Westinghouse Technology Systems Manual

Section 11.3

Westinghouse Electrohydraulic Control System

TABLE OF CONTENTS

LIST OF FIGURES

11.3 WESTINGHOUSE ELECTROHYDRAULIC CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the turbine Electrohydraulic Control (EHC) System.

2. Describe the sequence of events which results in a turbine trip when initiated by:

    a. Mechanical input (example: low condenser vacuum), and
    b. Electrical input (example: reactor protection signal).

3. Explain what function the following components perform in initiating a turbine trip:

    a. Solenoid trip mechanism,
    b. Interface valve, and
    c. Emergency trip valve.

4. List the input parameters to the control systems used for the following turbine operational modes:

    a. Speed control, and
    b. Load control.

5. Explain the difference between “impulse in” and “impulse out” during turbine load control operations.

6. Briefly describe the actions initiated by the overspeed protection controller (OPC) for the following conditions:

    a. 103% turbine overspeed, and
    b. Opening of the generator output breakers at high loads.

7. Explain how the following types of turbine runbacks are accomplished:

    a. Secondary system initiated, and
    b. Reactor protection system initiated.

8. List the turbine trip indication inputs to the reactor protection system.

11.3.1 Introduction

The purposes of the EHC system are as follows:

1. To control the speed of the turbine-generator from turning gear operation to synchronous speed (60 Hz),

2. To control the load of the generator from synchronization to 100 percent load,

3. To provide rapid shutdown capability (trip) to protect the turbine-generator, and

4. To limit turbine overspeed on partial load rejections.

The EHC system uses high pressure hydraulic fluid to open and position the steam inlet valves to the high and low pressure turbines in response to commands from an electronic controller. An auto-stop oil system interfaces with the high pressure hydraulic system to generate a quick closure of all steam inlet valves if an abnormal condition is sensed by one or more of the turbine protective devices.

11.3.2 System Description

A simplified diagram of the EHC system is shown in Figure 11.3-1. As shown on this figure, the EHC system can be divided into three subsystems. The three subsystems are as follows:

1. The electronic controller and the operator's panel are shown on the lower left side of Figure 11.3-1. The controller cabinet receives inputs from: the operator's panel located in the main control room, a speed transducer located on the high pressure turbine rotor, a pressure signal from the impulse chamber of the high pressure turbine, and finally governor valve position (not shown on this figure). The electronic controller sends signals to servo valves for the throttle and control valves.

2. The electrohydraulic (EH) fluid system, a high pressure hydraulic oil system, is shown in the right center of Figure 11.3-1. High pressure hydraulic fluid is supplied to the valve actuators for the throttle, governor, reheat stop, and interceptor valves. A drain path from the valve actuators returns the hydraulic fluid to the EH fluid sump via an emergency trip device. With the trip device closed, a high pressure is maintained at the valve actuators which keeps the steam supply valves open.

3. The final subsystem is a combination auto-stop and lubricating oil system. It is shown in the bottom right portion of Figure 11.3-1. This system provides lubricating oil to the turbine bearings and acts as a hydraulic fluid in the auto-stop oil system. This hydraulic system keeps the emergency trip device closed during normal operations. Should an unsafe condition exist, the auto-stop oil system pressure decreases, allowing the emergency trip device to open.

11.3.2.1 EH Fluid System

The valves that admit and control the steam flow to the high and low pressure turbines are opened by high pressure hydraulic fluid acting upon the valves' hydraulic actuators. This high pressure hydraulic fluid is supplied by the EH fluid system, which is shown in Figure 11.3-2. Each steam valve has an actuator (for opening) and a dump valve (for closing). When the EH fluid system is pressurized, the dump valves are kept closed. With the dump valves closed hydraulic fluid pressure is applied to the valve actuator; the force exerted by the EH fluid overcomes the spring force (used to close the steam valve) and opens its associated steam admission valve. When the EH fluid pressure is decreased by opening the interface valve or the emergency trip solenoid, the dump valves open and bleed the hydraulic fluid in the valve actuator to the EH fluid sump. Spring force closes the steam admission valves, blocking steam to the high and low pressure turbines. When all turbine steam valves are closed in this manner, the turbine is said to be tripped.

EH fluid system pressure is maintained by the operation of one of the two positive displacement EH pumps. The idle EH pump is placed in standby. If the pressure in this system drops below 1500 psig, the standby pump automatically starts. The system contains two unloader valves and one relief valve. The unloader valves maintain a desired pressure, while the relief valve prevents the over-pressurization of the system. The unloader valves regulate the hydraulic pressure by unloading (opening) at 2150 psig and closing at 1800 psig, while the relief valve opens at 2350 psig. Accumulators, which are not shown in this figure, are provided to smooth out pressure variations. Orifices are installed in the supply lines to the actuators and the dump valves to prevent repressurizing the system when the interface or the emergency trip valve opens.

The reheat stop valves and the intercept valves supply steam to the low-pressure turbines. These valves are either fully open or fully closed (never modulated). EH fluid is supplied through orifices (O-1 & O-2 as shown on Figure 11.3-2) directly to the valve actuators for these steam valves. The throttle (stop) valves supply steam to the high-pressure turbine through the governor valves. The throttle valves are generally fully open or fully closed. However, they do have a throttling feature, which is used during turbine acceleration from 0 to 1700 rpm. The governor (control) valves supply steam to the high-pressure turbine and are modulated to produce the desired generator output. Because the throttle valves and the governor valves must be capable of modulation, EH fluid is supplied to their respective valve actuators via servo valves. Each servo valve receives a command from the electronic controller, and increases or decreases the hydraulic pressure in its actuator, to either open or close its associated valve.

All turbine steam supply valves are testable to ensure that they close upon a turbine trip signal. The throttle valves and the governor valves are tested one at a time. The test is accomplished by closing and opening the valves individually with their respective servos. The reheat stop valves and the intercept valves have solenoid valves that open the dump valves associated with the valve being tested. The reheat stop valves and intercept valves are tested in pairs; the valves in each steam line from one moisture separator reheater to one low pressure turbine are closed simultaneously and then reopened. Turbine load, hence reactor power, is lowered to about 75% during valve testing so that the generator output can be maintained constant by the control system.

Overspeed Protection Controller (OPC)

The purpose of the OPC is to prevent an overspeed trip of the main turbine. This function is accomplished by securing steam to the turbine for a short period; or securing steam to the turbine until the condition that is generating the potential overspeed condition clears. Three conditions could cause the OPC to actuate.

First, the OPC is provided with a speed signal from a shaft-mounted speed transducer. If 103% of normal speed is sensed, the OPC solenoid valves open. When these valves open, EH trip fluid is dumped into the EH fluid sump. This action closes the governor and intercept valves. A check valve, installed in the EH trip fluid line, prevents dumping EH trip fluid from the throttle and reheat stop valves. When the overspeed condition clears, the solenoid valves close and the governor and intercept valves reopen.

Secondly, if the generator output breakers open when the power is above a preset value, the OPC solenoids energize, as discussed above, closing the governor and intercept valves. This signal resets after a preselected time delay.

Finally, if the difference between the main generator output and the low pressure turbine inlet pressure is greater than a preset value, the test solenoids of the intercept valves are energized to close the intercept valves. The intercept valves reopen when the difference clears. This circuit senses a loss-of-load and shuts these valves to prevent overspeeding the turbine-generator.

Emergency Trip Solenoid Valve

An emergency trip solenoid valve in the EH fluid system provides a backup for the interface valve (see Section 11.3.2.2). Opening of the emergency trip solenoid valve dumps EH fluid from the turbine valve actuators. The emergency trip solenoid valve is opened on any of the following signals:

- Manual turbine trip (from the control board),
- Reactor trip signal (train B),
- High-high level in any steam generator, and
- Low auto-stop oil pressure.

11.3.2.2 Auto-Stop Oil System

A combined lubricating and auto-stop oil system supplies lubricating oil to the turbine and generator bearings and keeps the interface valve closed during normal operation. Figure 11.3-2 shows this combination system. The EH fluid and auto-stop oil never come into contact with each other. The interface valve is the only component common to both systems, with EH fluid flowing through the valve upon a turbine trip, and auto-stop oil applied to the valve operator to close it against spring force. Low pressure in the auto-stop oil system allows the interface valve to open and trip the turbine.

Oil for the auto-stop system is normally supplied by a shaft-mounted centrifugal pump. When the turbine is not at rated speed, oil is supplied by the seal oil backup pump.

There are five protective trips for the main turbine generated via the auto-stop oil system:

- Low bearing oil pressure,
- Thrust bearing excessive movement,

- Low condenser vacuum,
- Solenoid (remote) trip, and
- Mechanical overspeed.

All five trips cause a low pressure in the auto-stop oil system, thereby opening the interface valve. The devices for the first four trips are located on one assembly, the protective trip block, as shown in Figure 11.3-2.

Low Bearing Oil Pressure Trip

Bearing oil is supplied to a spring-loaded diaphragm on the protective trip block. If pressure decreases to five to seven psig, the spring force lowers the diaphragm and raises the dump valve on the opposite end of the protective trip block. This set of events lowers the auto-stop oil pressure, which in turn opens the interface valve and trips the turbine.

Thrust Bearing Trip

This device warns the operator of excessive rotor movement in the axial direction and trips the turbine before such movement is enough to cause serious damage. The device consists of two small nozzles which discharge close to the thrust collar faces. Oil is supplied to the nozzles and through check valves to a spring-loaded diaphragm on the protective trip block. If the rotor moves toward either nozzle, pressure in that line increases. When pressure reaches 35 psig, a pressure switch actuates an alarm. When pressure increases to 75 - 80 psig, the diaphragm will move up and open the dump valve, causing the interface valve to open and trip the turbine.

Low Condenser Vacuum Trip

This trip also involves a spring-loaded diaphragm on the protective trip block. The diaphragm is subjected to the condenser vacuum. When the vacuum decreases (pressure increases) to 19 - 22 inches Hg, the diaphragm moves up and opens the dump valve. A vacuum trip latch is provided to permit starting the turbine with a low vacuum; it is engaged when the turbine is latched. The vacuum trip latch automatically disengages when the condenser vacuum reaches 23 - 25 inches Hg. Even if this latch is engaged it will not prevent a trip if the condenser pressure reaches 2.5 - 4.5 psig.

Solenoid Trip

This feature allows the initiation of a turbine trip from a remote point through the energizing of a solenoid on the protective trip block, which causes the dump valve to open. Solenoid trips include the following:

- Manual turbine trip (from the control board),
- Reactor trip signal (train A),
- Electrical overspeed (approximately 111%),
- High-high level in any steam generator,
- Failure of DC control power to the EHC system,

- Low lubricating oil level,
- Low EH fluid level,
- Low EH fluid pressure,
- Failure of cooling water to the main generator,
- High vibration,
- Loss of both main feedwater pumps,
- Generator reverse power (with a 30-sec delay), and
- Trips initiated by main output transformer protective relays.

Mechanical Overspeed Trip

The overspeed trip mechanism consists of an eccentric weight mounted inside a transverse hole in the high-pressure turbine rotor shaft. The weight is held in place by a spring; but because the weight is off-center, it moves outward, away from the center of the rotor, against spring force, when the turbine overspeeds. When the weight moves outward, it strikes a trigger which opens the overspeed trip valve, causing auto-stop oil to drain from the system and the turbine to trip. The setpoint for the mechanical overspeed trip is higher than the trip setpoint of the electric overspeed trip.

The overspeed trip mechanism also seals in any turbine trip developed at the protective trip block. When the dump valve opens in response to any of those trips, the auto-stop oil pressure decreases throughout the system. The absence of oil pressure at the overspeed trip valve allows a spring to deflect the overspeed trip trigger, opening the overspeed trip valve, which maintains an open drain path for the auto-stop oil. This feature seals in the trip, even if the initial condition clears and closes the protective trip block dump valve. The control room operator must reset the overspeed trip mechanism either locally or remotely to repressurize the auto-stop oil system.

The overspeed trip mechanism can be tested by injecting oil under the weight to move it into the trigger. To prevent an actual turbine trip during testing, the trip test handle must be manually held to prevent depressurizing the portion of the system containing the interface valve. The trip test handle must be held in the test position until the overspeed trip mechanism is reset and the auto-stop oil pressure is restored. The trips on the protective trip block are also tested while the trip test handle is held in the test position. Each trip tested trips the overspeed trip mechanism.

11.3.2.3 Electronic Control System

The electronic control system calculates deviations between reference signals and turbine speed, valve position, or turbine first-stage pressure (Imp In only). If the turbine is latched (not tripped), it is controlled in one of two operational modes: speed control or load control. Speed control is used to roll the turbine from turning gear speed (about 1 rpm) to synchronous speed (1800 rpm). When the generator output breakers are closed, the EHC system automatically shifts from speed control to load control. In load control, the EHC system controls the turbine’s power output.

Speed Control

Figure 11.3-3 illustrates the speed control circuit, which contains two modes of speed control: throttle valve control and governor valve control. Latching the turbine automatically places the speed control circuit in throttle valve control. When operating in this mode, steam passes through one throttle valve via an internal poppet. From this poppet steam is directed through all four, fully open, governor valves, into the steam chest of the high-pressure turbine and is called “full arc admission.”

Initially, after latching the turbine, the throttle valves and the governor valves are closed. Rolling the turbine for chest warming requires opening the governor valves. To accomplish this, the control room turbine operator depresses the valve position limit increase push button. Increasing the output of the valve position limit, forces the governor valves open due to the 100-rpm open bias input into the low value gate from the PI amplifier. The control room operator continues increasing the setting of the valve position limiter until it indicates 100% and the governor valves are full open. Applying a constant 100-rpm open bias with the integral action of the PI amplifier keeps the governor valves open.

To roll the turbine off its turning gear, warm up the turbine, and increase its speed to 1700 rpm, throttle valve control is used. The control room turbine operator selects a speed and an acceleration rate on the EHC panel (according to the turbine heatup and loading curves) and depresses the “GO” push-button. The proportion amplifier receives a speed error signal, without the 100-rpm open bias, and sends a proportional output signal to the throttle valve servos (Note: the contact from the 100-rpm open bias is open).

When the turbine attains a speed of 1700 rpm, the control room turbine operator depresses the “TV/GV” transfer push-button to execute the shift-over from throttle valve control to governor valve control. During the shift-over, the “TV/GV” pushbutton flashes alerting the control room turbine operator that the shift over is in progress. After the shift-over is complete, the “TV/GV” pushbutton stops flashing. The throttle valves receive a continuous 100-rpm open bias via a PI amplifier, which keeps the throttle valves fully open, and the speed error signal modulates the governor valves to maintain a speed of 1700 rpm. After completing the transfer, the turbine is increased to synchronous speed (1800 rpm) in preparation of paralleling the generator to the grid.

Load Control (Imp Out)

Two modes of automatic load control are incorporated into the design of the EHC system: impulse pressure out of service (Imp Out) and impulse pressure in service (Imp In). Imp Out is described first.

Referring to Figure 11.3-4, the input signals to this circuitry are two reference signals; speed and load reference, and two measured parameters; turbine speed and turbine impulse pressure. In addition, the governor valve servo circuit receives a feedback signal from governor valve position.

As discussed earlier, speed control is used to warm up the turbine and bring it to synchronous speed. After synchronizing the turbine to the grid, the turbine operator in the control room closes the main generator output breaker. This action automatically shifts the EHC system from speed control to load control. Imp Out is the default mode of operation when the shift-over takes place. The electronic controller sets the reference load at 5%, with a load rate of 1%/min. Increasing the load of the turbine to 5% ensures that the generator does not motorize.

Besides reference load, the control system is provided with a speed error signal developed by comparing a fixed reference speed (1800 rpm) with the actual turbine speed transmitted from a shaft-mounted speed transducer. Normally the output from this part of the circuit is zero. Supplying a speed error signal to this electronic control system allows the turbine-generator to assist the other generating units to maintain the stability of the offsite electrical system (the grid). If the demand load on the grid is greater than the supplied generating capacity, electrical frequency on the grid decreases. This decrease in frequency generates a speed error signal, which is added to the reference load. The increased demand opens the governor valves increasing the power output from the turbine. The electrical loads from the other turbine-generators tied to the grid are similarly increased. The combined effect should match the total plant power output to the total system power demand, returning and maintaining grid frequency at 60 Hz.

A proportional amplifier receives the combined reference load and speed error signal. A low value gate receives this proportionally amplified signal along with a valve position limit setpoint. The valve position limit is adjusted by the turbine operator to prevent the turbine governor valves' form opening beyond a preselected limit, i.e., prevents the secondary load from exceeding a preselected maximum value. As long as the demanded reference signal is less than the valve position limit, the governor valve servo circuit receives the reference load signal. If the load reference demand is greater than the valve position limit setpoint, the low value gate clamps the governor valves at a position demanded by the valve position limiter. If the governor valves are clamped, the reference window continues to increase at the rate input by the turbine operator. This action, reference window display increase, continues until the displayed value in the "Reference" window equals the value in the "Setter" window.

The function generator in each servo circuit [F(X)] accounts for the nonlinear effect of valve position on steam flow and provides a bias to open the governor valves in a sequence if desired. The output of F(X) is compared with the actual valve position provided by a linear variable differential transmitter (LVDT). Any error between the demanded valve position and the actual valve position is amplified and integrated over time to ensure that the valve reaches its demanded position. Only when the valve position feedback equals the demanded position will the proportional-plus-integral (PI) amplifier stop integrating. In the Imp Out mode valve position is the only feedback other than the speed signal.

Finally, if the turbine-generator is operating at 50% power, and the turbine operator is directed to increase power to 100% at 1%/min, the turbine operator, using the reference control increase push-button increases the target load to 100% (displayed in the "Setter" window). The operator also selects 1%/min on the load rate thumbwheel. To start the load increase the operator depresses the “go” push-button. The system electronically changes the reference load from 50% to 100% at 1%/min. As the reference load increases, as indicated in the “Reference” window, the governor valve servo circuits receive a steadily increasing signal, which results in the governor valves opening farther increasing steam flow to the turbine. The system opens or closes the governor valves to a position that is equivalent to the demanded power level.

Load Control (Imp In)

At 15% to 20% turbine-generator load, the operator may select impulse pressure (Imp In) as a feedback input into the load reference circuitry. Impulse pressure is an indication of actual turbine load. After switching the EHC system to Imp In, the load reference, as shown in Figure 11.3-4, becomes a combination of speed error, reference load and impulse pressure. A proportional-integral (PI) amplifier receives the reference load instead of a proportional-only amplifier. The PI amplifier provides a proportional output dependant upon the magnitude of the input error signal. The integral function increases the proportional gain to ensure that the governor valves open far enough to increase turbine load (as indicated by impulse pressure) to a value that is equal to the desired load.

The electronic control system receives two feedback signals: impulse pressure and valve position. To reach an equilibrium condition, the valve position feedback from each governor valve must be equal to the output of F(X), and the impulse pressure feedback must equal the reference load. There could be some “hunting” of the system while the outputs of the PI amplifiers decrease to zero. Although the design of the function generators is to linearize the load reference with respect to actual load (a function of governor valve position), linearity can only be achieved in the Imp In mode. Figure 11.3-5 illustrates the difference between the two modes of load control (Imp In vs. Imp Out).

Curve A represents operation with impulse pressure out of service. This curve shows the non-linear relationship between load reference (vertical axis) and generator output (horizontal axis). The non-linearity of this curve is due to the variable steam flow characteristics of the governor valves. This non-linearity is illustrated by the reference loads labeled r’ and r”, where r’ is at a lower value than r”. As the load reference changes from r’ to r”, actual generated load remains constant (P2) and is indicated by “c” on Curve A.

Curve B represents operation with impulse pressure in service. With Imp In selected, the control system changes governor valve position(s) until impulse pressure equals the load reference. Since impulse pressure is linear with respect to power, load reference becomes a linear function of power.

These curves also show how the load reference changes as a result of changing modes of operation. Assume that the system is operating in Imp Out, with power at P1 and load reference at R1. The operating point is “a” on curve A. During the shift-over to Imp In, the governor valves do not move. Meanwhile the load reference changes from R1 to R2; i.e., the reference window indication increases to equal the value at P1. The new operating point is “b” on curve B and the reference and setter window indication should be equal. Note the actual load (P1) has not changed, but the load reference has changed. Changing from Imp In to Imp Out results in a similar load reference change.

11.3.3 System Features and Interrelationships

Reactor Protection System

Two different signals from the turbine are sent to the reactor protection system to indicate that the turbine is tripped. One signal is four-out-of-four throttle (stop) valves fully closed, as indicated by the limit switches on the throttle valve stems. The other signal is low auto-stop oil pressure, as indicated by two-out-of-three pressure transmitters located in the auto-stop oil system.

Turbine Runbacks

Turbine runbacks are automatic reductions in turbine load. These runbacks are actuated based upon present plant conditions, if left unattended, could cause a plant trip. The runback signals can be initiated from either the primary or the secondary.

Two turbine runbacks are initiated by the reactor protection system. A runback signal is developed when the ΔT in two out of four reactor coolant loops is within three percent of the OTΔT or OPΔT trip setpoint. These trips are discussed in Chapter 12. If either of these runbacks is in effect, the EHC system reduces load at 200%/min for 1.5 sec (a 5% load change), then holds the load constant for 28.5 sec. If the runback condition has not cleared, the load will be reduced by another 5% in the next 30-sec interval.

The other turbine runbacks are initiated by secondary system conditions. Secondary system runbacks are accomplished via reductions of the governor valve position limit setpoint. Possible conditions that may cause a turbine runback include:

1. A combination of a main feed pump trip and turbine load greater than 80% (the turbine runs back to 75% power), and
2. Directing heater drains from the heater drain tank to the condenser instead of the suction of the main feed pump (the turbine runs back to 85% power).

11.3.4 Summary

The EHC system is made up of three main subsystems:

- EH fluid system,
- Auto-stop oil system, and
- Electronic control system.

High pressure electrohydraulic fluid opens the steam admission valves to the high and low pressure turbines. Pressure in this system is maintained by, EH control pumps, unloader valves, and an interface valve. The unloader valves maintain the pressure within design values, while the interface valve allows the system to be pressurized.

Auto-stop oil keeps the interface valve closed. If the interface valve is shut the EH fluid high pressure will be maintained at its design value. Opening the interface valve by dumping the auto-stop oil causes a turbine trip.

The electronic control system computes deviations between operator-initiated reference values and turbine speed and load. Deviations are transmitted to servo valves to reposition governor or throttle valves.

The turbine is operated in either speed control or load control. With the system in speed control, the throttle valves control the speed until a preselected speed is achieved and then speed control is shifted to the governor valves.

After the generator output breakers are closed, the system automatically shifts to load control with impulse pressure out of service. When operating in this mode, Imp Out, governor valve position is used as a feedback signal. The operator may select impulse pressure in service after power has exceeded some nominal power level. Once this action has taken place, turbine impulse pressure along with governor valve position are used as feedback signals.

Runbacks are provided to prevent either a reactor trip or a turbine trip. Runbacks may be initiated either from the primary protection system, or from the secondary system. Primary runbacks decrease the turbine load via a decrease in the reference load, while the secondary runbacks decrease the setting of the valve position limiter.

Finally, various protective signals are provided to trip the turbine. Whenever a turbine trip occurs, the overspeed trip device is actuated to seal in the trip. To prevent a turbine overspeed, an overspeed protection circuit is provided. This circuit momentarily closes the governor and the intercept valves. When the overspeed condition clears, the governor and intercept valves return to their open positions.

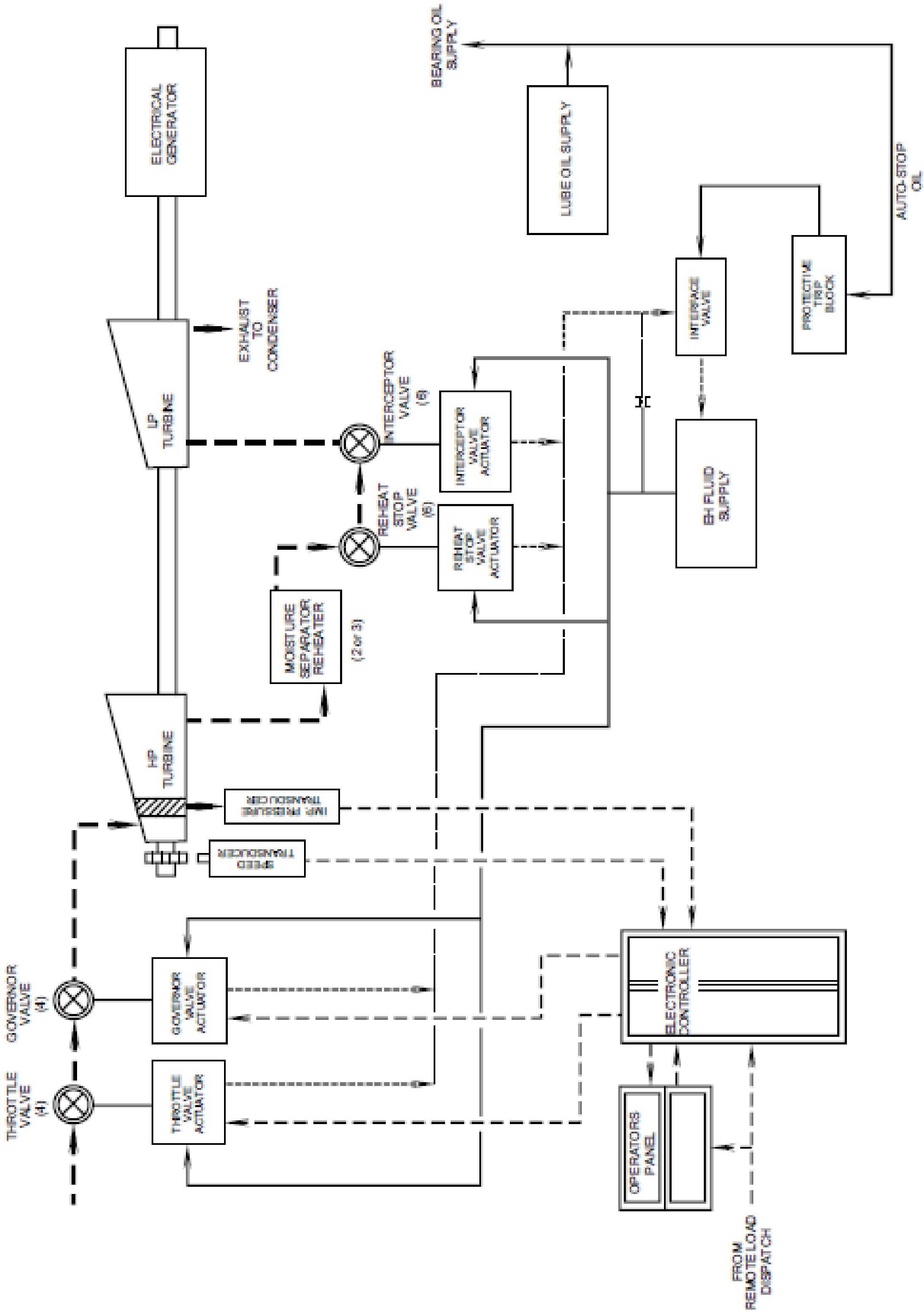

Figure 11.3-1 Simplified EHC System

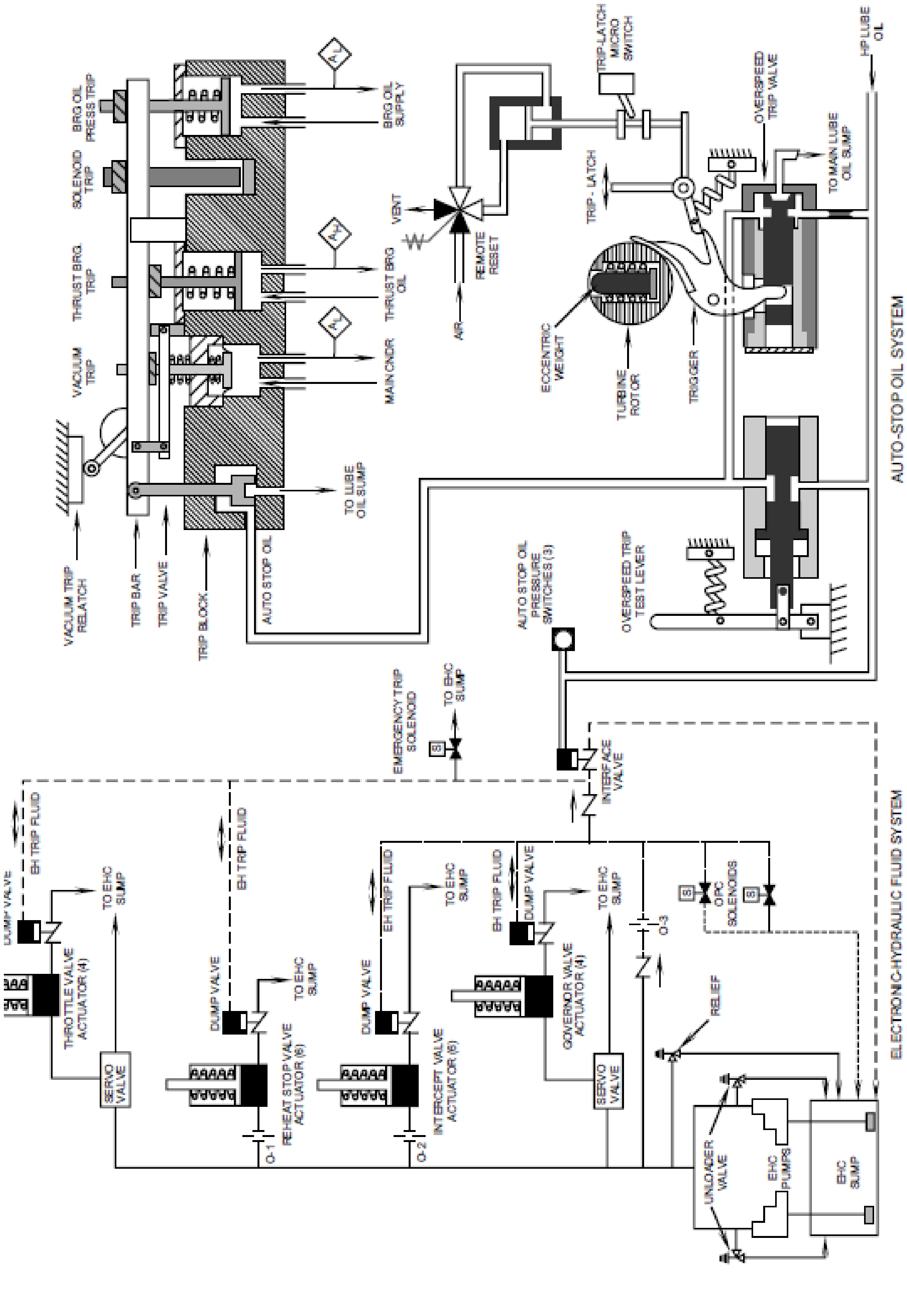

Figure 11.3-2 EH Fluid and Auto - Stop Oil System

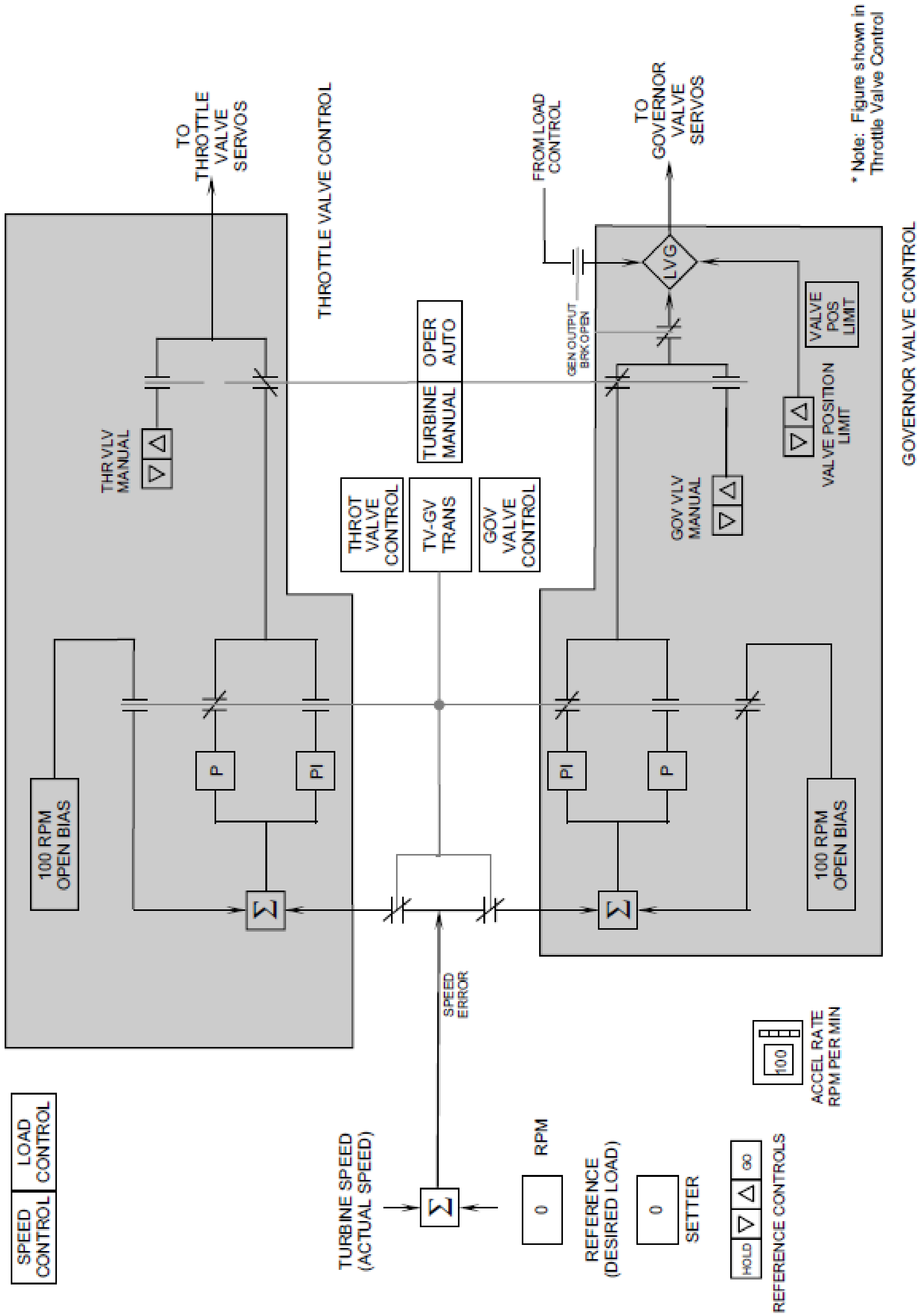

Figure 11.3-3 Speed Control

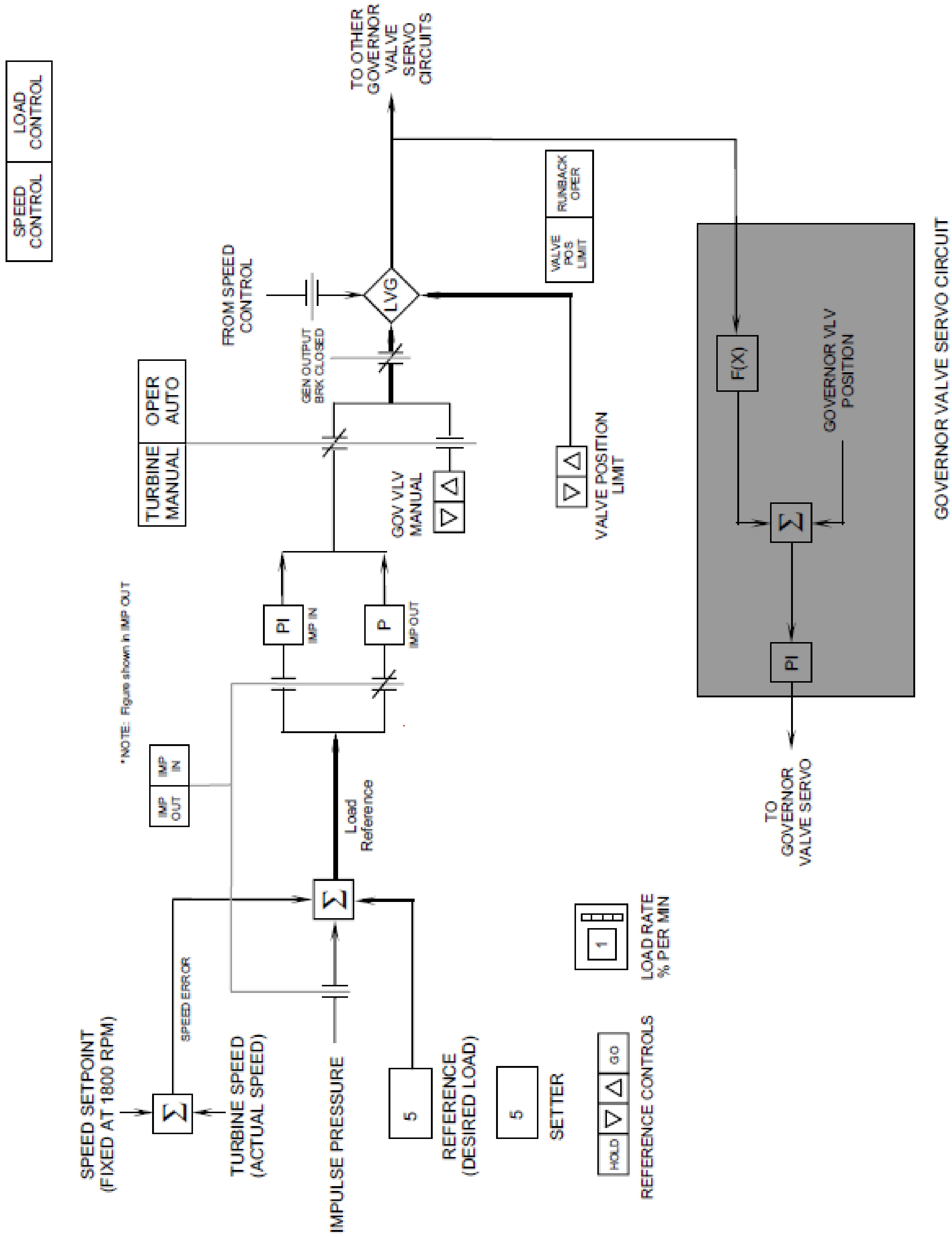

Figure 11.3-4 Load Control

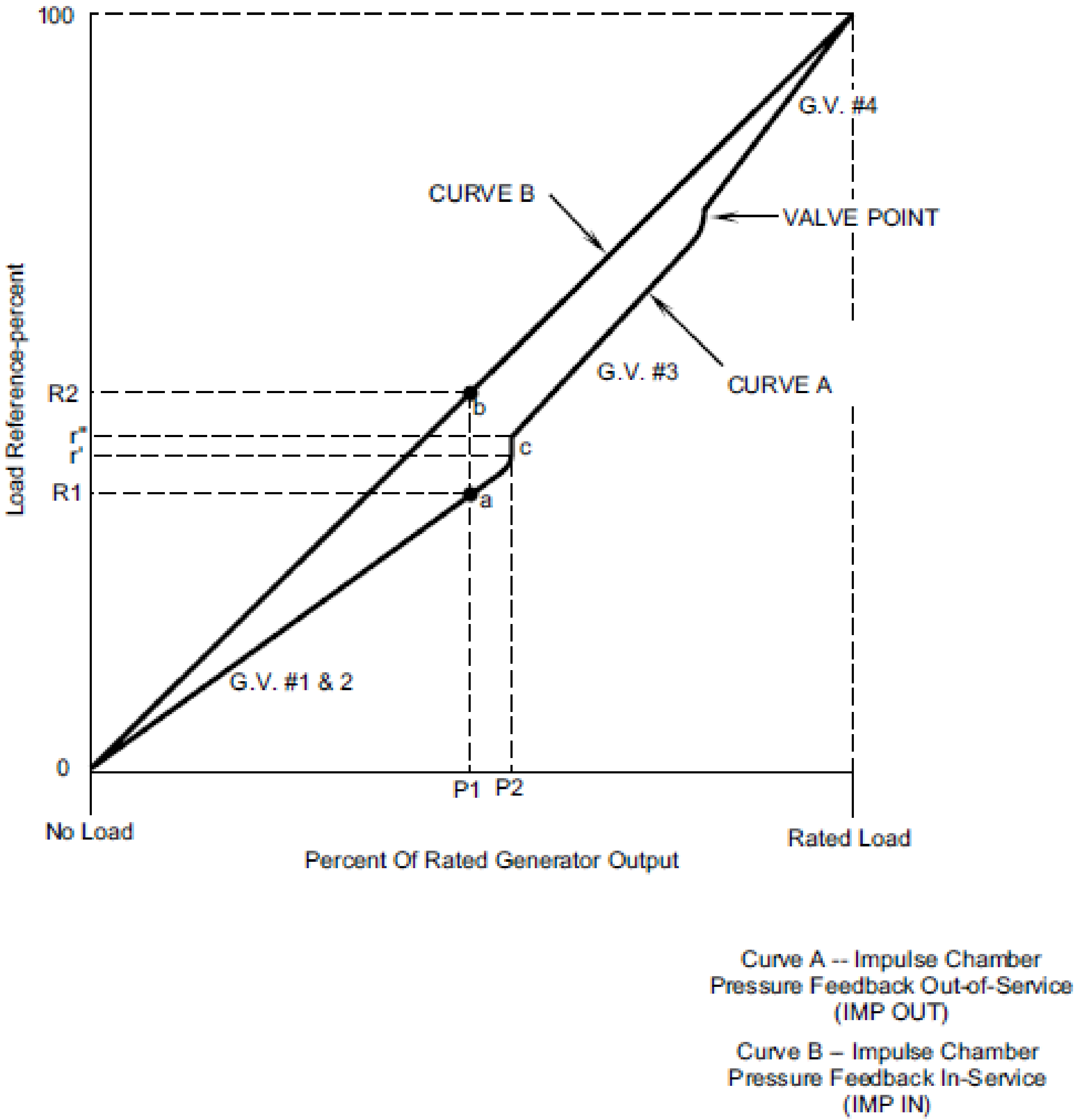

Figure 11.3-5 Impulse Chamber Pressure vs. Load Reference

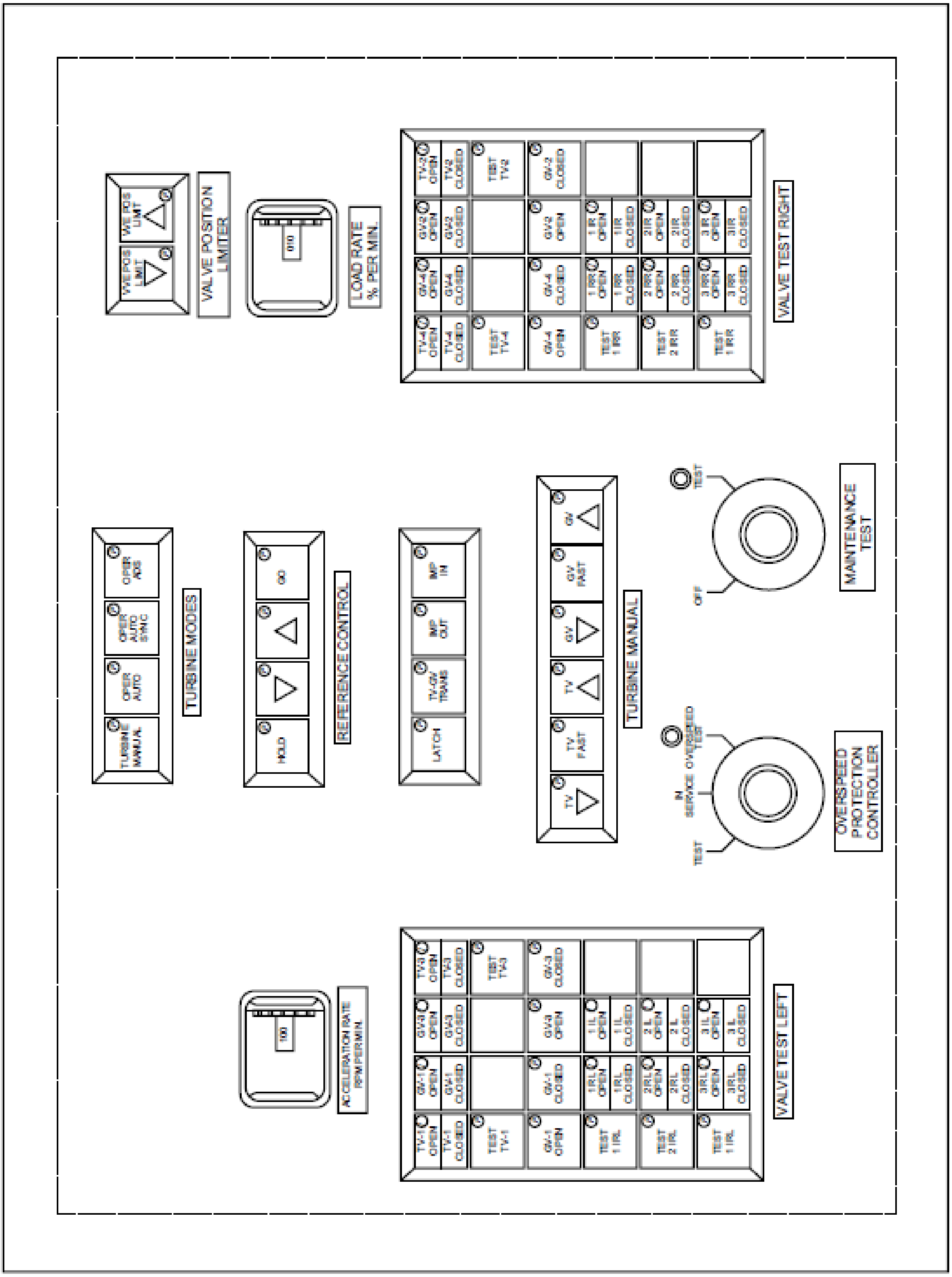

Figure 11.3-6 EH Control Panel

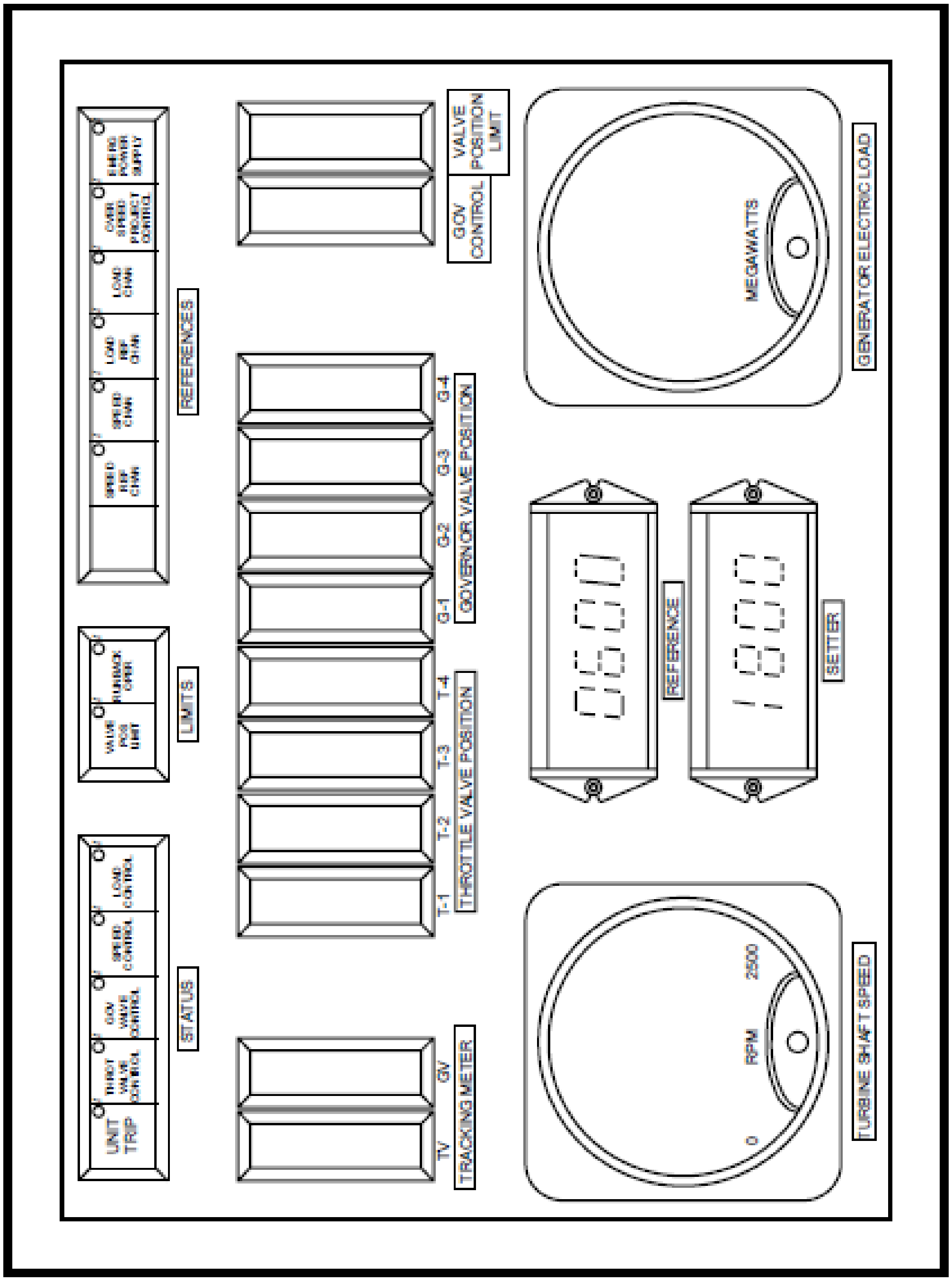

Figure 11.3-7 EH Indicating Panel