid valve and energizes the mechanical trip solenoid. Both the mechanical trip valve and the master trip solenoid will actuate to remove ETS pressure. The trip signals are sealed-in electrically and hydraulically.

Two pressure switches monitor ETS fluid pressure and provide a hydraulic seal-in upon a turbine trip condition. Signals are also provided to the EHC control logic to run back turbine load set to minimum and select "ALL VALVES CLOSED" if a turbine trip is initiated.

The turbine trip circuitry is reset in the control room. The reset push-button removes the seal-in circuit (trip signal must be clear except for low condenser vacuum) and resets the hydraulic trip system. The turbine can be reset with the low condenser vacuum trip signal present.

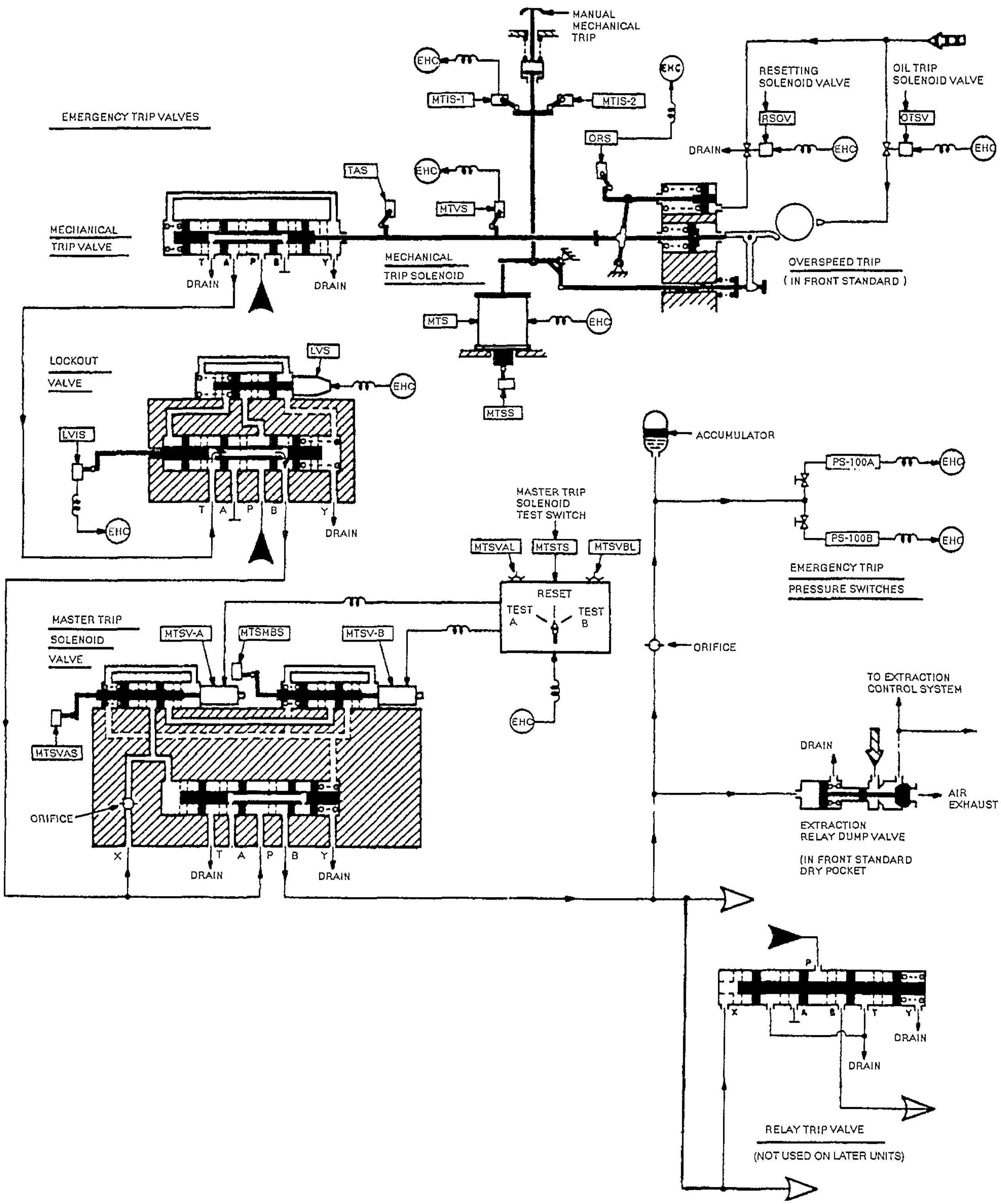


**Figure 2-12: Emergency Trip System (Mark I)**

The lockout valve is utilized during testing of the mechanical overspend trip mechanism. When energized by testing circuitry, the lockout valve by-passes the mechanical trip valve. Under these conditions, actuation of the mechanical trip valve will not result in a loss of the ETS fluid. Testing of the mechanical overspeed trip circuit can then be accomplished without generating a turbine trip. It should be noted that only the mechanical overspeed trip signal is bypassed and that receipt of any other turbine trip signal will generate a turbine trip using the master trip solenoid valve and also de-energize the lockout valve.

*MarkII.* The Mark II emergency trip system (ETS) can be divided into two major sections, the mechanical trip section and the electrical trip section. (See Figure 2-13.) The mechanical trip section is comprised of the mechanical shutoff valve, mechanical trip valve, mechanical lockout solenoid valve, and the mechanisms used to control these valves. The electrical trip section is comprised of the electrical trip valve, electrical lockout solenoid valve, and the mechanisms used to control these valves. In most cases, a trip signal will activate both the mechanical and electrical sections of the ETS. The protection system reliability is improved by not depending on one system.

When the system is reset, hydraulic fluid passes through the mechanical shutoff valve and bypasses the mechanical trip valve. The fluid then passes through the mechanical lockout solenoid valve, the electrical trip valve, the electrical lockout solenoid valve, and is supplied to the individual steam valves.

*Mechanical Trip Section.* The mechanical trip solenoid valve is energized to trip the turbine. When the mechanical trip solenoid valve is energized the oil supply from the lubricating oil system to the mechanical trip piston is shut off and the fluid line between the mechanical trip solenoid valve and the mechanical trip piston is drained back to the main lube oil reservoir. As this fluid is drained off the mechanical trip piston spring overcomes the fluid pressure and a mechanical stem rotates the overspeed trip lever. As the lever arm rotates, the mechanical trip pilot valve will shift to the drain position. At this point, the hydraulic fluid pressure is relieved in the pilot lines allowing the mechanical shut off valve and the mechanical trip valve to change position. This isolates and drains the ETS header. As the ETS header pressure drops, the steam valves shut and a turbine trip results.

Two turbine trips, not associated with the trip and monitoring system actuate the mechanical trip section of the ETS. These are:

- Mechanical overspeed trip
- Local manual trip

The mechanical overspeed trip is actuated by a slug located in the turbine shaft. When the turbine overspends the centrifugal force of the shaft rotating forces the slug outward. The slug strikes the overspeed trip lever arm and actuates the mechanical trip section of the ETS.

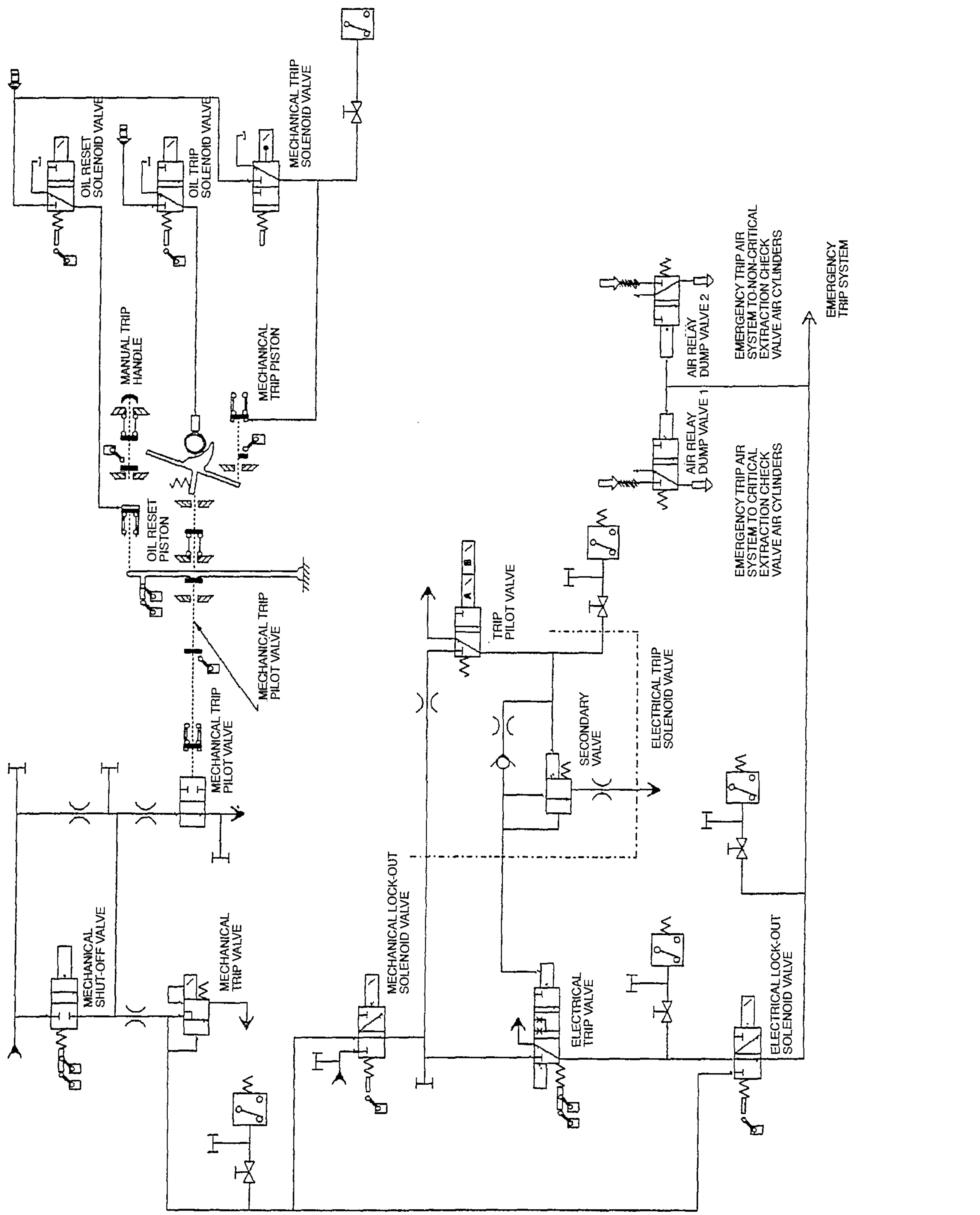


**Figure 2-13: Diagram of the Mark II Emergency Trip System**

The local manual trip is a handle connected to a shaft that rotates the overspeed trip lever arm and actuates the mechanical trip section of the ETS. The mechanical lockout solenoid valve is electrically controlled by the trip and monitoring system. This valve permits testing of the mechanical trip section during plant operations without depressurizing the ETS header.

*Electrical Trip Section.* The electrical trip valve is hydraulically controlled by the electrical trip solenoid valve. The electrical trip solenoid valve is made up of two internal valves; the trip pilot valve and the secondary valve. The trip pilot valve has two 24 volt solenoids on it which are normally energized by the trip and monitoring system.

When the Trip and Monitoring System sends a trip signal to the electrical trip section of the ETS, the two solenoids on the electrical trip pilot valve deenergize. This relieves the pressure holding the secondary valve shut. The secondary valve opens, relieving the pressure on the electrical trip valve. The electrical trip valve shifts to isolate the ETS supply line and drain the downstream header to the EHC fluid reservoir. Depressurizing the ETS header shuts all the turbine steam valves.

The electrical lockout solenoid valve permits testing of the electrical trip section. This can be done during plant operations without Repressurizing the ETS header.

#### 2.4.2.4 BWR Mark I

In a BWR, pressure is controlled by regulating the main steam pressure immediately upstream of the turbine stop and control valves through modulation of the control valves and/or bypasss valves. Control of pressure is extremely important due to the reactivity effects associated with the BWR system.

The EHC logic is comprised of several components/units which are grouped according to their function:

- Speed and acceleration control unit
- Pressure control unit
- Bypass control unit
- Load control unit
- Valve flow control unit

*Speed and Acceleration Unit.* The speed and acceleration unit develops speed and/or acceleration error signals which position the control and intercept valves to control turbine speed and acceleration rate during startup.

Two magnetic speed sensors provide the speed signals. The sensors are located over a toothed wheel in the turbine wont standard. As the wheel is rotated, the sensors generate a signal proportional to turbine speed. The signals are redundant and loss of one does not effect the system. Loss of both will initiate a turbine trip.

The desired reference is manually selected by the operator. Reference speeds available are:

- All valves closed
- 100
- 800
- 1500
- 1800
- Overspeed test

The overspeed test push-button actually overspeeds the turbine to test the overspeed protection equipment.

A circuit called the Wobbulator is incorporated in the speed control unit to slowly vary turbine speed. Speed is varied above and below set speeds that are near critical speeds to reduce the possibility of extended operations in a resonant condition, which could damage the turbine.

Discrete acceleration reference signals are also provided during turbine startup and are manually selected to provide for controlled rotor acceleration. The rates are:

- Slow (60 RPM/Min)
- Medium (90 RPM/Min)
- Fast (180 RPM/Min)

*Pressure control unit.* The pressure control unit compares turbine inlet pressure with a pressure reference setpoint and develops a steam flow demand signal which is provided to the load control unit for control valve positioning. This signal is also used to position turbine bypass valves if required.

*Bypass Control Unit.* The flow demand signal from the pressure control unit is sent to both the control valve and the bypass valve control circuitry. The bypass control unit generates a bypass valve demand signal in the event the turbine control valves cannot accept the total flow demand signal.

*Load Control Unit.* The load control unit develops a steam flow signal representing the desired load for the turbine. It receives signals from automatic protective circuitry (turbine runback and power-to-load unbalance) and the operator to develop an output signal. The signal from the load control unit will position the control valves only if it is less than the signal from the pressure control unit.

*Valve Regulation.* The valve regulation circuitry functions to properly position the control valves and intercept valves during turbine overspeed conditions.

Control Valve/Intercept Valve Regulation

1. Control valves are adjusted for "5%" regulation. This means turbine overspeed of 5% above the selected speed will result in a signal demanding full closure of the control valves.
2. The intercept valve control circuitry also responds to turbine overspeed conditions. The intercept valves are adjusted for "2%" regulation. This means turbine overspeed of 2% (after the control valves have closed in response to overspeed) will result in full closure of the intercept valves.

3. At 110% of rated speed, a turbine trip occurs and results in closure of the stop valves, control valves, intercept valves, and intermediate stop valves.

*Power Supplies.* The EHC control logic uses both 115VAC and 125VDC power. The 115VAC is typically supplied from either station power or the output of the permanent magnet generator (PMG) located in the main turbine front standard. One serves as a backup power supply to the other.

Essential DC power supplies (+22VDC, -22VDC, +24VDC, and +125VDC) within the EHC cabinet are redundant using the PMG or station batteries as sources and feeding the system through power diodes. If one source fails, power will not be interrupted.

The 125VDC is normally battery supplied. This 125VDC source is used to power the mechanical trip solenoid and the EHC logic operating relays.

#### 2.4.2.5 PWR Mark I

In a PWR the turbine control system is not used to control reactor pressure, therefore, the PWR MK I does not have the pressure control or bypass control units and turbine load is determined by inputs to the load control unit. The system is organized into three major subsystems:

1. Speed (and acceleration) control unit
2. Load control unit
3. Flow control unit

The speed control unit compares actual turbine speed with the speed reference, or actual acceleration with the acceleration reference, and provides an error signal for the load control unit. The load control unit combines the speed error signal with the load reference signal, limits, and biases to determine the desired steam flow signals for the control and intercept valves. Finally the flow control unit accurately positions the appropriate valves to obtain the desired steam flow through the turbine.

#### 2.4.2.6 PWR Mark II (BWR MK II differs only with pressure and by-pass control similar to the BWR MKI)

This control system is composed of four basic functional units:

1. The Speed and Acceleration Control Unit
2. The Load Control Unit
3. The Flow Control Unit
4. The Standby Control Unit

The control units operate together to accelerate the rotor to rated speed, hold that speed accurately enough to allow for generator synchronization, and admit steam as required to carry a given load.

*Speed and Acceleration Control Unit.* The Speed Control Unit provides an error signal for input to the Load Control Unit. There are three distinct error signals generated within the Speed Control Unit. Two error signals (one primary and one backup) compare a reference speed signal with the actual turbine speed signal. The third error signal is an acceleration error, derived by comparing the actual rotor acceleration with the reference acceleration signal. The smallest signal is sent to the load control unit.

The desired reference speed is manually selected by the operator. Several reference speeds are provided to allow warm-up of the turbine at various speeds. The reference speed signals available are:

- Close Valves
- 100 RPM
- 800 RPM
- 1500 RPM
- 1800 RPM
- Overspeed Test

The overspeed test push-button actually overspeeds the turbine to test the overspeed protection equipment.

A circuit called the Wobbulator is incorporated in the speed control unit to slowly vary turbine speed. Speed is varied above and below set speeds that are near critical speeds to reduce the possibility of extended operations in a resonant condition, which could damage the turbine.

Discrete acceleration reference signals are also provided during turbine startup. The acceleration signals are manually selected to provide for controlled rotor acceleration during startup. The acceleration rates are:

- Slow, 3 percent/minute of rated speed
- Medium, 5 percent/minute of rated speed
- Fast, 10 percent/minute of rated speed

Two magnetic speed sensors provide the primary and backup speed signals. The sensors are located over a toothed wheel in the turbine front standard. As the wheel is rotated, the sensors generate a signal proportional to turbine speed. If both signals are lost the unit will trip unless it is operating in the standby mode.

Only one circuit is used to provide the acceleration error signal. Therefore, the acceleration circuit uses a fail-safe system. A malfunction in the acceleration circuit transfers speed reference to Valves Closed. This shuts all the valves controlled by the EHC system.

*Load Control Unit.* The purpose of the Load Control Unit is to compute load reference signals for the Flow Control Unit.

- Sensing circuits are provided to detect and generate signals that affect loading the turbine.
- Limiting circuits are provided to electrically limit the flow reference signals.
- Computing circuits are provided to generate individual flow reference signals for the various steam valves.
- Logic circuits are provided to ensure that necessary permissive have been satisfied prior to changes in modes of operation. Logic circuits communicate status information between the Load Control Unit and other elements of the EHC system.

The Load Control Unit consists of several functional groups. These groups combine to generate the desired output. The Load Control Unit consists of the following groups:

- load set
- Loading rate and load set limit
- Load set runback
- Valve amplifier
- Load limit
- Throttle pressure limited
- Power to load unbalance
- Stage pressure feedback
- Shell and chest warming
- Throttle pressure compensator

The load set signal is used for synchronizing the main generator and establishing the final value of desired load. It is generated by a potentiometer which is positioned by a load set motor. "INCREASE LOAD" and "DECREASE LOAD" push buttons are provided for manual positioning of the load set motor from control panel.

The loading rate circuit controls how fast the load set motor can raise the output of the load set circuit. Push buttons are provided for selecting one of several discrete loads.

Load set runbacks are incorporated to reposition the load set motor when certain abnormal operating conditions are detected. Runbacks may be initiated by signals from the power/load unbalance circuit or any signal from the plant indicating that abnormal plant conditions require a reduction in load.

Three types of valve amplifiers are incorporated to produce flow reference signals for a main stop valve (typically #2), the control valves, and the intercept valves.

Normally the stop valve amplifier establishes a warming signal. This is a position command signal for the main stop valve bypass valve. The control valve amplifiers combine the speed error signal, the load reference signal, the stage pressure feedback signal, and an appropriate bias signal to produce a flow reference signal for each control valve. The intercept valve amplifier combines the speed error signal with the load reference signal and appropriate bias signals in order to produce an intercept valve flow reference signal. The flow reference signals are subject to the limits of the throttle pressure limit, load limit, and load setback circuits.

Load limit controls are provided to allow the operator to select a maximum load to be carried by the turbine. A hand-operated potentiometer located on the EHC control panel provides this signal. The load limit signal is compared to the flow reference signal of the control valves. If the flow reference signal exceeds the load limit signal, a load set runback is initiated. This runback drops the load set signal to slightly above the load limit setpoint.

The throttle pressure limiter prevents excessive decrease in main steam (throttle) pressure. When throttle pressure falls below a preset value the control valves will throttle shut. The valves will continue to shut until throttle pressure increases above the setpoint. The setpoint of the throttle pressure limiter is normally set at 90 percent of rated steam pressure.

The throttle pressure limiter is controlled on the EHC panel. The circuit may be selected using the "ON" push-button. The setpoint is adjustable from zero to 100 percent of rated pressure by using the "INCREASE" and "DECREASE" push-button. An "OFF" push-button takes the circuit out of service.

Associated with the load control unit is a rate sensitive power/load unbalance circuit. This circuit is designed for anticipatory overspeed protection. The power/load unbalance circuit will quickly shut the control valves following a sudden loss of electrical load. Valve closure occurs when the power of the turbine exceeds the electrical load by at least 40 percent and generator current is lost in a time span of 38 microseconds or less. Cold reheat pressure is used as a measure of turbine power, and generator current is used as a measure of electrical load.

When the detection circuitry provides a signal indicating a Power/load unbalance condition the load reference signal is grounded and the load reference motor is run back toward the no load flow condition. Should the condition clear quickly, the power/load unbalance circuit will reset automatically. If the loss of load condition does not reset within 45 seconds the load reference runback will be completed. The power/load unbalance circuit clears automatically when the cold reheat pressure drops below 40 percent.

The stage pressure feedback (SPF) circuitry provides two functions:

1. Produce a more linear turbine response to the desired load signal
2. To maintain near constant turbine output during control valve testing

A pressure sensor generates an electrical signal proportional to first stage pressure. This signal is compared with the load set signal. This will produce an error signal which indicates the difference between the designed load and the actual load on the turbine. The stage pressure feedback circuit will try to minimize this error signal. If actual load is less than desired load the circuit will boost the gain of the control valve amplifiers. This causes the control valves to open further and brings actual load closer to desired load.

Stage pressure feedback operating modes are manual, automatic, or off. In manual the operator controls the amount of SPF by using "INCREASE" and "DE-CREASE" push buttons. In automatic the circuit controls the amount of SPF as described above.

On some PWR's, main steam pressure drops approximately 100 PSI from no load to full load. The turbine is designed to maintain rated load at the rated full load pressure (approx. 1000 psig). At reduced loads, throttle pressure is higher than rated. This causes a nonlinear regulation.

The load control unit is designed to account for these changes in pressure by using a throttle pressure compensator. This compensator is in service at all times. A throttle pressure sensor adjusts the opening rate of the control valves in proportion to the difference between actual pressure and rated load pressure. This is because the flow capacity of a control valve is proportional to the pressure upstream of the valve.

Failure of the throttle pressure sensors will generate a compensation signal corresponding to the highest design throttle pressure to ensure the turbine is not overloaded. In addition to the effect of the throttle pressure compensator, the stage pressure feedback circuit works to maintain linear control valve operation. This further reduces the influence of the varying throttle pressure.

On PWR's with constant pressure, the compensator circuit is replaced by a throttle pressure limiter which limits a throttle pressure decrease to approximately 10%.

*Flow Control Unit.* The flow control unit receives the load/speed reference signals from the load control unit. The flow control unit uses these signals to position the steam valves and maintain them at the desired position. It can also use the signal from the standby control unit instead of the load control unit.

Actual valve position is compared with the load/speed reference signal. This produces an error signal proportional to the difference between the actual and desired valve position. The servo valve changes this electrical signal to a hydraulic output so the valve actuator moves the steam valve to the desired position.

The opening error signal is limited. This ensures the valve takes at least 10 seconds to open through its full stroke. There is no limit on the closing rate.

*Standby Control Unit.* The standby control unit can provide an input signal to the flow control unit if the speed or load control units are inoperable. The output of the standby control unit is controlled manually with a potentiometer on the EHC panel. Turbine operation may continue in standby control while repairs are made to the speed or load control units.

The operator may select standby control at any time, once certain permissives are met. Prior to shifting, the output of the standby control unit must be matched to the output of the load control unit. Lights on the EHC panel indicate when the signals are matched. The indicators are:

- Main stop valve (MSV) signal matched
- Control valve (CV) signal matched
- Intercept valve (IV) signal matched

The MSV and IV signals should be matched anytime the EHC system is reset. The operator must adjust the potentiometer on the EHC panel to match the control valve signal. Once the permissives are met, the operator may shift between manual and standby control using "ON" and "OFF" push buttons. When stand-by control is used the speed control unit and load control unit signals are bypassed.

The permissives may be bypassed if a malfunction in the analog control system makes it impossible to match the signals. To bypass the permissives the operator must press and hold a "BYPASS" button as he pushed the "ON" or "OFF" push-button. This is not a desirable method of shifting control, due to the possibility of large load fluctuations.

During normal "manual" operation the turbine has three levels of defense against an overspeed condition. In order, they are:

- Automatic speed control
- Mechanical overspeed trip
- Electrical backup overspeed trip

During standby control, automatic speed control is removed. To give added overspeed protection during standby control, the backup overspeed trip setpoint is reduced to approximately five percent. The mechanical trip setpoint is unchanged.

### 2.4.3 Siemens

The Siemens Electrohydraulic Control (EHC) incorporates a backup Mechanical Hydraulic Control system (MHC) into its design and uses significantly lower hydraulic pressure. The turbine generator is normally electrohydraulically controlled by the EHC system. A solid state electrical system directly measures and controls turbine speed and power output within prescribed limits by positioning the turbine control valves through electrohydraulic converters and follow-up piston assemblies. In BWR applications the system positions the control and bypass valves as required to maintain reactor pressure.

The turbine speed is measured electronically by a digital transmitter and hydraulically by means of a shaft driven hydraulic pump. If a fault occurs in the electronic system, control of the turbine is transferred to the backup MHC system.

The hydraulic fluid pressures used by the EHC and MHC systems are developed by the Control Fluid System. The Control Fluid System provides high pressure hydraulic fluid to operate the turbine system valves and low pressure hydraulic fluid for the EHC and MHC hydraulic control and safety functions. Three 50% capacity pumps provide the 455 psi high pressure and 114 psi low pressure fire resistant hydraulic fluid required by the control systems.

The two key elements in the hydraulic control system are the electrohydraulic converter and the follow up pistons (See Figure 2.14). The Electrohydraulic Converter is the connecting element between the electrical and hydraulic parts of the turbine control system and the follow-up pistons act as hydraulic amplifiers that amplify the hydraulic control signals before transmitting them to actuating devices.

Either the EHC or MHC is capable of starting and loading the turbine generator through its full speed and load range and in BWR applications provides pressure control. Under normal operating conditions the EHC controls the turbine and the MHC serves as back-up controller.

The EHC and MHC both transmit independent and redundant valve positioning signals to two separate electrohydraulic (EH) converters. The MHC controlling signal is hydraulic fluid pressure and the EHC signal is a voltage signal.

Each electrohydraulic converter positions a bank of mechanical hydraulic follow-up pistons, proportional to the EHC or MHC positioning signals. The outputs of the converter follow-up pistons are hydraulically connected in a low value gate arrangement. The converter in control is the one that is calling for the turbine steam valves to be in the least open position.

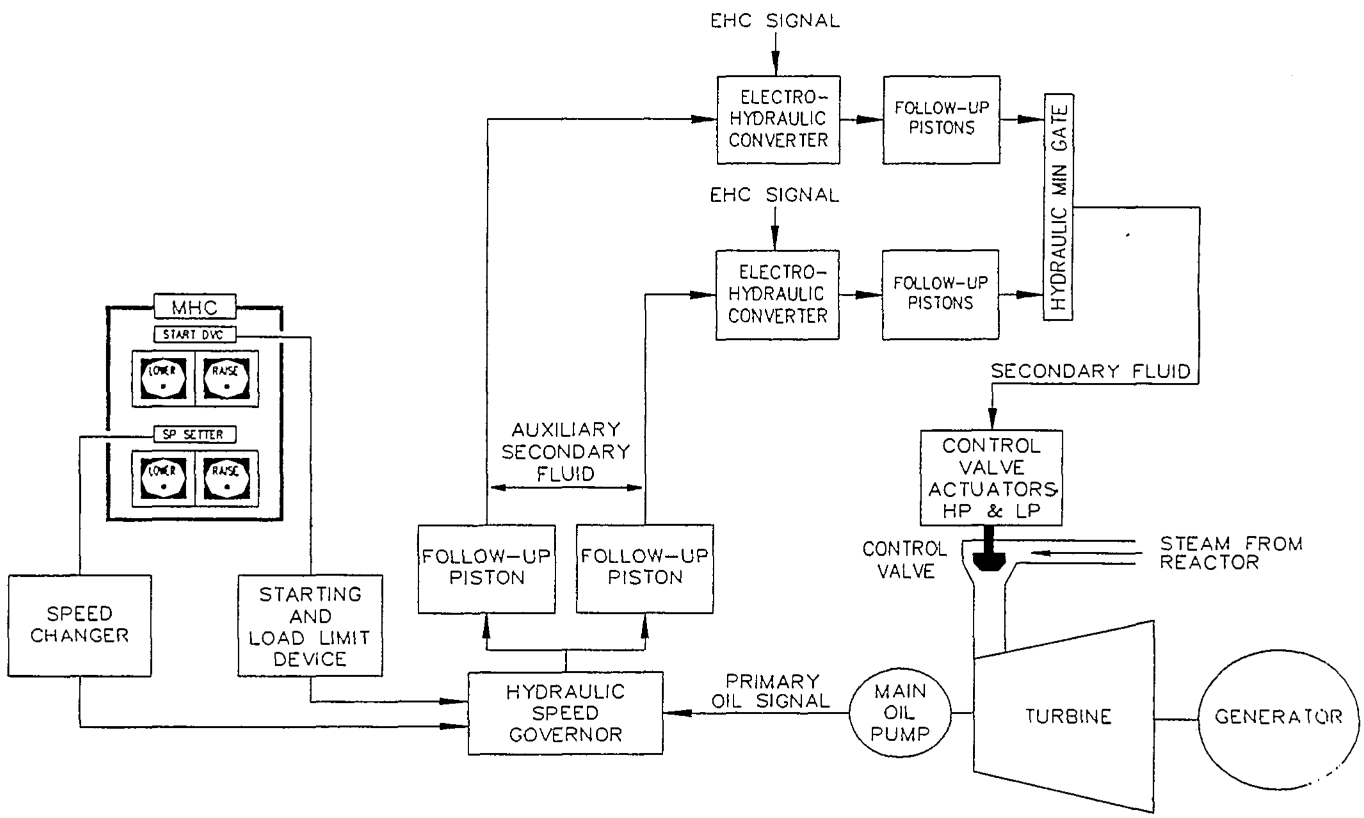


**Figure 2-14: Electro-Hydraulic Converter (Siemens)**

### 2.4.4 GEC (UK)

The GEC Electronic Governor performs essentially all the same functions as other electrohydraulic controllers. The hydraulic portion of the system however is somewhat unique in that each individual steam admission valve actuator is a self contained unit. In addition to the valve actuation components (servos, trip solenoids, test solenoids, etc.), each actuator has its individual oil reservoir, hydraulic pump, accumulators, filters, and pressure control components. With this arrangement, most actuator failures (including large fluid leaks) have no effect on the overall system and repairs can be made on line. Fire retardant fluid is not used in these hydraulic systems. Refer to Figure 2.15 for an example of a GEC actuator.

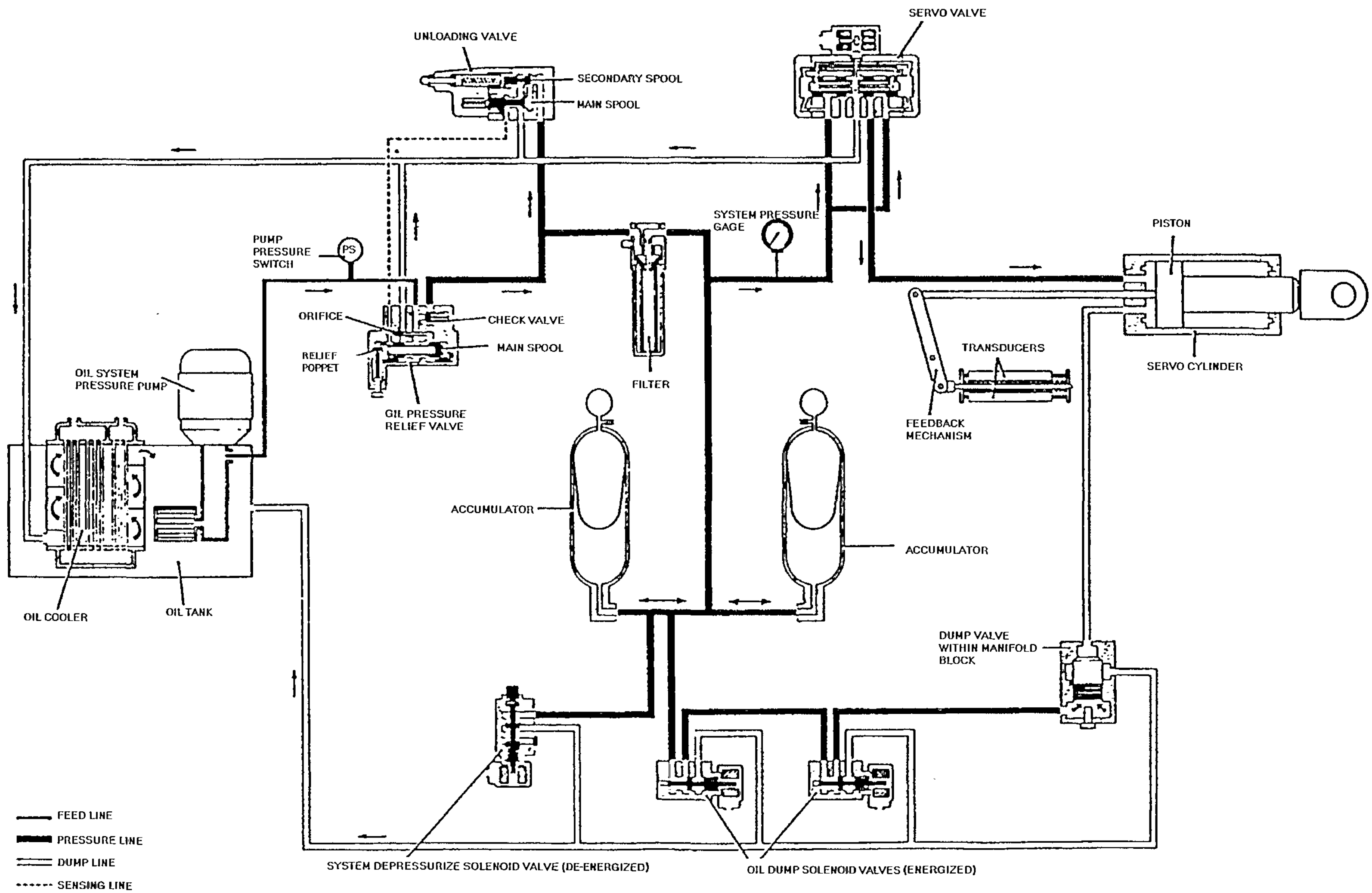


Figure 2-15: GEC Actuator

### 2.4.5 NEI Parsons

*NEI Parsons Electro Hydraulic Governor (EHG).* The Electro-Hydraulic Governor (EHG) has control over the Control and Intercept Valves of the machine, and speed control is effective from turning gear speed to the overspeed trip point. The governor also controls load from 0-100% power when the unit is synchronized to the grid. The system uses 3 turbine shaft speed signals (derived from a toothed wheel and probe system) feeding directly to the wide range and the narrow range (NR) governors. Each of these governors has independent control logic and interlocks. Refer to Figure 2-16 for the basic block diagram.

The control system reliability in critical areas relies on the use of triplex redundant sensors, signal channels, and electronic modules.

The Control valves are controlled by electrohydraulic servos actuated by hydraulic fire retardant fluid. Electrohydraulic servo positions are corrected by position feedback signals.

Each Control Valve is operated from three redundant control circuits with two out of three majority voting to ensure a high degree of reliability in the operation. A single fault in any one of the channels would not impact valve operation since the other two redundant circuits are available to perform the required operations.

The wide range (WR) speed control loop enables the machine to be run-up to synchronous speed using either manual, semi-automatic or computer-control mode. Typically, the WR governor affects the turbine operation from 15 rpm (turning gear speed) to 1800 rpm. Though the WR governor has speed control capability up to 2160 rpm, the speed control is taken over by the NR governor as soon as the speed control error is better than the WR governor. While running down, the speed control is restored to the WR control when the speed is lower than the above limit. When speed control is taken over by the NR governor, the WR setpoint is automatically driven to the top limit.

The NR governor assumes speed control when the turbine speed is around 1746 rpm. The unsynchronized control range of the NR governor is -6% to +6% of the rated speed and after synchronization, O to 150% load. The NR governor has a 4% fixed droop which corresponds to 100% to 0% of the Control Valve demand signal.

An auxiliary governor is provided which duplicates most of the functions of the NR governor and may be available to work in place of the NR governor as a contingency measure. One other important function of the auxiliary governor is to enable the turbine speed to rise up to 106%, at which point, the NR governor speed setting is raised by another +6%. Thus, the effective total speed setpoint can be taken to 112% of the rated speed to check the overspeed trip setpoint.

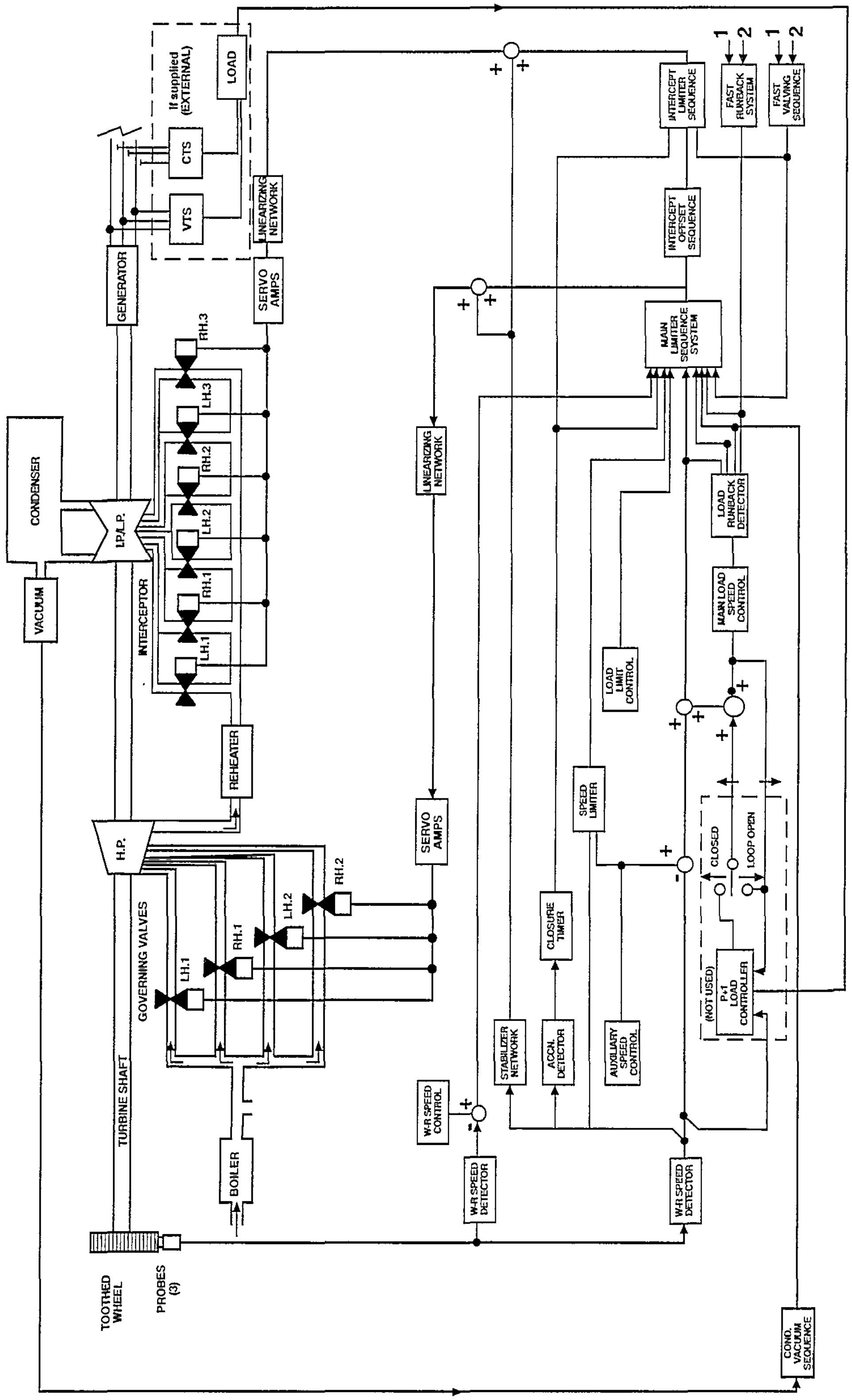


Figure 2-16: NEI-Parsons EHG Basic Block Diagram

## 2.5 Hydraulic Fluid

### 2.5.1 Introduction

The majority of high pressure hydraulic fluid systems used for large steam turbine control utilize a synthetic hydraulic fluid. The fluid is fire resistant to minimize the fire hazard potential should a leak occur. The root cause of many hydraulic system problems can be traced to failure to maintain the hydraulic fluid in good condition. Particulate contamination causes silting (a buildup of small particulate settling in low flow areas) resulting in sticking valves. Improper fluid chemistry control can cause solutions which attack seals and O-rings, leading to premature failure of servo valves and cause foaming and gelling of the hydraulic fluid.

Disposal and handling of synthetic fluids is an environmental concern and is considered hazardous waste in some areas.

### 2.5.2 Phosphate Ester Based Hydraulic Fluids

Phosphate ester fluids (specifically triaryl phosphates) are synthetic fluids and have been the accepted hydraulic fluid for high pressure utility steam turbine EHC systems for more than 25 years. Phosphate ester based hydraulic fluid is the predominant hydraulic fluid used in the utility industry.

Phosphate ester fluids are extremely sensitive to water contamination which increases the acidity of the fluid. At temperatures above 150°F the fluid will hydrolyze when exposed to atmospheric moisture resulting in formation of phenol and aryl phosphoric acids. This can cause the fluid to form grease-like deposits and foam. If left unattended it could lead to erosion of close tolerance hydraulic components such as the servo valve spools. To combat this problem, a conditioning filter is supplied which maintains the system acidity in the proper range. Initially, fuller's earth was used almost exclusively as the filter media but chemical absorbent compounds have been developed that can replace the fuller's earth filter media. (Regardless of the media used, this filter is usually referred to as the "fuller's earth filter").

The conditioning filter normally has a bypass to allow for filtering of the fluid during filling operation and other times when the fluid is suspected of contamination, to prevent plugging of the filter. The filter system may have a dedicated low pressure pump circuit or may draw from the main hydraulic pump discharge (with an orifice or control valve to reduce the pressure). The dedicated pump method allows for operation during shutdown without having to run the large main pumps but requires an additional pump and associated controls. Improper operation of the filtering system can lead to rapid deterioration of various hydraulic components, particularly the actuator servo valves which rely on extremely close tolerances for proper operation. The turbine protective trip system relies on a number of solenoid operated trip valves which have been known to corrode and fail.

The chemical properties of phosphate ester fluids require close attention to material selection. Materials used in petroleum based hydraulic systems are typically incompatible with phosphate ester fluids. Viton or EPR is generally used for O-rings, gaskets, and accumulator bladders. Stainless steel heat exchangers are recommended because metals such as copper and some copper alloys act as pro-oxidation catalysts which, at elevated temperatures in the presence of water, will accelerate the hydrolysis of the fluid.

Various environmental laws address the use of phosphate ester fluids and must be observed by the customer. Phosphate ester fluids have a specific gravity greater than one (1.0) meaning that spills cannot be skimmed from the surface of water. To deal with disposal issues, most fluid manufacturers have fluid return programs.

### 2.5.4 Hydraulic Fluid Parameters & Specifications

All hydraulic fluids require maintenance to achieve maximum reliability and service life. Plant personnel should maintain records documenting proper maintenance of the fluid. Acknowledging the impact of fluid condition on proper system performance, most hydraulic fluid manufacturers provide analysis of fluid samples in accordance with OEM recommended limits to their customers. In addition, vendors will normally provide assistance with problems concerning their fluid.

Cleanliness of the fluid is always a major concern. The hydraulic system has many small orifices and passages which can be easily clogged. Filters are usually installed at the pump discharges with differential pressure switches connected between the inlet and outlet sides of the filter cartridges to indicate when a filter is clogged and needs cleaning or replacement. A pump suction strainer may also be provided. The return line to the reservoir may also include a filter. Magnets in the reservoir collect ferrous particles. In some systems another filter is installed in the supply line to each valve actuator to provide an added measure of protection.

Proper fluid viscosity is required for operation of the hydraulic components. Temperature is a major factor contributing to changes in fluid viscosity. To control temperature, a heating system may be supplied to preheat the fluid prior to startup m cold environments. Heat exchangers remove excess heat during operation. If fluid overheating is suspected, a sample should be immediately analyzed.

## 3.0 Turbine Control Type Data Base

| UTILITY | PLANT | REACTOR | TURBINE | EHC TYPE | SITE PHONE |
|---|---|---|---|---|---|
| ENTG | ARKANSAS ONE 1 | B&W | W | AEH | 501 -858-5000 |
| ENTG | ARKANSAS ONE 2 | C-E | GE | MARK I | 501 -858-5000 |
| DUQ | BEAVER VALLEY 1 &2 | W | W | AEH MARK IV | 412-393-5217 |
| CPC | BIG ROCK POINT | GE | GE | MHC | 616-547-6537 |
| CWED | BRAIDWOOD 1 & 2 | W | W | DEH MOD II | 815-458-2801 |
| TVA | BROWNS FERRY | GE | GE | MARK I | 205-729-2000 |
| ONHY | BRUCE 1,2,3,&4 | AECL | NEI-P | MHG | 519-361 -2673 |
| ONHY | BRUCE 5,6,7,& 8 | AECL | GE | MARK II | 519-361 -2673 |
| CP&L | BRUNSWICK 1&2 | GE | GE | MARK I | 910-457-9521 |
| GWED | BYRON UNIT 1 & 2 | W | W | DEH MOD II | 815-234-5441 |
| UE | CALLAWAY 1 | W | GE | MARK II | 314-676-8000 |
| BG&E | CALVERT CLIFFS 1 | C-E | GE | MARK I | 410-260-4600 |
| BG&E | CALVERT CLIFFS 2 | C-E | W | AEH | 410-260-4600 |
| DUKE | CATAWBA 1 &2 | W | GE | GE/BAILEY(ETSI) | 803-831 -3000 |
| IPC | CLINTON | GE | GE | MARK II | 217-935-8881 |
| TUEC | COMANCHE PEAK 1&2 | W | SIEMENS | EHC/MHC | 817-897-4856 |
| AEC | COOK 1 | W | GE | MARK I | 616-465-5901 |
| AEC | COOK 2 | W | BBC | MHC | 616-465-5901 |
| NPPD | COOPER 1 | GE | W | AEH TO DEH | 402-825-3811 |
| FPC | CRYSTAL RIVER 3 | B&W | W | AEH MARK III / IV | 904-795-6486 |
| ONHY | DARLINGTON 1,2,3,&4 | AECL | ABB | EHC | 905-623-6606 |
| TOLE | DAVIS BESSE | B&W | GE | MARK I | 419-249-5000 |
| PG&E | DIABLO CANYON 1 &2 | W | W | DEH MOD I | 805-545-3100 |
| CWED | DRESDEN 2&3 | GE | GE | MARK I | 815-942-2920 |
| IESU | DUANE ARNOLD | GE | GE | MARK I | 319-851 -7611 |
| SNOP | FARLEY 1&2 | W | W | DEH MOD III | 205-899-5156 |
| DEC | FERMI | GE | GEC | EHC | 313-586-5300 |
| NYPA | FITZPATRICK | GE | GE | MARK I | 315-342-3840 |
| OPPD | FT. CALHOUN | C-E | GE | MARK I | 402-426-401 1 |
| RG&E | GINNA | W | W | AEH | 315-524-4446 |
| ENTG | GRAND GULF | GE | SIEMENS | EHC/MHC | 601 -437-2800 |
| CYAPC | HADDAM NECK | W | W | MHC | 203-267-2556 |
| SNOP | HATCH 1&2 | GE | GE | MARK I | 912-367-7851 |
| PSEG | HOPE CREEK 1 | GE | GE | MARK I | 609-935-6000 |
| CNED | INDIAN POINT 2 | W | W | MHC | 914-526-5400 |

| UTILITY | PLANT | REACTOR | TURBINE | EHC TYPE | SITE PHONE |
|---|---|---|---|---|---|
| NYPA | INDIAN POINT 3 | W | W | MHC | 914-526-8000 |
| WPSC | KEWAUNEE 1 | W | W | AEH MK II | 414-388-2560 |
| CWED | LASALLE 1 & 2 | GE | GE | MARK I | 815-357-6761 |
| PECO | LIMERICK 1 & 2 | GE | GE | MARK I | 610-718-1200 |
| MYAP | MAINE YANKEE | C-E | W | AEH | 207-882-6321 |
| DUKE | MCGUIRE 1 &2 | W | W | (W) BAILEY/ETS I | 704-875-4000 |
| NU | MILLSTONE 1 | GE | GE | MHC | 203-447-1791 |
| NU | MILLSTONE 2 | C-E | GE | MARK I | 203-447-1791 |
| NU | MILLSTONE 3 | W | GE | MARK II | 203-447-1791 |
| NSP | MONTICELLO | GE | GE | MHC | 612-295-5151 |
| NMPC | NINE MILE POINT 1 | GE | GE | MHC | 315-343-2110 |
| NMPC | NINE MILE POINT 2 | GE | GE | MARK I | 315-343-2110 |
| VPCO | NORTH ANNA 1 &2 | W | W | AEH MK II/III | 703-894-5151 |
| DUKE | OCONEE 1,2&3 | B&W | GE | MARK I | 803-885-3000 |
| GPU | OYSTER CREEK | GE | GE | MHC | 609-971 -4000 |
| CPC | PALISADES | C-E | W | AEH TO DEH MOD III | 616-764-8913 |
| APS | PALO VERDE 1,2&3 | C-E | GE | MARK II | 602-393-5000 |
| PECO | PEACH BOTTOM 2&3 | GE | GE | MARK I | 717-456-7014 |
| CEI | PERRY | GE | GE | MARK II | 216-259-3737 |
| ONHY | PICKERING 1,2,3 & 4 | AECL | NEI-P | MHC | 905-839-1151 |
| ONHY | PICKERING 5 6 7 & 8 | AECL | NEI-P | EHC | 905-839- 1151 |
| BECO | PILGRIM I | GE | GE M5 | MHC | 830-737-8000 |
| WEPC | POINT BEACH 1&2 | W | W | AEH | 414-755-2321 |
| NBEBC | POINT LEPREAU | AECL | NEI-P | EHC | 506-659-2220 |
| NSP | PRAIRIE ISLAND 1&2 | W | W | AEH MARK III/IV | 612-388-1121 |
| CWED | QUAD CITIES 1&2 | GE | GE | MARK I | 309-654-2241 |
| GSU | RIVER BEND UNIT 1 | GE | GE | MARK II | 504-635-6094 |
| CP&L | ROBINSON | W | W | AEH | 803-383-4524 |
| PSEG | SALEM 1 &2 | W | W | AEH | 609 -935 -6000 |
| SCEC | SAN ONOFRE 2&3 | C-E | GEC | EHC | 714-368-3000 |
| NHY | SEABROOK | W | GE | MARK II A | 603-474-9521 |
| TVA | SEQUOYAH 1&2 | W | W | AEH MK III/IV | 615-843-6000 |
| CP&L | SHEARON HARRIS | W | W | DEH MOD I | 919-362-8891 |
| HL&P | SOUTH TEXAS 1 &2 | W | W | AEH | 512-972-3611 |
| FP&L | ST. LUCIE 1 & 2 | C-E | W | DEH MOD 1 | 407-465-3550 |
| SCEG | SUMMER | W | GE | MARK I | 803-345 -5209 |

| UTILITY | PLANT | REACTOR | TURBINE | EHC TYPE | SITE PHONE |
|---|---|---|---|---|---|
| VPCO | SURRY1&2 | W | W | AEH MK IV | 805-357-3184 |
| PP&L | SUSQUEHANNA1&2 | GE | GE | MARK I | 717-542-2181 |
| GPU | TMI1 | B&W | GE | MARK I | 717-944-7621 |
| FP&L | TURKEY POINT 3&4 | W | W | MHC | 305-246-1300 |
| WNP | VERMONT YANKEE | GE | GE | MHC | 802-257-7711 |
| SNOC | VOGTLE | W | GE | MARK II | 706-554-9961 |
| ENTG | WATERFORD | C-E | W | DEH MOD II | 504-467-8211 |
| TVA | WATTS BAR | W | W | AEH | 615-365-8000 |
| WNP | WNP2 | GE | W | DEH MODII | 509-377-8000 |
| WCNO | WOLF CREEK | W | GE | MARK I | 31 6-364-8831 |
| CWED | ZION 1&2 | W | GE | AEH MK lll | 708-746-2084 |

# 4.0 Turbine Control System Problem Areas

A turbine control system must monitor as well as test turbine functions while continuing to operate and protect a turbine. Users should be aware of the unique problems and failure mechanisms that affect the performance of these systems.

## 4.1 Introduction

This section summarizes problems and identifies industry actions taken to correct them. To provide pertinent failure data, various information sources were reviewed to determine the type of turbine control system problems that the industry has experienced and to report on the actions taken in response to these problems. Information was gathered from an industry survey (distributed by NMAC February 1992), NPRDS, OPEC, and the Nuclear Network, plus comments from engineers and vendors who are experienced with turbine control systems. The review indicated that control problems continue to be a major contributor to plant outage hours and operation and maintenance (O&M) costs. Although steps have been taken to address some areas, particularly vibration and hydraulic fluid chemistry, there is still margin for overall improvement related to turbine control system performance.

Failure data is divided into four basic problem areas (1) fluid, (2) electrical and electronic, (3) general component, and (4) maintenance induced. The selected datum period for these failures is from 1989 through 1993. Although failures obviously occurred prior to this period, data reliability and its clarity made this a useful period from which to draw comparisons and conclusions.

The evaluated data indicates general trends, the degree of problems, and equipment locations. This presents a reasonably accurate picture of failure distribution and the relative contribution of various components to reliability. The following discussions and associated graphs provide a means to qualify the evaluated failure data and present it in a concise format. Turbine control system performance history is only summarized here; however, future documents will address unique problems and propose solutions.

This section also contains improvements and modifications employed by some utilities to eliminate or reduce potential problems. These are provided as information only; the reader should consider that the items listed might not apply in all cases.

A large number of incidents were evaluated to provide a basis for the failure analysis. All makes, models, and vintages were considered for the general data set. As indicated, four general categories of failures were chosen during the evaluation process. Some consideration was given to looking at all reported failures; however, the amount of data would require too much time and expenditure to analyze and might not reflect current industry practices. The datum period provided a manageable amount of data while also giving a relevant picture of current practices. The graph below provides a breakdown of the failure evaluation with no differentiation made for manufacturers or vintage.

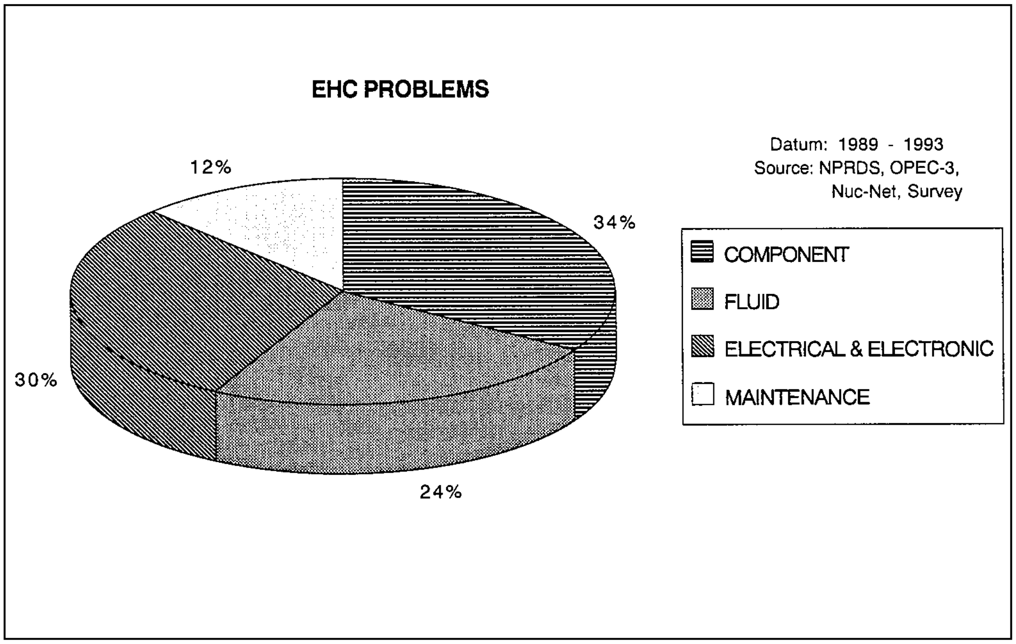


**Figure 4-1: Problem Areas**

About 34% of all reported problems fall into the general category of component failures, such as solenoid valves, pressure switches, pumps, etc., and constitute the single largest area of failure. However, two things of significance became apparent from this data. First, nearly one-fourth (24%) of the total problems were fluid related. Survey information from utilities indicates that they spent a considerable amount of money and time to reduce the number of failures in this area. Second, although 88% of EHC failures were equipment related, a number of failures were maintenance induced. Nearly 12% of all reported failures that led to some form of plant capacity reduction or reportable incident were due to some type of human error or testing activity.

As equipment spends more time in service, it is increasingly important for operators and maintenance personnel to understand the characteristics as well as practices that lead to improved and continued performance of turbines and turbine systems. Most systems have run well with minimum attention; however, recent incidents suggest a need for better understanding of control system makeup and system capability.

Improvements in the areas of training, procedural requirements, inservice testing, postmaintenance testing, and inspections could, in many cases, provide immediate benefits. Follow-on work will evaluate and recommend practices and methods to enhance measures already taken.

## 4.2 Hydraulic Fluid Problems

Fluid-related problems represent 24% of evaluated failures. Tubing, piping, and component leaks, mostly attributed to vibration, constitute more than 80% of these fluid-related failures. Many utilities have redesigned or added piping and tubing supports. Isolating piping from vibration is difficult and eliminating the sources of vibration might be virtually impossible. Wherever possible, pipes and tubing have been replaced with high-pressure flexible hoses.

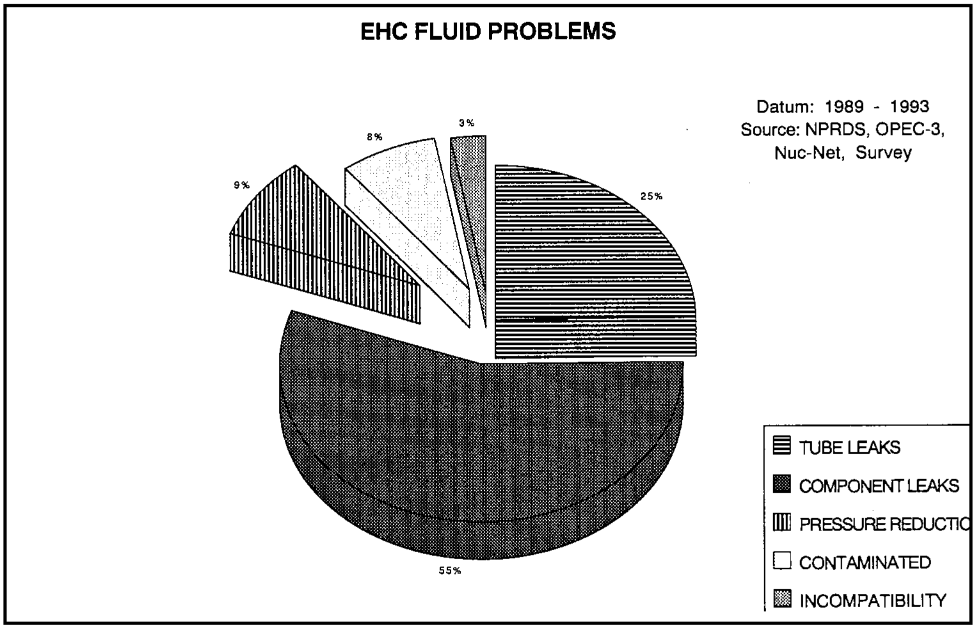


**Figure 4-2: EHC Fluid Problems**

Clogged filters, strainers, and other flow-reducing mechanisms suggest that improvements could be made in the handling and disposition of fluid leaks. Often the procedures for selecting and purchasing components that are compatible with EHC fluids are inadequate. Cleanliness requirements for such things as filter change-outs and tubing replacement have not been clearly defined, which often contributes to the introduction of contaminants into the system during these activities.

Hydraulic fluid contamination accounts for only 8% of reported fluid-related problems. However, in reality, fluid contamination is either directly or indirectly involved in many other hydraulic component failures. These failures include high internal leakage due to electrochemical erosion and sluggish movement or sticking of close tolerance components caused by either varnish buildup or particulate contamination. Contamination of the fluid comes from both external and internal sources. Reported causes of external contamination include:

- Cooler leaks
- Saturated (or lack of) breather desiccant
- Incorrect or dirty makeup fluid

- Inadequate cleanliness control during filter changes and other system maintenance activities

Internal contaminants are always being generated within the system and include moisture, metal particles, and fluid degradation products.

Low hydraulic pressure was usually traced to a problem with the pressure compensators or unloaders for the EHC pumps. Air in the hydraulic fluid, from failure of air bleed valves, piping configuration, and reservoir baffle arrangement, was also cited as causing pressure-control problems. Localized loss of pressure was usually caused by dirty in-line fluid filters.

Fluid dynamics can also lead to unexpected pressure problems. Some plants experienced hydraulic pressure dips when multiple valves traveled simultaneously, causing valves to drift shut or causing pressure fluctuations in trip headers, leading to spurious turbine/reactor trips. A turbine valve sequential reset circuit has been added to help limit these excursions and, in other cases, additional accumulators have been added. Inadvertent trips on low hydraulic pressure during valve cycling prompted the vendor to recommend installation of additional orifices in the fast-acting solenoid pressure ports.

Fluid leaks are a major contributor to O&M costs, not only in direct labor for leak repair, but also for replacement parts, replacement hydraulic fluid, cleanup, and waste disposal. One respondent to the NMAC survey cited fluid leaks as contributing to 31% of the maintenance performed on the EHC system. Although leaks did not constitute the greatest number of reported problems, in most cases involving leaks, unit operation was adversely affected. One obvious observation was drawn from this evaluation: systems with relatively high operating pressure tended to have more problems with leaks when compared with MHC units or EHC units with low operating pressures.

The majority of reported fluid leaks involved O-rings. Although some leaks were due to improper installation or the incorrect O-ring, a large number of failures have been attributed to O-ring degradation. The cause of this degradation is not fully understood, but it is generally believed to be due to one or more of the following:

- Vibration
- Stress on the O-ring
- O-ring storage/shelf life
- O-ring material or material quality
- Damage or contamination during installation
- Hydraulic fluid incompatibility
- Hydraulic fluid chemistry out of tolerance

To correct these problems, some sites replace O-rings on a regular basis (e.g., every five years). Installation procedures have also been instituted to ensure proper handling and correct selection of O-rings.

Most O-rings used in EHC systems are made of Viton or ethylene-propylene (EPR), which are compatible with the phosphate ester hydraulic fluid. Vendors and utilities have conducted studies to determine the correct material. Results of these studies demonstrated that some types of Viton used in O-ring manufacture perform better in EHC applications than others. Viton-A significantly swells when exposed to phosphate ester fluids, whereas Viton-GF exhibits reduced swelling. Changing to Viton-GF from Viton-A has been cited as a successful practice in reducing O-ring failures.

O-rings can also pose a problem to the EHC system when fragments are released into the hydraulic fluid due to deterioration or breakage. One site reported a failure of a combined Intermediate/Stop Valve to reopen during a valve movement test. A broken piece of O-ring was found lodged in the hydraulic shutoff valve.

Early EHC systems used flared-tubing fittings. In the EHC operating environment, these fittings experienced a high failure rate, resulting in numerous leaks. Since the early 1970s, EHC manufacturers have generally recommended the use of welded fittings and have provided information regarding replacement of flared fittings. The number of reported tubing fitting leaks appear to be on the decline, primarily due to replacement of mechanical fittings with welded joints. Additional corrective actions include:

- Increased emphasis on correct assembly and tightening of fittings
- Reexamination and tightening of fittings on a scheduled basis
- Relocation of tubing to relieve stress on fittings
- Uniform flaring using hydraulic tooling

Most EHC systems use stainless steel tubing and are subject to stress corrosion when halogen ions are present. In one case, halogens resulting from soldering of copper pipes with high chloride content solder flux fell on the EHC tubing and initiated stress corrosion cracking. Although no outage time resulted, the potential for a significant hydraulic leak existed and considerable expense was incurred in replacing the tubing.

Proper operation and control of hydraulic fluid is one of the most important aspects of turbine control maintenance and will be covered in a future volume of the Turbine Control System Guide.

## 4.3 Electrical and Electronic Control System

For this discussion, the electrical and electronic control system is defined as the electrical and electronic components supplied by the EHC vendor. Not included m this discussion are the field devices that provide input to the vendor-supplied equipment (i.e., transmitters, pressure switches, external power sources, etc.). Figure 3 provides a graphical summary of the electrical and electronic problems reported.

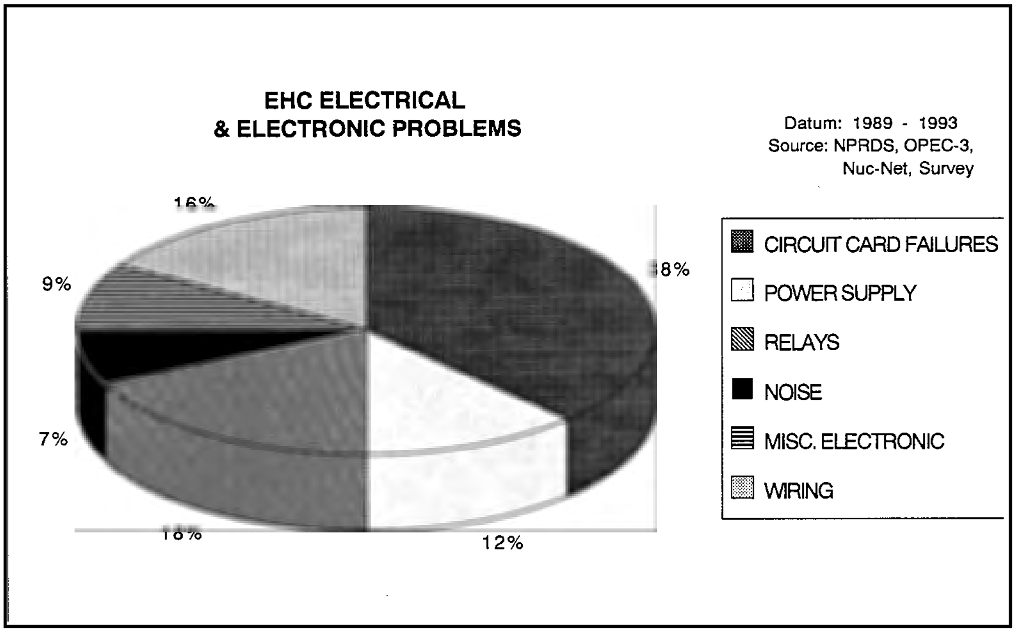


**Figure 4-3: EHC Electrical and Electronic Problems**

Turbine control systems are generally designed with a limited number of single-point failures that can result in a total loss of control. However, some systems do have single components, in which failure could result in a turbine trip. These components should be evaluated for modifications that add reliability to the system. In many cases, systems are designed to shift to manual control to allow for continued operation when a component failure occurs. There have been a large number of reported problems with control systems that severely impacted plant operations and resulted in turbine trips.

The electrical/electronic portion of the EHC system provides the means for automatic/manual control and system testing. This portion of the control system is supported by its own set of power supplies that are fed both from an external power supply and a unit-supplied generator. The external power usually supplies control power until the turbine reaches a percentage of rated speed (e.g., 90% of rated speed). There have been increasing reports of failure of internal power supplies; this is another item that might require increased preventive maintenance.

Most EHC system power supplies are redundant, so that failure of a single power supply does not typically result in an interruption in unit operation. Despite the built-in redundancy, more than 50% of reported power supply failures resulted in turbine trips. In addition, several of the incidents caused by power supply problems are associated with external events. Events such as outside voltage fluctuations caused by bus transfers, lightning strikes, and other distribution system transients can affect redundant power supplies and cause system failure.

Power supply drift was identified as a problem by several plants surveyed. Most turbine control systems use power supplies that require periodic calibration to compensate for the effects of component aging. Incorrect supply voltage can contribute to premature failure of the supplied circuitry and, in some cases, cause intermittent failures that are difficult to locate.

Some vendors now recommend "periodic loading" of standby power supplies along with spare power supplies to maintain the "form" of the electrolitic capacitors. Swapping load to the standby power supply for a period of time or powering the supplies by an alternative source during outages will ensure proper forming. Periodic testing of the supplies will also reveal performance deficiencies.

Improvements in external power sources, such as adding an uninterruptible power supply (UPS), have been made to prevent problems caused by power supply fluctuations.

Typical EHC systems, as with most modern electronic systems, use removable circuit boards. Each circuit board contains a large number of discrete electronic components. This design allows technicians to rapidly isolate problems to an individual circuit board, replace the faulty circuit board, and restore the system to operation. Since a typical EHC system might contain over 100 circuit boards, it is not surprising that circuit board failures account for a majority of electrical and electronic failures (38%).

Reducing circuit board failures could significantly contribute to improved EHC reliability. Efforts in the following areas could contribute to improved reliability:

- Improvements in circuit diagnostic procedures and techniques
- Improvements in postmaintenance and preinstallation testing
- Improvements in preventive maintenance programs
- Development of a predictive maintenance program

In general, turbine control systems supplied by the OEM are standardized systems that are modified as needed to perform with a specific turbine configuration. Most of these systems are used on both nuclear and fossil units. Several cases have been reported where incorrect system operation resulted from incorrect programming or circuit board configuration. At one site, a turbine runback occurred when a card failed. This caused a significant problem because the operators had not been trained to respond to runbacks. This feature was not supposed to exist. When standardized components are used, care must be taken to ensure that features not intended to be included in the particular application are disabled.

Turbine control system electrical failures are typical of failures in other electrical systems and are generally caused by such things as noise, loose wires, and switch malfunctions.

Noise spikes were attributed to several sources. Problems were noted with radio frequency interference (RFI) from radio transmitters, electric arc welders, and electromagnetic interference (EMI) from either natural phenomenon (lightning, electrostatic discharge, etc.) or electrical equipment (solenoids, relays, motors, etc.). Some remedies taken to address external interferences include limiting the use of some types of equipment within the proximity of EHC cabinets and providing minor circuit modifications that limit the effect of external signals.

No single component appeared to be more susceptible to loose wires than any other. Virtually every portion of the system, from operator panel push buttons to valve actuator terminal boards, has had some event caused by a loose wire. Grounds can also result from loose wiring or water leakage into cabinets.

Loose wiring can appear as an intermittent problem or it can cause unstable operation. Several units experienced steam valve oscillations resulting in power reduction to trouble shoot and effect repairs. A defective connection at the terminal board or at the affected field device was usually the root cause.

Relays are used extensively throughout the turbine control and trip circuitry. Relay failure modes include failure to operate, individual contacts not opening or closing, and sluggish operation.

Failure of a relay to operate can be attributed to a problem related to the operating coil. A relay coil can fail due to a break in the coil winding. Coil failures many times are caused by excessive heating in the vicinity of the relay or by overheating of the relay coil due to voltage transients or operating mechanism binding.

Sluggish relay operation can occur when relays change state infrequently. The organic materials in the relay may"set" and adhere to adjacent materials.

Excessive arcing of relay contacts can cause them to become pitted and not make electrical contact, or they can weld themselves together and fail to open when required. A problem sometimes encountered with relay contacts in small signal circuits is contact oxidation. Contact oxidation increases contact resistance and, in small signal circuits, can prevent the circuit from functioning. Most of these relay problems can be prevented by performing routine preventive maintenance and by correcting application problems.

Operator panel push buttons have caused several forced outages, generally due to sticking or failure to operate. Lamps in the push-button panels were also cited as a problem area. Because some operator panels do not have a lamp test feature to ensure that lamps are functional, lamp failures were undetected. This led to false indications and erroneous operator actions. Most plants with these panels now perform routine replacement of all lamps during each refueling outage. Some have replaced the operator panel with newer versions that contain a lamp testing feature.

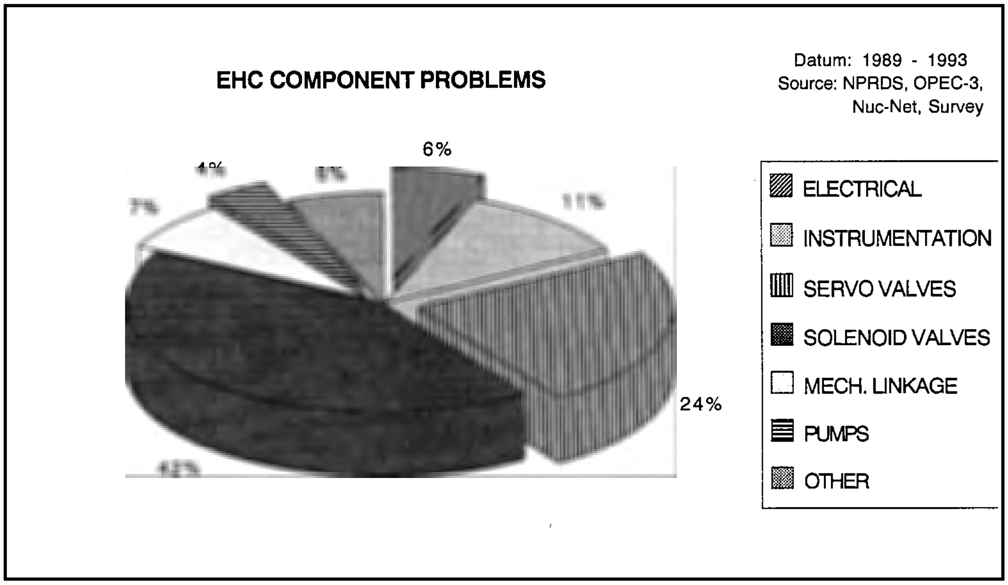


**Figure 4-4: Component Problems**

## 4.4 Components

Failure of field devices or components is the largest problem category representing over a third (34%) of all reported EHC failures. Solenoid valves comprise the single largest component category with 42% of the total failures, followed by servos with 24%.

### 4.4.1 Electrical Devices

There are limited numbers of discrete electrical components that can be singled out as causing failures. Relays, push buttons/switches, and power supplies have been discussed in Section 4.3 and will not be covered in this section.

Limit switch problems are usually classified as misalignments and are primarily attributed to vibration. One unit reported two instances within a two-month period where an out-of-alignment limit switch resulted in failure of a Stop Valve to fast close from the 10%-open position to zero during a test. Although this did not significantly impact overall plant operation, it did require maintenance time and expense to correct.

### 4.4.2 Instrumentation

Most switch problems (pressure, level, temperature) were caused by setpoint drift or spurious actuation and were generally attributed to vibration. Relocation of switches to areas less susceptible to vibration has been an effective measure. In many cases, redundant switches have been added to improve reliability. In some reported events, switches failed to operate, resulting in false inputs to the control system. For example: a pressure switch that stuck caused a turbine control system to remain in speed control following a turbine trip. This resulted in a rapid increase in speed (and potential overspeed) when the turbine was relatched. Switch failure in this case was attributed to internal corrosion. Switches less susceptible to corrosion have been installed. Additional testing to ensure proper operation has also been instituted in many cases.

Reported pressure transmitter and sensor problems all involved failure and drift, generally due to vibration. In these cases, the corrective action was to relocate the transmitter or sensor to a lower vibration area and increase the surveillance frequency. Pressure sensor manufacturers employ a variety of designs. Some are more tolerant of vibration than others. Some of the newer sensor designs are relatively unaffected by vibration.

### 4.4.3 Servos

Servo valves were cited most often for problems involving valve actuators because of their tight internal tolerances and resulting susceptibility to hydraulic fluid problems. Excessive internal leakage is generally a result of aging, which can be accelerated if hydraulic fluid is operated outside of specifications, particularly volume resistivity. Internal leakage degrades the performance of the servo and also can degrade the hydraulic fluids due to the shearing effects and heat buildup caused by this leakage. Internal contamination and clogging of the inlet strainer are caused by fluid contamination problems.

Preventive maintenance, which includes replacement of the valves on a regular basis, appears to be the most effective method of addressing servo problems. Generally valves are refurbished for reuse to reduce replacement costs. During refurbishment, the servo should be inspected for any abnormal wear or other affects. The servo valve inlet strainers are commonly replaced at each refueling outage.

### 4.4.4 Solenoid Valves

The failure modes commonly reported for solenoid valves were operating failure, binding, and internal leakage. This was usually attributed to clogging due to contaminated hydraulic fluid. One site reported that a fast-acting solenoid was stuck closed due to debris in the hydraulic fluid, resulting from defective filters. The filter problem was corrected and the hydraulic system flushed. Total failure was also due to solenoid coil burnout due to aging or heat deterioration. Internal leakage generally did not cause any loss of functionality but did create a maintenance problem.

Most solenoid problems were discovered during routine surveillance procedures. This illustrates the importance of preventive maintenance in discovering such problems before they advance to a more serious condition.

As with servos, replacement on a regular basis appears to be the most effective means of addressing solenoid problems. Following a turbine overspeed incident at a nuclear plant, the OEM issued a recommendation that the trip solenoid valves be replaced annually. (Refer to the NMAC Solenoid Operating Guide, NP-7414.)

### 4.4.5 Mechanical Linkages

Turbine control systems, especially MHCs, have many mechanical linkages. Most linkage problems have been attributed to vibration. Typical problems reported include loose set screws, bound linkages, and misalignment. In at least one case an incorrect style shear pin was installed resulting in binding of the linkage for a valve actuator. Valve position linear variable differential transformer (LVDT) linkages were cited in several cases as the cause of improper valve response.

### 4.4.6 Accumulators

Accumulators at most sites have regularly scheduled surveillances to monitor precharge pressure. No problems were reported due to failure of an accumulator to perform while the turbine was operational. Almost all failures associated with accumulators involved piston seal leaks. In some instances, this added large amounts of particulate to the fluid and resulted in clogged servo valve screens. At one station, a blown seal was not noticed by a maintenance crew when checking the precharge pressure. When the crew attempted to increase the nitrogen pressure, the leak passed the gas through the accumulator drain valve to the hydraulic power unit. The large volume of gas could not be adequately released by the reservoir vent, resulting in over-pressurization in the reservoir that blew the covers off and drained the reservoir of fluid.

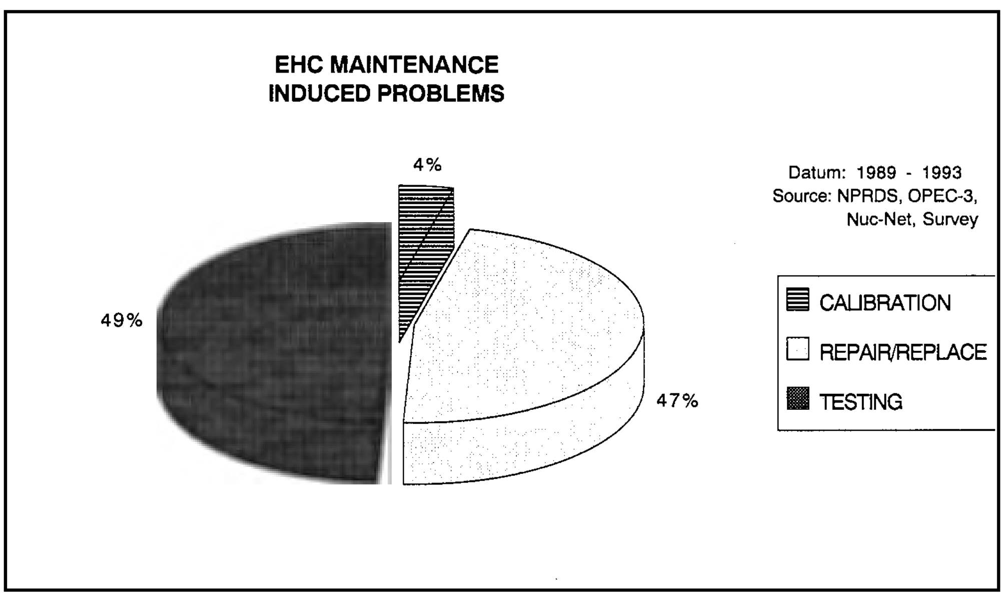


**Figure 4-5: Maintenance/Test Induced Problems**

### 4.4.7 Pumps

Despite the redundancy in pumping systems, there have been turbine trips due to low hydraulic pressure. Generally, this has not been due to any mechanical failure of the pump itself, but has been due to failure of the pressure compensators that are used on some units to adjust the volume output of the pump. The major source of problems reported with this type of pump is the compensators' susceptibility to hydraulic fluid contamination. Some units experienced problems with original pumps supplied with the skids; however, a new pump is now available from vendors and has been installed on several units. Unloaders used for pressure control in hydraulic pumping units have been a source of problems in some plants. The vendor has issued an availability improvement bulletin that suggests installing constant pressure pumps.

### 4.4.8 Thrust-bearing Wear Detectors

Thrust-bearing wear-detector failures were the major contributor to the "other" category. The failures were due to external causes such as test relays, test switches, test procedure deficiencies, improper reassembly, and lack of postmaintenance testing. Redesign of the testing logic to provide bypass or lockout during testing is the most common improvement. Some plants have removed the original detectors and installed a proximity probe system.

## 4.5 Maintenance Problems

Two problems areas appeared in numerous events:

- Deficient maintenance and test procedures or practices
- Equipment failures experienced during a testing activity

Incorrect maintenance involved use of incorrect O-rings, improper assembly of components (especially O-rings and other seals), and failure to follow procedures. Numerous O-ring failures were attributed to incorrect installation techniques. Use of an incorrect O-ring resulted in a hydraulic fluid leak, allowing a Governor Valve to shut with a unit at full power. Another unit received a Reactor 1/2 Scram signal on a Turbine Control Valve fast closure. The incident was caused by loss of fluid due to improper installation of a fitting in the EHC tubing to the control valve, allowing the fitting to separate.

A large percentage of reported EHC events occurred during routine testing activities. Because the purpose of these tests is to determine the working condition of the system, it is not unexpected that component failures would appear during these activities. In many cases, the event was caused by failure of the testing devices, which would not have affected control of the turbine. For example, at one site the combined Intermediate/Stop Valve was closed for a routine stroke test but only reopened to 7%, even with a 100% demand. This was caused by a test valve orifice that was clogged by contaminated hydraulic fluid. The valve was fully functional from an operational perspective; however, due to the failure of a test device, the unit was affected.

Surveillance activities and schedules vary widely between units. Some plants reported extensive programs developed by the utility while others followed manufacturers' recommendations. This subject will be covered in detail in future volumes of this guide.

All failures fall into three general categories: calibration, maintenance, and testing. In each of these categories, the major contributor was some form of human error. Although human error cannot be completely eliminated, it can certainly be reduced. The 12% contribution to total EHC problems (as shown in Figure 4-1), while the smallest, is not insignificant.

The high-percentage of human error causing failure can be attributed to improper techniques and procedural weaknesses. Improper techniques are generally the result of inadequate training, either in content, methodology, or technique. It is necessary to provide maintenance personnel with the correct tools to perform tasks properly and safely.

Although the majority of maintenance personnel are knowledgeable, working on a complex system on an infrequent basis can be difficult. Procedures should be reviewed to alert personnel to unique situations, requirements, order of events, and potential dangers to equipment and personnel. Testing levels and expected results should be listed in the procedures, along with the acceptance range of these values.

## 4.6 Maintenance Improvements

Improvements in maintenance have been largely directed at the electrical/electronic area, even though more than two thirds of reported failures are in hydraulic/mechanical equipment areas.

Most of the maintenance improvements reported in the hydraulic/mechanical areas involve efforts to control contamination in the hydraulic fluid. The following summarizes the efforts reported in this area:

- Establishing a dedicated sampling and trending program
- Providing procedures to ensure representative and consistent sampling
- Changing from periodic to continuous flow through a neutralization filter to maintain better control of fluid chemistry
- Establishing cleanliness control requirements for fluid handling and maintenance activities
- Predrying Fullers earth before installation to reduce moisture contamination
- Prewashing Fullers earth (with hydraulic fluid) before installation to reduce particulate contamination

Following are reported maintenance improvements in the hydraulic/mechanical area:

- Monitoring and trending pump cycle time and/or pump current to detect component degradation (internal leakage)
- Initiating use of an "electrohydraulic system analyzer" to perform operational and leakage diagnosis of hydraulic components

In the area of electronic maintenance, one topic that receives a lot of attention is circuit board replacement. There are basically three schools of thought. The first is to replace after failure. The second is to replace a percentage of critical circuit boards on a fixed schedule so that all critical boards will be replaced in a given interval. The third is to replace all critical circuit boards at one time at a prescribed interval. Each method has its advantages and disadvantages. Many facilities start out replacing circuit boards when they fail and then change to one of the other methods as they gain experience with the equipment.

Facilities have also indicated that they have made a significant number of improvements in the area of circuit board maintenance and testing. Many facilities have indicated that they have developed or upgraded procedures and preventive maintenance (PM) routines to troubleshoot, repair, test, and monitor performance of circuit cards.

Other improvements in electronic equipment maintenance are as follows:

- Replacing electrolytic capacitors on selected cards per vendor recommendation, based on time in service and application
- Initiating EMI testing and evaluation
- Restricting the use of radio-frequency transmitters in the cabinet area
- Modifying PM to isolate digital to analog converter cards during test of the control system to prevent inadvertent trips
- Enhancing or developing instrumentation calibration PM activities
- Fine tuning the control system to reduce valve oscillations
- Initiating programs to pretest circuit cards before installation

In the electrical area, plants have made improvements in the following areas:

- Improving PM and work instructions to provide proper lamp replacement techniques
- Developing PM activities to ensure proper hand switch operation
- Developing PM activities for testing cables for high-impedance grounds
- Developing PM activities for checking wiring for loose connections

Most of the changes involved improvements to procedures, additional training, and enhanced management control of maintenance activities. Many plants are evaluating extending the time between tests to reduce the risk of tripping equipment during testing.

## 4.7 Modifications

A major area of concern at many plants is vibration, which affects not only mechanical components but electrical and electronic components as well. The following are various modifications undertaken by plants to reduce vibration-induced failures.

- Replacing rigid piping and tubing with flexible tubing in areas where high vibration is present
- Moving pumps from the skid to the floor to reduce cavitation and cavitation-induced vibration
- Installing vibration dampers on piping
- Installing additional supports and relocating existing supports
- Rerouting of tubing to reduce stress
- Replacing threaded-type tubing and piping connectors with a welded type for greater resistance to vibration
- Relocating electrical cables to prevent cable damage from vibration-induced chafing
- Relocating instrumentation susceptible to vibration-induced spurious trips to areas of lower vibration
- Adding redundant instruments
- Replacing older pressure sensors with transmitters that are more vibration tolerant
- Modifying or replacing steam valves to reduce steam flow-induced vibration
- Modifying valve programming to position valves so vibration is minimized
- Full-to-partial arc emission sequencing for turbine valve opening

The following modifications have been implemented to help maintain the quality and purity of the hydraulic fluid:

- Adding in-line filters for components susceptible to particulate contamination
- Installing thermal insulation on hydraulic lines exposed to high temperature to minimize fluid breakdown
- Modifying the system to allow use of dehydration or additional filtration units as needed
- Installing desiccant in reservoir breathers

- Replacing the air dryer with one with an air filter and stainless steel piping
- Replacing fluid coolers with a new style recommended by the vendor
- Replacing various carbon steel plugs, flanges, and fittings with stainless steel
- Changing from stacked to single filter elements to minimize bypassing (required filter housing modifications, in some cases)

The following additional modifications have been implemented on the pumps, piping, and valves:

- Replacing original pumps with constant pressure pumps due to problems with unloader valves
- Modifying pump piping arrangement to eliminate air entrainment in standby pump
- Modifying pump compensators to include shouldering of roller retainer pins and enlarged pin for better interference fit
- Relocating unloader sensing lines to reduce chatter and resulting pressure fluctuations
- Relocating air bleed valves to allow for more complete venting of the system
- Modifying the relief system to allow pumps to start unloaded (soft start)
- Replacing the Governor Valve pin holding stem to operator with a stainless steel pin
- Replacing Turbine Control Valve test plug with new hex head design that allows application of the correct torque
- Improving Stop Valve Actuator position locking by adding set screws to hold restoring arm position
- Adding more accumulators to improve pressure control

In one case, where continuing problems with the hydraulic system became unbearable, the entire hydraulic package (skid) was replaced. This may seem extreme, but the result has been quite satisfactory. In addition, the new system uses air-cooled heat exchangers, which helps minimize the moisture content of the fluid.

In the electrical/electronic area, the modifications have been aimed at improving the reliability of the electronic circuitry or eliminating circuitry that has been proven to be unnecessary. The following is a list of some of the electrical/electronic modifications that have been implemented:

- Eliminating closing bias on GE servo driver cards, because servos have springs that perform the same function
- Eliminating the throttle pressure limiter card

- Moving the electronic circuitry to temperature-controlled environments to increase reliability
- Adding fans, air ducts, etc., to improve the environment around the electronic equipment
- Installing redundant power supplies to improve reliability of electronic power distribution system
- Replacing power supplies with upgraded power supplies to provide better voltage stability
- Installing a UPS system to improve the reliability and quality of power supplied to the EHC system
- Separating the power and control cables to avoid crosstalk
- Adding surge suppressors across relay contacts to prevent contact pitting and welding due to arcing
- Replacing Mercury-wetted relays with dry-contact types that are better suited to the application

## 4.8 Summary

The lists of modifications and improvements are based on information obtained from surveys and interviews with utility personnel and is not all-inclusive. Only a few of the OEM improvement recommendations have been identified here, and it is suggested that all applicable recommendations be reviewed and addressed.

The majority of maintenance activities related to turbine control systems have focused on corrective maintenance. There have been some preventive efforts, but the real potential lies in the area of predictive maintenance.

The failures evaluated for this report show that fluid contamination is an area that presents potential for improved monitoring. Also, material compatibility and a means to evaluate material condition are also important.

Future work related to this equipment needs to focus on identifying parameters that can be monitored and corrective measures that prevent inservice failures.

In the face of a continuing attention to operations and maintenance costs at nuclear power plants, the future of the industry depends largely upon increasing plant availability and improving operating efficiency. The success in achieving these objectives is dependent upon the success of each plant's equipment maintenance program.

**NMAC'S goal**

The goal of the Nuclear Maintenance Applications Center (NMAC), operated by EPRI, is to provide member utilities with practical, proven maintenance practices and expertise which will assist power plant personnel in effectively managing their planned and emergent maintenance requirements; and, to facilitate the transfer of maintenance-related technology at a working level within the nuclear power industry.

## About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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