maxDNA Steam Turbine
Control & Protection System

The maxDNA distributed steam turbine control system is divided into two partitions – one for control and the other for protection. Control functions include automatic startup and speed control, synchronization, load control, frequency control and valve testing. Protection functions include monitoring critical turbine parameters, overspeed runbacks and tripping, load rejection anticipation and trips for low hydraulic oil pressure, lube oil pressure, and vacuum pressure. Although separate partitions, the system is integrated into the maxDNA distributed power plant automation system. It uses the same components and shares the same operator interface and communication network. It utilizes industry standard hardware and software.

Background and Introduction

Because the steam turbine is fundamental to the purpose of the power plant its control system must be extremely reliable, therefore redundant, and highly responsive, to the extent that protective action is taken in several milliseconds.

Turbine control systems have evolved over the last forty years from electro-mechanical systems, to analog electrohydraulic (EHC), to proprietary based digital systems, to micro-processor based systems. The subsequent advancements have mirrored advancements in computer technology - faster, more powerful, less expensive, less proprietary, more flexible, etc.

Today, turbine control is an integral part of the plant automation system, whose components share the same characteristics, software, look and feel. The turbine control is no longer a stand-alone system.

Key Features

- Separate, redundant control and protection functions – improves plant reliability and availability
- Automatic speed control – faster, safer startups
- Automatic load control – linearizes control valve response and provides smooth, faster load changes
- Redundant 2-out-of-3 speed measurement and trip modules – protects turbine from a single point of failure
- Programmed to operate turbine on designated valve points – improves unit efficiency when in variable pressure mode
- Plant constraint coordinator – load changes at fastest allowable rate
- Rotor stress calculations keep acceleration less than limits – increased availability and longer life
The advantages of a single integrated plant automation system include:

- Common operator interface
- Integrated operations reporting
- Reduced overall capital cost
- Fewer types of spare parts
- Simplified maintenance
- Single interface to Automatic Dispatch System (ADS)
- Common Coordinated Boiler-Turbine Control Operation
- Flexibility – ease of expansion
- Common tool set for configuration

Why Modernize?

Many power plants are now over 20 years old, but never the less, they still have great value to economically generate power. Modernizing these plants has become a better alternative to building new generating capacity, especially in a deregulated market. There are many plants still successfully operating with the originally installed turbine control systems. These aging control systems have become obsolete and are difficult to operate and maintain.

Today’s electric power market requires increased availability, reliability and efficiency. Modernizing the turbine controls can be one way to achieve these goals. A modern distributed turbine control system has many features that can provide immediate results. Unfortunately it is still sometimes difficult to quantify and justify the cost related to modernizing an entire control system. However, the modular nature of today’s modern distributed control systems makes it possible to upgrade in stages and accrue advantages as features are added.

Common problems attributable to older turbine controls are:

- Forced outages resulting in unplanned power purchases at much higher unit cost
- High cost of preventive maintenance, usually from 3rd party sources familiar with older equipment
- Difficulty getting spare parts
- Additional mechanical stress during startup and overspeed conditions
- Slow load changes and poor load following capability
- No redundancy and/or subject to single point of failure
- Poor interface with DCS
- Poor diagnostics

Modern integrated plant automation and information management systems have gained wide acceptance for virtually every part of the power plant. They are fault tolerant and provide high availability. The distributed nature of these systems permits partitioning the turbine control, thus providing a level of independence and security, while providing all the advantages of an integrated system.

maxDNA Turbine Control

The system has two partitions, one for control and one for protection. Redundant sets of Distributed Processing Units (DPU) are provided for each partition. Also, each partition has its own set of redundant AC/DC power supplies. The redundant DPUs are in constant communication, thus providing the backup unit with an up-to-date database. In the event of a fatal error in the primary DPU, transfer to the backup DPU will be automatic and bumpless.

In addition, communication with the operator interface and other DPUs in the system is through a redundant high-speed network. All turbine data and control performance is available to all processing units in the plant automation system including report generators, operator workstations, historians and plant information management systems. Supervisory systems, such as rotor stress calculations, automatic startup programs and performance calculations can also easily access the control system over the communication network. Note that the DPUs can operate without the ability to communicate with operator work-stations. This means the turbine will be protected even if total plant communication should be lost.
Each partition has dedicated I/O modules to perform specific tasks. Each control valve has its own interface (valve positioner) module. The valve positioner has dual output channels and dual position feedback channels. It receives demand signals over a high speed bus from the DPU and executes its positioning routine every 5 ms. On-board diagnostics periodically test and report on its health. A fatal error will result in full closure of the control valve in question.

The protection partition monitors the turbine for “overspeed” conditions. Two speed measurement and tripping modules are used. Note that the tripping function is executed in the I/O modules, not the DPU. This assures overspeed detection and tripping will be executed as fast as possible. Each module interrogates the same three speed signals. If two out of three are greater than the trip point a contact closure is provided. Highest reliability is assured because either module can initiate a trip. This protects the turbine from a single point of failure. Interrogation and execution of the trip function takes less then 5 ms.

Note that the first overspeed condition causes all high-pressure steam control valves to be closed by opening the hydraulic fluid dump valves. The reheat intercept valves are pulsed closed until the speed is brought back within acceptable range. At that point the main steam control valves are opened and control is returned to normal.

A second higher level overspeed condition will cause all steam control valves to close and the turbine to be tripped.

In addition, the protection partition is also responsible for the following other functions, which execute in the DPU:
- Hydraulic oil pressure low
- Lube oil pressure low
- Vacuum pressure low
- Throttle pressure low
- HP cylinder temperature high

### Load Rejection Anticipation

If electrical load is suddenly lost (main breaker open), the turbine power and the braking torque of the generator are greatly mismatched. This will cause the turbine to immediately accelerate. The protection partition DPU’s will close the control valves rapidly and reduce the load reference setting to “house load,” which will initiate the closing of the intercept valves to minimize overspeed. The turbine will accelerate to a maximum speed below the trip point. The re heater steam is then released at approximately 102% of rated speed and single valve (full arc admission) will be engaged.

![maxDNA Turbine Control System Diagram](image-url)
The **maxDNA** system includes means to:

- Accelerate the turbine to operating speed while providing variable rates of acceleration
- Transfer from single valve control to multivalve control (full arc to partial arc)
- Control electrical load
- Participate in load and frequency control
- Test control valves while maintaining load
- Override the normal valve position signal to prevent the valve from exceeding a limit

In addition, the control system is designed with:

- Individual valve control autonomy
- Redundant controllers
- High speed processing
- Coordinated control system (CCS) capability

### Speed Control

The maxDNA system accelerates the turbine from turning gear to synchronous speed including transfer from single valve control to multivalve control. An automatic time vs speed program is provided to assure a safe and fast startup. In addition, a rotor stress calculation program may be employed to ensure the turbine will startup in the minimum time with minimum stress. The operator has the ability to adjust the speed reference and acceleration through any workstation.

Depending upon the turbine design, the unit is synchronized in single valve (full arc admission) control or sequential valve control (partial arc admission). The speed is trimmed by the system until speed and phase angle are matched with the line. (Means to close the circuit breaker are the responsibility of the plant owner.) Note that the median of three speed signals are used in the system.

*Figure 2 - maxDNA Turbine Control Functions*
Valve Management

The maxDNA system provides individual control of all the steam admission valves (main throttle or stop valves, control or governor valves and the intercept valves). Each valve has a different purpose depending upon the mode of control. Sequential control of these valves during startup, automatic load control and shutdown are performed automatically by the system. Switching control modes is automatic and bumpless.

During startup, when controlling speed, the throttle valve (typically a bypass valve built into one of the stop valves) controls steam flow. Under these conditions the control/governor valves are wide open, thus allowing steam admission to the entire nozzle block. Depending upon the turbine design, transfer to sequential control (control valves / governor valves) takes place before or after synchronization.

At the transfer point the governor valves are closed in sequence and the throttle/stop bypass valve continues to control steam flow. When the throttle bypass valve reaches its full open limit, control is transferred to the control (governor) valves that then open in sequence to increase speed or load. All throttle/stop valves are opened to their limit at a controlled rate.

When reducing load the reverse transfer occurs automatically at a preset load point. On a rapid loss of load the transfer will take place after the reheater has been unloaded.

Load Control

Load control, commonly called Automatic Generation Control (AGC), is used after synchronization takes place and above a preset low load limit. The system allows the operator to set the load reference in MW and the rate of change or loading rate in MW per minute. The maxDNA system will automatically control the governor valves to increase load in a linear fashion which duplicates the load demand curve as established by the operator or the Automatic Dispatch System (ADS).

Note that the maxDNA system employs the Unit Constraint Coordinator, which permits the operator to set the loading rate at a level higher than most other systems.

Valmet Automation employs a unique approach to AGC that uses turbine first stage pressure ($P_1$), gross generation (MW) and system frequency ($f$) in a cascade control loop. This control loop has been proven over many years to provide optimum performance, with or without a coordinated control system (CCS). It is the same control used in the D-E-B/400 CCS that has been employed on over 900 fossil fired generating units worldwide. It makes maximum use of boiler stored energy and linearizes the governor valves. Figure 3 shows typical response to a load ramp in AGC mode. Note that the AGC and valve management algorithms are executed in the DPU every 10 ms.

Figure 3 - MW response in AGC mode

Note figure 4, which is a unit master display, provided for the operator to set the load reference, loading rate and limits.
Frequency Correction
There are two elements to frequency control, sometimes called regulation - the “natural” element provided by the turbine control (governor) and the planned element provided by the Energy Management System (EMS). The maxDNA turbine control provides for natural frequency correction capability. Regulating capability is necessary for area wide frequency control as well as system wide control. Without frequency correction the network would not be stable.

Regulation is the change in steady state speed expressed in percent of rated speed when power output of the turbine is gradually reduced from rated power to zero power output. It can also be stated as the percent speed (frequency) change that results from a full opening or closing of the governor valves. Thus the greater the value of percent regulation, the less will be the sensitivity.

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\% \text{ Regulation} = \left( \frac{S_1 - S_2}{S_2} \right) \times 100
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\( S_1 = \) Speed at zero load
\( S_2 = \) Speed at rated load

Percent regulation is adjustable up to 10% with a nominal setting of 7%. Frequency correction is used even when the unit is in coordinated control mode.

Throttle Pressure Control
There are circumstances when it is necessary to control pressure with the governor valves. This is normally referred to as turbine follow mode. In this mode the valves respond to the throttle pressure error by closing the valves to increase pressure and vice versa.

Turbine follow mode is normally used when in an emergency condition and it is important to immediately balance the boiler with the turbine. AGC is suspended under these conditions. However, if Turbine Base mode is available with the boiler control this can be initiated after boiler turbine stability has been restored.

Turbine follow mode is automatically initiated when the throttle pressure drops below a dangerously low limit. This is done to protect the turbine from water induction.

Remote Auto Permits
Installations that have a foreign boiler control system can operate in coordinated mode i.e. control the turbine in parallel with the boiler. The maxDNA system will accept a demand signal via serial communication or hard wired. A digital signal called “Remote Auto” is sent to the boiler control as a permit for coordinated control.
The maxDNA turbine control system positions the steam admission valves by sending demand signals to servomotors (servos) mounted on or near the hydraulic valve actuators. Hydraulic fluid is controlled to the spring-loaded pistons by the servos. A maxPAC I/O module, called a “valve positioner”, provides an analog output to the servo. Since most servos have two coils, dual outputs are provided.

The “valve-positioner” also has means to receive two valve position feedback signals from LVDTs mounted on the valve. The positioning algorithm uses the greater of the two signals. Since the LVDTs are nonlinear and vary with temperature, means are provided to calibrate the LVDT on a periodic basis.

A proportional-plus-integral (PI) positioning algorithm is executed every 5 ms. The position demand for each control valve is computed in the Distributed Processing Unit (DPU) and updated over the I/O bus.

The “valve positioner” also has the capability to receive a speed signal, which is transmitted to the DPU for use in AGC mode.

The “valve positioner” has been designed with its own DIN rail mounted termination facility, which includes signal conditioning and a resistor network for matching the coil to the proper output. A prefabricated cable connects the module to the termination board.

**Advantages of the maxPAC Valve Positioner**

- Dual isolated outputs – operates valve even if one servo coil fails
- Dual isolated position feedback channels (Uses the higher of the two signals) – continued operation even if one LVDT has failed
- Speed feedback signal for frequency control – AGC does not depend upon speed signals from protection partition
- Detects if servo coil has failed (open or shorted) – provides online alarm without requirement to take valve out of service
- Detects stuck valve – alarm to operators permits immediate attention before a total failure
- Configurable output failure modes (reset or fail in place) – allows for keeping valve in last position on fatal error if desired
- On-line valve testing and calibration of LVDT – can calibrate valve control without taking control out of service
- High speed (<5 ms) processing speed – executes PI algorithm at maximum rate
- Serial port for loading control algorithms and calibrating feedback signals – Can be loaded and tested without the engineering workstation
- High resolution outputs (16 bits) – provides for accurate positioning control of valves and steam flow – results in accurate AGC

![Turbine Control Valve Interface](image)

**Figure 5 - maxPAC Valve Positioner Module**
Unit Constraint Coordinator

One of the most significant challenges to operators today is to provide maximum response to requests for a load change and not overstress aging plant equipment. Care must be taken to not put undo stress on superheater headers, turbine rotors, reheat headers, boiler drums, as well as pumps, fans and valves.

During a load change the Plant Constraint Coordinator monitors critical turbine and boiler parameters and will automatically reduce the unit-loading rate if it is determined that excessive stress is likely to occur. When the transient condition clears and stress rates are reduced, the loading rate is automatically returned to the original operator-adjusted setting (See Unit Master station in Figure 4). The stress determination is calculated in real time and is available for review by plant operators.

The Constraint Coordinator also monitors, in real time, the availability of plant auxiliaries, such as fans, pumps, coal pulverizers, etc. it automatically adjusts the maximum and minimum limits for load changes based upon this availability.

Benefits of Constraint Coordinator

- Improve unit ramping rate consistent with instantaneous load changing capabilities
- Enable unit response to ADS requirements
- Operate with stress limits for extended life
- Avoid purchased power cost due to slow load response
- Extend life of auxiliaries and avoid unplanned outages

Hydraulic Equipment

Most turbines installed more then 25 years ago will have mechanical hydraulic (MEH) or analog hydraulic (AEH) control systems. Hydraulic supply systems are relatively low, in some cases around 300 psig. In addition, the valves are not controlled on an individual basis, but by a set of cams or a “gang bar” that opens and closes the governor valves in sequence. Automatic operation of the valves is through a DC governor motor that is used to set a counterbalancing force to hydraulic oil pressure that drives the valve positioner. Also, in some cases the hydraulic fluid and the lubricating oil are one in the same, which causes contamination with metal particles.

Some of the problems:

- Response times are slow because of signal delays
- Use of mechanical levers and pinions responsible for errors and inaccuracies over time
- Governor motor, oil pump and control unit all subject to inaccuracies and non-repeatability
- High maintenance costs since there are many moving parts
- Lack of spare parts for most older machines
- Servicing is very difficult because of poor location

To provide the best overall performance and availability it is recommended that the hydraulic equipment be replaced, if not in the first phase of the modernization, but in subsequent phases. Equipment to be installed is as follows:

- Individual high pressure hydraulic actuators with high pressure oil supply system
- Servo positioners for each valve
- Redundant LVDT position feedback devices
- Dump valves and accumulators