Advanced distributed control of industrial steam turbines

Leonard A. Sterle and Roger L. Hull

Lower maintenance and training costs, a reduced spare parts inventory, and the ability to maximize overall profit through linear programming are among the benefits that could result from the distributed control of steam turbines.

The primary function of steam turbines in the pulp and paper industry is to efficiently reduce the pressure of steam from high-pressure boilers so that this steam can be used as a source of process heat. Unlike the large, condensing steam turbines employed by central station utilities, power generation is usually only of secondary importance to owners of industrial steam turbines. Unfortunately for the industrial owner, most turbine control systems are designed as if power generation were of primary concern. Consequently, these control systems cannot adequately contend with the unique requirements of the industrial user.

Recognizing this deficiency, Bailey Controls introduced the NETWORK 90 Distributed Turbine Control System. The flexibility of distributed microprocessor technology allows the implementation of basic control and supervisory control strategies. These strategies can be tailored to industrial turbines in control hardware designed for fault tolerance, low maintenance, and superior control performance.

Basic control strategies

Figure 1 illustrates a typical steam turbine arrangement in an industrial setting. Two boilers supply 625-lb steam to a pressure-reducing valve and to Turbine No. 1. One high-pressure boiler supplies 950-lb steam to a pressure-reducing valve and to Turbine No. 2. The turbines expand the steam from the high-pressure header to a lower pressure for process steam use and for generating electrical power.

This approach is more economical than dissipating the internal energy of the steam through pressure-reducing valves. Control valves control the flow of steam into the turbine, while an extraction valve controls steam flow to the 50-lb process header. Vent valves in the low-pressure header act to relieve excess pressure during abrupt load changes.

Sterle is marketing manager for energy management, and Hull is marketing manager for utilities at Bailey Controls Co., 29801 Euclid Ave., Wickliffe, Ohio 44092.

In the distributed control system, a number of basic control strategies are used, including speed, load, and extraction control.

Speed control

During startup, the turbine is in the speed control mode. In this mode, the extraction valve is kept fully open, allowing no extraction flow, and turbine speed is controlled by a proportional integral derivative (PID) loop acting through the control valves. The operator accelerates the turbine from its turning gear to various speed hold points by selecting the proper speed setpoint and acceleration rate in accordance with the turbine manufacturer's recommended startup procedures.

Actual turbine speed is measured by three magnetic pickups located in close proximity to a 60-tooth wheel mounted on the turbine shaft. Two of the three speed input settings must be in agreement for the system to allow automatic speed control. Separate overspeed protection logic is in service at all times, which acts to close the turbine stop valves in the event that the turbine speed exceeds a preset limit.

Load control

The control system automatically loads the turbine to a preset initial electrical load to prevent motoring of the generator when it is connected to the utility power grid. The load setpoint can be selected locally by the operator, or it can be provided by a supervisory controller. If precise control of electrical load is necessary, an electrical load feedback loop can be engaged.

During the extraction operation, this feedback loop functions as a front-end trim controller in concert with the extraction control signal to determine the control valve position demand. During full condensing operation, with extraction valves fully open, the electrical load feedback loop acts directly on the signal, indicating the control valve position demand until the electrical load error becomes zero.

A throttle-pressure regulator and a speed feedback loop are also provided; both acting through the control valves. The throttle-pressure regulator prevents the throttle pressure from dropping to a level that could damage the turbine, while the speed feedback loop corrects for system frequency fluctuations.

Extraction control

A major problem with most control systems for extraction turbines is their inability to control concurrently the extraction pressure and the electrical load. The distributed turbine control system solves this problem through both the electrical load feedback loop and an independent extraction control loop.

While the turbine is in the speed control mode, the extraction valve is wide open to permit maximum steam flow through the condenser. Once the turbine is carrying a 20% load, the mode for control by local extraction pressure may be engaged. Before initiating this control mode, the extraction demand signal is automatically set equal to the process variable that permits a bumpless transfer of control mode. In the local extraction pressure mode, the operator selects the extraction pressure setpoint, and the control system calculates the extraction valve setpoint as a PID function of the error between the extraction pressure process variable and the extraction pressure setpoint.

In addition to the modes of local extraction pressure control and flow control, the system also has remote pressure and flow control modes to accommodate supervisory control strategies. In the remote modes, a remote extraction setpoint signal simply replaces the local extraction setpoint signal. The operator has the capability to override the remote signal at any time.

Transfers between local and remote modes are transparent, as are transfers between automatic and manual control. On entering manual control from automatic, the control system sets the manual extraction valve setpoint equal to the automatic extraction valve setpoint. When returning to automatic from manual, the local extraction loop is engaged, and the control system sets the extraction pressure setpoint to equal the extraction pressure process variable.

Supervisory control strategies

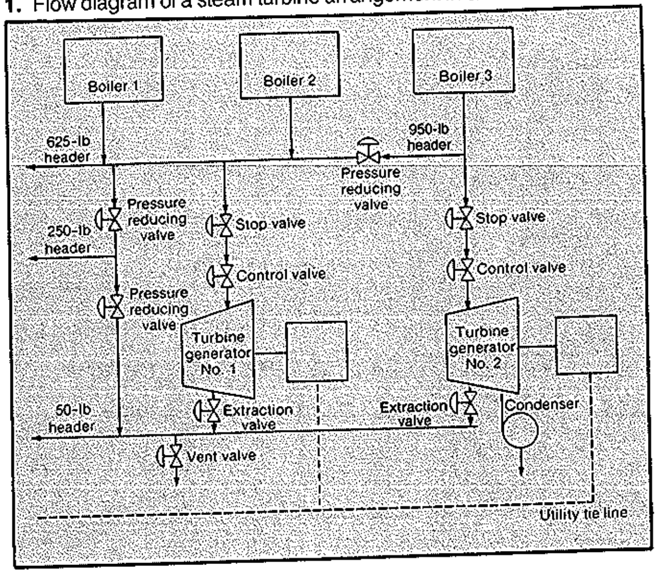
While distributed control systems certainly provide superior basic control performance for turbines, their greatest value lies in their ability to execute supervisory control strategies that have operational and economic benefits.

Automatic turbine startup

In automatic turbine startup, the control system accelerates the turbine from the turning gear to synchronous speed in accordance with the turbine manufacturer's recommended startup procedures without the need for operator intervention. Automatic synchronization of the turbine generator can also be provided. The advantages of an automatic turbine startup system include:

- The ability to start the turbine up as quickly as possible without causing damage to the turbine
- The need for only one operator to start up the turbine
- A reduction in operator training requirements.

1. Flow diagram of a steam turbine arrangement in an industrial setting



Isochronous speed control with load shedding

In many industrial settings, it is necessary for the turbine generator to provide electrical power to keep a mill running in the event of a disconnection from the utility grid. Avoiding a millwide power trip is sometimes impossible with older turbine control systems if the facility purchases more power than it produces. Distributed turbine control systems offer two key advantages for this kind of requirement.

First, fast loop execution speeds are possible with distributed microprocessors, and these speeds improve isochronous speed control. Greater execution speeds are critical because speed control is closed loop and load control is open loop.

Greater execution speeds allow the control system to take quick action to move the control valves in response to turbine speed (frequency) fluctuations. Fast action is especially important in isochronous mode since turbine speed (frequency) changes occur very abruptly when there is no tie to the utility grid (electrical phasing of the turbine generator with the grid keeps turbine speed relatively constant).

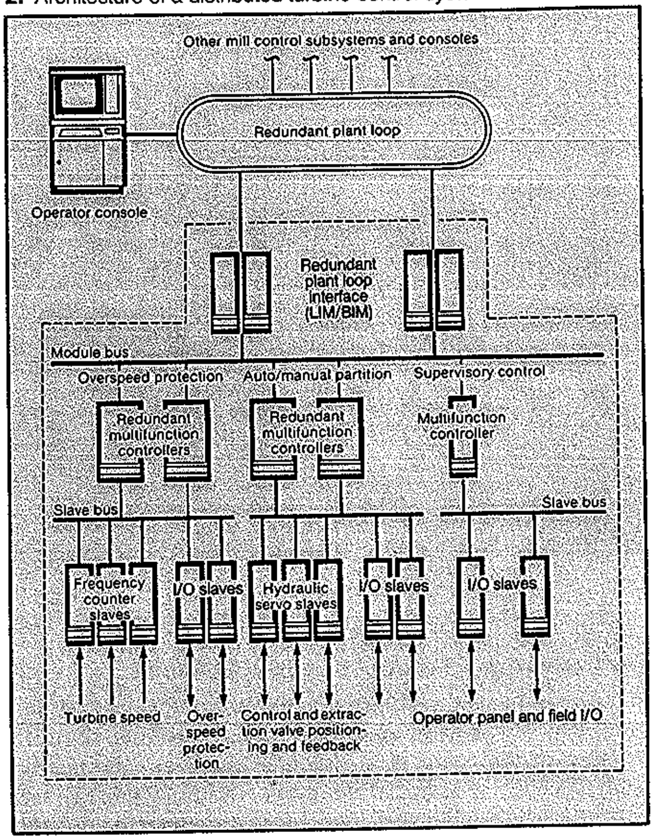
Second, a load shedding scheme can be automatically executed in the event of a loss of the utility tie line. Such a scheme caused the shedding of noncritical loads, thus avoiding a millwide power trip.

Advanced header pressure control

Variations in header pressure for process steam arise from a lack of coordination between multiple turbines and pressure reducing valves and are a common occurrence in many facilities. Advanced strategies for controlling header pressure can be implemented as part of a distributed turbine control system.

Typically, only one of the extraction turbines is used to control header pressure. This strategy is possible because each turbine has separate loops for both extraction control and load control. The advanced header-pressure controller furnishes an extraction setpoint to the turbine controlling the header pressure. Where the process steam demand is

2. Architecture of a distributed turbine control system



unusually high and restricts power generation or another steam header supply, a pressure-reducing valve is opened to satisfy steam demand. If header pressure rises unacceptably because of abrupt load changes, the header vent valve is opened to bring the pressure back in line.*

Advanced control of purchased power demand

Distributed turbine controls have the ability to control purchased power to a calculated setpoint to minimize overall electric power costs. The purchased power setpoint is the constant power consumption that would result in a power demand equal to site-specific, on-peak and off-peak demand limits.*

The purchased power demand controller provides the load setpoint to the load control and subsystem of the turbine. To avoid excessive modulation of the load reference, the demand controller is set to control the total power purchased during a demand period, not to control instantaneous purchased power. Cost savings resulting from the avoidance of demand penalties and the production of unnecessary power during off-peak periods sometimes exceed $100,000 per year.

Distributed system architecture

Figure 2 presents an overview of a distributed turbine control system for a typical industrial steam turbine. At the heart of the basic system are two sets of redundant multifunction controllers (MFC). These achieve control loop execution speeds in approximately the 50 ms through multitasking techniques and the use of powerful 32-bit microprocessors.

Additional MFCs may be added as required to incorporate supervisory control strategies into the system. The advanced design of the distributed system affords many operational and maintenance advantages in addition to those already covered.

Fault tolerance

Separate overspeed protection and automatic and manual control partitions are provided, each with a dedicated set of MFCs and dedicated input/output slave modules. The primary and backup MFCs are completely identical; if the primary MFC malfunctions, the backup MFC assumes control automatically and is transparent to the process.

Each extraction valve and control valve has a dedicated hydraulic servo slave module that provides a redundant current output to the hydraulic servo valve and accepts a linear variable differential transformer (LVDT) position feedback signal. In the unlikely event of a loss of an MFC set, an emergency manual mode is automatically entered which allows manual control of the turbine valves directly through the hydraulic servo slave modules.

Turbine speed is monitored by three independent frequency-counter slave modules, and a two-out-of-three validity check is performed. Redundant diode auctioneered module and input/output power supplies are the rule. Redundant operator interface can be provided through an operator's console and a pushbutton panel or two operator consoles.

Lower maintenance costs

The distributed turbine control system employs extensive on-line diagnostics which allow rapid pinpointing of failures. Failed modules can be replaced on-line in minutes from a stock of spare parts, eliminating the need for a service call and drastically cutting mean times to repair.

Since there are relatively few types of modules, spare parts inventories can be kept to a minimum. Turbine valves can be precisely calibrated in a matter of seconds from a CRT console, whereas this task used to take several hours, even with the assistance of the vendor's service engineer.

Control accuracy and responsiveness

Besides the ability to incorporate advanced supervisory control strategies into the distributed system, there is also a substantial improvement in the accuracy and responsiveness of basic regulatory controls. Turbine speed is precisely controlled to within ± 0.25 rpm. Faster and more accurate responses to load and process header changes are possible because turbine valves can be positioned more accurately and the speed of the control loop is improved.

Enhanced human interface

The distributed turbine control system provides operations, maintenance, and engineering personnel with accurate and timely information in convenient formats, enabling them to make informed decisions regarding operation and maintenance of the turbine.

Quick access to on-line data, including alarms, system status, valve status, and point values, are available from

*Advanced cogeneration steam turbine control, Bailey Controls Co. Application Guide, AG-0000-051-01, Wickliffe, Ohio 44092.

a CRT console. Customized dynamic graphic displays allow operators to quickly comprehend process changes and to take appropriate control action. Trending and logging capabilities provide data for the analysis of operating and maintenance procedures, leading to improved plant efficiency and the identification of potential problems before they cause process downtime.

Expandability

The modular nature of the distributed control system permits the user to add capability to a basis system for extraction and load control in a cost-effective and incremental fashion as budgetary considerations permit or as process needs change. Often, the implementation of supervisory control strategies can be effected without the need for additional system cabinets.

Conclusions

Distributed control technology can provide many economic and operational benefits when applied to the control of steam turbines. Since the distributed turbine control system employs the same field-proven hardware as used on paper machines, digesters, recovery boilers, power boilers, and other major areas in the mill, this equipment can be easily incorporated into a complete millwide control system. The advantages of such an approach include lower engineering, maintenance, and training costs, reduced inventories of spare parts, and the ability to maximize the overall profit function of the mill using linear programming and other optimization techniques.

Received for review Jan. 6, 1988.

Accepted Jan. 30, 1988.

Presented at the 1988 Annual Meeting.