# Upgrading the control & safety systems of reheat steam turbines

**The replacement of the hydraulic turbine control and safety systems of older steam turbines by modern electronic systems, tied into a general refurbishment strategy for the power plant, extends operational lifetime whilst securing compliance with the latest environmental legislation. Advant Power® systems, such as Turbotrol® and Turbomax®, offer proven solutions with optimized interfaces for retrofits of ABB as well as non-ABB turbines. To date, ABB has retrofitted over 50 steam turbines with Turbotrol electronic controllers.**

With many older power stations around the world becoming increasingly inefficient as they approach the end of their useful lives, utilities are faced with the choice of either upgrading them or constructing new plants. It has often been shown in recent years that it can be more cost effective to modernize an existing plant than to build a new one. The decision to upgrade is borne out by advantages such as lower first-time costs and the avoidance of the risks and time-consuming procedures involved in gaining approval for new plants.

The primary goal of an upgrade is to secure the operational capability of the power plant units for a further 20 to 25 years, plus, in many cases, full compliance with the latest environmental legislation. Another reason for upgrading comes from the area of automation: modern control systems offer capabilities and features that make an important contribution to the overall objectives of an upgrade, such as:

- Reduced wear and stressing of plant components/materials due to better operational control
- Longer service life
- Increased plant availability
- Improved plant efficiency
- Optimized deployment of operating personnel
- Increase in profitability
- Integration of the turbine control in the overall power plant I&C system

The control system upgrade is more often than not tied into a refurbishment strategy for the entire power station, covering, in addition to the I&C equipment, the civil works, the electro-mechanical equipment and the power systems. Often, for cost, quality or technical reasons, a utility will decide to replace the existing control system in stages rather than wholesale (ie, everything from the control room to the field equipment in one go).

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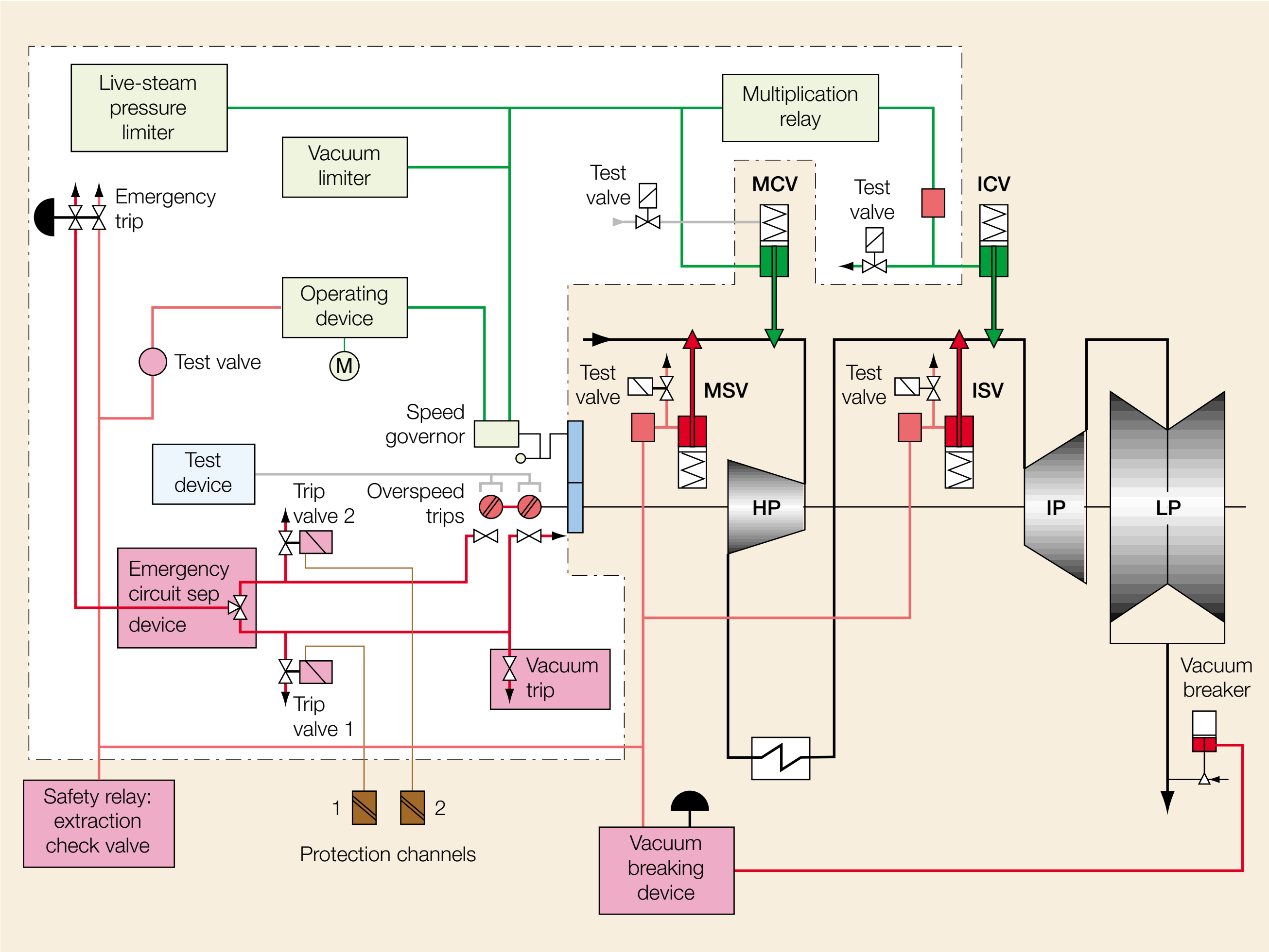
### Modernization of the control system and changes to the steam turbine components

ABB has extensive experience in planning, constructing, modernizing and providing support for steam turbine power plants, and undertakes retrofit work on such plants whether it was the original equipment supplier or not. The type and scope of the retrofit or modernization can be adapted at any time to the given operating conditions.

A block diagram of a typical hydraulic control and safety system as used in the 1960s and 1970s for ABB reheat steam turbines is shown in **1**. The first generation of electronic controllers was installed in the late 1970s [1, 2], with improved versions added through the 1980s [3]. For the steam turbines in new plants built by ABB in recent years, these systems have been largely replaced by the new S90 electro-hydraulic safety system featuring 2-out-of-3 tripping and actuators with directly mounted electro-hydraulic converters as well as the Advant Power turbine control system, Turbotrol 8 [4].

Excellent field experience with the new components and systems has provided a platform offering new options for plant modernization with an emphasis on improved availability and flexibility. In such cases, all the mechanical-hydraulic controllers and safety devices which




***Typical hydraulic control and safety system used in the 1960s and 1970s by ABB for its steam turbines. The boxed area (white) is realized today with advanced Turbotrol® technology.*** **1**

HP *High-pressure turbine*
IP *Intermediate-pressure turbine*
LP *Low-pressure turbine*
ICV *Intercept control valve*
ISV *Intercept stop valve*
MCV *Main control valve*
MSV *Main stop valve*

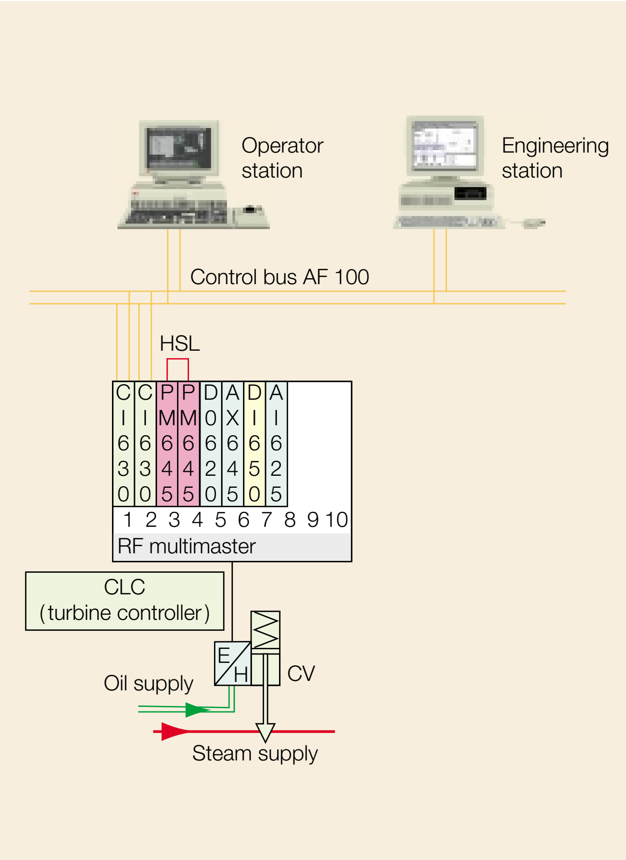
need to be replaced by electronic components are dismantled and removed. The modular design of the retrofitted components, which are also proven in the field, enables them to be used successfully with ABB turbines fitted with different types of control. Furthermore, the same components can be adapted for use on non-ABB turbines. Another possibility is the step-by-step modernization of the turbines. The control and safety systems can be removed either simultaneously or separately, eg when carrying out an overhaul.

**Advant Power® control with Turbotrol® 8**

With Advant Power, ABB offers a modular, distributed control system that not only meets all the requirements of power plant operation but also features control 'per mouse-click'.

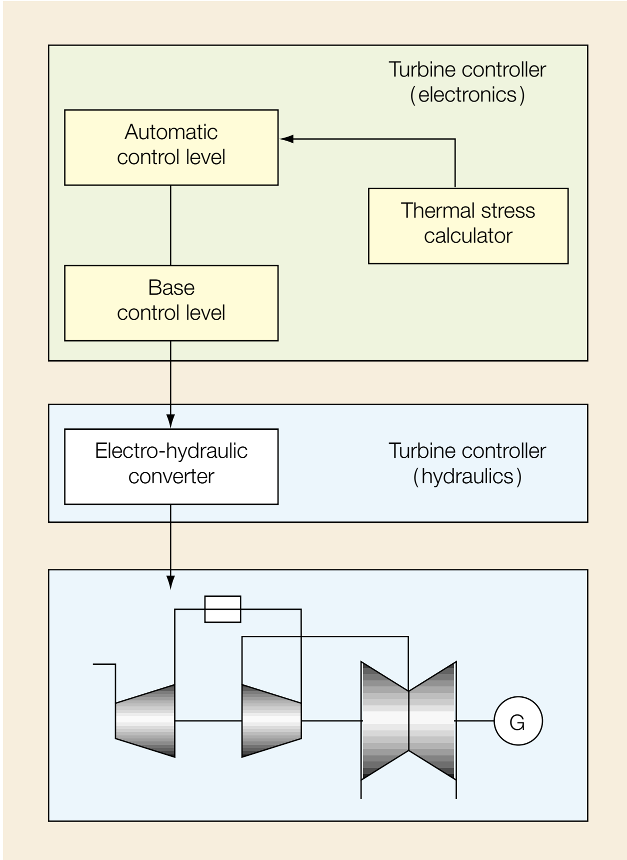
The Advant platform was originally developed for the process control system Advant OCS (Open Control System), which is used for a wide range of applications in industrial processes. By making use of *de-facto* standards for communication and data access, Advant OCS allows individual configurations. It works with information management and logistical systems, with quality control systems and with laboratory information and maintenance systems, etc. With its extensive capabilities, Advant improves the economy and flexibility of processes across a wide spectrum of industries. Trouble-free operation into the next millennium is also ensured by the year 2000 compliance of its new components.

ABB also employs the Advant Power control system in power plants on the




***Schematic of the Advant Power configuration used for steam turbine control*** **2**

CLC *Closed-loop control*
CV *Control valves*
HSL *High-speed link*




***The software modules of the turbine controller are located and programmed in the same processing module in the AC 160 station.*** **3**

basis of this platform. Application packages, eg Egatrol® for gas and Turbotrol for steam turbines, perform more demanding closed-loop and open-loop turbine control functions. Controllers of various equipment modules and with different levels of functionality condition measured values and control and monitor the system at the process level. The modular controllers are scalable and can be programmed either directly, using a PC (Notebook) or a central engineering tool.

The user can program small controllers with the AMPL function-block-oriented language used for the larger processing stations. This user-friendly graphic language is able to handle logic operations equally as well as arithmetic functions or continuous control functions. Depending on the level of availability and reliability required by the process technology, the functions are either single-channel or multi-channel (ie, redundant).

The use of standard hardware and software for the man-machine interface allows different solutions, ranging from simple monitors to complex architectures with large-screen projections. In addition to the operator station (Advant OS) for the operation and monitoring, there is an engineering station (Advant ES) for programming and testing **2**. Each station is connected to an information network employing standard protocols (TCP/IP). Users can access the process data in the plant according to their specific user authorizations. Operation of the power plant is controlled, monitored and optimized from this ‘control room’. In addition, Advant Power offers a system platform for function packages in the areas of operations control and information management, eg lifetime supervision or process optimization functions. Both ABB products and non-ABB software can be integrated.

No more know-how is required to use the operator station than is needed to use a standard PC. Instead of lamps and pushbuttons, modern control stations are built around the PC and mouse capability, which has become the operating tool of choice for utilities. The mouse is used to open windows, operate drives and set reference values. In other words, the power plant is operated 'per mouse-click', with support given by advanced video technology.

## Modernization of the turbine controller

### Electronic turbine controller

The present generation of turbine controllers offers both high flexibility and precision, the quality of the control as well as the control procedures having progressed today to a point unthought of just a few years ago.

By shifting the controls, which previously were mainly mechanical components, into the software environment, it has become possible not only to perform the machine-related control tasks more easily but also to adjust them fast and efficiently to changing task assignments on-line.

The entire turbine governor software is located and programmed in the same processing module in the Advant Controller station AC160. Two redundant (master/slave) processing modules of type PM645 run with the same application program for maximum availability.

The 1-out-of-2 redundancy is designed as a master/slave configuration. The slave continuously updates its registers to match the master register, thereby guaranteeing 'bump-free' changeover in the event of a fault in one of the processor modules.

The turbine controller is split into the following logically independent software modules **3**:

- Base controller
- Automatic controller
- Thermal stress calculator (Turbomax®)

*Base controller*

The base controller **4** is designed for manual operation, and has all the functions required for safe manual control of the steam turbine. The main setpoints, such as speed and valve positions, can be set manually, although during normal operation the setpoints are given by the automatic controller. In the event of a disturbance in the automatic control (eg, disturbed measurements), control is smoothly transferred to the base controller, which ensures that the steam turbine continues to run safely.

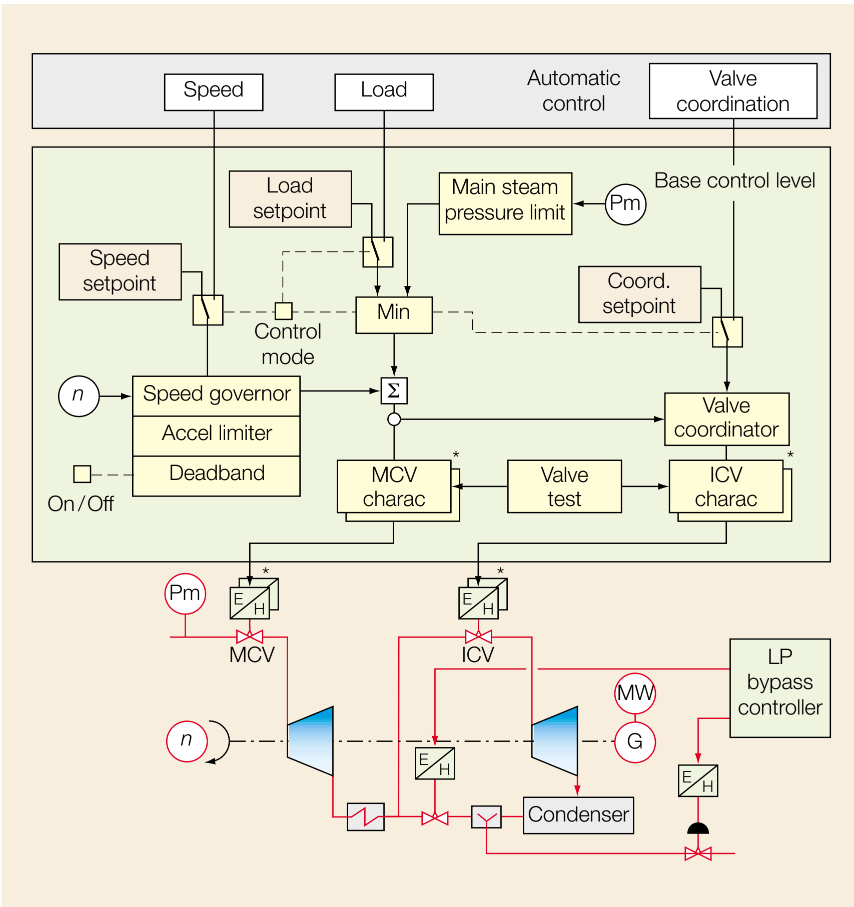
The main tasks of the base controller are speed control and the position control of the main turbine control valves. The positioning signal is the sum of the speed controller output and the manual setpoint of the main control valve position. The base controller requires only two redundant measurements: the turbine speed and the live-steam pressure. The functions performed by the base controller are:

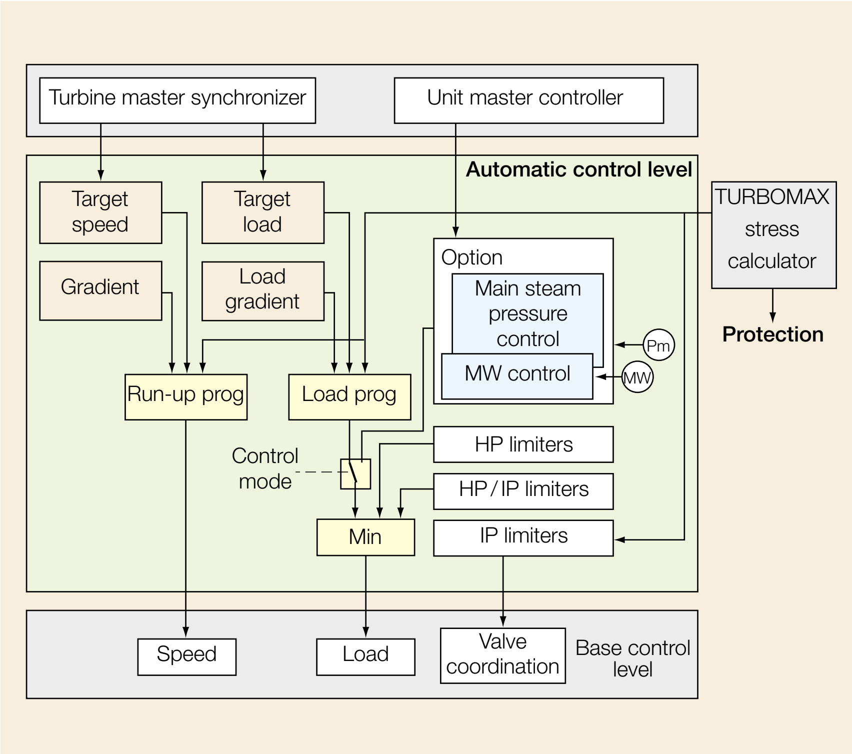
- Manual start-up
- Synchronization
- Load operation
- Linearization of the valve characteristic
- Limitation of initial pressure decrease and of acceleration
- Manual HP/IP trimming (for turbines with bypass)
- Control of intercept control valves

***Block diagram of the base control module. This controller ensures that the steam turbine continues to run safely in the event of a disturbance in the automatic control.*** **4**

MW *Generator output*
Pm *Main steam pressure*

*Other notation, see Fig. 1*






***Block diagram of the automatic control module. The automatic controller relieves the operators of certain control duties.*** **5**

*Notation, see Fig. 4*

*Automatic controller*

The automatic controller **5**, which is at the next-higher hierarchical level, is designed to provide more comfort and relieve the operators of certain control tasks. It consists mainly of a run-up program and a load program. The speed setpoint from the run-up program is fed directly to the base controller, whereas the load setpoint from the load program is limited by the lowest output of the limiters before passing to the base controller. The superimposed controllers act in the same path; if one of them is switched on it will override the load program.

The automatic controller uses the load setpoint and the initial pressure setpoint from a unit control system (UCS) to perform a coordinated unit operation. Among its main functions are:

- Automatic run-up
- Loading and load shedding
- Initial steam pressure control
- Electrical load control
- Forced load shedding (thermal stress)
- Automatic HP/IP trimming during run-up and loading (for turbines with bypass)
- HP exhaust temperature limitation (for turbine with bypass)
- HP and IP thermal stress limitation
- Coordination with UCS
- Minimum hot reheater pressure limitation (for turbines with bypass)

*Turbomax® thermal stress calculator*

Turbomax **6** limits the load automatically should the thermal stresses of the turbine rotor exceed the permissible limits. The initial run-up rate (for cold, warm or hot starting) is determined by the average rotor temperature. During turbine run-ups the initial run-up rate may be reduced if the thermal margins narrow. Turbomax ensures the fastest run-up and loading times whilst keeping thermal stresses to a minimum.

## Modernization of actuators with built-in EHC

The solutions offered today are based on field experience with the latest actuators in new plants:

*Replacement of existing actuators by new ones* **7**

An important component of every actuator is the electro-hydraulic converter (EHC). ABB took a new approach to the development of its latest generation of actuators.

A fast-acting electro-hydraulic proportional valve controls, via a plate-type drain valve, the amount of hydraulic fluid passing to the power piston of the actuator. The valve works with an open/close function and has an operating time of about 2 ms. If a control signal with a defined value is exceeded in the 'closing' direction, the drain valve opens and the actuator moves at its limit speed. An analogue position controller is used in order to be able to interrupt the movement of the actuator at a predefined intermediate position. As long as the predefined value is not exceeded, the drain valve will not open and the amount of hydraulic fluid passing to the piston is controlled by the proportional valve.

The position of the valve is fed back to the position controller in the electronic control module by a stroke transducer.

The dynamic responses of the electro-hydraulic proportional valve and the plate-type valve are carefully synchronized.

The dynamic properties of the actuator and frequency response are given in **8**.

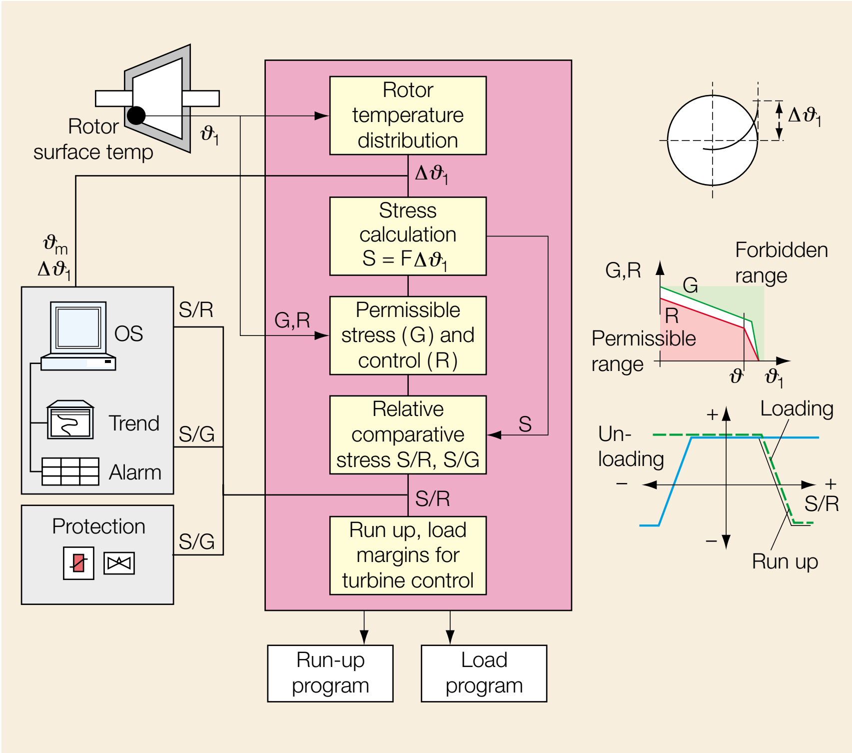
*Conversion of an existing actuator in the plant*

In order to convert an existing actuator **9**, a stroke transducer has to be mounted in place of the mechanical feedback device. The hydraulic pilot control is removed and an adapter with EHC and drain valve – the same type used with the actuators in new plants – is installed. These replacements eliminate the well-known disadvantages of the existing, relatively complex actuators. The number of parts subject to wear is thereby drastically reduced.

### Benefits of modernizing the turbine controller

The advantages of modernizing the control system as described above are:

- Improved part-load behaviour due to the addition of further optimal valve points in the turbines with a control stage. Existing plants have 3 optimal valve points. After conversion of the actuators, 8 optimal valve points are theoretically possible. However, this option depends on the actual plant and has to be studied from case to case.
- Mechanical valve linearization in the actuator is replaced by software in the electronic controller.
- Valve-testing can be carried out directly during operation with the EHC of the actuator. Various mechanical-hydraulic relays as well as piping for

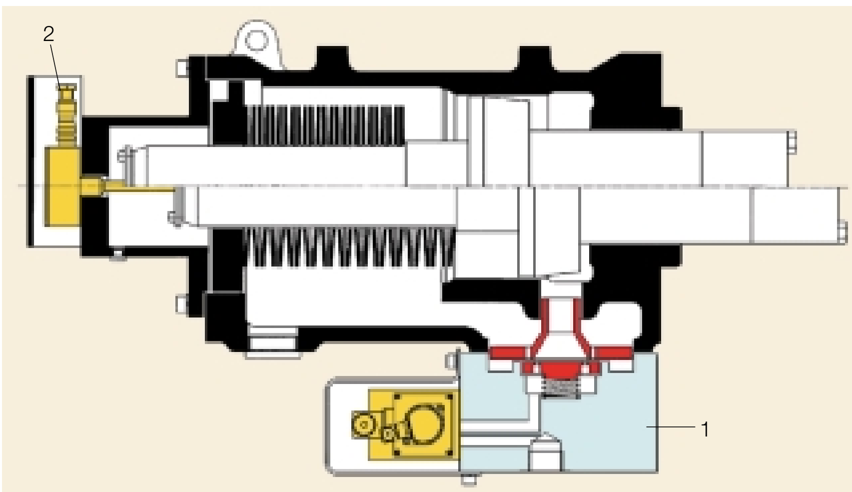


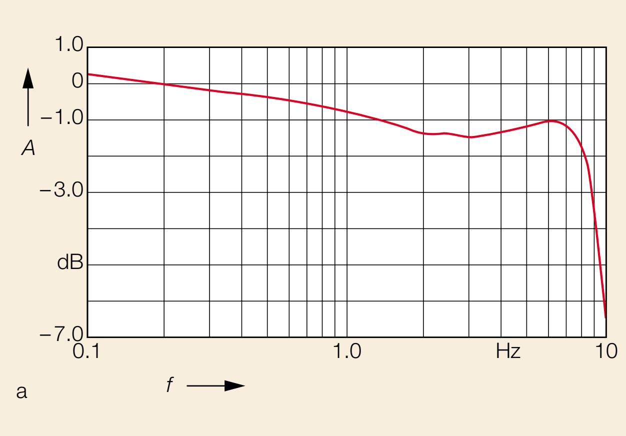

**6** ***Block diagram of the Turbomax thermal stress calculator. This module ensures the fastest run-up and loading times whilst keeping thermal stresses to a minimum.***

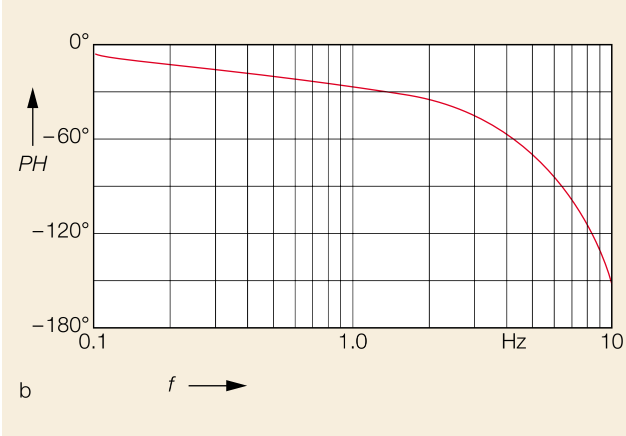
| | | | |
|---|---|---|---|
| $\vartheta$ | *Temperature* | G | *Trip limit (green)* |
| $\vartheta_1$ | *Rotor surface temperature* | R | *Control limit (red)* |
| $\vartheta_m$ | *Mean rotor temperature* | OS | *Operator station* |

**7** ***Replacing an existing actuator with built-on electro-hydraulic converter (EHC)***

1 *EHC block*
2 *Stroke transducer*






***Amplitude ratio (a) and phase position (b) for an input amplitude of ± 5 % and a stroke of 50 %*** **8**

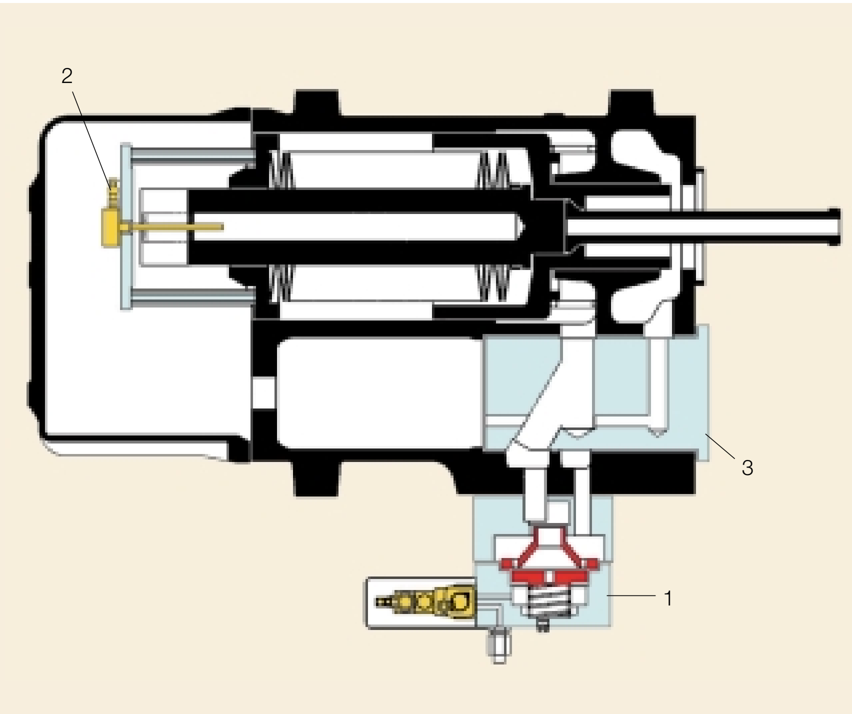
*A Amplitude ratio* *PH Phase position* *f Frequency*

the hydraulic and pneumatic systems can be dismantled, making the system simpler.

- The dynamic response, the quality of the control system and the run-up and loading procedures (Turbomax) are improved **6** and **8**.
- Improved operational flexibility and ease of maintenance.
- The cost of maintenance and overhauls as well as the size of the spare-parts inventory can be drastically reduced.

***Conversion of an existing actuator in the plant. A stroke transducer is fitted in place of the mechanical feedback device.*** **9**

1 *EHC block* 2 *Stroke transducer* 3 *Adapter piece*




## Modernization of the turbine protection

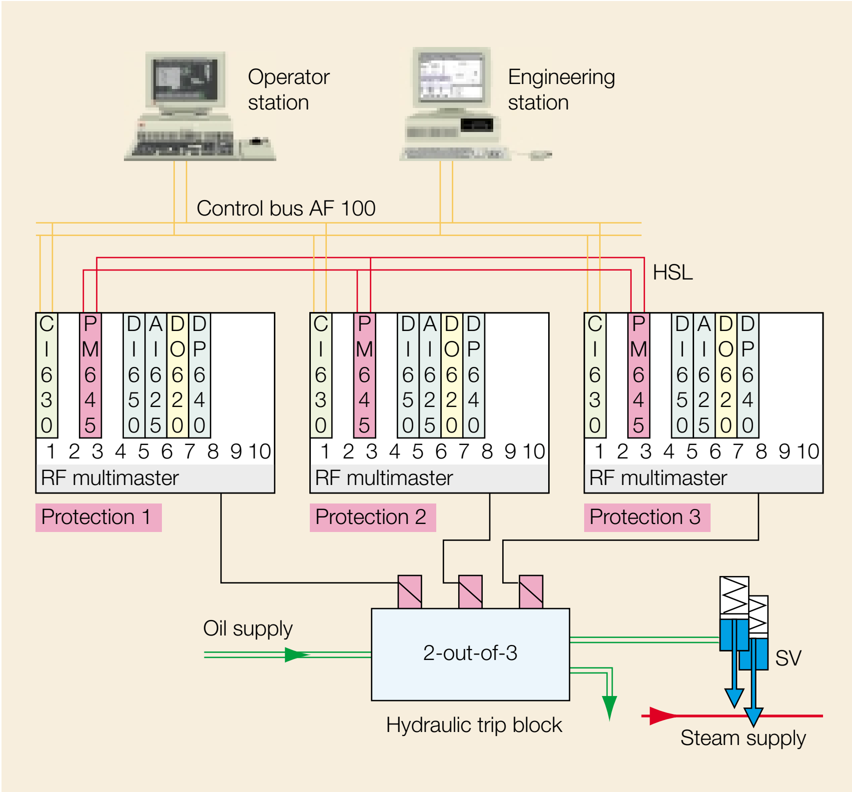
When requested by the customer, the safety system of existing turbines can be modernized at the same time as the control system in order to improve the availability of the turboset. This involves replacing the mechanical overspeed bolts by an electronic protection system in a 2-out-of-3 configuration **10**. Another possibility is to have a mechanical overspeed protection channel run alongside the new electronic protection. Modular, proven solutions and components are used for protection system retrofits. The modules and components are the same as those used in new installations, irrespective of whether ABB or non-ABB turbines are being modernized.

## Control system concept and solutions

Three-channel redundancy with 2-out-of-3 selection is used to provide maximum safety and availability, single-failure tolerance and the option of on-line testing. The turbine protection concept is based on a 'fail-safe' design to ensure that single failures cannot cause a dangerous plant condition to develop.

Data communication between the three processor modules, configured to provide 'station redundancy', takes place over a high-speed link. This link transmits data between the three stations such that each protection station receives the limit values from the other two channels. A 2-out-of-3 selection is made in each channel and the result compared with those from the other two protection stations. Each protection channel sends the result of the evaluation independently as a binary signal to the 2-out-of-3 solenoid block.

Each of the three electronic channels of the safety system is fed via separate automatic circuit-breakers from the central 24-V control voltage system, which receives its power from two independent DC voltage sources via diodes.




***The availability of the steam turboset can be improved by upgrading the safety system at the same time as the control system. This involves replacing the overspeed bolts by an electronic protection system in a 2-out-of-3 configuration. The modules and components are the same as those used in new plants, whether ABB or non-ABB turbines are being retrofitted.*** **10**

HSL *High-speed link*

SV *Stop valve*

### Overspeed protection

The overspeed protection is provided by specially designed pulse-counting modules (DP640). Each of the protection channels has one of these modules, which measures the pulses coming from the speed probe and opens a circuit-breaker the moment a predefined limit value is exceeded (eg, 110 % of the nominal speed). This overspeed trip setpoint is stored in a non-volatile EPROM on the DP640 module. The conventional trip signal of the protection channels, which is formed from the limit values of the other measurements, is sent via the DP640 circuit-breaker to the solenoid hydraulic block in a 2-out-of-3 configuration.

The probe or speed-sensing module of one channel can be replaced on-line, with the overspeed protection still active.

### Safety system, hydraulic/mechanical systems

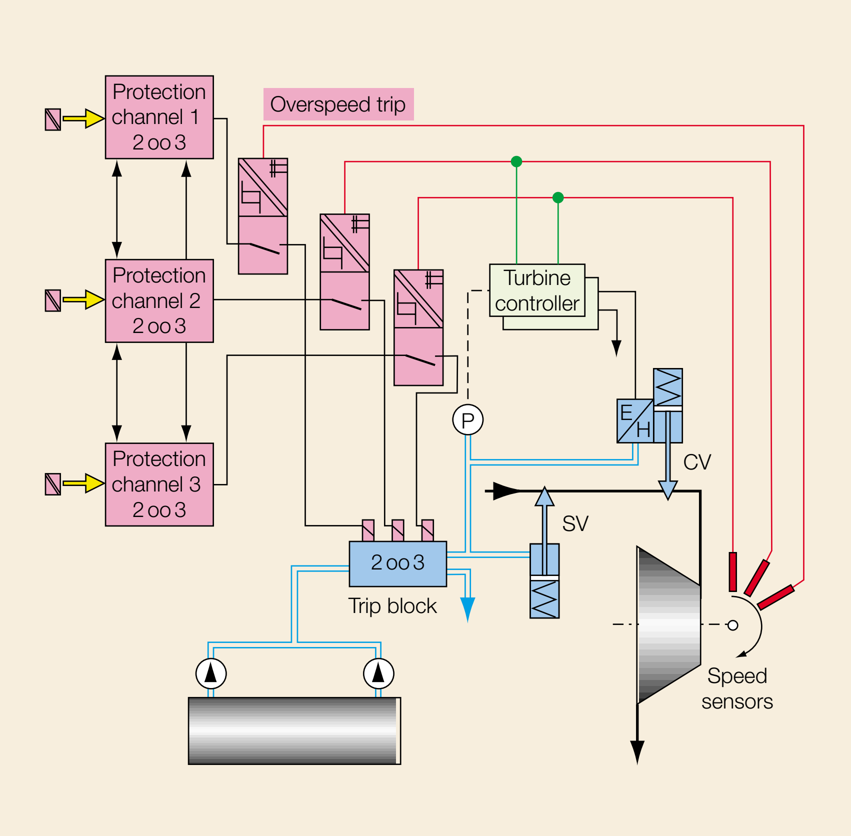
The 2-out-of-3 trip block in existing hydraulic systems is also retrofitted. This block is the link between the electronic and the hydraulic safety system. The 2-out-of-3 circuit is implemented in the hydraulic part, so that the entire safety chain can be tested. The trip signals are led to the solenoid valves, which are connected in a normally energized 'fail-safe' circuit. By optimizing the functional reliability of the hydraulic components, ABB more than compensates for the theoretically slightly poorer reliability of the 2-out-of-3 circuit compared with a 1-out-of-2 circuit.

The output of the 2-out-of-3 trip block is connected to a sequence valve. This enables a so-called '2-pipe system' to be used in new plants, ie the hydraulic safety system previously used is combined with the hydraulic feed system. The task of the sequence valve is to prevent surging during filling of the empty hydraulic pipes.

### Benefits of modernizing the turbine protection

The advantages of upgrading the turbine protection are:

- Numerous mechanical-hydraulic relays and test devices are eliminated.
- The complex readjustment of the mechanical overspeed protection that




***The ABB turbine retrofit concept ensures that the control system for the hydraulic solution is adapted in a way that ensures its optimization.*** **11**

CV *Control valves*
SV *Stop valves*

2 oo 3 *2-out-of-3 selection*

is necessary after overhauls is avoided.

- The entire safety chain can be tested.
- A defective tripping channel can be repaired on-line.
- The availability and ease of maintenance are improved.
- The spare-parts inventory is reduced in size.
- No surging in the hydraulic system after re-arming of the safety system and during filling of the hydraulic pipes.

**Turbotrol 8 retrofit of the turbine control system**

Although the turbine control and protection can be considered as separate modules and have been described as such in the above, a look at the mechanical components as a whole shows that together they form a single unit in which the protection and control modules have to be carefully matched to each other.

**Example of a steam turbine control and safety system upgrade**

**Installation before upgrade**

*Turbine:*
1300-MW (cross-compound unit)
Boiler: Coal-fired
Commissioned: 1972
*Control:*
Mechanical-hydraulic, closed-loop system with motor-driven setpoint adjuster
*Automation:*
Automated function groups with Turbomat
*Reason for retrofit:*
To increase availability and tie the machine control into a higher-order control system

**Conversion**

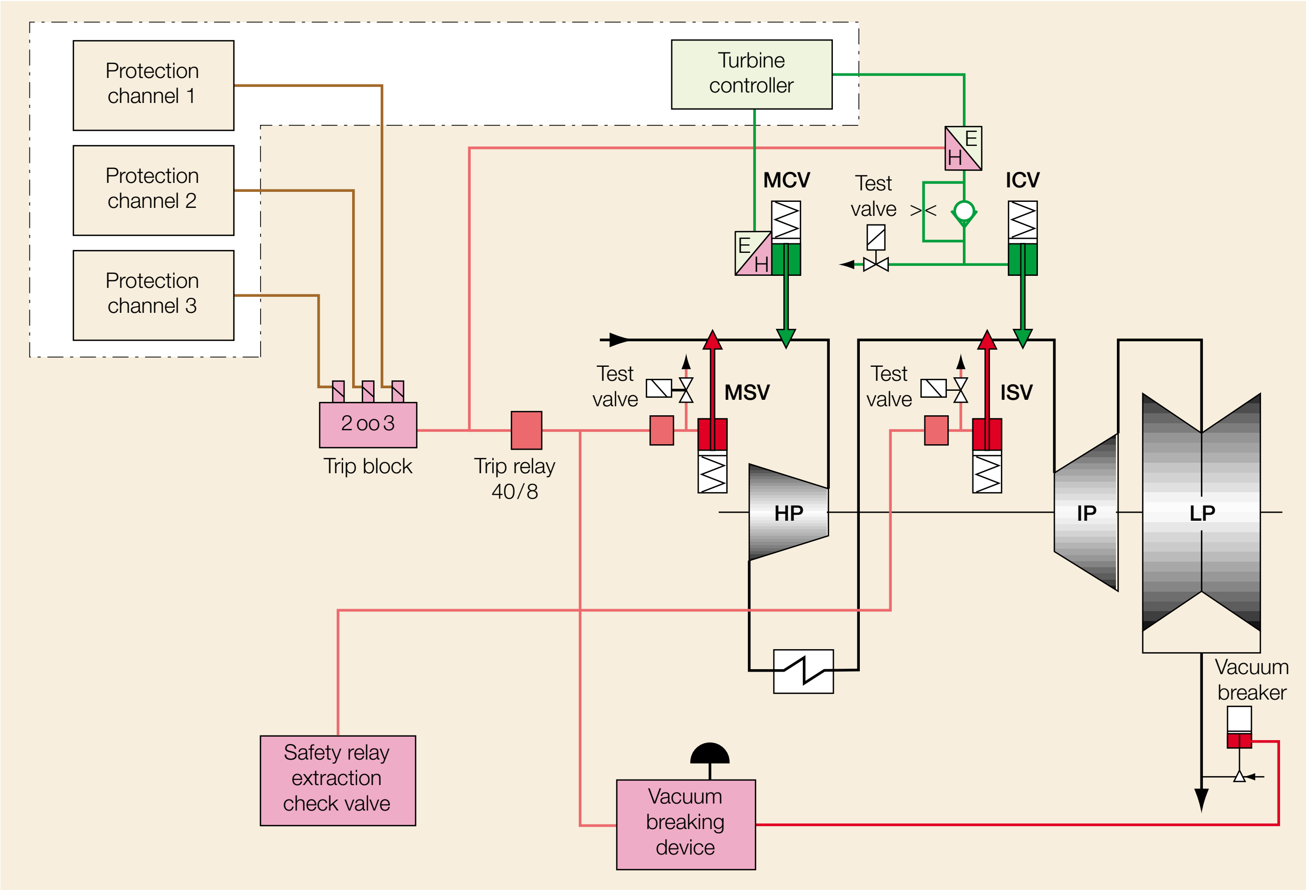
For this project, retrofitting of the higher-level control system includes the latest ABB system improvements in the area of electro-hydraulic control and protection. The live-steam valves receive new actuators and the mechanical-hydraulic control, safety and test modules, all implemented in Turbotrol 8 technology, are replaced.

**Tasks taken over by electronic control & safety system**

- Closed-loop speed control in no-load operation
- Load/frequency control
- Coordination with the higher-order unit control system
- Live-steam pressure control
- Calculation of thermal stress (Turbomax)
- Condenser pressure limitation with protection
- Overspeed protection
- Acceleration limitation for both shafts
- Linearization and optimization of the valve characteristics

**I&C system**

The new turbine control system is accommodated in two Advant Power cubicles, the turbine closed-loop controller being installed in one cubicle and the three turbine protection stations in the other.




***Optimized circuit for an upgraded control and safety system. The drawbacks of the mechanical components have been eliminated and the interface to Turbotrol 8 adapted accordingly.*** **12**

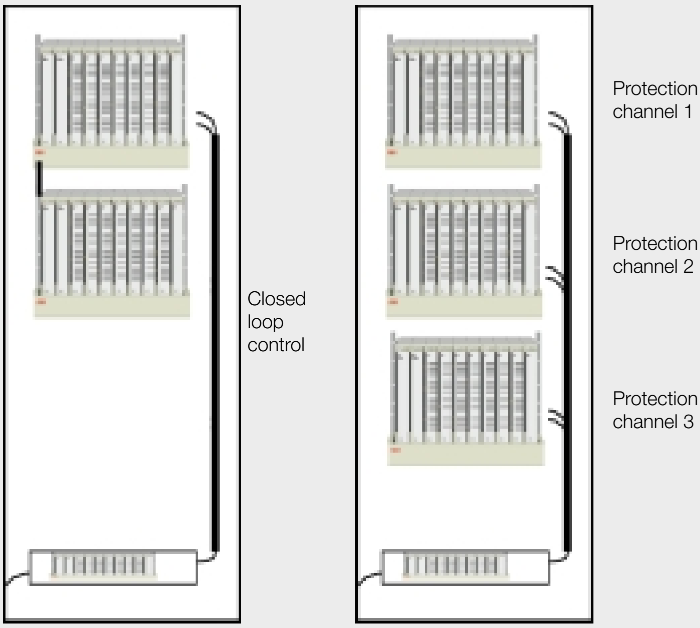
2 oo 3 *2-out-of-3 selection* *Other notation, see Fig. 1*

**Closed-loop control system**

The HP turbine has four inlet valves, the actuators of which are equipped with integrated electro-hydraulic converters. The turbine controller controls each of the valves separately via a position set-point. This enables the smooth running of the valves to be tested separately by means of the turbine controller.

**Time schedule for the retrofit**

The function-tested control and protection system was delivered just 9 months after receipt of the order. The installation of the system took approximately 2 weeks. Commissioning took place during the re-start after an overhaul of the steam turbine.




***Two Advant Power cubicles accommodate all of the equipment belonging to the new turbine control system.***

In the turbine retrofit concept, the control system and the hydraulic solution are therefore adapted in a way that ensures an optimum unit, without bottlenecks or weaknesses **11**. The chosen concept even ensures that during the development of the electronic modules user-specific profiles are specified for optimizing the integration in the turbine control system.

Experience has shown that an optimum result can only be achieved through across-the-board collaboration between the two disciplines, ie involving both the mechanical and the electronic retrofit. A major user-benefit results when the upgrade can be offered as a single, complete package, with only one supplier interface.

**Summary**

To date ABB has modernized over 50 steam turbines, including non-ABB units, to customers' requirements [5, 6, 7]. Standardized retrofit packages are defined for units in ABB technology, the interfaces between existing and new equipment being given special attention during the upgrade. A typical, optimized circuit for an upgraded control and safety system is shown in **12**. In this solution, the existing drawbacks of the mechanical components have been eliminated and the interfaces to the Turbotrol 8 system adapted accordingly. Mechanical-hydraulic components used for retrofits and in Turbotrol 8 are proven and are used widely in ABB's new plant business.

Since the retrofitted installations can be quickly got back on stream, payback of the capital investment begins immediately, eg in the form of lower operating costs due to shorter start-up times and a better heat rate during part-load operation – the result of the increase in the number of optimal valve points for turbines with a control wheel.

Furthermore, planning, delivery and installation times are short, enabling utilities to profit from the advantages of automation, eg reduced component wear and increased availability and reliability, in the shortest possible time. Installation and commissioning can be carried out during a routine overhaul.

A liberalized electric power market will change the dynamic requirements of power plant control. Quick load changes, as demanded by the grid, and load reduction and shedding to house load must be possible. The electro-hydraulic actuators that ABB uses for its turbine control valves have the dynamic properties needed to perform these tasks without having to add other hydraulic devices.

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