Turbine Control System
ME 4012

Application Report

- Turbine Speed and Power Control
- Electronic Turbine Protection
- Turbine Auxiliary Systems
- Turbine Operating Modes
- Process Control System: Features

Introduction to Digital Turbine Control with ME 4012

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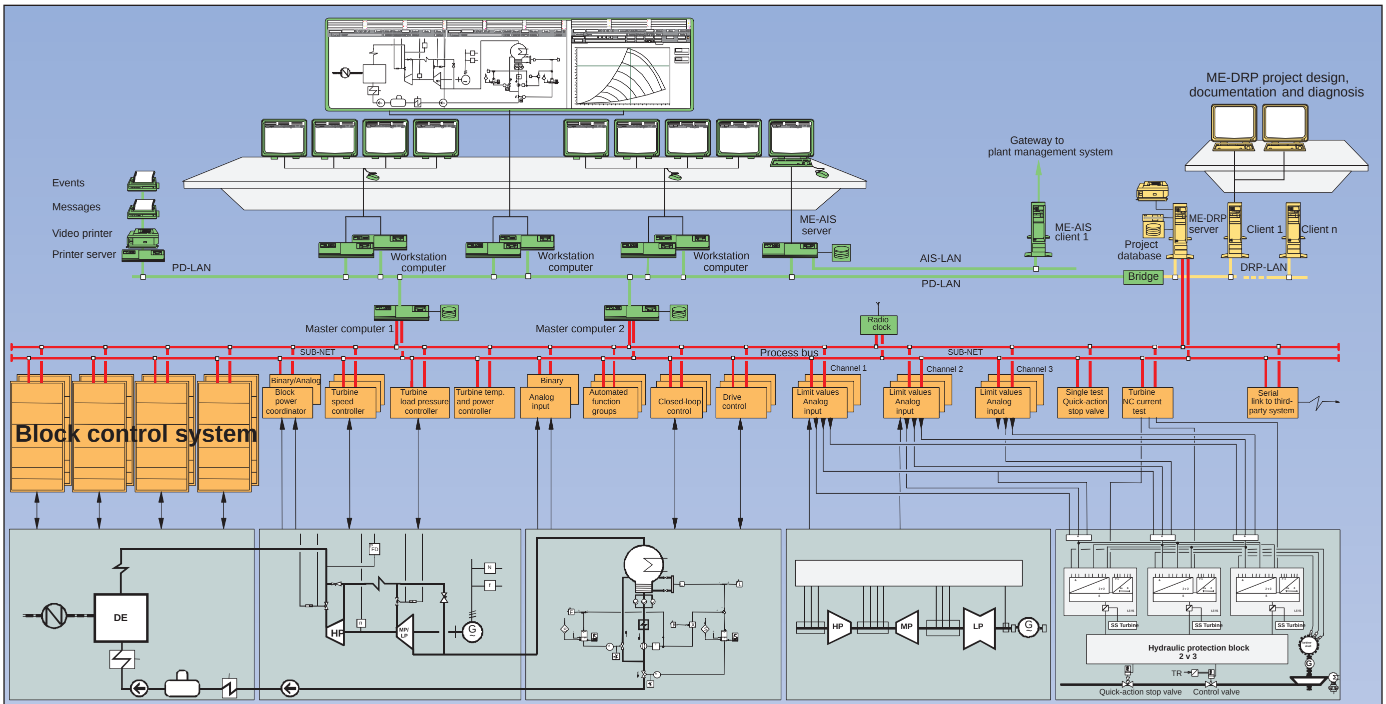


Steam generator
- Coaling, pulverization
- Air / flue gas
- Coaling (fail-safe)
- Feed -water
- Superheater
- Condensed steam
- Long-range energy branch
- House service

Auxiliary plants
- Flue gas desulfurization
- DeNOx, NH_3 tankage
- Water treatment
- Condensed steam treatment
- Coal, lime supply
- Ashes, gypsum disposal

Turbine controllers
- Speed and speed master controller 1v2
- Power and power master controller
- Live steam prepressure and limit pressure contol
- Hot reheater accumulation control
- Heat extraction control
- HP / MP coordinator
- Valve positioner HP, MP/LP
- MP bypass control with pressure and injection control

Turbine temperature and power controller (TLFG)
- **TFD** ,**TZÜ** and turbine power
- Transient limiting
- Logging and reporting

Block power coordinator
- Setpoint control Steam generator
- Setpoint control Turbine

Turbine auxiliary plants
Closed-loop control
- Gland steam pressure control
- Gland steam temperature control
- Bearing oil temperature control
- Condenser level control
- Condenser minimum quantity control
- Generator auxiliary control circuits

Function groups
- Function group Cooling water
- FG Condensed steam transport
- FG Bearing oil, actuating fluid and rotary mech.
- FG Evacuation
- FG Blocking steam
- FG Bleeding
- FG Water extraction
- FG Turbine control

Turbine monitoring
- Shaft oscillation
- Bearing housing oscillation
- Relative expansion
- Shaft position
- Absolute expansion
- Axial thrust

Turbine load current protection
- Dual-channel
- Dual-channel processing
- Trip criterion 1v2

Single test Quick-action stop valve

Turbine no-load current protection
- Overspeed
- Condenser pressure
- Bearing oil pressure
- Tank protection
- Generator protection
- Tail blade protection
- Shaft position
- HP outlet temperature

Sensor and processing 2v3, trip NC current 1v2

Protection monitoring No-load current
- Electronic protection system
- Hydraulic 2v3 protection block
- Single test Quick-action stop valve
- Single test Control valve

Uniform and coherent digitale turbine control with ME 4012

ME 4012 system cubicle with digital turbine controller and digital turbine protection

Power station technology has - just like all other engineering branches - undergone an enormous technical change over the last two decades. Especially in the field of steam turbines, new developments based on the latest findings on the strength and long-term behaviour of materials, on flow dynamics and on mechanical design have turned the relatively simple turbine of the past into a high-tech unit. This advanced complexity in power station technology puts an even greater demand on operational safety, plant availability and the service life of the turbine.

With our ME 4012 process control system, we offer a digital turbine controller that meets these strict requirements. The ME 4012 turbine controller is capable of observing each single aspect of the complex turbine process, and controlling it with very high accuracy within specified ranges. Our technology is in line with the stringent requirements laid down by the DVG guidelines, the former National Association of German Electricity Network Operators, now known as VDN. (See http://www.vdn-berlin.de). Supervisory automated function groups ensure optimum interaction of the individual control processes and smoothly integrate them into the overall power station scheme. This means that the turbine plant - which is after all an installation of huge capital expenditure-, can be operated safely and economically far into the future.

For safe, reliable and efficient operation and control of the power station's turbogenerator set, the ME 4012 process control system has to meet very specific requirements for its five principal operating states:

- Start-up and synchronization
- Loading and power generation, taking into account network regulator and frequency influencing quantities
- Controlled deceleration and securing station services at load shedding
- Load ramp operation
- Shut-down

During turbine control, the ME 4012 process control system continuously monitors the actual status of the plant so that changes can be detected. This provides information from which conclusions about optimum plant operation can be drawn so that necessary adjustments can be made.

The employment of leading edge turbine control technology ensures:

- Highest possible plant and operational safety
- Highest possible plant availability
- Minimum wear and tear on equipment
- Maximum service life of the turbine
- Complete integration of turbine control in the supervisory plant control system and easy operator control
- Maximum depth of fault diagnostics and easy system maintenance
- Longer service intervals

Future-Oriented Digital Turbine Control

With the development of a digital turbine controller, the automation and process control experts at Mauell GmbH have truly created a first. Their creation was the result of many years' experience accumulated in the field of process control and the related subjects of

- Systems development
- Project planning and design
- Components and systems manufacturing
- Systems assembly and on-site erection and installation
- Commissioning and technical training

This focus on the total integration of individual ME 4012 control functions into a complete power station control system has yielded an efficient and consistent control philosophy that can be applied to all sections of power station unit and turbine generator control.

ME 4012 process controls are particularly suited for applications with extremely high demands on turbine control criteria, such as:

- Controller cycle time (e.g., for turbine speed control)
- Accuracy of measurement (e.g., for frequency and speed measurement)
- Safe signal and information processing for electronic turbine protection

Essential parts of the ME 4012 turbine control system are:

- Turbine controller (speed, power and live steam pressure)
- Turbine Temperature and Power Reference Control Unit (TPR unit) for the calculation of temperature and power transients
- Open circuit turbine protection (material vibration, expansion, temperatures)
- Failsafe turbine protection (overspeed, generator and boiler protection, emergency shut-off)
- Turbine auxiliaries (measurement, drives, HP/IP bypass station control, function groups)
- Failsafe protection for HP and IP bypass stations
- Continuous self-test of open-circuit and failsafe protection systems
- Turbine control room (monitoring, operator control, message and alarm logging)
- Fault diagnosis, configuration and documentation at one central point
- Interfacing to station unit equipment via SUB-NET process bus, serial connection to third-party systems

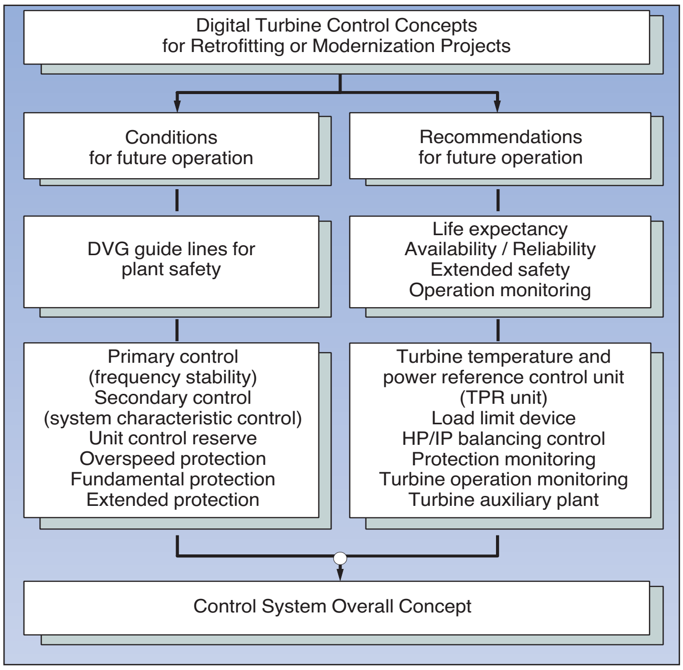
ME 4012 provides the power station industry with a turbine control philosophy that offers uniformity and coherence in all parts of the control system, namely in:

- System hardware
- Firmware
- Documentation
- User interfaces

Consistent and efficient automation, reliable process monitoring and convenient operator control – these are characteristic ME 4012 features in all phases of the power station process including:

- Steam generation
- Turbine generator set
- Auxiliary installations for plant operation and pollution control

The concept of integrating all control aspects into one consistent control strategy for the entire turbine plant can be applied to retrofitting projects as well as to new turbine plant developments of any size and power capacity. Existing plant operation strategies and control schemes can be transposed to new technologies and enhanced with new control algorithms.



The Turbine Controller

The turbine controller is a task-oriented configuration using standard software function blocks of the ME 4012 process control system. Its modular design allows single-channel structures for the control of industrial turbines as well as dual-channel structures with bumpless changeover for power station turbines.

Functions of the turbine controller

- Measured data conditioning
- Speed control
- Pressure control
- Power control
- Coordination of the HP and IP turbines
- Valve positioning control
- Control logics
- Message generation and alarm annunciation
- Operator guidance

Special features of the turbine controller

• Controller cycle time	2 ms, typical
• Controller response time	5 ms, typical
• Speed signal resolution	0.5 mHz
• Speed measurement accuracy	2 mHz absolute, at 50 Hz

Turbine Temperature and Power Reference Unit (TPR Unit)

The Temperature and Power Reference Unit (TPR unit) reads a number of process quantities, such as steam pressure, steam temperature, turbine valve positions and turbine speed, and calculates thermal stress values on the basis of these input quantities. It then compares the results with the admissible stress parameters defined for the high pressure and temperature components of the turbine which are subjected to the highest strain (i.e., the turbine shafts). The TPR unit controls the rate of change of the steam temperatures (i.e., of the live steam and intermediate superheater steam) and the rate of change of the turbine power such that the limit strain values are never exceeded. This ensures optimized turbine operation while at the same time taking into account thermal stress limitations associated with the turbine with the aim to avoid thermal stress-related fatigue and achieve the envisaged service life of the turbine.
As the hardware of the TPR unit is installed in the turbine controller cubicle and directly connected to the process bus, it is optimally integrated in the overall control strategy of turbine operation.

The Temperature and Power Reference Unit comprises:

- Industrial computer
- SUB-NET process bus connection through the serial interface to the turbine controller CPU; this connection handles all process data acquisition and control command output
- Hard disk
- Monitor and keyboard connection (for system administration and parameter setting only)

Turbine Auxiliaries Control

In addition to the automatic control of turbine speed and power, the turbine auxiliary equipment plays an important role in ensuring efficient and safe turbine operation. These auxiliaries are basically in charge of the following tasks:

- Gland steam pressure control
- Gland steam temperature control
- Control of high pressure (HP) and intermediate pressure (IP) bypass stations

These separate control and automation tasks are solved by standard modules of the ME 4012 process control system. They are smoothly incorporated into the overall turbine control scheme to provide a fully integrated control solution.

The auxiliary system comprises the following modules and facilities:

- Field units for process data acquisition
- Field installations and cabling
- Measured value conditioning
- Binary signal conditioning
- Drive control
- Closed-loop control and power actuators
- Failsafe modules with type approval
- Message generation and alarm annunciation
- Automated function groups
- Operator control, logging and reporting facilities

These control components and modules fulfil the following principal tasks:

- Closed-loop control of the turbine auxiliary servo loops
- Control of the auxiliary drives
- Failsafe protection for the HP and IP bypass system
- Automatic function groups to ensure controlled operation
- Operator guidance
- Operator control and plant monitoring in a central control station

Turbine Operation Monitoring

Turbine operation is monitored by the following functions:

- Measured value conditioning
- Signal evaluation and limit value generation
- Display of measured values, message generation, alarm annunciation

Amongst others, the following process parameters are monitored:

- Shaft vibration (eddy current measurement in x and y directions)
- Bearing vibration (seismic sensors)
- Relative/absolute expansion (expansion and distance sensors)
- Shaft position (distance and eddy current sensors)
- Axial thrust (evaluation of strain gauges)

Electronic Turbine Protection

The electronic turbine protection system monitors all process criteria that may cause damage to human life or plant equipment. Turbine operation is interrupted as soon as one of the critical values is found to be out of the permissible range. For best meeting the stringent demands on turbine reliability and availability, the protection criteria are grouped according to the guidelines issued by the German VGB PowerTech Association (Guidelines VGB-R103-M "Supervision, Limiting and Protection Devices in Steam Turbine Units", see http://www.vgb.org). Protective tripping acts onto all shut-off and control valves as well as onto all controlled stop valves (i.e. non-return valves).

Electronic turbine protection is structured into the following protection groups:

- Overspeed protection, 3 channels
- Limit value generation and signal logics
- Failsafe trip signal generation (i.e., the trip relay is energized under normal conditions and de-energizes upon alarm or upon loss of power)
- Online test facilities for all protection components

These facilities fulfil the following tasks:

- Overspeed protection
- Basic protection
  Bearing oil and condensate pressure, shaft position, LP end blade protection, boiler protection, generator protection, Emergency Stop, HP outlet temperature
- Extended protection
  Shaft vibration, relative expansion, bearing temperatures, exhaust steam temperatures, temperature differences between HP and IP turbine casings

All signal processing is protected by a safe and available 2oo3-type protection scheme (i.e., 2-out-of-3 reliability). In this scheme, the trip criteria of the basic protection level and those of the extended protection level (i.e., the signals generated by the failsafe overspeed protection module) are logically linked with the trip signals generated by the overspeed relays. In retrofitting or modernization projects, a 2oo3-type hydraulic block is installed. It has the purpose of converting the electronic signals into a hydraulic control signal which controls the spring-powered shut-off and control valves. In newly built installations, it is more economical to use 2oo3-type power electronics to directly control the bypass solenoid valves (2 channels for each shut-off and control valve). A test program allows channel-by-channel online testing of the entire failsafe protection scheme, inclusive of the trip action for the shut-off and control valves. The test covers both the electrical and hydraulic operation and can be carried out at any time without affecting running turbine operation.

Operator Control and Plant Monitoring

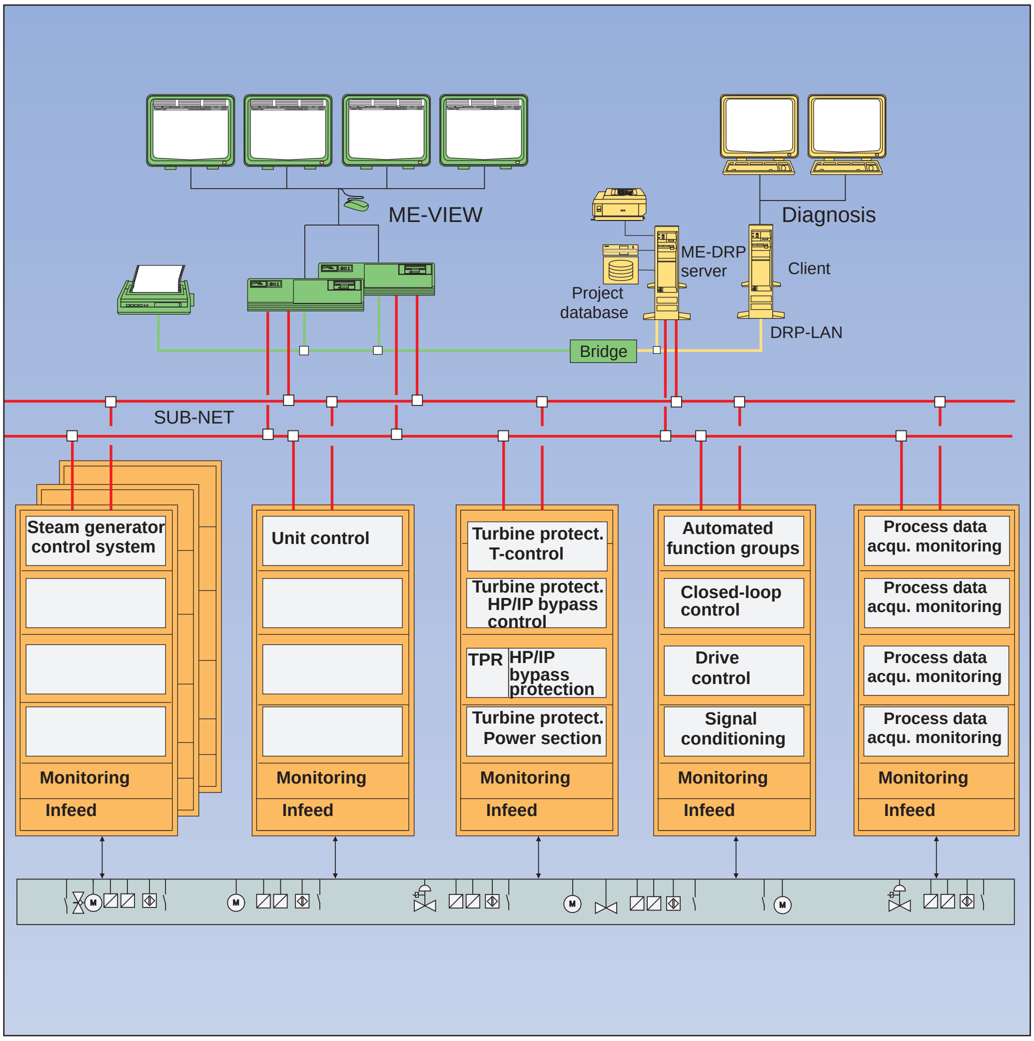
One of two different approaches can be adopted for operating and monitoring the digital turbine control system:

1. Use of the Mauell-T-LT system, employed as an autonomous ME 4012 process control system with serial connections to the third-party supervisory unit control system.
2. Use of the Mauell-T-LT system, employed as an integral part of the supervisory unit control system.

The integrated approach offers a number of advantages over the autonomous ME 4012 control system such as:

- Identical configuration methods and tools throughout the system
- Identical plant documentation
- Consistent alarm and message processing, alarm logging and reporting
- Identical graphical user interface and operator control concept
- System configuration and fault diagnosis at a central point

The use of a local ME-VIEW operator station is a cost-effective solution for on-site operator control and plant monitoring.



Overview of the hardware of the ME 4012 control system for steam turbogenerators

The success of digital control of steam turbines in the 9 to 600 MW range is based upon standard components of the ME 4012 process control system. The automatic controller of the ME 4012 system can be installed in new turbine installations as well as in retrofit projects.

Principally, the turbine is controlled by the quantity of live steam fed to the HP turbine. If the turbine is of the intermediate superheating type, then control also considers the quantity of the superheated steam fed to the intermediate and low-pressure parts. Servo-hydraulic actuator drives implement the control action.

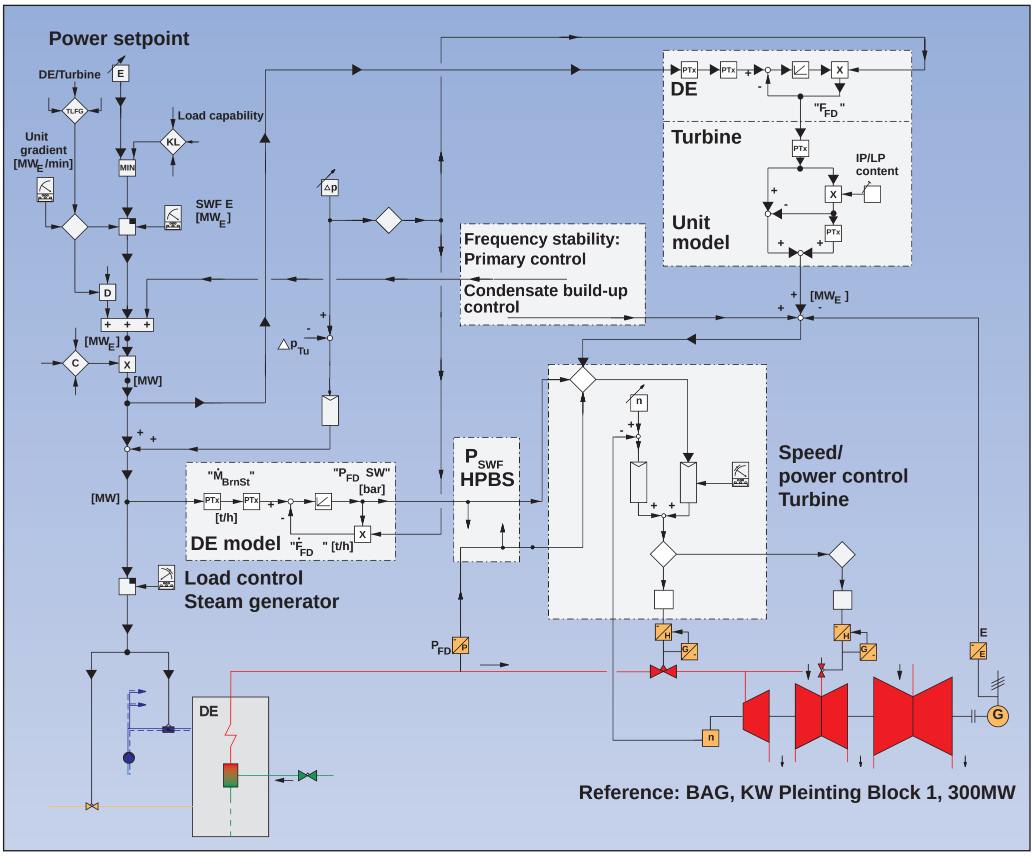
The closed-loop control strategy described in this application report has been applied to a condensing turbine with superheating. It runs on the ME 4012 process control system and uses ME 4012 standard function blocks as well as function blocks specifically developed for highly dynamic processes. The completed configuration of the software controller and the turbine controller hardware can be tested on a unit simulation device. The ME 4012 controller also allows automatic control of other turbine types, such as back-pressure turbines, bleeding turbines, tapped back-pressure turbines, condensing turbines and tapped condensing turbines. The multi-variable control rule is always designed according to the German VDI/VDE guidelines, no. 3521, sheet 3.

The Control Strategy

Of course we cannot look at the turbine as an isolated self-contained entity. On the contrary, a turbine set must be considered as only one component of the technological process of a power station and as such it forms an integral part of the overall dynamic process consisting of the steam generator and the steam turbine, each with their auxiliary plant.

Now, let us have a closer look at a control strategy that produces optimum dynamic results of the entire process, both at sliding and constant pressure operation. The approach described in the following also allows the optional change to pre-pressure control which is required when the pressure must be kept constant at a precise value.

Valve position control offers the additional benefit of allowing selection of specific valve points, which is required particularly for turbines with stage valves or for constant-pressure controlled turbines equipped with a regulating wheel. Reduced wear and tear and improved heat consumption are the main advantages of this control method. However, if this way of setting the valve points goes hand in hand with the admission of a pre-pressure or power controller, then this would inevitably lead to instabilities.



Unit load and power control with modelling for steam generator and turbine

In our example, the steam generator is controlled by a power controller which is capable of providing the required transfer power of the unit at a sufficient precision. U.S. technical literature refers to this type of control for power station units as "turbine follow mode". To date, for the control of drum-type boilers, turbine follow mode is applied much more frequently than the better known "boiler follow mode" usually applied in the control of forced flow-through boilers (also known as Benson boilers).

Today, digital process control systems such as ME 4012 allow us to implement the simulations of fairly complex controlled systems and elaborate control algorithms. This method yields the required maximum dynamic response while at the same time reducing the strain on the high-pressure power station components. Such implementations could for instance be the import and export processes that may be caused by fluctuations in the grid frequency, or that may even be desirable in the event of scheduled load changes. In addition, digital control allows selective intervention and adjustment of turbine valves in the event of fuel problems in order to restore process stability.

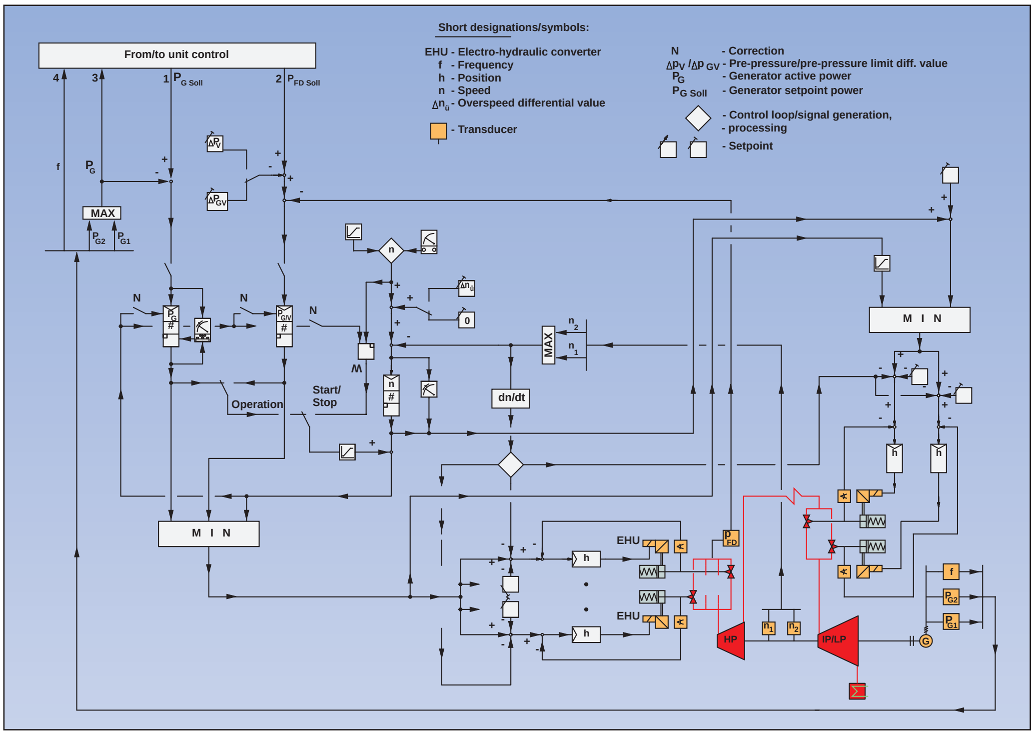
During the start-up phase of the steam generator and turbine units -which is the initial non-coordinated operating phase- a start-up regulator controls fuelling in order to run the steam generator up to the required start-up power. At the same time, the turbine set is warmed up and run up to its nominal speed, and the start-up control of the HP/IP bypass system ensures the superheater through-flow required for boiler start-up.

After grid synchronization, the generator is started under load by applying a target power value to the setpoint transmitter of the unit coordinator. As a result, the base power value in the coordinator changes in line with a permissible transient value generated at the transient selection point until finally the predefined target power is reached.

This transient selection restricts the preselected power transient by applying external influencing quantities, such as the permissible steam generator and turbine transients. The turbine transient is calculated by the Temperature and Power Reference Unit (TPR unit) on the basis of the stresses measured in the HP and IP turbine rotors. If the power setpoint of the unit exceeds the volume of the start-up fire during start-up under load, then the HP bypass unit closes and the power between steam generator and turbine continues to rise in a coordinated manner. Now, this has the effect of changing the power setpoint for the turbine on the basis of an observer model in line with the dynamical behaviour of the steam generation process in the steam generator.

The load controller responsible for fuel control receives the controlled variable _p. The control valve of the HP turbine and the power controller of the turbine (using two transducers for the generator power) compare the actual power derived from the steam generator observer with the generator power. For load ramps that are in line with the schedule there is no deviation, unless the comparison of a boiler model with a boiler observer has produced a difference. Such a difference could lead to the conclusion that there is a deviation in the calorific value of the fuel. In this case the power controller follows up.
If the accumulated steam of the live steam system is to be utilized for scheduled load ramps, the turbine governor valves can be pilot controlled accordingly. However, a live steam accumulation model placed at the comparator of the boiler load controller compensates for the excess power that is dynamically generated by the live steam released from the live steam accumulator. The result is merely an offset of the power release; later -at steady state operation- there will be no need for larger quantities of fuel.

The behaviour of the frequency influence required for maintaining network stability is similar. Therefore, the frequency influence which can be suppressed in some load situations (e.g., low load), is added to the unit setpoint and fed to the boiler and turbine units, directly and without delay. In this process, the utilization of accumulated live steam is desirable and enhances network stability. However, in those phases in which steam production has not yet reached the new power setpoint (derived from unit setpoint and frequency influence) due to the slower dynamic response of the steam generator, the effect of the frequency influence upon the deviation of the live steam pressure can be limited such that no unwanted operational states occur.



Turbine speed and power control

At the same time, the dynamic part of the setpoint power derived from the frequency deviation is fed through a steam generation model and added to the output of the steam generator observer whose only purpose is to process the changes of the base power value of the unit. In this way, the pressure setpoint necessary for the current operational status is calculated.

In the event of fluctuations in the grid frequency, the turbogenerator set contributes to the restoration of frequency stability by means of primary control. The frequency deviation is fed to the turbine controller such that there is a linear relationship between the actual power and the frequency. If the grid frequency and, as a result, the turbine speed increase, the controller throttles the valve and consequently reduces the generator power. Should the grid frequency fall, the generator reacts by producing a higher output value than is set by the normal setpoint. The amount of contribution to frequency stability provided by the turbogenerator set depends on the slope of the frequency-power characteristics which can be set as proportional gradient.

This control strategy is thus based on the principle that the load controller which affects fuelling will only take action upon an actual change in the calorific value of the fuel, whereas changes due to dynamic processes in the network do not cause any change in the error signal of the power controller. To avoid the so-called "wrong control" effect it is therefore not necessary to replace the electrical power and instead calculate, say, the mechanical power of the turbogenerator set which must typically be obtained as wheel chamber pressure for constant pressure machines with wheel regulator, or by means of complex algorithms that compute the thermo-dynamical parameters.

Turbine Controller

The digital turbine controller is an integral part of the overall power station process. It complies with the DVG regulations (DVG=German Association of the Transmission System Operators) for feedforward control with bumpless changeover involving the output signals of the power, speed and limit power controllers.

Due to its high processing speed for analog process values, the multifunctional processor is used in turbine control for the implementation of complex control loop structures and arithmetic functions.

The extensive ME 4012 firmware library assists the process engineer in configuring the structures of the control tasks and transferring the configuration to the controller module. Dedicated function blocks, specifically developed for the control of power station processes, execute the complex control and arithmetic functions required for turbine control at extremely high speeds. Integrated analog and binary functions allow the logical interconnection of the turbine controller with the sequential control programs for turbine start-up, running up under load and shut-down. The controller is part of the redundant SUB-NET process bus system and fully integrated in the functional structures of the steam generator.

The turbine controller is of modular design and made up of standard modules of the ME 4012 process control system. Principally, it consists of a subprocessor module for information processing and of interface modules that handle the process signals coming from the plant I/O equipment. In addition, special control modules drive subordinated highly dynamic servo valves. The control strategy is based on the principle that each admission valve has its own servo drive. This concept allows easy controller adjustment to different configurations of the plant I/O equipment.

The turbine controller can be employed in a single-channel or dual-channel master/slave arrangement with bumpless changeover.

Its typical cycle time of less than 2 ms, its speed measurement accuracy of +/- 2 mHz (which corresponds to 0.004% approx.) at nominal speed, and its high signal resolution of 0.5 mHz make it the ideal controller for the following tasks:

- Maintaining frequency stability
- Attenuation of phase swinging and grid instabilities
- Logical combination (summation) of the power limiting controller and the speed controller
- Safe turbogenerator recovery maintaining unit service load in the event of disconnection from the grid
- Safe turbogenerator recovery at a selectable part load above the service load criterion
- Safe response to grid faults of any kind
- Deviation control and stabilization after jerky load changes of up to 10 % approx. of rated power during isolated operation keeping frequency deviations below 1 Hz.
- High sensibility of the speed governor for fast response to the slightest frequency changes during isolated operation

Design of the Turbine Controller

The turbine controller comprises the following components:

- Power supply (decentralized arrangement; installed on each processor module)
- Speed controller and speed master controller
- Power controller and power master controller (if not part of the unit control system)
- Pre-pressure controller
- Limit pressure controller
- Accelerometer for RPM measurement (with two speed measurement channels and maximum value selection)
- Pulse preamplifier for every RPM sensor at the turbine, with 3 decoupled output channels each
- HP/IP preset potentiometer
- Load limit device (HP turbine)
- Bumpless changeover from full-arc to partial-arc admission
- Valve position controller for the HP and IP control valves with cascaded voter circuit for the construction of redundant turbine controllers with bumpless changeover (1v2 configuration) to the other functioning I/O channel
- Test device for turbine controller (option)

The turbine controller is capable of driving each valve separately. This means, it can control the HP valves sequentially or in parallel mode, and in any random combination. The controller's highly sensitive position control for the admission valves ensures an extremely efficient and accurate transfer of the control dynamics to the actuating units.

The turbine controller is divided into two function sections:

- Speed control with integrated valve position control
- Power control / pre-pressure control

Additional functions can be implemented, such as:

- Unit power control
- Speed / bleed pressure control
- Speed / back pressure control
- Speed / pre-pressure control
- Bleed pressure / back pressure control
- Bleed pressure / pre-pressure control
- Back pressure / pre-pressure control

One part of the controller is reserved for time-critical functions. It is configured as a speed controller and fulfils the following tasks:

- Speed measurement
- Speed setpoint master
- Acceleration measurement
- Feedforwarding of additive and multiplicative correction signals to the controller output YDR
- Acquisition and processing of binary signals which are required as starting condition for the speed setpoint master controller.
- Manual/automatic sequence control logics
- Alarm acquisition and signalling
- Limit value processing and event time stamping
- Setpoint transfer to the integrated HP and IP valve position actuators (also referred to as 'valve positioners') for the following tasks:
- Actuator control for each servo drive without steady state error
- Position feedback with load independent current and normalization of rising or falling characteristics
- Selection of setpoint position by means of selectable max/min selection
- Linearization of the valve characteristics
- Bumpless change of the operating mode of several parallel-driven servo drives (full-arc/partial-arc admission)
- Valve check with selectable closing speed
- Control of electrohydraulic transducers with load independent current (4 to 20 mA)
- High-speed closing via cascaded intrinsically controlled cartridge valves
- Position measurement monitoring
- Alarm signalling and annunciation

The base speed controller has a special operating system which ensures a typical arithmetic cycle time of less than 2 milliseconds for all functions required for speed control.

The electrohydraulic transducers with integrated jitter voltage generation ensure highest precision in the control of servo control valves. Their power amplifiers are driven by standard 4 to 20 mA signals.

All other functional sections of the turbine controller are in charge of the following tasks:

- Power control, taking into account frequency influences
- Pre-pressure control
- Limit pressure control
- HP/IP balancing

The turbine controller is available in redundant master/slave configuration with hot standby for high availability.

Reliable I/O signal processing is a particularly important factor for the availability of the overall turbine controller system. Special emphasis has therefore been placed on the development of I/O modules with robust electronic characteristics that meet the high requirements in power station operation. For detailed specifications of the modules employed in the described turbine control project, please refer to chapter "System Hardware of the Digital ME 4012 Turbine Control System" at the end of this application report. However, the acquisition and processing of speed values will be explained in more detail on the next pages as speed control in particular puts a fairly high demand on input signal processing.

Firmware with Function Blocks

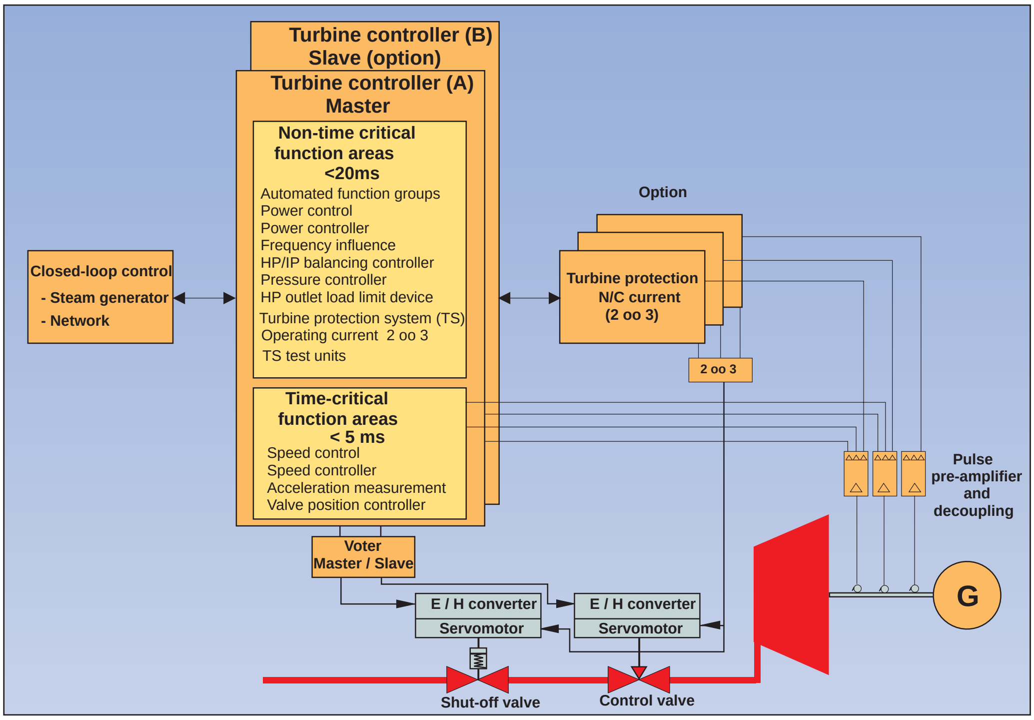
The configuration that implements the turbine control system was 'programmed' with the aid of function macros offered by the ME 4012 firmware library.

The process control engineer responsible for the turbine control strategy may decide to divide the controller into a slow and a fast acting function.

- Functional section for time-critical tasks (faster than 5 ms). This functional section is reserved for the control algorithms of the turbine speed control and of the individual valve positioners.
- Functional section for standard tasks. This functional section contains all the other control tasks, including the turbine protection system.

All configuration work and parameter setting can be done during online operation. Developing and expanding the configuration has no noticeable effect upon the cycle time of the fast-acting controller section.

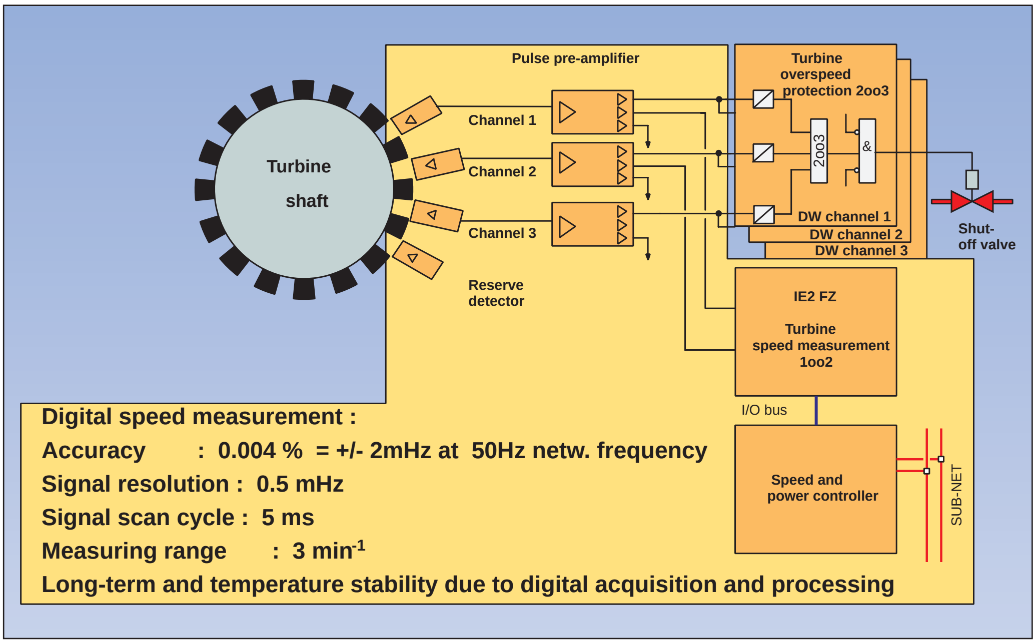
The possibility of carrying out all configuration work and parameter setting during online operation is of considerable importance for the different phases of commissioning, test runs and process optimization.



Master/slave turbine speed and power controller with functional sections for time-critical and slow control tasks

Digital Measurement of the Turbine Speed

The turbine is equipped with a trigger wheel for speed measurement. The trigger wheel's teeth are scanned by three separate magnetic pulse generators. The resulting signals are amplified directly at the point of scanning and then transmitted in the form of 24V square pulses to the turbine controller via screened cables. The frequency at nominal speed is approximately 10 kHz. Supply, protection and monitoring of the ISV3 preamplifiers installed in the vicinity of the machine are provided by the protected power supply of the turbine controller cubicle. The three pulse generator signal trains are decoupled and sent to the turbine controller, to the turbine protection facilities and to the independent turbine speed measurement facility, respectively..



Pulse signal acquisition with sensor /pulse pre-amplifier (three-channel, decoupled outputs) and signal conditioning for the areas turbine protection and turbine speed control

The IE2F2 Pulse Input Module

To obtain the turbine speed, the pulse trains produced by the three magnetic pulse generators are processed by a module that has special redundant pulse input channels. Should one of the speed transmitters fail, a MAX selection logic in the turbine controller ensures that the maximum value of each pulse signal train is read and passed on for further processing.

Efficient turbine speed control requires high-precision acquisition of the turbine RPM value. To ensure that the signals of the pulse generators reach the IE2F2 input module safely and free of noise, the signals are transmitted by screened cables at a signal level of 24V +/- 20%. The input channels of the IE2F2 module are designed for pulse frequencies in the range from 2 Hz to 500 kHz. At nominal turbine speed the frequency is about 10 kHz. The pulses are evaluated by a gating circuit which adjusts to the RPM value. Thus, if for instance the turbine speed is low, the speed is not measured by counting the scanned trigger wheel teeth in a specified period, but by letting a quartz-stabilised oscillator obtain the time between two leading tooth edges. To compensate for possible mechanical inaccuracies, this procedure is carried out over several tooth edges depending on the RPM value. For low turbine speeds, but particularly for very high turbine speeds, this procedure ensures a digital and very accurate speed measurement on the basis of the number of teeth of the trigger wheel.

The absolute accuracy of this type of speed measurement is +/- 4‰ which corresponds to 2.0 mHz at 50 Hz nominal frequency. The accuracy of the quartz-stabilised time base is 15 ‰. The resolution of the speed measurement is as high as 0.5 mHz.

To ensure safe pulse signals, every pulse generator is monitored for device faults and wire-break in the signal lines. The pulse inputs are electrically isolated to prevent potential carry-over.

The pulse input module is supplied by two separate d.c. voltage transducers which ensure an electrically isolated power supply for the two independent input channels. Due to the high measuring accuracy of the pulse input modules, the turbine speed controller can also be used for frequency stability operation.

To ensure fast and accurate conversion of the pulse signals into speed signals, the pulse input module is connected to the speed controller module through the I/O bus.

The speed controller compares the input signals of the pulse transmitters with the specified setpoint and calculates the command signal for the actuators of the HP and IP control valves. The control of the cascaded servo drives is based on the principle that the servo valve modulates the differential pressure at a follow-up piston unit (which is the main slide valve of the servo drive) according to the control error of the actuator. The proportional gradient which is typically set to 8% is continuously adjustable in the wide range from 2% to 11%.

The start-up unit of the speed controller controls turbine acceleration from slewing gear mode to nominal speed. A speed master controller modifies the speed setpoint in line with a set fixed transient value until finally the selectable target speed is reached. The speed controller obtains the difference between the speed setpoint value and the speed actual value and provides at its output the command signal to the HP and IP control valves.

Load Shedding

During load shedding it is desirable to keep speed overshooting as low as possible. To maintain a sufficient distance to the emergency shut-off speed even at full-load turbine stop, an accelerometer monitors the dh/dt ratio of the turbine shaft. If the dh/dt ratio exceeds a selectable limit value, a signal is generated that intervenes in the position control loop of the servo drives such that the control valves are closed quickly.

The steady state control error xw depends on the specified proportional-action control component, as follows:

xp 4 to 6% approximately.

xw max. depends on various influencing quantities, such as:

- Specified proportional-action range
- Live steam pressure
- Residual load at isolated operation
- Response of the control valves (100% seating stroke < 200 msec) and of enclosed steam volumes which is +5% to 8% max. (This corresponds to +150 to +240 min-1).

Power / Pressure Controller

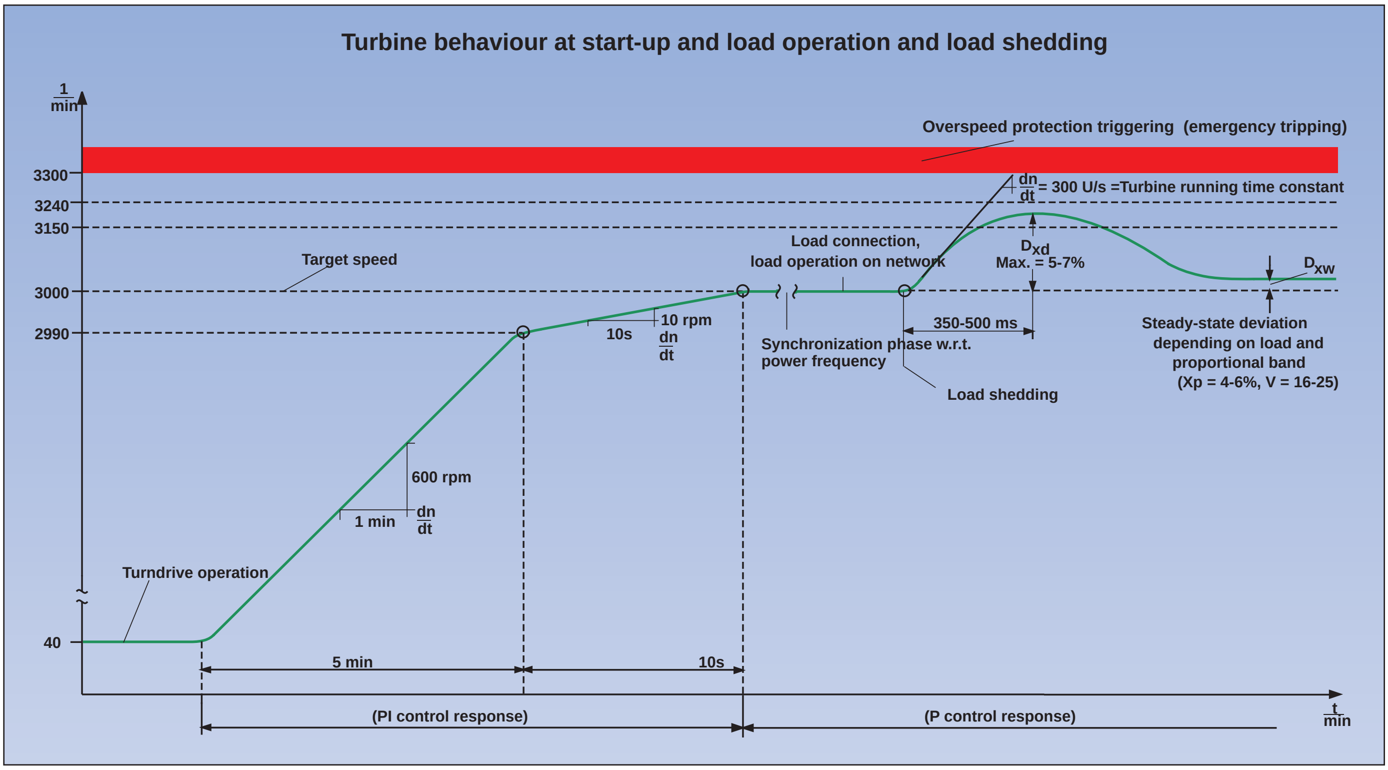
A power master controller reads the target power value issued by the unit control and converts it to a power base value to which the frequency influence (which can also be disabled) is added. The power controller applies a PI control algorithm to the control deviation, calculated from the frequency-dependent power setpoint and the actual power value. The actuating variable of the speed controller is then added to the control output of the power controller. This control principle complies with the recommendations of the DVG, the National Association of the German Electricity Network Operators. The role of the power controller within the turbine control system depends on the unit control strategy selected. The base control loops of the system are enhanced by feedforwarding additional control quantities.

Maximum turbine and unit power values can be defined by specifying a power limit value. For efficient power limiting, the power limit value is integrated in the load capability unit and thus acts as the upper limit for both the steam generator and the turbine.

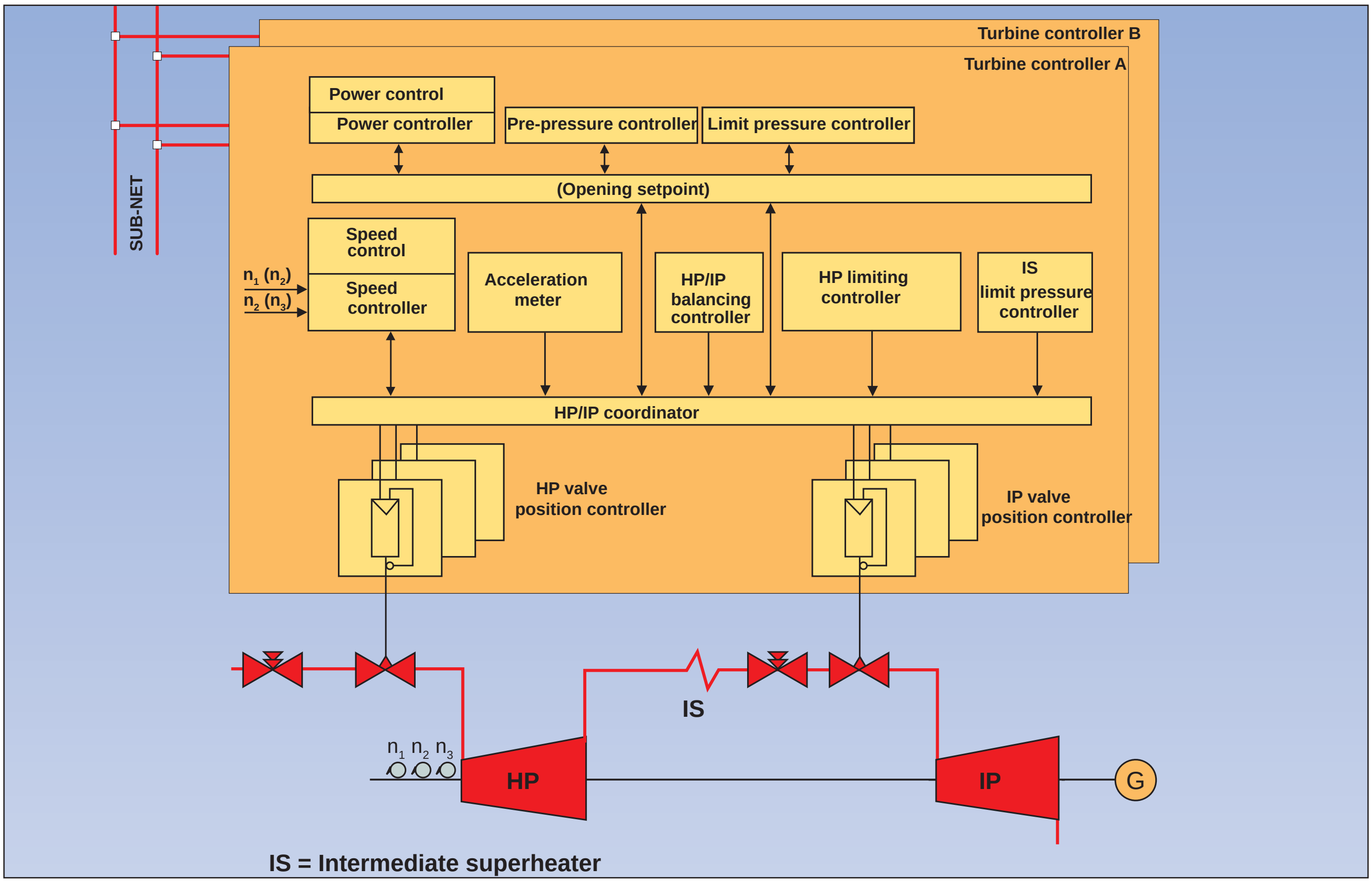
The limit pressure controller throttles the turbine admission valves as soon as the live steam pressure has dropped below its setpoint by a specified amount. Should the live steam pressure continue to fall, the limit pressure controller demands a power reduction that is proportional to the pressure drop.
A live steam pressure controller is provided for the case that the turbine is put in charge of live steam pressure control, i.e. the "turbine follows boiler" mode is applied. The live steam pressure controller is a PID controller. It must be provided with the required live steam pressure signal from an external source. A changeover from power control (provided that this is part of the turbine control scheme) to live steam pressure control can be done during running turbine operation. When power control is enabled, the actuating variable of the live steam pressure controller is feedforwarded. Vice versa, when live steam pressure control is enabled, it is the actuating variable of the power controller that is feedforwarded. This method ensures a smooth changeover from one control mode to the other.

Changeover from Full-Arc to Partial-Arc Admission

A turbine equipped with a regulating wheel must be warmed up and run up to speed with as little wear and strain as possible. For this purpose, a changeover sequence control can be activated that controls the order in which the control valves are opened. At any point of turbine operation, this changeover sequence control allows a smooth change from full-arc admission (i.e., parallel opening of valves) to partial-arc admission (i.e. sequential opening of valves), and vice versa. The changeover logic ensures that the sum of all steam volumes going through the control valves remains constant during the changeover process irrespective of the changeover signal, and thus prevents additional thermal rotor voltages.



Turbine behaviour at load shedding



HP/IP Coordinator

The actuating variables (i.e., the outputs) of the turbine controller correspond to the mass flow required by the HP and IP turbine units. However, the final distribution of this mass is coordinated by the HP/ID coordinator module. It coordinates the opening strokes of the valves for two purposes: to prevent overstepping thermal limit values, and to achieve the fastest possible turbo generator start-up and loading by shifting the steam mass flows as needed.

HP /IP Balancing Controller

During start-up and no-load turbine operation, two contradicting tasks must be accomplished: First, there must be sufficient cooling steam for the end blades of the LP turbine. Yet, at the same time, the outlet temperature of the HP turbine must not exceed the permissible value. A balancing controller solves this problem. It increases the steam flow allocated to the HP turbine as soon as the outlet temperature exceeds a specific value which is a function of the live steam temperature. At cold start-up, when the turbine casing temperature is below 100 °C, and after grid synchronization, the steam flow to the IP turbine is increased at a slow transient value to about 10% of the nominal steam volume.

HP Limiting Controller

In high-capacity steam turbines, the problems that arise at no-load and off-peak operation are due to the fact that in those situations the HP turbine requires only very low volumetric flow rates. This may lead to blading windage in the turbine end stages and, as a result, to power losses in form of heat given off to the outside.

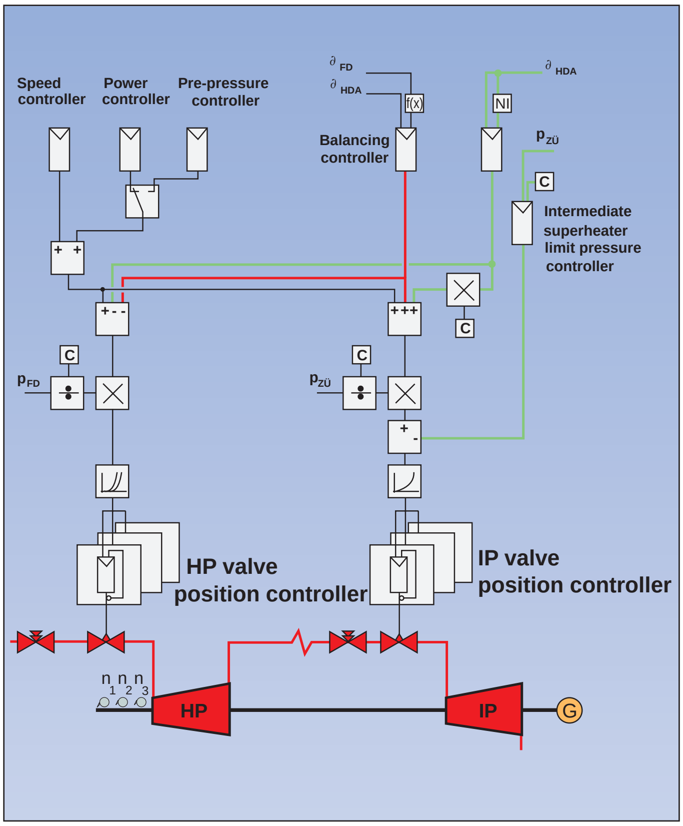
The HP limiting controller has the task of counteracting these effects. It is active in the following situations:

- Turbine loading after a longer stretch of no-load operation
- Turbine reloading after load disconnection
- Turbine reloading after off-peak operation and isolated operation

During turbine reloading, following such no-load or low-load phases, the HP limiting controller controls the opening of the control valves and, as a result, the power input to the HP turbine, always keeping an eye on the flange temperature at the HP outlet, in order to prevent thermal overloads at this point of the turbogenerator. The aim is to keep the difference between the steam temperature and the flange temperature, measured at the centre line, below 60 K.

Therefore, the HP limiting controller redirects the steam flows from the HP turbine to the IP/LP turbines in order to ensure that the specified cooling transient of the HP outlet is not exceeded. This is to prevent the worst case from happening which would be the distortion of the joint. Should during this control process the pressure of the intermediate superheater (IS) drop below its minimum limit, the IS limit pressure controller sees to it that the IP valves are not opened any further.

The allocation of the two valve groups for the HP and the IP turbine section can be adjusted. In normal situations, the static characteristics show that the actuating variable for the mass flow of the IP valves changes proportionally with the actuating variable for the mass flow of the HP valves. Dividing these actuating variables by the live steam setpoint (or by the intermediate superheater pressure setpoint) produces a constant operational controller gain in all operating states. The actuating variable obtained by this calculation then passes through a linearization circuit, of which there is one for every control valve and its associated servo drive. This circuit linearizes the heavily non-linear flow rate response of the control valves. After having been smoothed out, the actuating signals reach the valve position controllers where they are converted into hydraulic signals by the E/H transducers of the hydraulic servo drives.



Servo Drive and Control Valve

The admission control valves are single-seat valves with a pilot plug for pressure relief when opening. They regulate the steam flow to the turbine by reducing and increasing the free space between the valve plug and the valve seat.

Every control valve has its own servo drive. This servo drive receives its control commands through a servo valve which is flange-mounted to the hydraulic amplifier.

To open the valve, the control signal generated by the valve positioner causes a hydraulic amplification in the servo valve which in turn deflects the control piston. This has the effect of deflecting the main spring-loaded valve stem built into the hydraulic amplifier such that it connects the control fluid pressure with the space underneath the piston. As a result, the piston moves against the closing spring force towards the orifice together with the coupled control valve. An electric feedback transmitter mounted to the end of the piston rod informs the position control loop about the executed valve travel. The piston movement is stopped as soon as the setpoint and the actual value of the valve position coincide. In the same way, the closing action of the servo drive, too, is driven by the control signal issued by the valve positioner.

Rapid closing in the event of turbine tripping is driven by a cartridge-type valve. It connects the control valve servo drive with central protection pulse hydraulic fluid (Pi) and ensures controlled rapid valve closing.

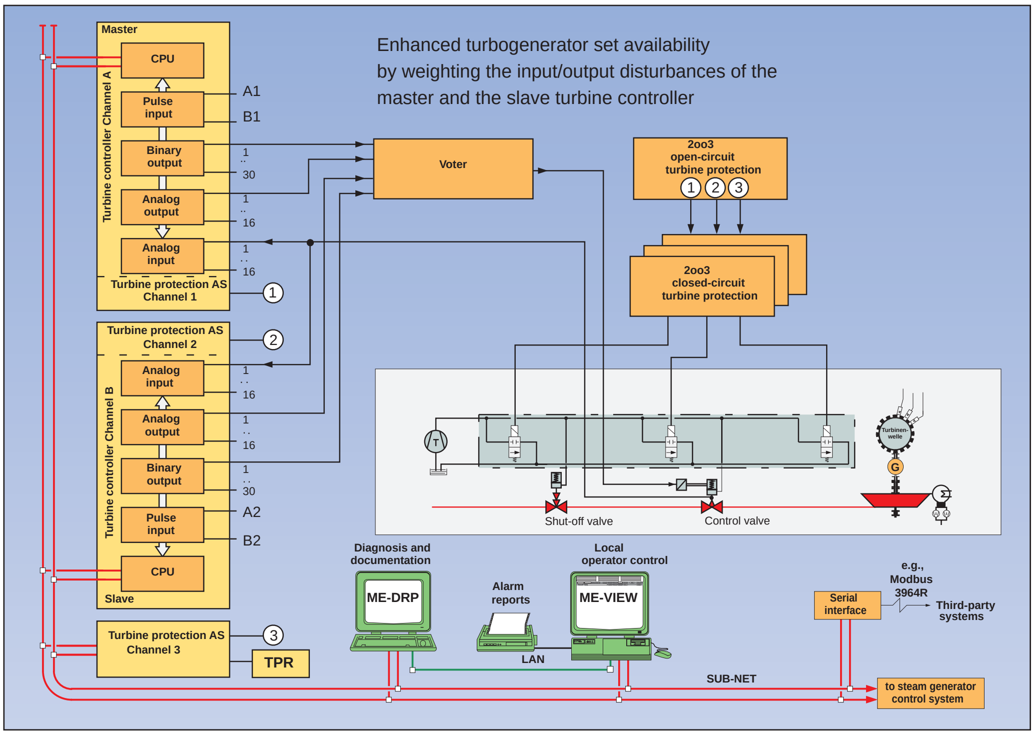
However, safety is principally ensured by the turbine shut-off valves specifically installed for this purpose.

For rapid closing operations due to load shedding (also referred to as ‘load rejection’) or turbine tripping, the servo drive piston and the connected control valve jackscrew reach maximum closing speed. To prevent the valve plug from hitting the valve seat at high speed at the end of the closing movement, the piston enters a damping chamber containing hydraulic fluid, which softens the impact. The impact speed can be adjusted by means of a throttle. The control fluid line to the servo drive is connected to bottom part of the servo drive. As the servo drive is mounted horizontally, feeding the control fluid from below ensures that no hydraulic fluid lines run in the vicinity of turbine admission components and hence near hot steam pipes. For additional safety, the pressure oil lines that run through free spaces are embedded in guarded pipes to prevent oil leakages to the outside which could cause oil fires. Flexible tubing for the feeder lines to the servo drives ensures sufficient flexibility inside the valve unit.

Availability and Redundancy

To achieve the highest possible degree of availability of the turbine controller modules, the overall control concept was given a distributed redundant structure. The following design features were put in place to meet these requirements:

- Redundant inputs for speed measurement for every controller, i.e. for master and for slave (1v4)
- Independent hardware inputs for analog signal conditioning with single fusing (1v2)
- Electronic modules, system cabling and control cubicles of high-quality design and construction
- Supply voltage rating for switchgear according to highest safety standards
- Noise-proof I/O equipment



Turbine controller hardware (master/ slave) and open- and closed-circuit protection (2oo3)

- Highly efficient deployment of best-of-breed electronic components by increased use of VLSI circuits and low dissipation HCMOS circuits
- Use of highly integrated components, SMD technology and completely ventilation-free equipment
- Computer-aided test of all modules
- Heat endurance and function test of turbine controller
- Hardware and software test in conjunction with turbine simulator

ME 4012 System Cubicle

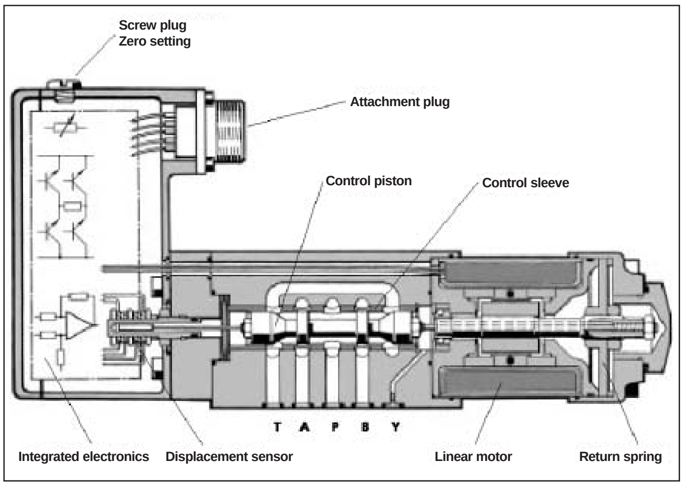
Typical Layout of Functional Areas

Turbine controller (master/slave), Turbine protection with shunt tripping (2oo3), Turbine protection with failsafe tripping (2oo3), Turbine Temperature and Power Reference unit (TPR unit), Control of the HP and IP bypass stations, Failsafe trip protection of the bypass stations, Electronic power stages (2oo3) for the control of the control valve and shut-off protection functions.

Electrohydraulic Power Actuators (E/H Transducers)

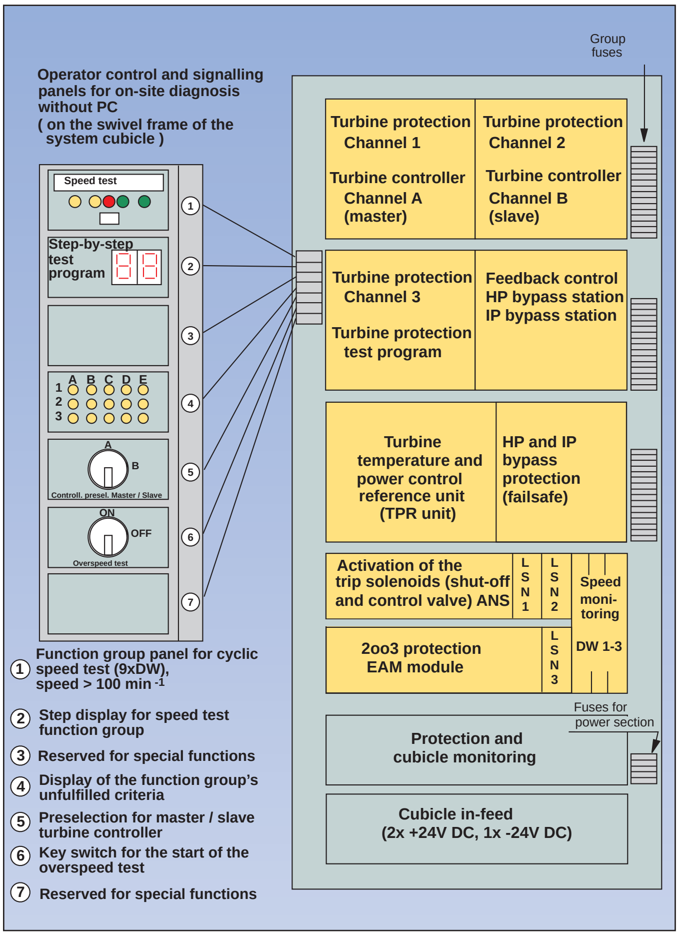
Today's balanced valves require only low actuating forces which in turn allows the servo drives, too, to operate with low hydraulic fluid or spring forces. In modern turbogenerator installations, every admission valve has its own hydraulic servo drive whose hydraulic pressure opens the valve against the force of the closing springs.

The electrical actuating signal supplied by the turbine controller is converted to an oil-hydraulic actuating signal by a proportional-action valve. The valve's control piston is located inside a control cylinder and is driven by a 4 to 20 mA current signal supplied by a linear motor. Due to the setting of a built-in return spring, the motor drives into a safety position (i.e., A to boiler, P to B) in the event of signal failure or wire break. The electronic position control loop integrated in the proportional valve section amplifies the actuating signal and -based on the travel information picked up by the built-in displacement transducer- it compares the setpoint with the actual value of the piston position. The position controller drives the piston until finally setpoint and actual value of the piston position coincide. The position of the control piston is hence always proportional to the electrical actuating signal.

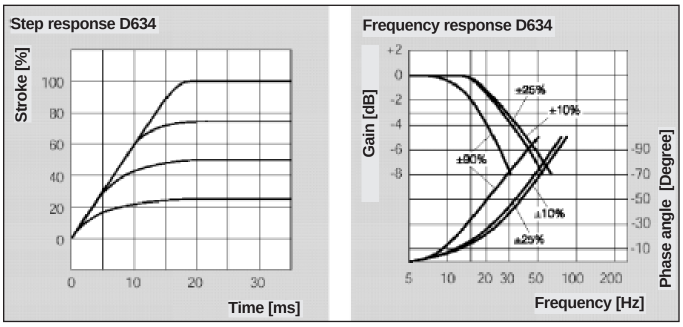


Proportional valve (electro/hydraulic transducer)

Due to its low number of moving parts, the proportional-action valve offers particularly good dynamic characteristics (i.e., actuating delay for 0 to 100% stroke <= 12 ms) and achieves an excellent conversion of the electrical actuating pulse to a hydraulic actuating



Cubicle layout for the control of turbo sets (up to 300 MW)



Transfer characteristics of modern E/H transducers

signal for the servo drive which is proportional to the volumetric flow.

Servo Drive and Group Operation of the Steam Admission Control Valves

The steam admission valves are typical single-seat valves whose operating principle we have described earlier on. Control valve movement is initiated by the control signal supplied by the positioner. Electrically amplified in the valve's proportional-action section, the signal causes the valve piston to move.

The four HP valves are driven by a servo motor with associated group drive comprising the lever system and the camshaft.

The group drive of the five IP valves is driven by two actuating cylinders connected in parallel which in turn are controlled by a common proportional-action valve.

Valve Position Controller

Each group servo drive is equipped with a mechanical coupling. It is this mechanical coupling which physically changes the position of the HP and IP control valves. The valve position controllers driving the individual servo drives are integrated in the turbine controller in the form of function blocks.

Servo Drive

Principle of Operation and Hydraulic Interaction

The servo actuator opens upon increase of the hydraulic fluid pressure against the spring force, and closes upon decrease of the hydraulic fluid pressure assisted by the spring force.

Activation of the hydraulic turbine protection (pi) initiates the cartridge valve to move into its sealed position which in turn triggers the interaction between the digital turbine control and the hydraulic turbine protection system. The control signal provided by the digital turbine controller is sent to a proportional-action valve which is fixed to the side of the servo drive by means of a screw-mounted adaptor plate. Here, the control signal is converted into the actuating pulse, the so-called piston pressure pK. This actuating signal determines the actuator displacement in the opening or closing direction, depending on the control deviation.

Rapid closing of the servo actuator is taken care of by a cartridge valve which is installed specifically for this purpose.

An electric feedback transmitter mounted to the end of the drive's piston rod picks up the piston travel executed. When the setpoint and the actual value of the feedforwarded controlled variable coincide, piston movement is stopped by the turbine controller.

The feedback transmitter also indicates the 'Open' and 'Closed' actuator limit positions, i.e. the total travelled positions.

In the event of turbine tripping, hydraulic turbine protection bypasses the control loop and uses its pi signal (pi = turbine trip pulse oil) to directly control a cartridge valve whose operation is not affected by the control loop.

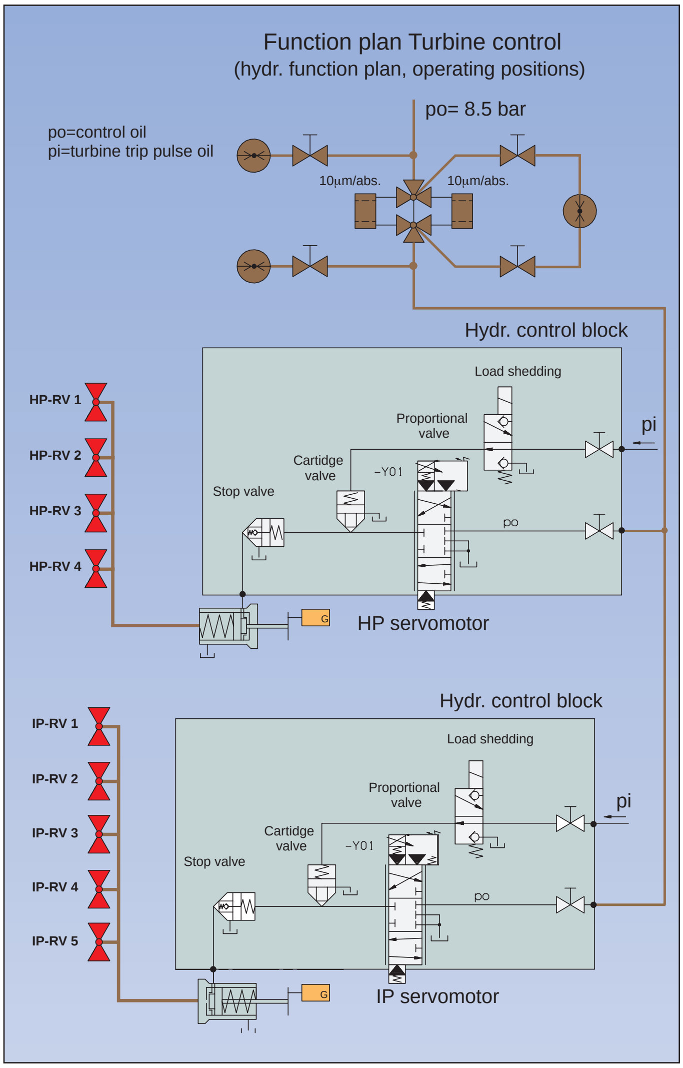
The piston pressure pK rapidly drops to zero and the servo drive closes at maximum speed using the cartridge valve. The re-activated hydraulic turbine protection will automatically close the cartridge valve. It resets the servo drive to control mode so that it is ready again to receive signals from the turbine controller.

During load shedding, both cartridge valves are rapidly de-pressurized by the load shedding valves which operate on the make circuit principle. At the same time, the piston pressure variable pK fed through the proportional-action valve is disconnected which relieves the cartridge valves even further. This initiates the closing movement of the servo drive.

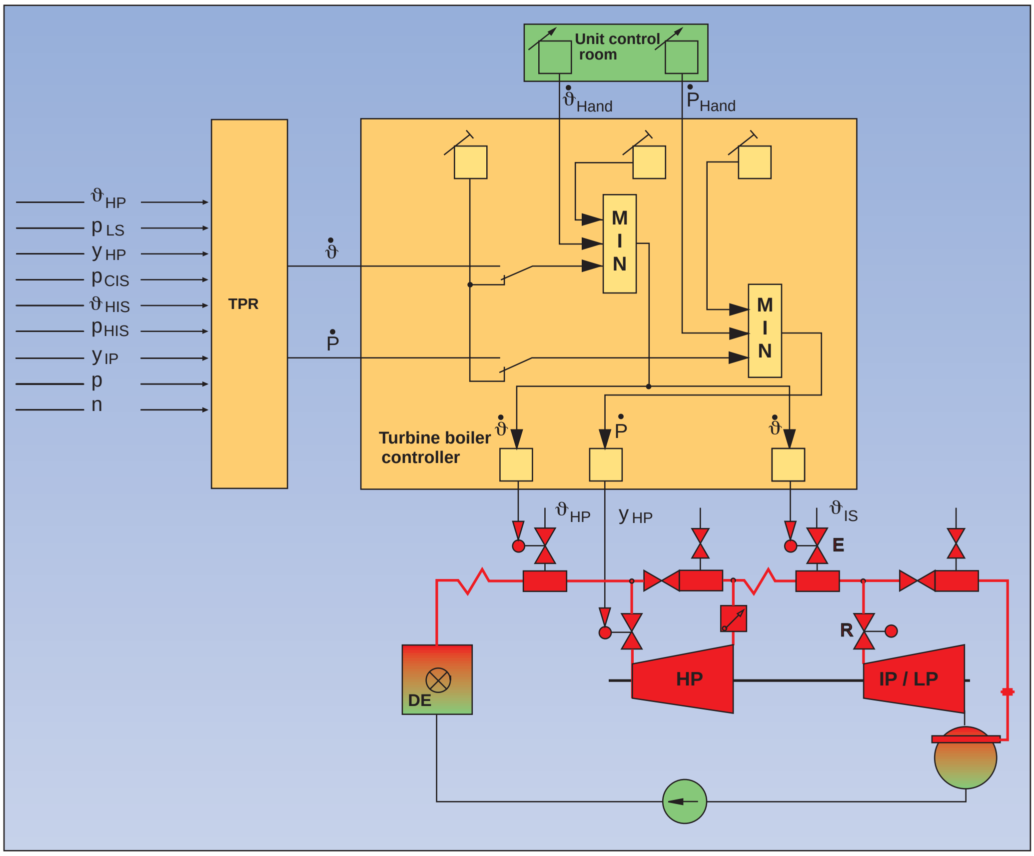
The stop valves (pi, po) are used to stop the oil supply to the servo drive. A protective cover must be removed to gain access to these valves.

This allows the replacement of faulty components, of a valve for instance, while the feed pump is running.

- Control oil filter
  To maintain a sufficiently long de-energizing time of the hydraulic components it is necessary to operate the main control oil filter at 10um nominal, and the downstream control oil filter at 10um absolute.
- Control oil pipes
  They should ideally be made of high-quality steel.



Turbine control (functional diagram of hydraulic control in normal operating positions)



TPR unit influencing variables for unit and turbine start-up

The Turbine Temperature and Power Reference Unit (TPR unit) has the task of calculating temperature and power transients taking into account tension and stresses affecting the turbine shafts. To gather the required information, material strain is measured at different points of the turbine. The temperature and power reference values calculated by the TPRU unit therefore allow optimum turbine operation in all phases (i.e., cool, warm and hot start-up, on-load operation) while at the same time observing the permissible strain limits for the turbine material.

How the TPR Unit Influences the Turbine Controller

Turbine control is piloted by the autonomous turbine and unit control system which receives the permissible target power, and the reference temperature and power transients from the unit control room. Temperature and power setpoint changes are controlled by a MIN logic which selects the minimum value of the following quantities:

- The transient supplied by the unit control room, and
- The transient authorized by the TPR unit, or
- The maximum value of the transient.

The temperature transient is fed to the unit control whereas the power transient is sent to the power master controller. This means that the TPR unit only intervenes in the control of the turbine and the boiler. The simplified representation in the above block diagram shows the unit control room and the TPR unit. It illustrates the points of intervention of the turbine/boiler controller where it affects the temperatures, and the positions of the injection valves E (which belong to the boiler system) and of the turbine control valves R. The schematic diagram is restricted to the interaction of the unit control room and the turbine/boiler control (i.e., the turbine control system) with the TPR unit. The control loop shows that the TPR unit can only intervene in the turbine control system when the transient calculated by the TPR unit is fed forward to the control loop in the form of the minimum value. Should the TPR unit fail, the turbine and boiler controllers do not accept any transients from the TPR unit. In such a situation, safety transients that are set to a defined value and stored in the turbine controller maintain uninterrupted unit operation governed by the turbine/boiler controller. Response and operation of the turbine control system are thus not adversely affected by a faulty TPR unit.

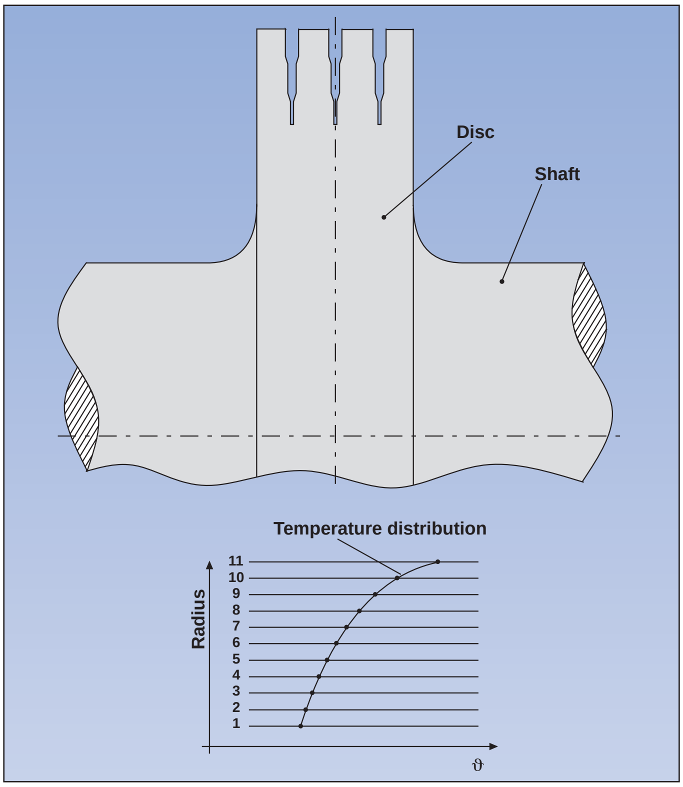
Thermal Stresses in the Turbine

Some parts of the turbine are subjected to material stresses due to considerable changes in the temperature. In large turbines, highest material stresses occur in the first turbine stage at the points where the discs join the shaft.

As direct measurement at the shafts is not possible, the local steam parameters (i.e., pressure, temperature, heat transfer, temperature distribution, thermal stress) are calculated for the critical shaft cross-sectional areas. The results are compared with the permissible thermal stress values, and temperature and power transients are calculated on this basis. To be able to continuously calculate the actual conditions of the turbine components that are subjected to high material stresses, not only the turbine characteristics must be known (i.e., its geometrical, thermo dynamical, flow and material-specific characteristics), but also a large number of measured values and logical quantities must be taken into account. The combination of known and measured information is the basis for program initialization and for determining the actual operating states of the running turbine.

Arithmetic Models: Thermodynamics, Shaft Temperature and Stress

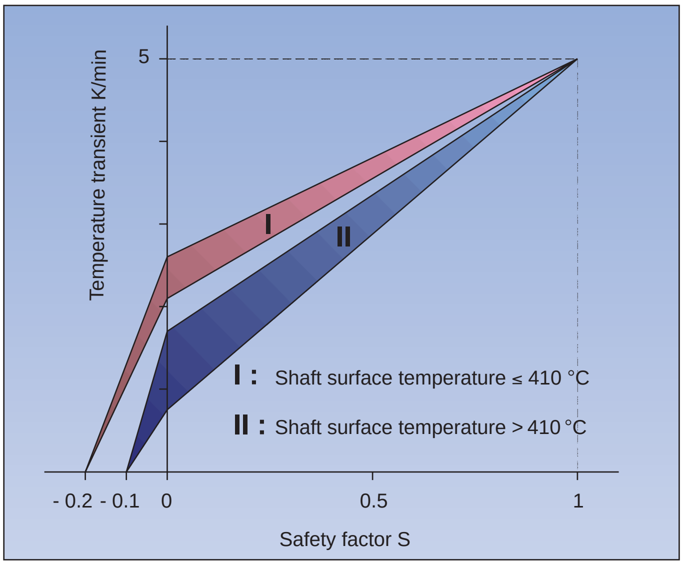
The arithmetic model of the thermodynamic behaviour of the turbine considers the turbine through which steam is flowing as a multiple orifice system. The steam parameters -pressure, temperature and heat transfer- for the shaft cross-sectional area under investigation are obtained by iteration, always taking into account the valve characteristics and the power efficiency of the turbine stages. The physical material characteristics are determined on the basis of a 'steam characteristics table' which is stored in the TPR unit. In the 'Cooling' and 'Heating' phases, the turbine casing temperature is used as the reference for all further calculation. Next, a one-dimensional differential calculation method is applied to obtain the radial temperature distribution. The mean shaft temperature is calculated by integration over the 11 pivotal points. Knowing the temperature-dependent characteristics of the material, the thermal stress in the disc-shaft connection can now be calculated. The calculated thermal stress and mechanical stresses serve as the basis for a calculated stress reference value which is then compared with the known permissible stress. The resulting safety coefficient S is a measure for the current material stress.



Arithmetic model for the shaft temperature distribution

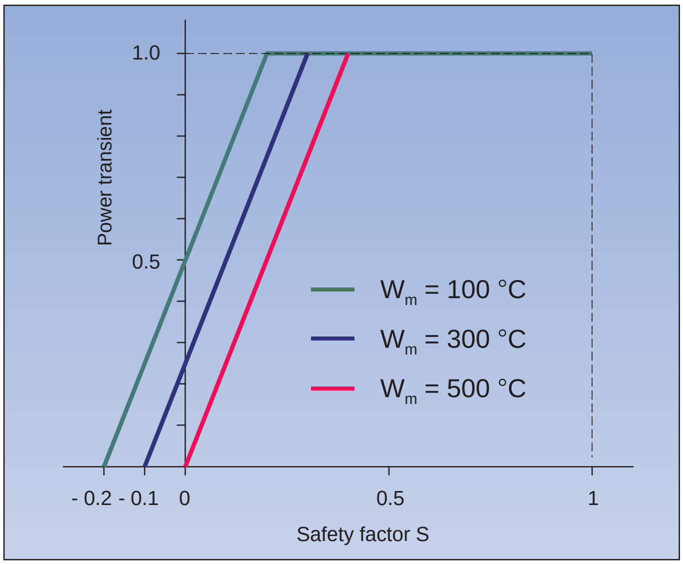
Temperature and Power Transients during On-Load Operation

The steam turbine transient ϑ for temperature changes at the turbine is determined from the safety coefficient S and the shaft surface temperature ϑ_{Wo}, as shown in the figure below.



Determination of the temperature transient

When the security coefficient S is equal to 1, the thermal stress is at zero and the temperature can rise at the maximum rate. If S is equal to 0, the reference thermal stress is equal to the permissible thermal stress and the temperature $\dot{\vartheta}$ must be reduced. When S is below zero, the permissible stress is exceeded and the temperature must be reduced even further. The temperature transient $\dot{\vartheta}$ is a control quantity in the unit control system and affects the actuating variable of the injection valves.



Determination of the power transient

Another control quantity in the power controller is the power transient P which is derived from the safety coefficient S and the mean shaft temperature ϑ_{Wm}. The above diagram shows the rate of change of P as a function of S and ϑ_{Wm}.

Hardware of the TPR Unit

The industrial-type computer for the TPR unit has been designed for DIN rail mounting and is installed in the system cubicle of the turbine controller. It comprises the following components:

- PC of industrial design
- Serial connection e with multi-function processor, with SUB-NET connection to channel 3 of the failsafe protection system
- Printer (Centronics)
- Keyboard
- Monitor
- Hard disk drive
- Floppy disk drive

The computer uses the OS2 operating system. In its basic configuration, the system offers the following I/O devices for system operation:

- 1 ink jet printer
- 1 keyboard, mouse
- 1 monitor

All process data conditioning and preprocessing is done by the I/O modules and subprocessors of the ME4012 process control system. Data traffic between the TPR unit and the turbine control system is handled by the dualized SUB-NET process bus. The results provided by the TPR unit can be displayed graphically on the colour monitor of the local ME-VIEW operator station. Data transmission to third-party systems in the power station can be done through serial links.

Signal Exchange through the SUB-NET Process Bus

Analog signals coming from the process bus

ϑ_{FD} = Live steam temperature before the shut-off valve
$\dot{\vartheta}_{HDli}$ = Temperature, HP inner casing, inside flange
P_{FD} = Live steam pressure before shut-off valve
P_{HDA} = Pressure HP outlet
Y_{RV1HD} = Position, Control valve 1, HP
Y_{RV2HD} = Position, Control valve 2, HP
Y_{RV3HD} = Position, Control valve 3, HP
Y_{RV4HD} = Position, Control valve 4, HP
$\vartheta_{ZÜ}$ = Temperature, IS before shut-off valve
ϑ_{MDli} = Temperature, IP inner casing, inside flange
$P_{ZÜ}$ = Pressure, IS before shut-off valve
P_{1MD} = Pressure, 1st IP tap
Y_{RV1MD} = Position, Control valve 1, IP
Y_{RV2MD} = Position, Control valve 2, IP
Y_{RV3MD} = Position, Control valve 3, IP
Y_{RV4MD} = Position, Control valve 4, IP
f_T = Turbine speed (RPM)
P = Power

Binary signals coming from the process bus

Speed	>100 min^{-1}
All control valves	= 0 %
Shut-off valve in travel limit position	
1 shut-off valve	= 100 %
HP heating valve	= 0 %
IP heating valvel	= 0 %
Fault in analog inputs	
Generator connected to grid	

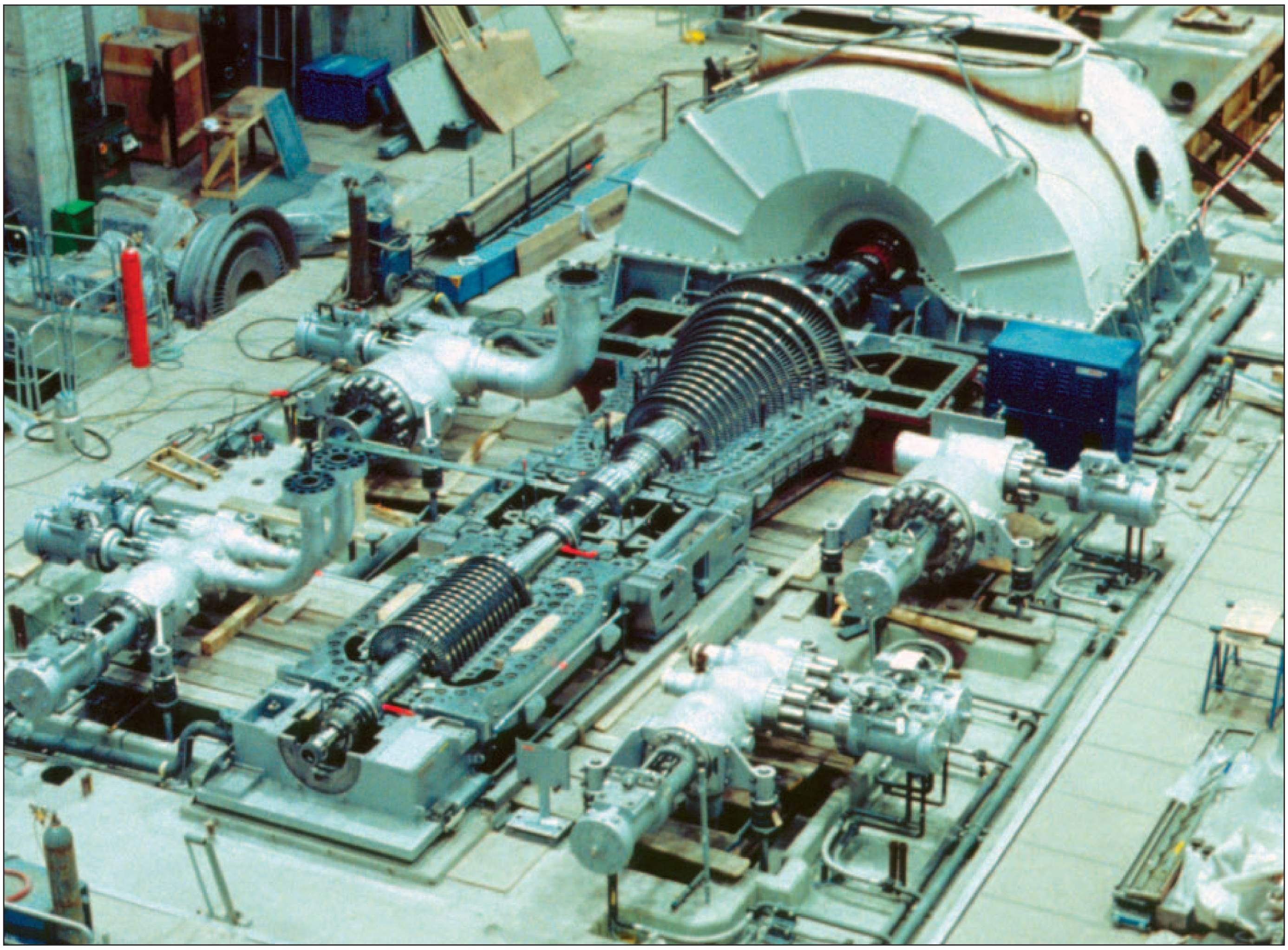
Analog signals going to the turbine controller

$\vartheta_{oFD}(t)$ = Permissible temperature, live steam
$\dot{\vartheta}_{oMD}(t)$ = Permissible temperature, IP
$h_{HDo}(t)$ = Permissible temperature, HP valves
$P_o(t)$ = Permissible power transient

The permissible transients for the temperature and for the valve positions, as well as the reference safety coefficients of the HP, IP and LP turbines, are displayed in the control room.

Binary signals going to the message indicating system:

Enable TPR unit
Faulty TPR unit



Inspection work on HP and IP turbines

Measuring Equipment Used in Turbine Operation Monitoring

The turbine monitoring system relies on measuring devices that supply information on the following physical quantities:

- Turbine speed
- Shaft vibration
- Bearing housing vibration
- Relative expansion
- Shaft position (block bearing)
- Absolute expansion
- Axial thrust

Shaft Vibration Measurement

Points of Measurement

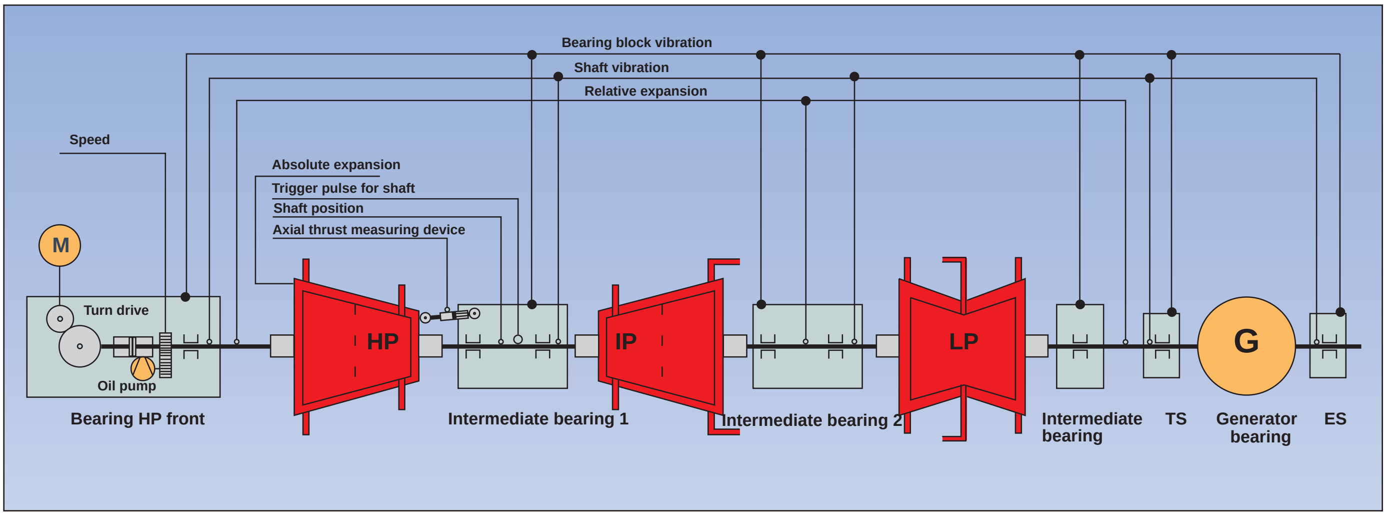
HP bearing front, intermediate bearing I, intermediate bearing II, generator bearing, turbine side (TS), generator bearing, excitation side (ES)

Principle of Operation

As the transmitters for shaft vibration are directly mounted to the bearing shells, the relative shaft vibration is measured by proximity-type sensors based on the inductive or eddy current principle.

Design

The measuring unit consists of plug-in cards that are inserted in the 19" subrack of a control cubicle, together with other measurement units for turbine operation monitoring.



Placement of measuring points for turbine operation

Turbine Speed Measurement

Point of Measurement

Spur gear mounted in the first bearing block or in intermediate bearing no.1. Turbine operators must always be able to rely on high-precision speed measurement and speed display in digital form, irrespective of the speed and power control applied. To avoid a deterioration in the accuracy of the displayed speed caused by D/A and A/D transducers with larger tolerance bands, signal transmission to the display instrument is digital.

Display range:	0-3600 min^{-1}
Display accuracy:	± 0.027 %

Adjustable, reproducible limit values with zero-based accuracy are generated over the entire speed range and fed to the automatic function groups responsible for turbine control.

A special case of speed monitoring is the speed measurement at turbine standstill. In these situations, an active signal each is generated for speed values $n = < 2\,min^{-1}$ and $n \geq 2\,min^{-1}$.

Principle of Operation

High-frequency pulse counting (500 kHz) between two tooth flanks of the trigger wheel and multiplication with the number of teeth.

Design

The speed measurement unit is a multifunction controller with redundant pulse input.

It comprises:

- Pulse generator
- Preamplifier
- Pulse input module IE2FZ

The measuring unit comprises:

- Sensor
- Transducer
- Transducer monitoring

Usage

Analog	Output 4-20 mA, >> 0-200 µm limit values for interlocking, alarm and turbine protection + (shut-off) are generated in the ME 4012 system

Bearing Vibration Measurement

Points of Measurement

HP bearing front, HP/IP intermediate bearing I, IP/LP intermediate bearing II, LP turbine rear, generator bearing (TS), generator bearing (ES)

Principle of Operation

A seismic sensor picks up the absolute mechanical vibrations of the bearing housing.

Design

The sensor is mounted onto the bearing housing. The vibration measuring unit consists of plug-in cards that are inserted in the 19" subrack of a control cubicle, together with other measurement units for turbine operation monitoring.

The vibration measuring unit comprises:

- 5 sensors
- 1 scanner with 5 channels
- 1 transducer

Usage

Analog	Output 4-20 mA, >> 0-50 µm

Relative Expansion Measurement (Rotor/Bearing Housing)

Point of Measurement
HP bearing front, IP/LP intermediate bearing II, centre bearing (LP, generator)

Principle of Operation

Expansion measurement is based on the measurement of currents in induction coils and is contactless. The axial displacement of a shaft shoulder invokes a change in the reactance.

Design

The relative expansion measuring unit consists of plug-in cards that are inserted in the 19” subrack of a control cubicle, together with other measurement units for turbine operation monitoring.

The expansion measuring unit comprises:

• Sensor

• Transducer

• Sensor monitoring

Usage

Analog	Output 4-20 mA, >> e.g., - 5 + 15 mm
Binary	Limit values for alarm +/- and for turbine protection +/- are generated by the open-circuit shunt trip circuit (AE 4012).

Shaft Position Measurement (measurement of wear and tear on block bearing)

Point of Measurement
Intermediate bearing I

Principle of Operation
Measuring the shaft position in the block bearing is based on the same principle as applied for bearing vibration measurement. This measurement, however, is a static type of measurement static.

Design
Relative expansion measuring unit

Usage

Analog	Output 4-20 mA, >> -2 +1 mm
Binary	Limit values for alarm ± and for turbine protection ± are generated by the open-circuit shunt trip circuit (AE 4012)

Absolute Expansion Measurement

Point of Measurement
HP bearing, front

Principle of Operation
A linear inductive displacement sensor picks up the absolute expansion. Its transducer supplies a current signal of 4 to 20 mA.

Design

The absolute expansion measuring unit consists of plug-in cards that are inserted in the 19” subrack of a control cubicle, together with other measurement units for turbine operation monitoring.

The expansion measuring unit comprises:

• Sensor

• Transducer

Usage

Analog	Output 4-20 mA, >> 0-50 mm

Axial Thrust Measurement (if provided)

Point of Measurement
Block bearing

Principle of Operation
Piezoelectric pressure sensors measure tensile and compressive stresses that occur in the block bearing’s support poles.

Design

The pressure sensor pins are mounted inside the push rods. The axial thrust measurement unit is made up of plug-in cards that are inserted in the 19” subrack of a control cubicle, together with other measurement units for turbine operation monitoring.

The axial thrust measuring unit comprises:

• Sensor

• Transducer

Usage

Analog	Output 4-20 mA, >> ± 400 kN

Tasks of the Turbine Protection System

The turbine protection system detects hazardous operating conditions that may injure people or cause damage to equipment and installations. According to the guidelines issued by the German VGB PowerTech Association (Guidelines VGB-R103-M "Supervision, Limiting and Protection Devices in Steam Turbine Units", see http://www.vgb.org), turbine protection criteria are classified in four criteria groups. These criteria represent the scope of protection required for a steam turbine. It is not permissible to run the turbogenerator set without these protection circuits. As soon as one of the turbine protection criteria exceeds its permissible value, special protective devices interrupt turbine operation by closing all shut-off valves (i.e. emergency stop valves), control and backpressure valves via the turbine emergency trip system.

Criterion group	Designation	Trigger value	Delay (s)	Comments
	Failsafe protection (RS)	**Without delay**		
1	Speed (channel 1)	≥ 110 %	0	Failsafe / energize to trip
1	Speed (channel 2)	≥ 110 %	0	Failsafe / energize to trip
1	Speed (channel 3)	≥ 110 %	0	Failsafe / energize to trip
1	Emergency shut-off		0	Failsafe / energize to trip
	Open-circuit protection (AS)			
2	Condensator presssure	≥ 250 mbar	0	
2	IP exhaust steam pressure		0	For turbines with butterfly control valves
3	Steam temperature, condenser	100 °C	2	
3	Exhaust steam temp., HP casing	430 °C	60	
	Temperature difference			
4	- Live steam/HP inner casing	≤ 0 K	2	Live steam temperature transient
4	- HP inner casing, top/bottom	≥ 40 K	2	
4	- IP inner casing, top/bottom	≥ 40 K	2	
	Shaft position			
2	Shaft position (thrust bearing)	> 0.7 mm	0	Tripping for both thrust directions
2	Shaft position (thrust bearing)	< -1.7 mm	0	Tripping for both thrust directions
	Relative expansion			
3	- HP front	≥ max.	2	
3	- LP 1 front	≥ max.	2	
3	- LP 2 rear	≥ max.	2	Or with last LP flooding
	Shaft vibration (resultant of x, y)			
3	- HP front	≥ 100 µm	2	
3	- IP front	≥ 100 µm	2	
3	- LP 1 front	≥ 100 µm	2	
3	- LP 2 front	≥ 100 µm	2	
3	- LP 3 front	≥ 100 µm	2	For third LP section
3	- Gen., turbine side (TS)	≥ 100 µm	2	
3	- Gen., excitation side (ES)	≥ 100 µm	2	
2	**Bearing oil pressure**	< 1.2 bar	0	
3	- Radial bearing 1	≥ max.	2	
3	- Thrust bearing front	≥ max.	2	
3	- Thrust bearing rear	≥ max.	2	
3	- Radial bearing 2	≥ max.	2	
3	- Radial bearing 3	≥ max.	2	
3	- Radial bearing 4	≥ max.	2	
3	- Radial bearing 5	≥ max.	2	
3	- Radial bearing 6	≥ max.	2	
3	- Radial bearing 7	≥ max.	2	
3	- Radial bearing 7	≥ max.	2	
3	- Radial bearing 8	≥ max.	2	
3	- Radial bearing 9	≥ max.	2	For third LP section
3	- Radial bearing 10	≥ max.	2	For third LP section
3	- Radial bearing Generator TS	≥ max.	2	
3	- Radial bearing Generator ES	≥ max.	2	
3	- Radial bearing Exciter	≥ max.	2	
	Automatic function group			
2	Emergency shut-off, control room		0	
2	Emergency shut-off, local		0	
2	Fire protection		0	
2	Steam generator protection		0	
2	Generator protection, process control		0	
2	Generator protection, electrical		0	

Explanations:

Criterion group	Protection level
1	Turbine speed protection
2	Fundamental protection
3	Extended protection with delayed tripping
4	Extended protection with delayed tripping

Possible protection tripping criteria and tripping values (examples) for turbine protection (acc. To VGB R-103-M)

Types of Turbine Protection

Turbine Protection Replacing an Existing Hydraulic Overspeed Protection (typical for retrofit projects)

This is a cost-effective method of modernizing an existing hydraulically operating turbine overspeed protection system. A combination of sensors, electronic signal conditioning and processing modules is installed together with a centralized hydraulic protection block using 2-out-of-3 logic. The new protection block is incorporated in the existing hydraulic system.

In the design of the protection system, care must be taken to meet the demands on tripping safety and availability which differ in the individual sections of the overall protective system, as there are:

- Process value measurement
- Information processing
- Protective tripping

Failsafe Protection (FS)

In compliance with the VGB R-103-M guidelines, this group of protection criteria covers turbine overspeed protection and emergency stop switches.

Overspeed Protection (2-out-of-3 logic)
Decoupled by preamplifiers, the measured signals supplied by three pulse generators are sent to three independent DW modules (i.e., speed monitoring modules). Each DW module comprises three speed monitors which check the three turbine speed values, both for underrange and overrange conditions
(i.e., < 3 min-1, > 3300 min-1).

The processing and speed monitoring logics on the module are based on the failsafe principle. To enhance safety and availability even further, the DW modules are connected in a 2-out-of-3 failsafe protection logic. This prevents spurious tripping.

The tripping signals are pulse-width modulated by the speed monitoring modules and then forwarded to 3x2 solenoid valves mounted onto a central hydraulic 2oo3-type protection block.

Speed Monitoring Modules (DW Modules)

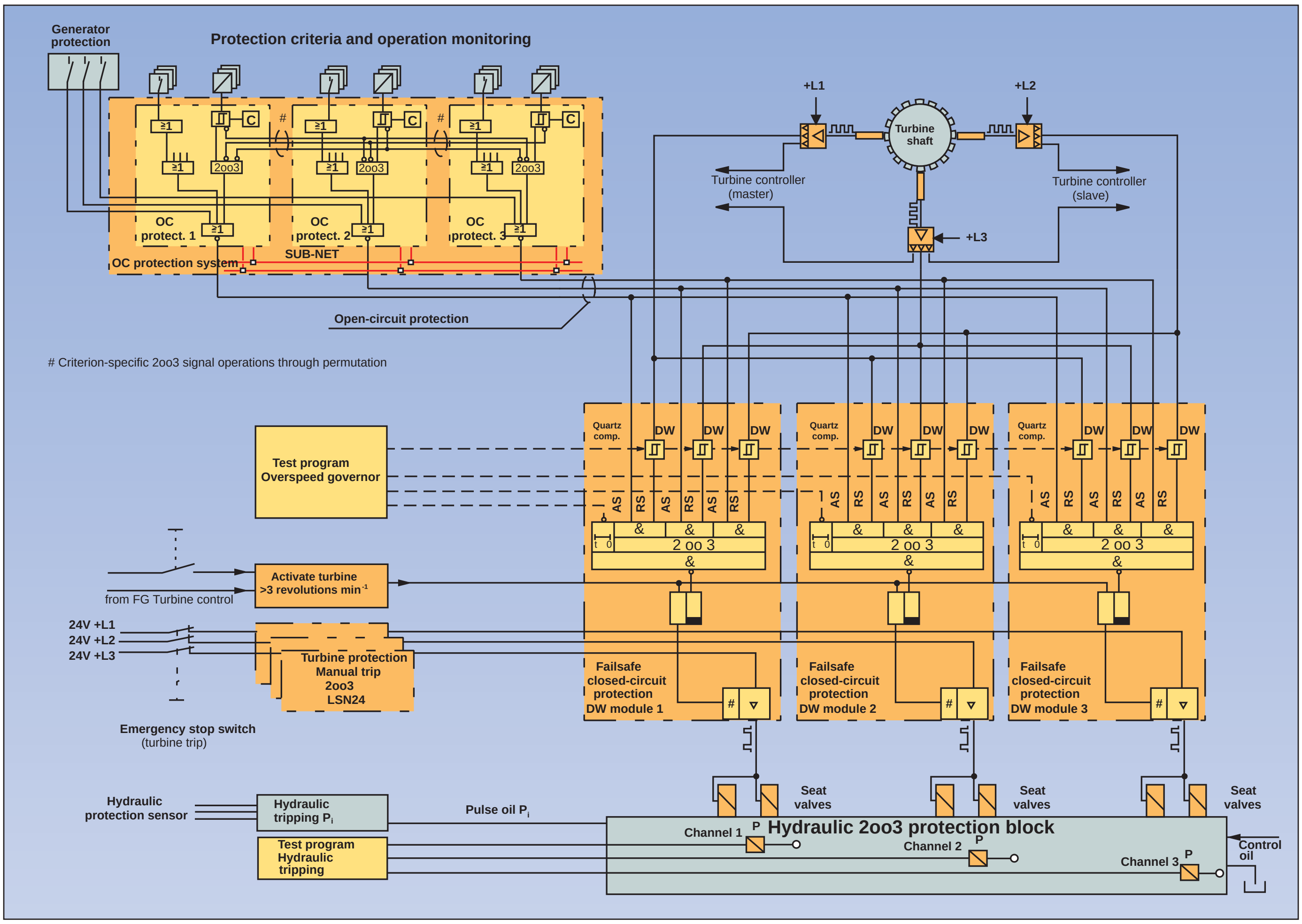
DW Modules: Design
The speed monitoring module is a highly integrated double-height printed circuit board, also referred to as sandwich-type Eurocard. The speed monitoring circuit, the logics and the important functional units are implemented in 2oo3 logic circuits. The use of SMD components made it possible to provide each channel in a dualized and autonomous arrangement to ensure redundancy.

All binary inputs are surge proof and electrically isolated by means of optocouplers. The binary outputs are short-circuit proof and non-reacting.

The module's faceplate indicates operating states and faults. Important parameters can be sampled through 2mm multiple-string wire plugs.

Using a key switch or binary input, the electrical overspeed trip can be triggered for turbine speeds lower than 3300 min-1.
The following trigger values can be selected:

750 min^{-1}
1500 min^{-1}
3000 min^{-1}
3300 min^{-1}



Turbine protection system (open-circuit shunt trip) with cascaded failsafe turbine protection

DW Modules: Principle of Operation

Measured by three speed sensors mounted on the turbine shaft, the turbine speed is fed to three autonomous phase comparator circuits on the DW module which compare the measured value with the permissible values for:

Maximum speed f_{max} and
Minimum speed f_{min}

The phase comparator triggers when the actual turbine speed is out of range. If two of the three phase comparators of a DW module indicate an out-of-range condition, the 3-channel failsafe trip sequence is activated. The downstream centrally placed solenoid valve initiates a seat valve which in turn reduces the protection oil pressure. The max/min speed evaluation is based on a frequency reference value. Every DW module generates its own frequency reference. When 2 or 3 DW modules are combined to form one protection unit, the first DW module assumes the role of the pilot (or master) module. The cascaded modules then synchronize with respect to the reference frequency dictated by the pilot module. The DW modules offer an electrical overspeed test function. Using the key-operated switch on the module faceplate, overspeed limit values can be set on each of the speed monitoring modules. During overspeed testing, the DW module recognizes the selected "test overspeed" and triggers the protection mechanism, even if the actually measured turbine speed lies within the permissible range and would therefore not give rise to overspeed tripping. This test function allows live testing of the entire overspeed protection system during turbine start-up from standstill without subjecting the turbine installation to excessive stresses.

To trigger all protection channels, one after the other, it is necessary to operate the key switch on the master module. Operating the key switch of the second module would activate the online overspeed test of the second and of all subsequent DW modules. To keep the power loss of the solenoid valve down to a minimum, the electrical trigger signal coming from the DW module is regulated by pulse-width modulation. This produces a mean current that sufficiently differs from the minimum retaining current of the solenoid valve. Also, the de-energizing delay due to the remanence of the solenoid is reduced to a minimum during tripping. In addition, this current control allows monitoring of the closed-circuit operated power transistor switch which acts just like an electronic circuit-breaker. The electronic circuit-breaker is continuously monitored to verify that it is capable of reducing the current well below the minimum retaining current of the solenoid valve if so required by the turbine protection scheme. Should a passive fault be under way, the protection sequence automatically starts itself off without any other command signal being necessary.

Due to their failsafe design and operation, the DW speed monitoring modules offer extremely reliable turbine protection. Its safety, diagnostics and operational efficiency are far superior to those of conventional protection mechanisms that are purely hydraulically operated.

DW Modules: Features

- The turbine speed is monitored by 3 channels connected to a 2-out-of-3 logic. Each channel is an autonomous circuit which can be checked cyclically by a user-defined test program.
- Three test programs are available for checking the DW module for correct functioning:

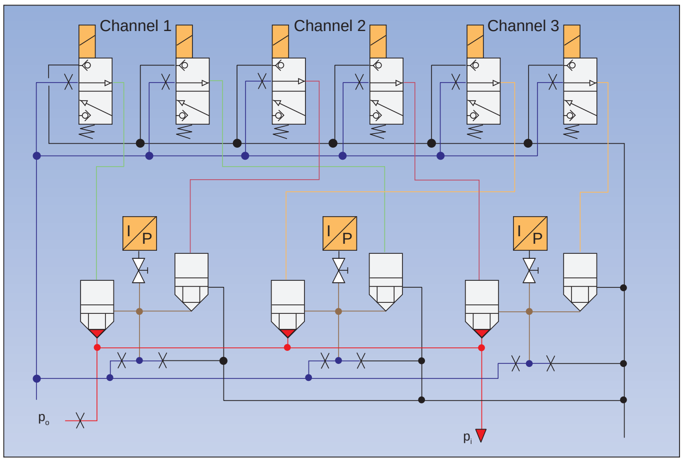
1st Test:	Turbine protection, DW
2nd Test:	Turbine protection, electrical tripping mechanism
3rd Test:	Turbine protection, steam valve (shut-off valve)

- An internal test rejection facility automatically interrupts the test programs applied from outside the DW module if the DW module is found to be faulty.
- The module's make circuit input allows delayed or non-delayed activation of the turbine protection circuit.
- The DW module controls the solenoid valve via a pulse-width modulated RS signal (i.e., set-reset signal supplied by an RS flip-flop). Pulse-width modulation reduces the power dissipation in the solenoid valve by 30 to 70%. This increases the valve's availability and service life while shortening its response time considerably.
- The module collects real-time current values and uses these to monitor the power circuit-breaker for its zero crossing at each switching operation of the current controller. In this way it continuously verifies the circuit-breakers breaking capacity.
- An internal auto-monitoring facility checks the module's critical functional units and recognizes and indicates errors. The module automatically resets itself to a safe operational status if a passive fault is imminent. (This module function is optional.)
- A key-operated switch located on the module faceplate can be used to trigger an overspeed condition for test purposes.

The three failsafe-operated speed monitoring modules (DW modules) control the seat valves of the hydraulic 2oo3-type protection block, which in turn pilot six cartridge valves that are interconnected in a 2-out-of-3 logic.

Protection Block for Central Hydraulics

Through a double-orifice inlet arrangement, the space between two adjacent cartridge valves is supplied with hydraulic fluid (i.e., oil). Pressure transducers monitor the intermediate value, which is reached at about half of the operational pressure. This allows continuous monitoring for cartridge valve leakages during normal turbine operation. If the turbine speed exceeds the trip value, the output of the overspeed monitor de-energizes, and as a result the failsafe-operated monitoring circuit of the DW module de-energizes the downstream trip solenoid. Should more than one overspeed monitoring module trip, the pressure in the protection pulse fluid circuit of the hydraulic 2oo3 trip block (i.e., the emergency trip pressure) is reduced to zero. The emergency stop valves and the control valves of the turbine act as the actuating elements of the protection system. Each valve is operated by its own spring-loaded servo drive which is controlled by the central hydraulic 2oo3- trip block as described above. In the event of an emergency trip, the pressure of the central pulse oil line reduces to close the servo drives. In such an emergency situation, the emergency stop valves (i.e., the shut-off valves) operated by the servo drives close in about 150 milliseconds. An emergency trip also closes the control valves as these are driven by the cartridge valves which -in an emergency- open due to the reduced pressure in the central pulse oil line.



Hydraulic 2oo3 protection block (at normal operation) for a highly reliable electrohydraulic conversion of the trip signals, also offering online test facilities

Open-Circuit Protection System (OC Turbine Protection)

Turbine protection criteria of the classes 2 to 4 are monitored by an open-circuit shunt protection system (also known as reverse-acting tripping) whose components must energize to trip. In the hierarchy of turbine protection mechanisms, open-circuit turbine protection is placed one level above the failsafe protection system. We say it is 'upstream' from the failsafe system. The open-circuit protection sequences comprise two or three channels. The signals coming from sensors and transducers placed in or around the turbine are pre-processed in the control cubicle in which three independent CPU modules handle all limit value generation and binary signal processing. The open-circuit part of the turbine protection system comprises three functional sections:

- Analog signal conditioning
- Binary signal conditioning
- Processor groups for logic operations

All measured analog process values required for turbine protection are collected in analog signal processing units. Critical values that are measured twice by two redundant measuring points are collected channel by channel and kept and processed by separate CPUs and signal conditioning modules. To achieve the highest possible degree of availability, the open-circuit protection system is powered by a dualized 24V d.c. power supply.

Monitoring of the OC Protection System

Static monitoring of the measuring chain:
The measuring chains that are part of the open-circuit protection system are continuously monitored for the following faults in the protection system to prevent unwanted turbine tripping caused by these types of faults:

- Wire break
- Short circuit
- Earth fault
- Voltage failure
- Voltage recovery
- Out-of-range signals

Should a fault of this type occur, the associated limit values are actually generated and any tripping initiated by these values is suppressed. Instead, a fault message is produced, displayed and recorded, and the reliability logic is changed from 2oo3 to 1oo2 or from 2oo2 to 1oo1.

Logic and Permutation Operations on the Turbine Trip Criteria

Depending on the weighting of the protection criterion, the emergency trip signals are processed by a 2oo3 or 2oo2 reliability logic and forwarded to the DW speed monitoring modules. Messages are generated with information about the process signal that caused the tripping, as well as about the operational and error states prevailing at the instance of tripping. Comprehensive monitoring of the signals and the electronic modules ensures that errors are detected and indicated. To avoid unwanted tripping caused by the open-circuit protection system, the protection criteria of the three protection channels are permutated to form criterion-specific 2oo3 reliability logic. This arrangement prevents tripping in situations, such as
Channel 1 "Condensate pressure > max."
Channel 3 "Shaft vibration > max.".
The protection system only triggers when 2 out of 3 channels indicate the same criterion violation. In all other cases, the detected faults and criterion violations are only indicated. They generally serve for plant monitoring and can mostly be eliminated on plant in service. The data informing about the status of the monitored protection criteria is transmitted over the SUB-NET process bus. Prior to transmission, the signals are negated at their source so that the signals transmitted over the bus can be considered as failsafe signals. To prevent the neighbouring channel from triggering, the signals received through the SUB-Net bus are negated a second time before they are finally connected to the 2oo3 logic. The extremely safe data transmission over the SUB-NET process bus ensured by its redundant and distributed architecture and the balanced and active network nodes makes the OC turbine protection system highly immune to spurious tripping. A failure of one of the network nodes does not affect the operative direction of the trip system in any way. However, permutation can no longer take place. Should several network nodes fail, however, then the OC protection system triggers immediately. All analog signals and criteria data are available for further processing: for message generation with time stamp, for processing in automatic function groups, for archiving and display, for instance.

Trip Criteria

Apart from the existing hydraulics devices responsible for overspeed tripping, modernization of turbine protection systems usually involves the installation of additional hydraulically-operated encoders which will supply measured data on additional protection criteria, such as:

- Bearing oil pressure
- Condenser vacuum
- Shaft position in block bearing

Modernizing the turbine protection system and changing to electronic methods of measurement usually does not require any mechanical changes in the turbine equipment. Only the shaft displacement measurement makes it necessary to do some retrofitting as the new measurement system must be fitted inside the block bearing. Depending on the conditions of the machines and the retrofitting plans decided by the power station company, the hydraulic transmitters are replaced completely or partially by electronic sensor/transmitter equipment and signal processing in the OC protection system. The principal protection criteria and their permissible trip delays:

Deenergize-to-trip system (failsafe, 2oo3), non-delayed trip:

- Speed (channels 1 to 3)
- Emergency Stop

Fundamental protection (2oo3), non-delayed trip

- HP outlet temperature (60s delay)
- Condenser pressure
- Bearing oil pressure
- Shaft position at thrust bearing
- End blade protection
- IP outlet pressure (at butterfly valves in overflow passage)

OC protection system (energize to trip, 1oo2), delayed trip (2s)

- Bearing temperatures
- Steam and casing temperatures
- Steam pressure before turbines
- Shaft vibration (vector quantity)
- Relative expansion
- External criteria (generator, boiler, fire protection)

Test Programs for the Turbine Protection System

The test programs of the turbine protection system allow a functional check of the following modules and equipment:

- DW modules, for overspeed monitoring and sensor failure
- Trip solenoid valves (seat and cartridge valves)
- Emergency stop valves and control valves

The test programs can be executed on the plant in service without affecting the protection of the running machine in any way. To test the DW modules for correct overspeed monitoring and the hydraulic protection block, a step program is started either automatically at regular intervals, or manually by a command from the control.

Testing the DW Modules (Turbine Overspeed Monitoring)

With the turbine running at nominal speed, an overspeed situation is simulated to trigger an overspeed monitoring circuit on the DW module to be tested. The overspeed situation is simulated by disconnecting the actual speed value and substituting it by a speed signal which has a trigger value of +10.1% with crystal-controlled accuracy. A feedback signal is sent to the test program. In a similar way, the speed sensors and their complete transmission lines (i.e., cabling, preamplifiers) are tested for correct functioning (drop below the minimum speed of 3 min-1). Due to the 2-out-of-3 failsafe logic, the test is executed without tripping the hydraulic protection block which is also based on 2oo3 logic. Overspeed monitoring tests are in-situ tests. They are carried out cyclically while the turbine is running. Error situations found by the test program are indicated by the Criteria LEDs and the step numbers concerned and can be viewed directly in the control cubicle.

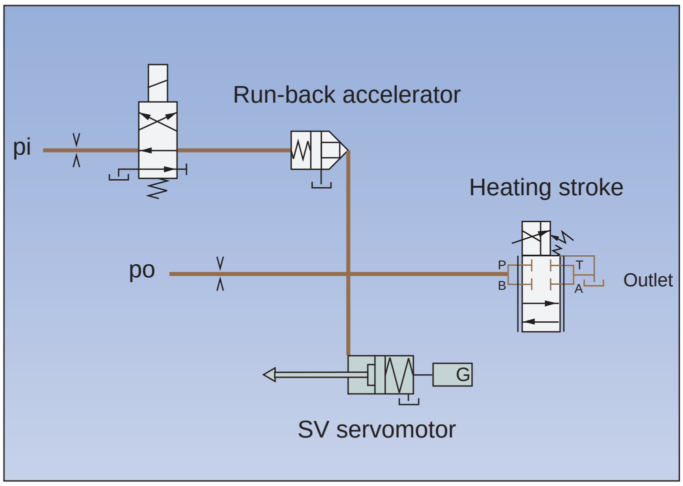
Another task of the test program is to check the downstream failsafe logic and the electronic power circuit-breaker for their correct trip behaviour and disconnect capacity. Triggering the protection channel deenergizes the switch output of the DW module and opens both seat valves of the hydraulic 2oo3 protection block.

Testing the Hydraulic Protection Block

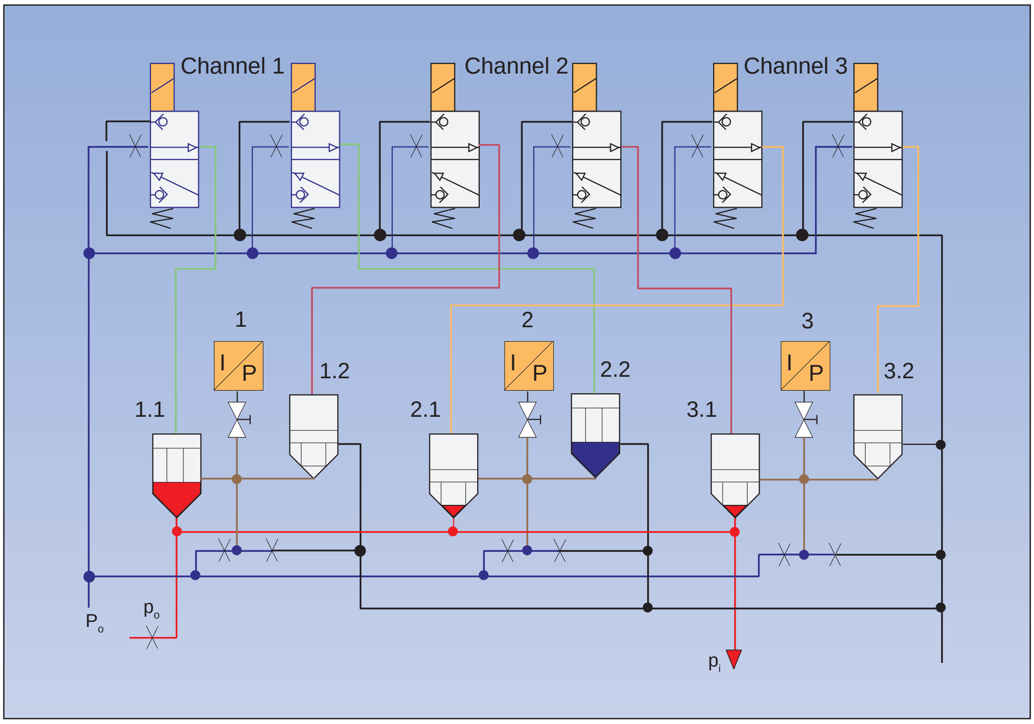
Again, the test is carried out in situ without interrupting turbine operation. A step program triggers an electronic switch on the DW module and monitors the response of the hydraulic protection block. The figure on page 25 shows the protection block in normal turbine operating mode. The pressure in the connecting lines between the transducers and the two associated cartridge valves are at the average value of the operational pressure of the hydraulic fluid system and the discharge pressure. For instance, if protection channel no. 1 is triggered for test purposes (see figure below), both seat valves of channel 1 open and the associated cartridge valves 1.1 and 2.2 open. The pressure measured by transducer 1 rises to operational level as the system is now connected with the protection pulse fluid pressure Pi and cartridge valve no. 1.1 has opened. The pressure measured by transducer 2 drops to zero as the pressure close of cartridge valve 2.2 is now connected with the discharge line. After completion of the channel test, both pressure transducers must show again the average value of the operational pressure of the hydraulic fluid system and the discharge pressure in order to ensure that both cartridge valves have properly closed. This is a precondition for enabling the test of the next channel and prevents false tripping caused by the test.

In-Situ Test of the Emergency Stop and Control Valves

To carry out an in-situ test of an emergency stop and control valve combination, the test program will first of all instruct the turbine controller to throttle the control valve to a 10% close position while observing a given transient curve. Then the test valve of the associated servo drive is operated to initiate a trip action. After completion of the trip test, the valves are brought back into their operational states by first resetting the emergency stop valve and then the control valve.



Hydraulic circuit for testing the emergency stop valve



2oo3 hydraulic protection block in test mode

Overspeed Test

To carry out an in-situ overspeed tripping test, you can reduce the trip value to 3000 min^{-1}, 1500 min^{-1} or 750 min^{-1}. This setting can then be applied during special turbine start-ups, say after a turbine inspection, to test overspeed tripping without having to go through complicated procedures and without shortening the remaining service life of the turbine.

As the trip speed can be obtained very accurately during the overspeed monitoring test (i.e. the DW module test), it is in most cases not necessary to actually run up the turbine to an overspeed of 3300 min^{-1} to test the emergency stop and control valves.

Electronic 2oo3 Turbine Protection with Distributed Hydraulic 1oo2 Trip

In new turbine installations, and in installations that require extensive repair and maintenance work on the hydraulic and the servo drive equipment, a turbine protection system with distributed hydraulic trip facilities is often the best and most economic solution.

With this approach, the method of criteria acquisition, conditioning and processing is principally the same as described earlier. The main difference lies in the conversion and implementation of the trip signal.

In this distributed arrangement, the DW modules do not drive the 2oo3 hydraulic protection block, but electronically control special protection modules instead, the EAM 15A modules. These modules are responsible for disconnecting the control voltage of the solenoid valves (always 2 channels at a time) and as a result activating the emergency stop valves.

The 24V power bus bar which supplies the emergency stop solenoid valves and the associated ANS-MV current control modules is disconnected by a 2-out-of-3 failsafe trip circuit obtained by interconnecting three identical EAM 15A modules.

The EAM 15A protection modules are driven by the outputs (NF signal) of the DW modules. To ensure a continuous and selective test of the three protection channels during turbine operation, the DW modules have special test inputs that are connected to an "Electrical trip" function group. A trigger signal coming from the "Electrical trip" function group activates the protection trip of the channel selected.

The DW module's monitoring channels generate check-back messages of the trip circuits. These feedback signals tell the "Electrical trip" function group that it can continue the test program. In the event of errors, an error message is fed back and the cyclical test program is stopped.

ANS MV Modules for Solenoid Valve Control

The ANS-MV modules are interfaces to the distributed solenoid valves. The solenoid valves convert the electrical trip signals to hydraulic signals that drive the emergency stop and control valves.

To achieve shortest possible valve release times, pulse-width modulation is applied to the solenoid valves after energizing which regulates the valve power down to the minimum that is required for holding in the solenoid.

The ANS-MV module's special test inputs allow in-situ trip testing while the turbine is running.

Manual Release of the Emergency Stop Function

When the 3-channel Emergency STOP switches provided locally on site and in the control room are in their normal non-tripped operating mode, the three power contactors LNS 24V can be energized. Going through a 2-out-of-3 reliability logic, the contacts of these power contactors activate the turbine control system, including the turbine shut-off valves for emergency stop and the control drives. The 2oo3 reliability logic ensures a high degree of safety and availability. A single-channel error can be corrected on plant in service. If two of the three channels trigger, the turbine is safely shut down.

Test Programs

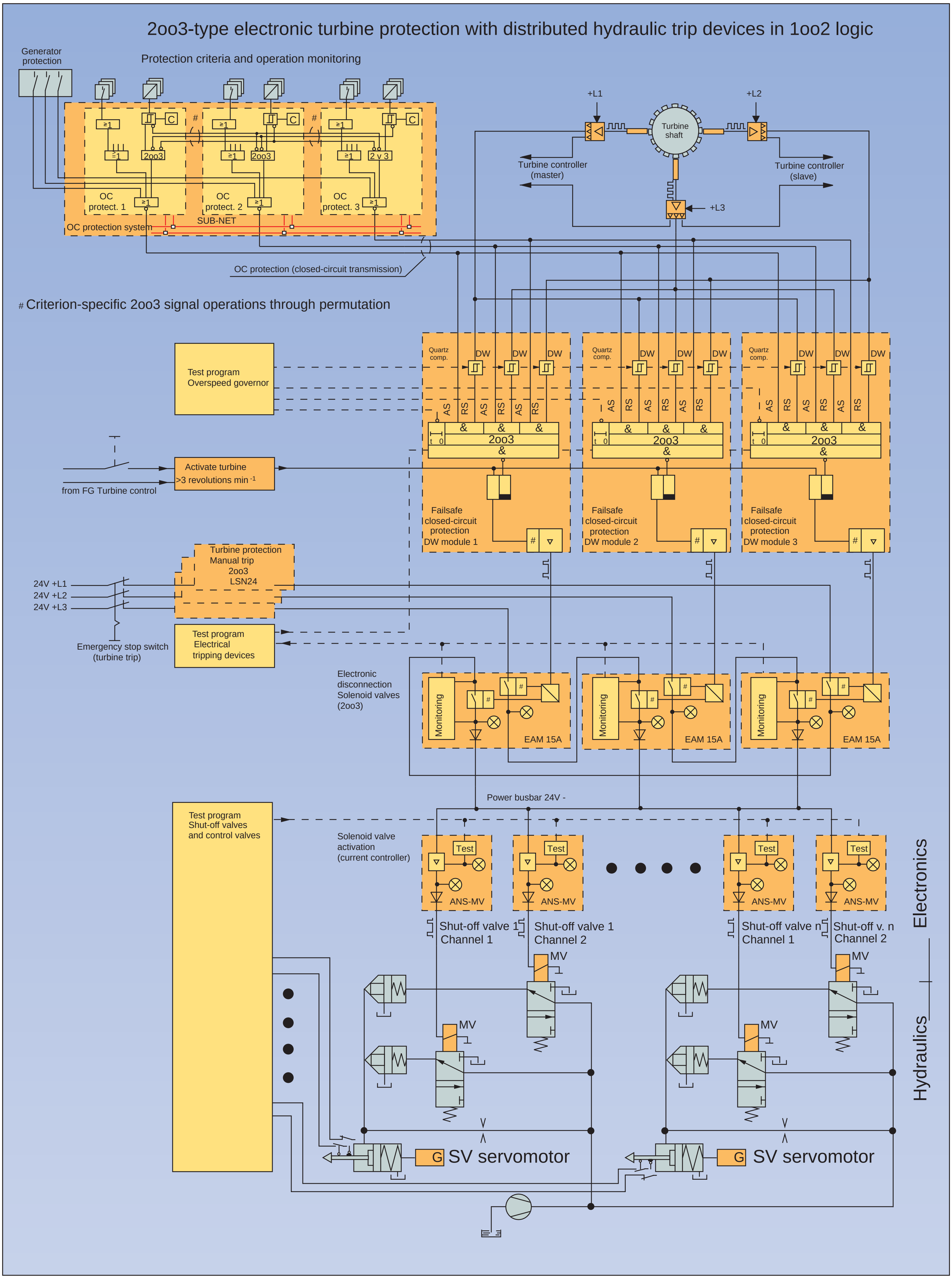
In plants that work without the hydraulic protection block, special test programs are put in place in addition to those described earlier on. They ensure that all parts of the turbine protection system that have distributed hydraulic trip devices are automatically tested at regular intervals on plant in service.

Test Program "Electrical Trip Device"

This test program is started either manually by the operator or automatically at regular intervals, once a day, for instance. Detected errors are indicated in the electronics section of the ME 4012 system control cubicles. Again, the errors can be eliminated in situ with the turbine running as the error logic is based on the 3-channel principle. Electrical protection is provided by the EAM 15A 2oo3 modules which replace the complete functionality of the complex hydraulic turbine protection block employed in earlier turbogenerator plants.

Test Program "Steam Valves"

This test program checks whether the steam valves are running smoothly. It can be started manually by the operator or automatically and can usually only be run at part-load turbine operation. This again depends on the number of shut-off and control valves employed and on their layout in the plant.

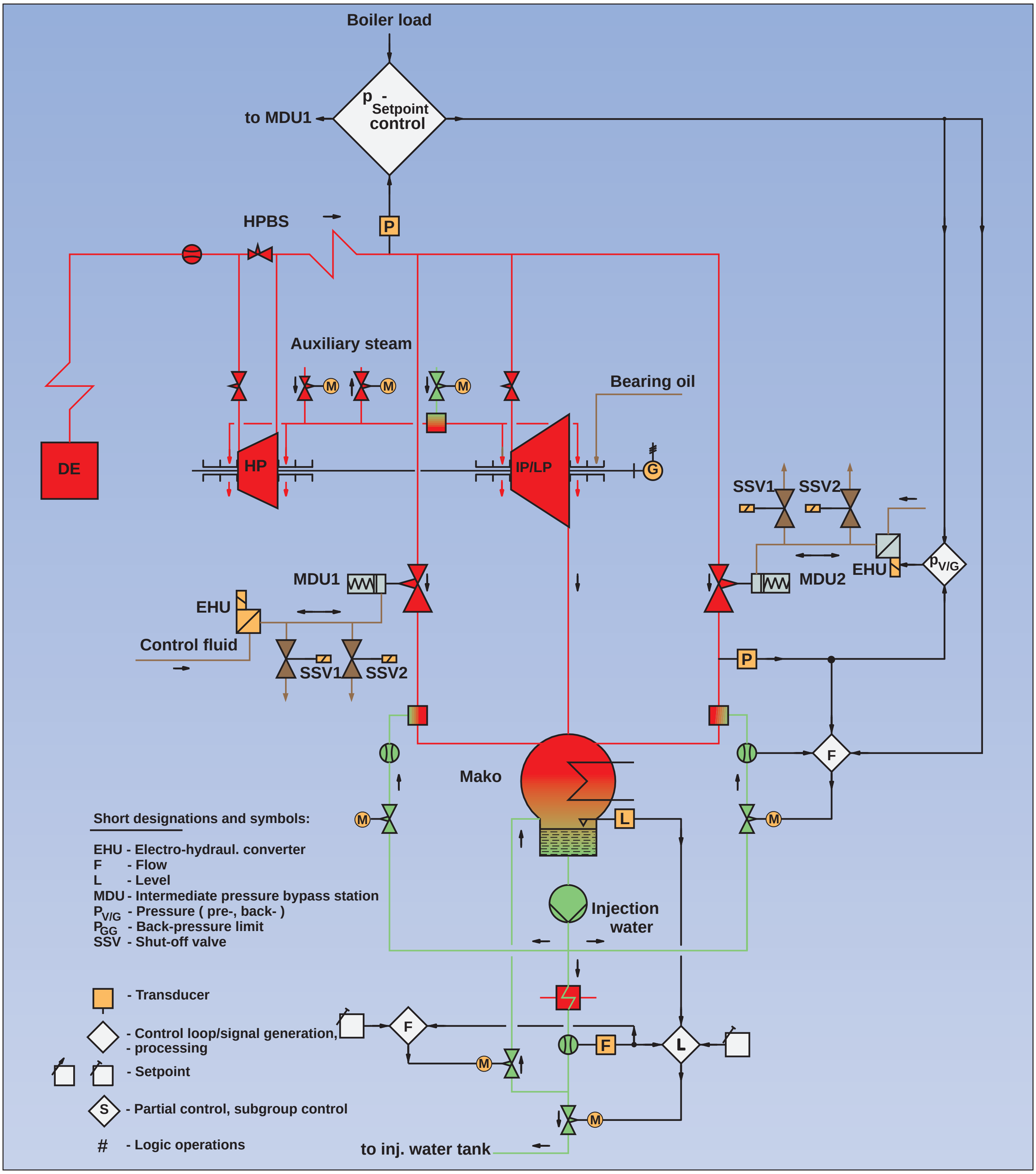


2oo3-type electronic turbine protection with distributed hydraulic trip devices in 1oo2 logic

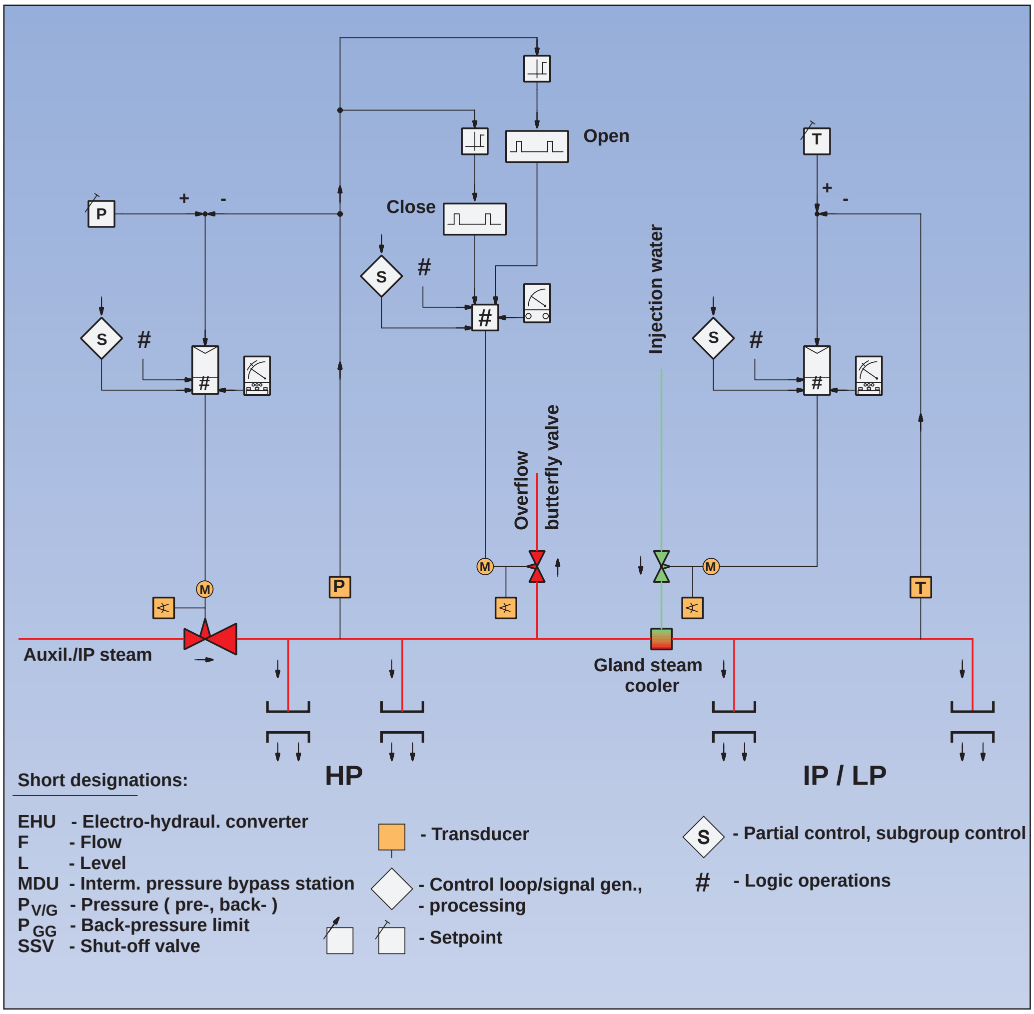
Turbine Auxiliary Installations

In addition to the all important turbine speed and power control system, the auxiliary equipment is vital for efficient and safe turbine operation. The auxiliary plant is typically responsible for the following tasks:

- Gland steam pressure control
- Gland steam temperature control
- Bearing oil temperature control (oil flow control)
- Bearing oil temperature control (coolant flow control)
- Control fluid temperature control
- Condensate level control
- Condensate minimum flow control
- IP bypass control with pressure and injection control
- Generator auxiliary control loops
- Condensate congestion control



Overview of the turbine auxiliary control loops



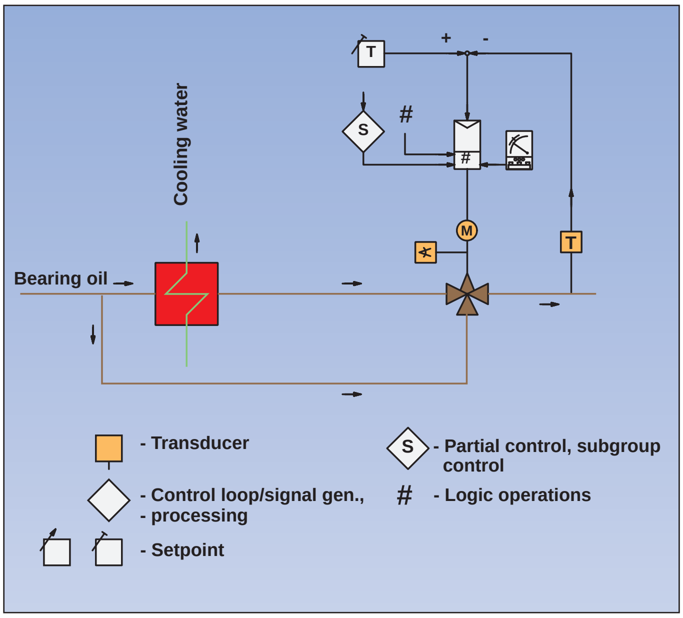
Gland steam pressure and temperature control

Gland Steam Pressure Control

To ensure that the gland steam system suffers neither from lack of steam nor from excessive steam supply, the gland steam controller tries to maintain the steam pressure constantly at a low overpressure level of about + 15 mbar (selectable) by feeding in seal steam through a supercritical gland steam pressure valve. In the event of excessive steam, a subcritical overflow butterfly control valve continues to increases the volume of the discharged steam until a point is reached where the gland steam pressure valve maintains control with a very low stroke, just sufficient to keep the seal steam feeder line warm.

Gland Steam Temperature Control

The steam going to the LP shaft seals must be kept constant at a sufficiently low temperature of about 150 °C. However, the temperature of the steam coming from the gland steam pressure valve or from the shaft and spindle seals is usually not constant but varies with the load situations of the turbine. To provide low-temperature steam of about 150 °C at the LP shaft seals, the temperature controller feeds the required condensate volumes to the injection nozzles of the gland steam cooler.



Bearing oil temperature control (as oil flow control)

Controlling the Bearing Oil Temperature by means of Oil Flow Control

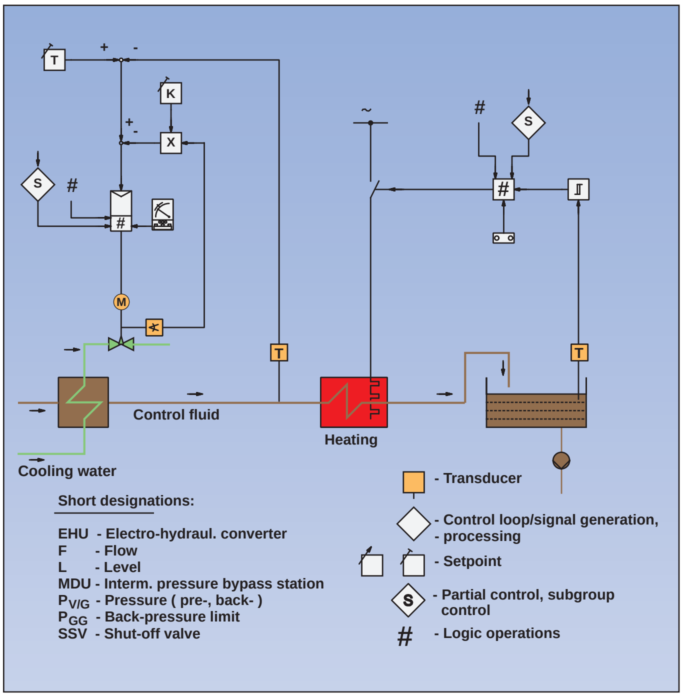
The controller regulates the oil flow rate to keep the temperature of the bearing oil constant.

Controlling the Bearing Oil Temperature by means of Coolant Flow Control

This control method is applied alternatively to the oil flow control principle. It keeps the temperature of the bearing oil constant by regulating the coolant flow rate.

Control Fluid Temperature Control

The coolant flow rate is regulated to keep the temperature of the control fluid constant.



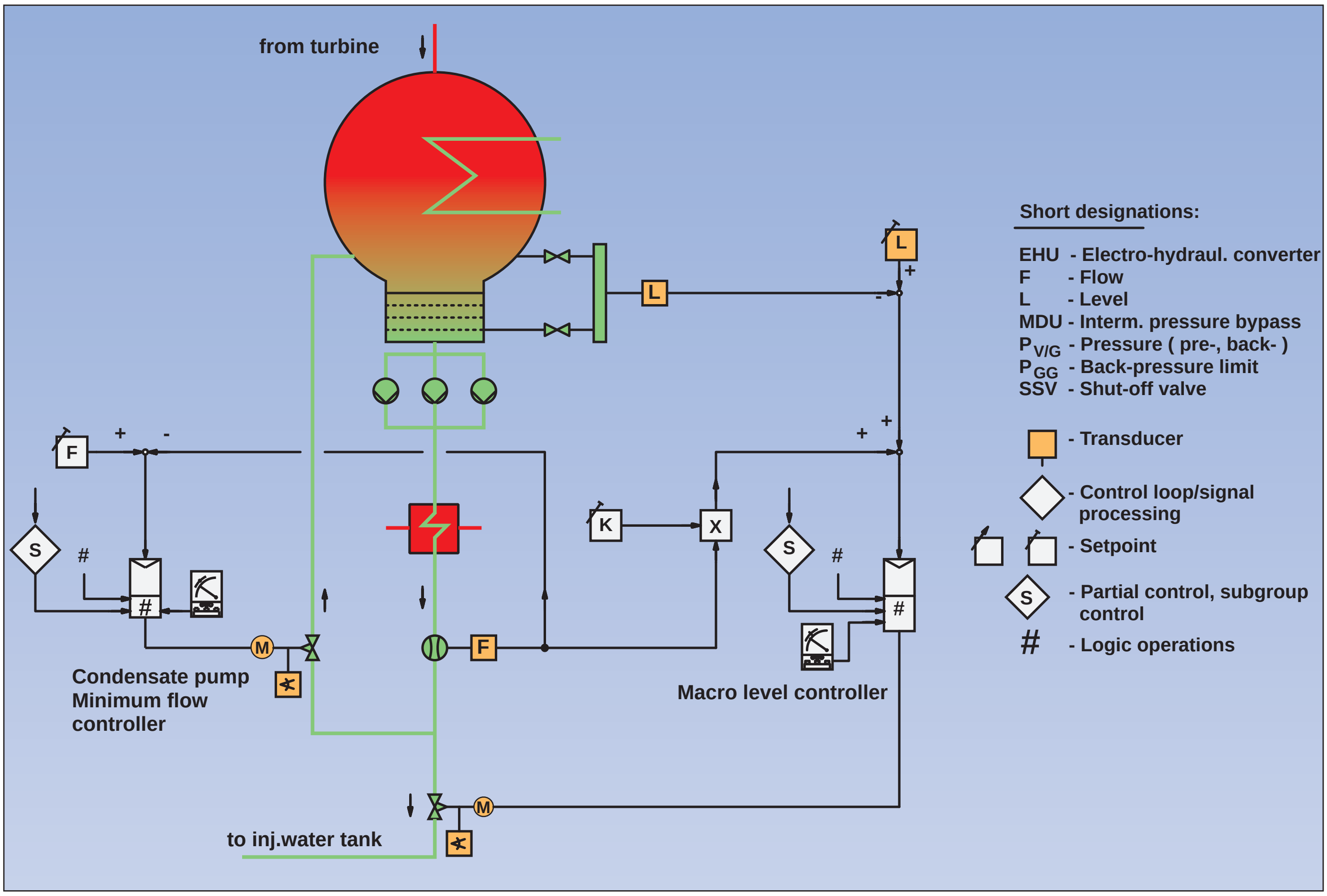
Control fluid temperature control

Condensate Level Control

This control loop maintains a constant level in the condenser.

Condensate Minimum Flow Control

The flow rate of the condensate must not fall below a minimum value. This control loop ensures a minimum flow rate taking into account the number of condensate pumps in operation.

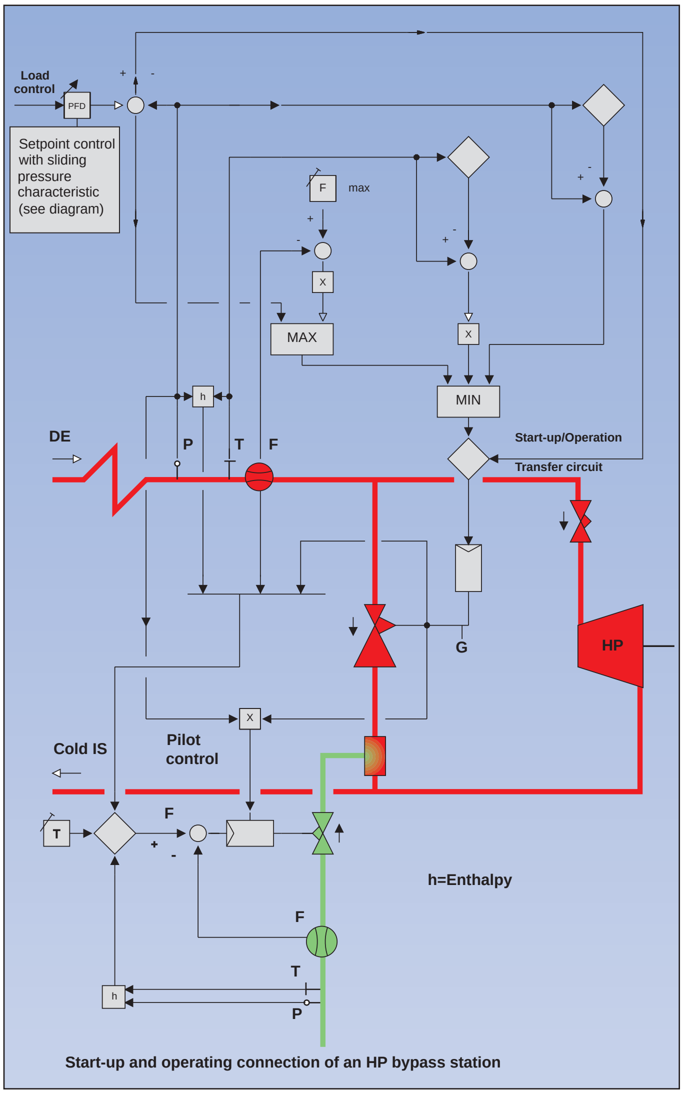


Condensate minimum flow control

Operation Modes of the High Pressure Bypass Station (HPBS)

Start-Up Operation

The HP bypass station has the task of bypassing the generated steam to the cold intermediate superheater (CIS) until the steam has reached the pressure, temperature and quality required for turbine start-up and until the entire steam volume generated by the boiler can be admitted by the turbine.
During this start-up mode sufficient cooling of the The HP and intermediate superheater heating surfaces must be ensured and the boiler's permissible rates of pressure and temperature change must be taken into account.
We distinguish between cold start, warm start and hot start, whereby the valve positions and the minimum opening at every start-up are determined by the actual boiler parameters.



Start-up and operating connection of an HP bypass system

Start and Operating Connection of an HP Bypass Station

Normal Operation with Turbine Connected

At normal operation with the turbine connected the HP bypass station is closed. It only intervenes if turbine malfunctioning causes the pressure in the steam generator to rise above the permissible limit. In this situation, the The HP bypass station will then open and adjust the live steam pressure to the specified load-controlled setpoint.

The "sliding pressure adjustment" has the advantage that the increasing live steam pressure is adjusted even before the calculated pressure is reached.

This is particularly important under partial load conditions as during during an emergency stop at partial load the pressure build-up can take several minutes depending on the boiler load. This pressure build-up delay is counted from emergency tripping to reaching the pick-up pressure of the steam test unit (maximum permissible pressured). With non-sliding pressure adjustment, the heating surfaces of the superheater would -during this period- not be sufficiently cooled, or even be exposed to heating without any cooling at all. This is prevented by sliding pressure adjustment which determines the opening criteria of the HP bypass station. The diagram on page 34 illustrates this response. The opening criteria characteristics of the HP bypass station run in parallel with and just above the modified sliding pressure characteristics.

Depending on the system pressure reached, the HP bypass station opens normally with an actuating time of about 30 seconds (regular start), or at the higher speed of about 5 seconds (rapid start). In an emergency situation, i.e., when the approved pressure is reached and the safety mode is activated, the bypass system opens with an actuating time of less than 2 seconds.

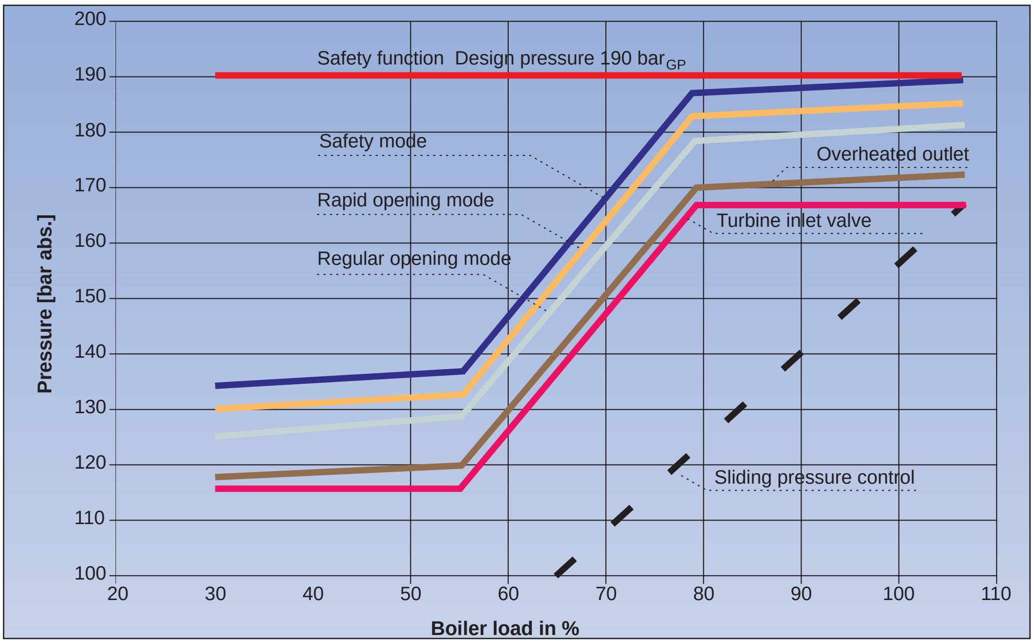
The pressure setpoints at which the HP bypass station opens in regular or rapid opening mode are corrected by applying gradient control in accordance with the boiler load.

At normal turbine operation, the temperatures of the cold intermediate superheater (CIS) are stored. When a sudden bypass operation becomes necessary, these temperature values are used as setpoints for the steam temperature at the outlet of the HP bypass station.

Example of a HP Bypass Station (HPBS) Pressure Characteristic

Pilot Control of the HPBS Injection

When the steam output of the HP bypass station reaches a specific value, injection pilot control takes effect in addition to the normal temperature control to ensure that the required CIS temperature is already reached when the HP bypass station opens. The pilot control signal is generated taking into account the position of the HPBS, the steam capacity, and the difference between the live steam temperature and the CIS setpoint temperature. The lower limit of the steam temperature after the HP by-pass station is set to 20 °K above the relevant boiling temperature.



Sliding pressure characteristics of the high pressure bypass system (HPBS)

Shutdown

The boiler load is reduced to circulation operation and the turbine is shut down. The HPBS opens and regulates the steam to the required pressure of approximately 120 bar. The HPBS, too, is shut down ("FIRE OFF") so that the boiler pressure can be sustained on the highest possible level. If necessary, the HPBS reduces the pressure in line with a specified gradient and target setpoint before the system is restarted.

Standstill

The HPBS remain shut after ”FIRE OFF”.

If at system restart the pressure at the HP outlet exceeds the maximum start-up pressure, the HP bypass station opens and the pressure is reduced taking gradient correction into account. If the HP outlet pressure is below the maximum start-up pressure, the pressure is not reduced; the HPBS then only opens when a rise in pressure is detected after ”FIRE ON”.

Boiler Cool-Down

If the boiler has to be cooled down (e.g., for repairs), the boiler pressure is released through the HP bypass station (gradient: 3 bar / min approx.).

Emergency Situation

The three pressure switches of the steam test unit respond to a tripping pressure of 190 bar$_{GP}$. The HP bypass station opens as soon as one of the three pressure switches is activated. (In two-circuit systems, both HP bypass stations open.)
At a reset pressure of about 188 bar$_{GP}$ on all three pressure switches the units close, i.e., the turbine control system takes over the task of maintaining pressure stability.

Turbine Emergency Trip

Turbine emergeny tripping (grid operation) directly activates the HP bypass stations in the rapid opening mode. These control the pressure according to the pressure characteristics.

Overpressure Conditions

The sliding pressure adjustment is only active at "FIRE ON". If the modified sliding pressure characteristics (see pressure diagram above) are exceeded by more than 8 bar approximately, the valves open in regular mode. If the sliding pressure characteristics are exceeded by more than 12 bar., the valves open in rapid mode and the pressure is controlled in line with the pressure characteristics. If the pressure exceeds the rapid opening characteristics by more than 5 bar, the safety mode is activated and pressure control is based on the sliding pressure characteristics

Isolated Operation

The HP bypass stations are activated directly if at load shedding the steam output is higher than a defined percentage, depending on the load shedded. Initial boiler status prior to full-load shedding (example)

	Boiler outlet	via HPBS	to Turbine	IS inlet
Mass flow [t/h]	1068	0	1068	922.4
Pressure [bar$_{GP}$]	172.5	172.5	165.7	40.3
Temperature [°C]	540	540	538	333.5

Boiler status at steady-state isolated operation with a steam output of 40 % and an electric power output of 8 %

	HP outlet	via HPBS	to Turbine	IS inlet
Mass flow [t/h]	415	299	116	337.1
Pressure [bar$_{GP}$]	136.8	136.8	135.5	10.3
Temperature [°C]	540	540	538	340

Enthalpy Control of the HP Bypass Station Outlet Temperature

The energy content of the live steam is derived from the steam’s pressure and temperature values.
The setpoint ($\dot{m}_{setpoint}$) of the injection water flow rate regulator is based on an energy balance taking into account the live steam and the desired HPBS temperature drop and the enthalpy of the cooling water.

Operation of the IP/LP Bypass Stations (IPBS)

Normal Operation with the Turbine Connected

At normal operation with the turbine connected the IPBS are closed. They intervene only if turbine malfunctioning ("Fire ON" mode) leads to a pressure rise above the permissible limit. The IPBS will then open and adjust the pressure of the hot intermediate superheater (HIS) to the specified load-controlled setpoint.

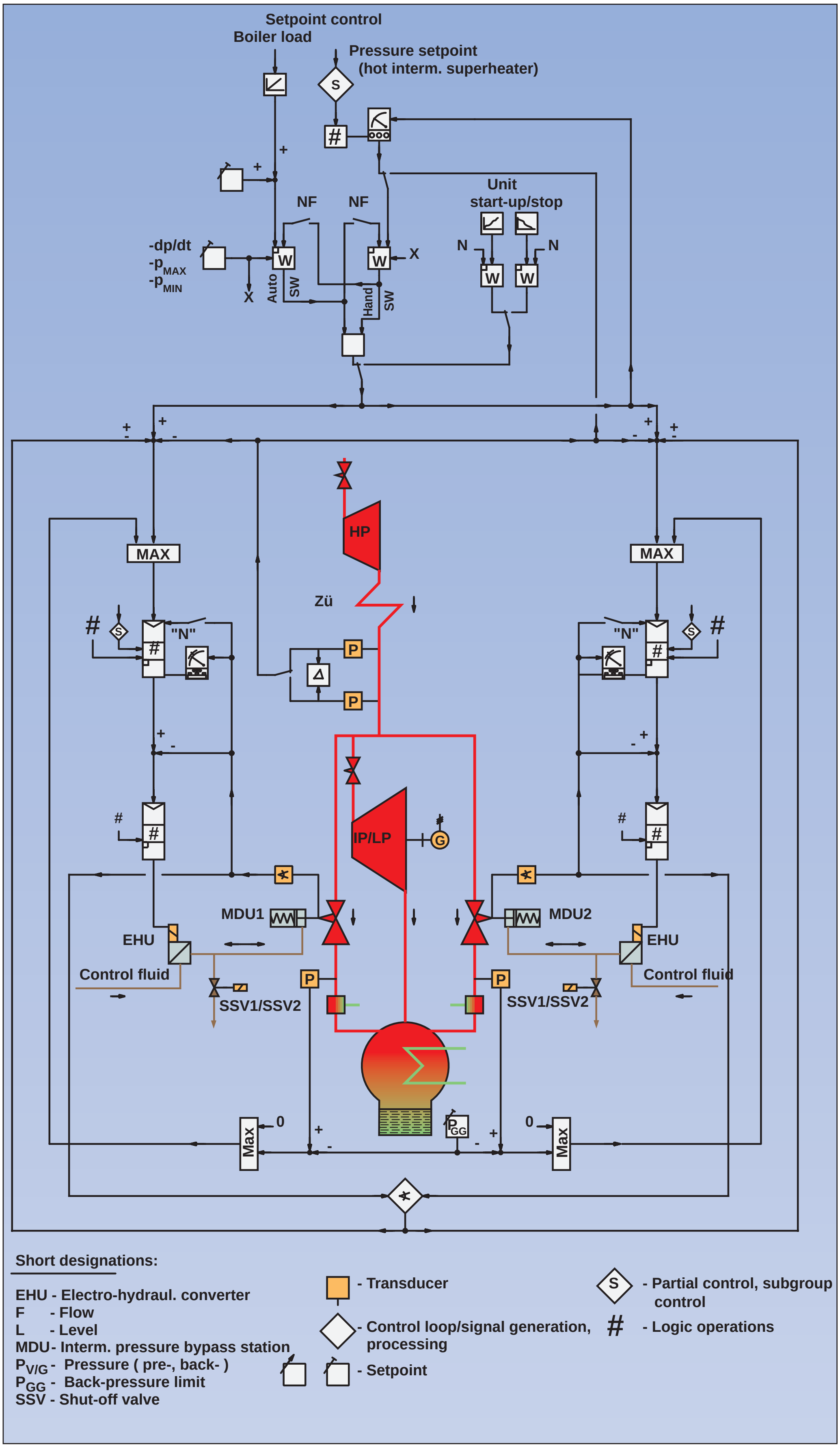
Pressure Adjustment of the Intermediate Superheater (IS)

The "sliding pressure adjustment" has the advantage that the increasing IS pressure is adjusted even before the calculated pressure is reached. This is particularly important under partial load conditions as the pressure build-up at - emergency tripping at these conditions can take several minutes (from triggering to the build-up of the operating pressure of the steam test unit (i.e., maximum permissible pressure)), depending on the boiler load. With non-sliding pressure adjustment, the heating surfaces of the superheater would -during this delay- not be sufficiently cooled, or would even be exposed to the heating process without any cooling at all. The sliding pressure adjustment determines the opening criterion of the IP bypass station. For a boiler load of ≥ 60 %, the characteristic curve of the opening criterion is in parallel with and above the sliding pressure characteristics. It is activated with "FIRE ON". The setpoint of the IP bypass station opening pressure is corrected according to the boiler load.

Emergency Situation

The three pressure switches of the steam test unit respond to a tripping pressure of 44 bar_{GP}.

The IP bypass opens as soon as one of the three pressure switches is activated. At a reset pressure of about 42 $barr_{GP}$. on all three pressure switches the units close.

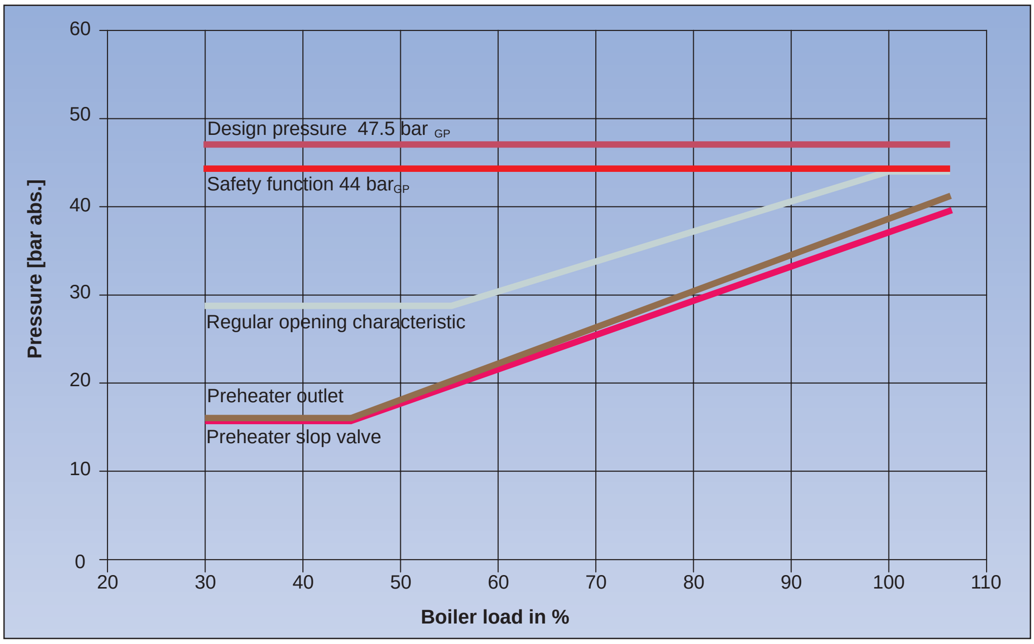


IP bypass station pre-pressure control

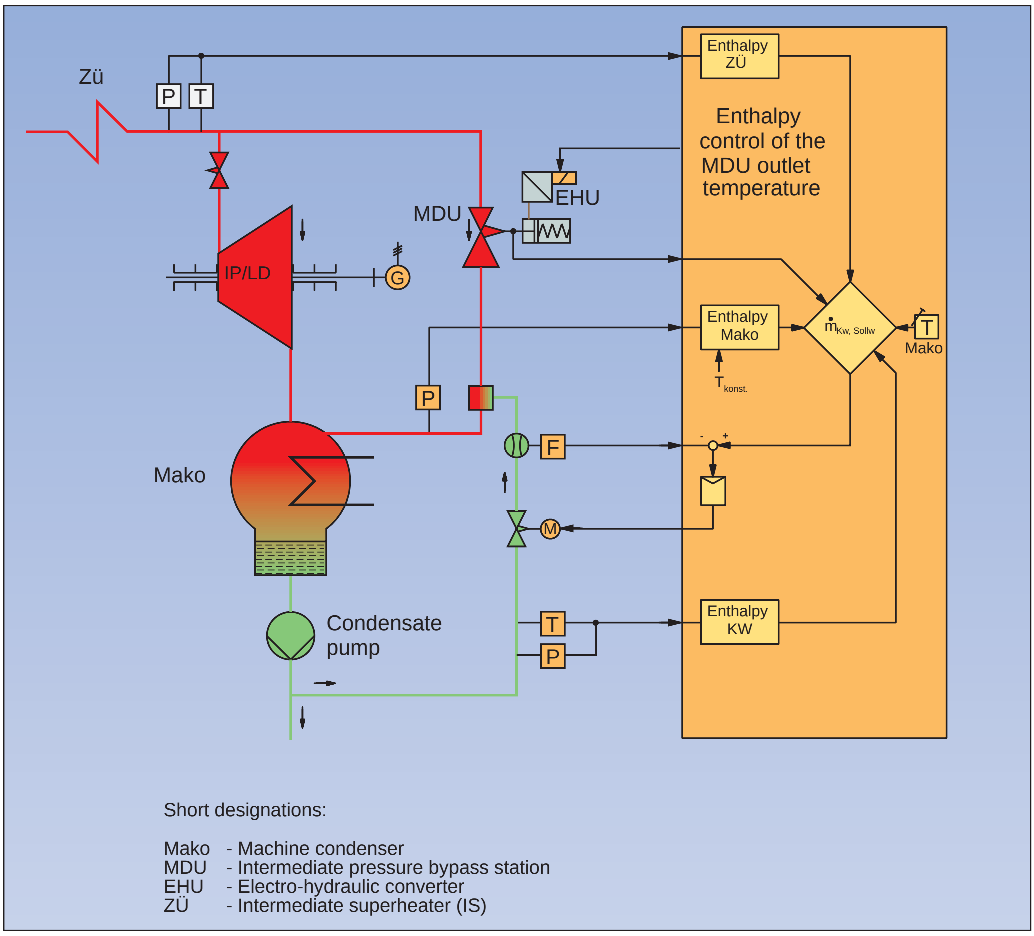
Pressure Stability

Maintaining pressure stability is not based on finely tuned pressure adjustment processes: As soon as the pressure reaches the control characteristic, the valves open by a minimum. Should the pressure continue to rise the valves open a little further, depending on the pressure increase.

The valves close when the pressure drops to a value below the opening characteristics. The closing pressure difference should not exceed a value of about 2 bar.



Pressure characteristics of the IP bypass station with sliding pressure adjustment



Temperature control of the IP bypass station

Overpressure Conditions

The sliding pressure adjustment is only active at "FIRE ON". If the sliding pressure characteristics (see pressure diagram) are exceeded, the valves open and the pressure is adjusted.

Temperature After the IP Bypass Station (IPBS)

Space is a factor when it comes to the integration of IP bypass stations in today's turbo generator-set and machine condenser systems. This may result in measurement difficulties due to restricted space. The distance between the pressure reduction station and the machine condenser, for instance, is too short for the cooling water to condensate before the temperature is measured.

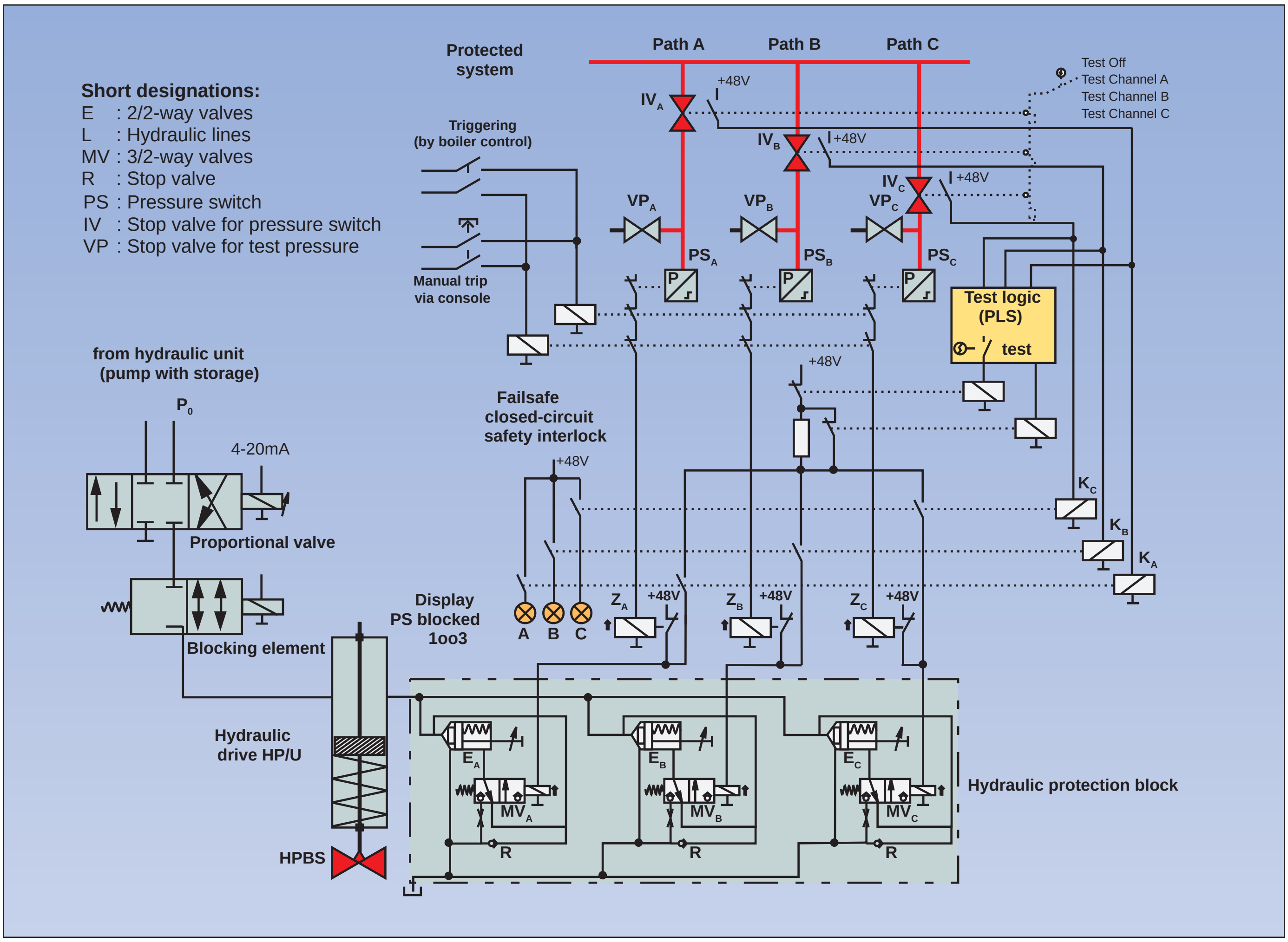
Temperature control can therefore not be based on the temperature measurement in the heat exchanger. So, if the steam temperature after injection cannot be accurately measured, the cooling water quantity must be controlled on the basis of a model.

Control of the Water Shut-off Valve

As soon as the HP bypass valve opens, the water shut-off valve, too, opens to 100%. It closes when the HP bypass valve closes.

IP Bypass Control

If the IP bypass station is adequately dimensioned, all of the IP surplus steam can be routed directly to the condenser or heat extraction system. The relief valves of the intermediate superheater (IS) will thus not be activated and noise emission, wear and persistent leaks can be avoided.



HP and IP bypass stations, failsafe overpressure protection

HPBS/IPBS Overpressure Protection with Failsafe Control

Steam overpressure protection for hydraulically operated HP overflow and HP and IS relief valves is implemented with our ME 4002S Failsafe System.

Principal of Operation

The ME 4002S Failsafe System works identically for HP overflow valves with safety function and for IS relief valves, irrespective of the number of parallel relief valves (two, three or four valves) used in the steam system.

The reliability logics are based on the "3 out of 3" principle, i.e., the relief valves open as soon as one of the three paths A, B, C is activated. Closed-circuit protection on the deenergize-to-trip principle is implemented for all three paths.

Each relief valve has three solenoid valves which are normally energized and thus closed under normal conditions. As soon as a solenoid valve de-energizes, it opens and subsequently the spring-powered relief valve is opened. This means, however, that a power failure, too, would cause the relief valve to open. Therefore, the failsafe protection system is supplied by two power supplies. This redundancy structure ensures continued plant availibility.

As valve operation is not based on a hydraulic force, overpressure protection is not affected by hydraulic pressure failure

.

If the pressure in the protected system rises above the operating pressure of the pressure switch PS, the electric circuit to the 3/2-way seat valve is interrupted via the intermediate relay Z. This valve opens the way for the control fluid pressure to the 2/2-way built-in valve E which is subsequently relieved. The hydraulic pressure acting on the valve plug of the 2/2-way built-in valve opens the valve against the spring force. Hydraulic fluid fed through the hydraulic lines L1 and L4 flows from the lower to the upper piston space of the hydraulic servo drive. The force exerted on the valve plug by the medium opens the relief valve.

Upon activation of the failsafe functions the normal closed-loop control function of the HP overflow valves must be interrupted. This interruption is monitored by two channels. For this purpose the failsafe control system offers two relay contacts for every valve. If the pressure drops below the operating pressure, normal closed-loop control takes effect again and the valves are closed. Intermediate superheater relief valves do not have a closed-loop control function. The failsafe control system therefore offers one output for every relief valve for the activation of a solenoid valve which keeps the relief valve shut under normal conditions.

The relief valves can also be opened by releasing the intermediate relay Z either manually from the operator console, or by means of an additional signal coming from the boiler control system. These signals, too, are usually connected in a redundant circuit.

In the event of errors, the failsafe protection system generates an error message signal by means of a relay contact. The following situations are indicated:

- Contact fault Checkback contact Isolating valves IV
- Isolating valve IV isolated and lockswitch test not "ON"
- High system pressure during test (non-blocked pressure switch activated)
- Pressure switch activated, relief valve has not opened
- Supply fault, 24 V DC
- Automatic circuit breaker of power supply tripped
- Oil pressure too low (medium voltage supply only)
- Key switch test more than 8 hours "ON"

The messages are transmitted to the higher-level ME 4012 process control system where they are time-stamped at a resolution of 1 ms.

In addition, a ”Failsafe protection triggered” signal is transmitted via relay contact.

Test Circuit

The failsafe protection system allows regular testing of the relief valves, including the pressure switches and all signal paths. The function test is carried out separately for each path, i.e., two of the three paths always remain active so that overpressure protection is ensured at all times during a test procedure.

Two types of tests are available:

- Test of all valves and stroke limiting
- Test of individual valves, full stroke

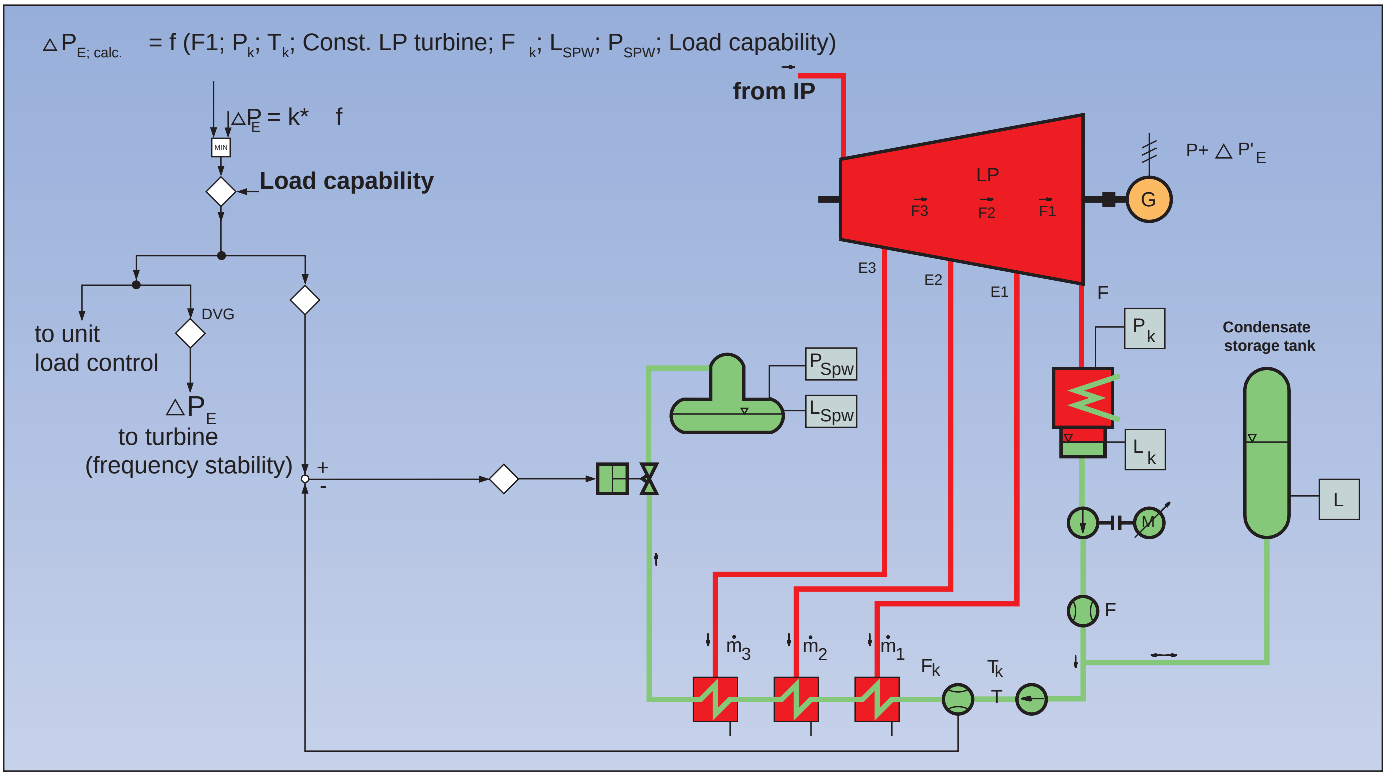
The test logic of the higher-level ME 4012 process control system is linked to the three paths of the failsafe protection system via the crosspoint relays K. An end contact of the shut-off valve IV establishes the electric connection between the test logic and the failsafe protection system. This connection is only available during the test procedure. A mechanical key interlock ensures that only one shut-off valve IV is closed at the time and thus only one of the three paths is put out of operation. In addition, the test logic must be enabled by the operator by means of an electric key switch on the operator console.

To start the test procedure, the operator closes the shut-off valve IV of the relevant path. Via the shut-off valve VP and using a hand pump, pressure can now be built up in pressure switch PS until the switch responds. This is the switching point that must be checked. Now, pressing the test button switches over the 3/2-way valve M (of one or all relief valves, depending on the test mode preselected). As a result, the relief valve (or all relief valves) starts to open. When the required position is reached (indicated by a limit switch on the relief valve) or when the defined maximum period has elapsed, the 3/2-way solenoid valve is switched back and the relief valve is closed again.

Generator Auxiliary Servo Loops

The generator auxiliary servo loops can be integrated in the general auxiliary servo loop section if turbine and generator are part of the same station design and installation project.

Condensate Build-Up Control



Condensate build-up control

Condensate build-up control forms the basis for the efficient generation of the active-power seconds reserve in accordance with the requirements laid down in the DVG guidelines. The reserve power fed into the grid for the purpose of maintaining frequency stability must be made available by the power unit within a specified period of time in line with the supply obligations agreed upon with the power distribution board.

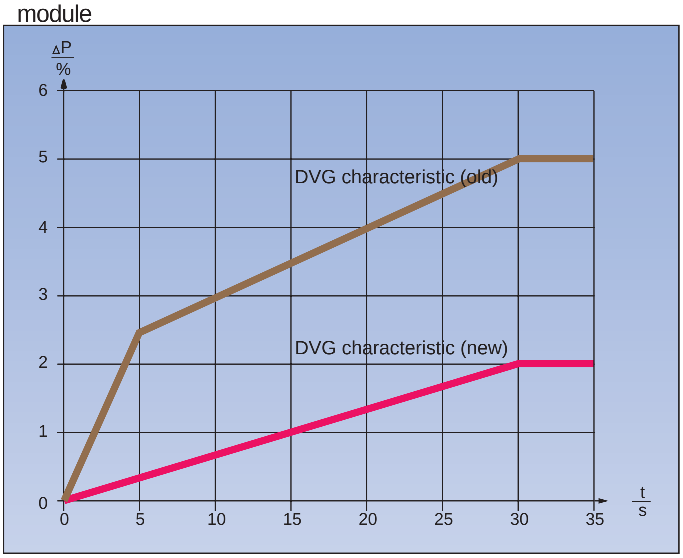
Condensate build-up control is based on the principle that power can be generated by momentarily building up the condensate flow and expanding the diverted bleed steam via the turbine. The usual throttling of the admission valves and the use of the boiler as the steam accumulator is thus avoided. This way, an additional electric power in the range of 2 to 3.5% can be produced within a period of 30 seconds.

By integrating the condensate build-up control strategy in the steam generator unit model, the block power setpoint and the steam generator and turbine load control can readjust to accommodate the additionally required ”spontaneous” reserve. As a result, the additionally drawn power can be followed-up in line with the dynamic process conditions and the condensate built-up can be resolved again.

By avoiding the usual throttling of the turbine admission valves, efficiency can be increased by approximately 0.5 %. Moreover, the integration of the condensate build-up control into the unit control model leads to a measurable stabilization of the steam generator control and increases the plant’s operational flexibility.

Many of the new regulations for essential enhancements in the connection conditions for power generation units laid down in the GridCode 2000 (Edition May 2000) have by now become binding requirements. (The GridCode2000 specifies the network and system rules for the German transmission system operators.) Thus, for instance, for generating units with 100 MW capacity or larger, the primary control conditions for maintaining frequency stability for generating units ≥100 MW have been newly defined. Today, the generating unit must be capable of activating, within 30 s, at least ± 2 % of its nominal capacity for primary control at a quasi-steady frequency deviation of ± 200 mHz, and of maintaining supply for at least 15 minutes. The neutral zone must be below ± 10 mHz. In order to successfully fulfil the above supply obligations on the basis of condensate build-up control, the following must be implemented:

- Condensate control valve with quick-action operating mechanism
- Control volume of the feed water or cold condensate collector
- Unit control with frequency stability and condensate build-up module



Former and new DVG requirements for thermal power stations concerning the active-power seconds reserve for the primary control of grid frequency stability

Function Groups

For automatic plant operation, the turbo generator set and its auxiliary equipment are divided into individual plant sections, so-called function groups (FG), that combine the specific technological functions of a section. The group control level represents the control level above the switching level and single control level. If motors, actuator drives and controllers are to be automatically coordinated from the group control level, the function groups must contain sequence cascade programs for starting and stopping the plant.

The start-up sequence can be closely monitored with the ME-VIEW operator control and process monitoring system. It displays missing stepping criteria in plain-text format and guides the operator to make the required inputs.

Availability

The high degree of availability of the ME 4012 process control system is a result of its decentralized structure:

- Subprocessors for arithmetic and closed-loop control functions, drive control and function groups
- Interface modules for binary and anlog inputs for the supply and monitoring of all field units
- Redundant SUB-NET process bus for consistent communication
- Direct access to the single control level from the operator control and process monitoring system; available even if the group control level fails
- Interface modules for binary and anlog inputs for the supply and monitoring of all field units
- Redundant SUB-NET process bus for consistent communication
- Direct access to the single control level from the operator control and process monitoring system, even if the group control level fails

Plant Sections

A plant is typically divided into the following function groups:

- Condensate extraction
- Oil circulation and turn drive
- Sealing steam supply and air exhaustion
- Turbine control with drainages, valve block preheating and synchronization

Function Groups: Principle of Operation

The principle of operation of the individual function groups is briefly described on the following pages.

Function Group: Condensate Extraction

This function group includes the following plant components:

• Pre-condensate pumps	2 x 100
• Main condensate pumps	2 x 100
• Outlet controller 1 - Condenser	1 x
• Minimum quantity controller	1 x

The outlet control valve is closed before the first pre-condensate pump or the first main condensate pump is started and then released with delay to avoid overloading. When the plant is running, the pumps are connected one after the other, depending on the measured volume, measured quantity or depending on whether an already operating pump has produced a breaker tripping signal. The automatic control circuit responsible for these actions is activated and deactivated by the function group. The function group switches the outlet controller from the ”Manual” position to the ”Control” position, and vice versa. In the ”OFF” program, the outlet control valve is closed.

Function Group:

Oil Circulation and Turn Drive

The following table shows the drives, controllers and automatic control circuits. The use of redundant processors or the direct mirroring of redundant circuits in the control and instrumentation systems results in a very high degree of availability.

The following plant components are included:

Control circuits/drives	TS*	AS*	RK*
Bearing oil pump1		X	
Bearing oil pump 2		X	
Standby oil pump		X	
Oil vapour blower 1		X	
Oil vapour blower 2		X	
Oil temperature control			X
Control fluid pump 1		X	
Control fluid pump 2		X	
Turn drive		X	
Lifting oil pump 1		X	
Lifting oil pump 2		X	
Fluid temperature control			X
Fluid recirculation pump 1		X	
Fluid recirculation pump 2		X	
Fluid circulating pump			X
Fluid vapour blower		X	
Oil heating		X	
Bearing oil pumps 1+2	X		
Standby oil pump	X		
Oil vapour blower 1+2	X		
Control fluid pumps 1+2	X		
Lifting oil pumps 1+2	X		
Fluid recirculation pumps	X		

*TS = partial control and automatic transfer switching
AS = drive control system, RK = Multifunction controller

The Oil Circulation and Turn Drive function group controls the turbo set's bearing oil circulation system so that the conditions for the slewing gear mode and turbine run-up of are fulfilled. The function activates and deactivates (at turbine shut-down) the oil temperature control. It is assumed that the cooling water for the oil coolers is provided by means of an auxiliary cooling water circuit.
This function group also ensures the circulation of the control fluid by activating the control fluid pump. The oil circulating system also activates the lifting oil pumps. The turn drive motor is started after a delay period which is necessary for the relief pressure to build up, and after a number of criteria have been scanned, such as bearing metal temperatures, relative expansions and generator status. The lifting oil pumps are switched off as soon as the turn drive speed is reached. The turn drive motor is switched off at a rotational speed of $n \geq 100\ min^{-1}$, and switched on at speeds of $n \leq 100\ min^{-1}$. If the rotational speed drops down to or below $40\ min^{-1}$, the lifting oil pumps are activated. The turn drive motor and lifting oil pumps are switched off in the "Off" program.
The bearing oil circulating system is deactivated when the turn drive is shut down. The oil circulating system has a start and a stop program.

Function Group:

Sealing Steam Supply and Air Exhaustion

The following plant components are included:

- Vacuum breaker 1 x
- Auxiliary steam valve 1 x
- Sealing steam controller Pressure 1 x
- Sealing steam controller Temperature 1 x
- Air exhaustion slide valve 2 x 100 %
- Start-up and duty units Air exhaustion 2 x 100 %
- Mist ventilator 2 x

Upon opening of the auxiliary steam valve, the function group activates the start-up air exhaustion. When a specific vacuum is reached, it activates the corresponding duty units. During operation, start-up air exhaustion is activated when the vacuum drops or the duty unit fails. Protective circuits prevent non-permissible operating states within the duty units. In the "Off" program, the vacuum breaker is opened after the bypass operation has ended ("End") and all units are switched off. If the vacuum drops below 10 %, the auxiliary steam valve is closed.

Function Group:

Turbine Control

The following plant components are included:

- Master/slave turbine controller with: speed master controller, power master controller and valve position controllers 2 x
- Preheating valves after HP shut-off valves 2 x
- Preheating valves after IP shut-off valves 2 x
- Drainage valves 20 x
- Synchronization facilities 1 x

After numerous criteria have been scanned, the hydraulic emergency protection is activated. This opens all shut-off valves.

Also, all drainage valves of the turbine are opened or closed depending on the current process conditions. The shut-off valves and control valves are warmed up by means of the preheating valves (the valves open or close according to the permissible temperature differences). After the steam has reached the required start-up temperature and various additional criteria have been scanned, the speed master controller of the turbine controller accelerates the turbo set to nominal speed.

When the nominal speed is reached, voltage controller activation, generation and synchronization are enabled. As soon as the generator is connected to the network, the power master controller takes over the setpoin control in line with the permissible transient values calculated by the Temperature and Power Reference Unit (TPR unit), until the set target power is reached or the control valves are fully open.

The processes described next apply to a condensing turbine with reheat which is equipped with an IP bypass station and started up in the sliding pressure/sliding temperature operating mode. The start-up and load period is determined by the permissible temperature transients of the principal turbine components. The influence of the turbine temperature at the beginning of the start-up process and the behaviour of the boiler, particularly in the lower temperature and load range, must be taken into account.

In order to keep the initial temperature jump at start-up and the subsequent temperature transient within permissible limits, it is necessary to adjust the inlet steam temperatures to the current temperatures of the main turbine components.

Bypass stations allow non-coordinated operation until the steam temperatures are in line with the temperature values required by the individual turbine stages and the steam parameters fulfil the connecting criteria.

At cold start-up, the steam temperatures cannot always be sufficiently reduced. Therefore the component temperatures must be adjusted to the lowest stable steam temperature the steam generator can provide before the turbine is run up to its nominal speed. For this reason, the turbine is equipped with a casing heating facility which allows casings and rotors to be warmed up with auxiliary steam of 12 bar and 320 °C supplied by the auxiliary steam circuit.

Start-up of the Turbo Generator Set

Preparations

To prepare the plant for the heating and bypass operation the function groups and systems are activated in the following sequence:

- Cooling water circulating system
- Oil circulating system and turn drive (still active at warm start-up)
- Condensate extraction
- Sealing steam supply
- Air exhaustion

The turbine is now in turn drive mode and under vacuum conditions. The condenser is ready for the admission of heating steam and bypass steam. All drainage systems within the turbine are open.

Heating of the Turbine Housings

When the centre line temperatures of the HP inner casings and IP inner casings are below 220 °C of the IP inner casings and 200 °C, respectively, (e.g., after down times longer than 80 to 90 hours), the turbine's heating valves are opened and the turbine is run up to a heating speed of about 700 min^{-1}. The casing heating remains active until the centre line temperatures of the HP inner casings and the IP inner casings are risen above 220 °C and 200 °C, respectively.

To keep the LP outlet temperature within permissible limits, the LP casing injection is activated as soon as the condenser pressure has reached a value of 0.4 bar.

Drainage of Casings and Piping

At a power output of more than 15 % all casing or inlet piping drainage systems are closed. At a power output of less than 15 % all casing or inlet piping drainage systems are open.

The drainage systems of the piping towards the non-return valves are opened when the non-return valves are closed. They are closed when the non-return valves open.

All drainage systems are closed when the turbine is at rest.

Sealing Steam Supply

Auxiliary steam with a temperature > 270 °C must be provided for the shaft sealing.

Activation Criteria for the Emergency Trip System

The activation of the emergency trip facilities opens all shut-off valves. The steam flowing to the shut-off valves must therefore be within a specified temperature range so that the temperature jump in the valve housings does not exceed the permissible limit.

Apart from the temperature difference between the steam and valve housings, and various generator criteria, the following values are taken into account:

• Temperature difference upper/lower housing section	< max.
• Condenser pressure	< max.
• Live steam and IS pressure	> min.
• Bearing temperatures	< min.
• Bearing oil temperature	> 30 °C

The bearing oil must have a minimum temperature of 30 °C to avoid

- Inefficient lubrication due to higher oil viscosity
- Reduced clearance due to sudden cooling of the bearing shell

The maximum bearing oil temperature should always stay below 50 °C to prevent the turbine protection facilities from tripping due to high bearing metal temperatures during turbine acceleration to nominal speed.

Warm-up of Live Steam Piping and HP Valve Housings

To ensure that the steam attains the condition required for the opening (activation) of the shut-off valves, the piping towards the valves must be warmed up in line with the permissible component transients.

The pressure in the live steam pipe is in line with the pressure build-up in the boiler. Taking into account the saturated steam's rate of temperature change, the boiler's rate of pressure change must be adjusted to the permissible rates of change

- Of the live steam piping and
- Of the fittings of the live steam piping.

The turbo generator set is ready to activate the protection facilities when the steam flowing to the HP and IP shut-off valves has reached a temperature that is higher than or equal to the metal temperature of the control valves, but is at least at 250 °C. In addition, the pressure in the live steam line should be above 5 bar, and above 2 bar in the hot IS line. If the HP and IP inlet line temperatures are below 260 °C and 210 °C, respectively (e.g., after down times of more than 36 hours), the short-stroke facility of the shut-off valves is enabled so that they work in short-stroke mode only when the emergency trip system is activated. The same criteria apply to the opening of the warm-up valves of the valve housings. The control valves remain closed at this stage. The steam generator is run up to a start-up fire of about 20 %. In this phase, the target value issued for the setpoint control of the live steam and hot reheater steam temperature corresponds to the optimum temperature for the HP and IP turbine stages.

Warm-up of the Inlet Lines

After down times of more than 36 hours (i.e., HP inlet line temperature below 260 °C, IP inlet line temperature below 210 °C), the inlet lines, too, must be warmed up. The speed master controller is set to automatic mode and opens the turbine control valves via the speed controller until a warm-up speed of about 1500 min^{-1} is reached. The steam flows through the shut-off valves (which now work in short-stroke mode), and through the associated widely open control valves (which are now widely open), to the HP and IP turbines. At start-up, turbine control should always be switched to full-arc admission to ensure a uniform warm-up of all inlet parts.

The warm-up process is enabled when the following conditions are met: the boiler's live steam and hot reheater temperatures have exceeded 350 °C, the live steam temperature is 40 K above the centre line temperature of the HP inner casing, the hot reheater temperature is above the centre line temperature of the IP inner casing, and the casing heating has heated the turbine casings to a minimum temperature of 160 °C (HP inner casing and IP inner casing).

Run-up to Nominal Speed

The turbine is accelerated to its nominal speed in line with a set fixed transient for all start-up conditions.

Prior to acceleration all mechanical and thermal states and conditions are scanned. Provided all measured values are within the permissible limits, the speed master controller is enabled and the turbine is run up to its nominal speed with a constant acceleration of 600 min^{-2}.
If the measured values are out of range, the turbine protection system interrupts the admission of steam.

Prior to turbine acceleration to nominal speed, the standby oil pump is tested for correct functioning by measuring the delivery pressure leading to the non-return valve.

Turbine Speed Acceleration

If all criteria are fulfilled (e.g., the temperature differences between steam and casings are within permissible limits, the steam quantity m is above the minimum), the speed master controller is switched to automatic mode.

The speed master controller continuously adjusts the setpoint of the start-up speed controller within a specified period until the nominal speed of 3000 min^{-1} is reached. The turbo generator set is now ready for synchronization.

Criteria to be fulfilled before the turbine is accelerated to its nominal speed (example values):

• Temperature differences	
Live steam/valve housings	< 150 K
Hot IS/valve housings	< 200 K
Live steam/HP inner casing (centre)	> 40 K
Live steam/HP inner casing (centre)	< max.
Hot IS/IP inner casing (centre)	> 0 K
Hot IS/IP inner casing (centre)	< max.
• Temperatures	
HP inlet line	> 250 °C
IP inlet line	> 150 °C
HP inner casing (centre)	> 220 °C
IP inner casing (centre)	> 200 °C
• Live steam mass flow	> 15 %

Load Variation

The temperature increase of the HP exhaust steam is kept under control by the HP/IP balancing controller so that a synchronization process of normal duration will not impose any restrictions to the subsequent load connection.

When the HP exhaust steam increases during a longer stretch of no-load operation, the HP/IP controller redirects the steam flow to the HP turbine. To prevent the HP outlet temperature from dropping too fast, the HP limiting controller redirects the non-required steam quantity to the IP turbine when the turbo generator set is brought onto load.

Minimum Load Connection

By resetting the power setpoint control to automatic mode after synchronization, the turbine is set to minimum stable operation.

In this mode, the steam generator should produce the maximum permissible start-up fire power. The permissible rates of temperature change for live steam and hot reheater steam are continuously calculated by the temperature and power reference unit (TPR unit) on the basis of the stress values measured in the turbine rotors.

After downtimes of more than 65 hours, the HP and IP inner casings will have cooled down to temperatures below 250 °C which means that the IP turbine may not be charged with the full bypass amount after synchronization. In this case, the automated function group issues a command ("Reduce IP mass flow") to limit the IP mass flow to a maximum of 15 % approximately.

Load Increase and Bypass Shut-down

When all turbine components are sufficiently warmed up, and rotor stress values have been reduced, the IP valves are released and the steam is directed to the IP turbine.

The power master controller increases turbine speed in line with permissible or predefined power transients until the specified target power is reached.

Loading after Bypass Shut-down

When the power setpoint exceeds the maximum value for the start-up fire, both bypass stations are closed and the firing power of the steam generator follows the power setpoint characteristics until the specified unit target power is reached.

Load Rejection

When the unit power is set to a value below the current power value, the turbine's power master controller reduces the turbo generator load at the deceleration rate determined by the unit power transient until the new target power is reached.

Minimum Permissible IS Temperatures

To prevent erosion of the turbine blades the intermediate superheater (IS) temperature should not fall below the nominal temperature by more than 50 K both at normal and increased condenser pressure.

This restriction does not apply to loads below 40 %.

Turbo Generator Set Shut-down

When the target power is set to "0", the turbo generator set is unloaded and disconnected from the grid. Reverse power protection is applied.

Load Rejection up to Control Valve Closure

To disconnect all load from the turbo generator set the target power must be set to "0". The power master controller reduces the load down to a power of 15% in line with the specified power transient. Beyond this point, the turbo generator set is rapidly unloaded applying transient control until reverse power is reached. This prevents an unpermissible increase of the HP exhaust steam temperature.

Disconnection from the Network

The turbo generator set is disconnected from the grid by applying the long-term reverse power protection. Any switchover to service load must be carried out prior to disconnection.

Turbine Tripping and Deceleration

Disconnecting the generator from the grid triggers turbine tripping. The turbine decelerates and is kept rotating by the turn drive until the HP housing temperature measured at the centre line is below 100 °C.

If the turbo generator set is to be withdrawn from service for a longer period, the turbine is slowed down at full vacuum. At a coasting speed of less than 1500 min-1, the vacuum can be broken after bypass operation has ended.

Turbine Cool-down

If maintenance jobs require a fast shut-down of the turbine, the steam inlet temperatures must be cooled down to the lowest possible value right at the starting point at the beginning of load rejection, always in line with the permissible transients.

The cooling phase can be speeded up by injecting air through the heating nozzles during turn-drive operation.

To be able to shut down the turn drive of the turbine after a period of about 24 hours air must be injected into the HP and IP turbines. Cooling transients (indicated on the casing metal temperature measuring points) of 0.5K/min should not be exceeded.

Turbine Shut-down

When air exhaustion and condensate extraction are stopped, the equipment of the sealing steam supply system is shut down.

The oil circulating equipment, however, remains in operation until the turbo generator set is restarted or until finally the turn drive is shut down, too.

Water for oil cooling must be provided for a minimum period of 48 hours. To avoid corrosion on the condenser pipes a water circulation speed of about 1.5 m/s must be maintained, or the condenser must be emptied.

When the temperatures of the turbine casing metal have dropped below 60 °C, and if a turbine restart within the next 24 hours is not scheduled, the turn drive, oil pumps and lifting oil pumps are switched off.

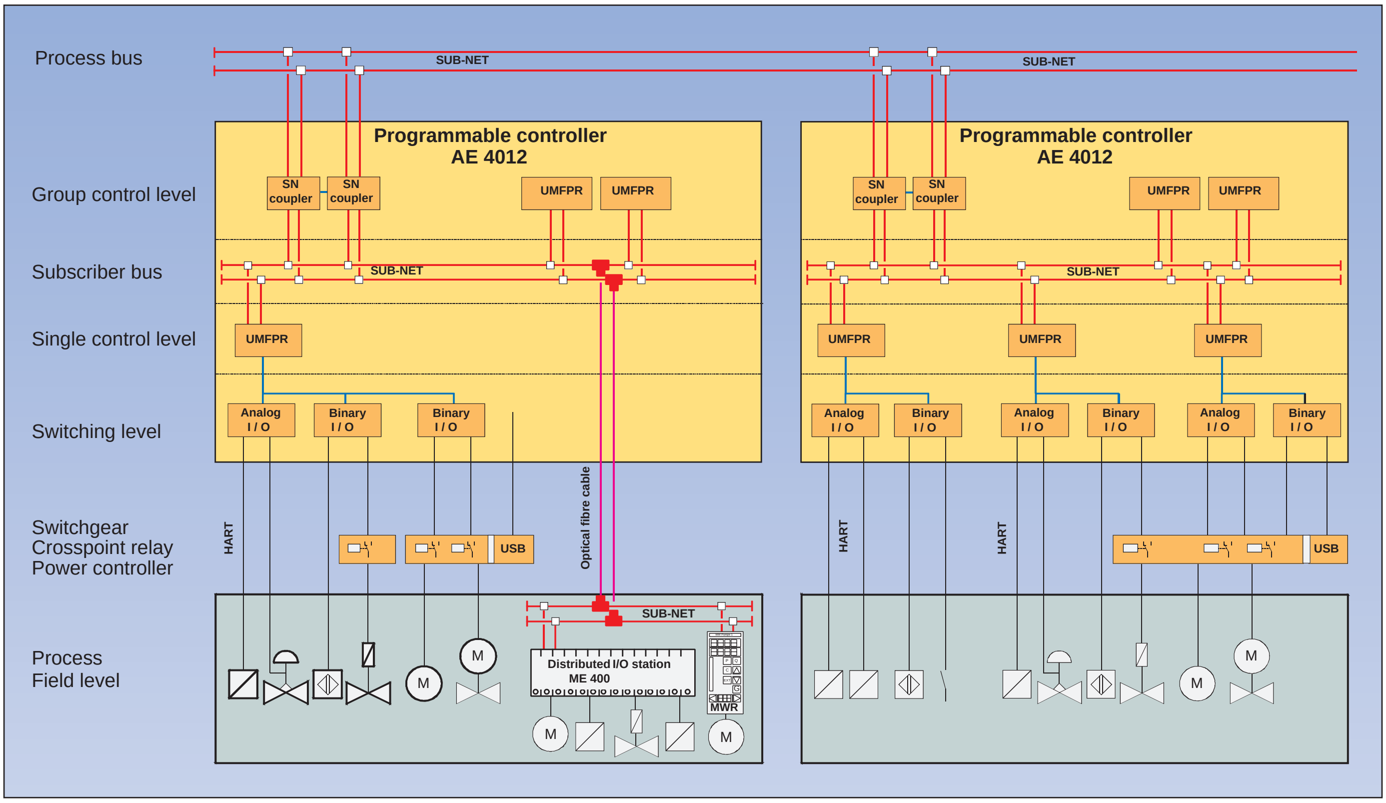
The AE 4012 Programmable Controller

The AE 4012 programmable controller is at the core of our digital turbine control system. It offers modules for the following tasks:

- Signal conditioning (analog standard signals , analog transmitter signals, binary state variables)
- Signal processing (sequence control, closed-loop control, arithmetic and monitoring functions)
- Actuating signal output (drives, step-action and continuous-action control equipment)

To ensure a high degree of availability the AE 4012 is designed as multi-processor system of distributed architecture. This means that all modules are equipped with a microprocessor and are capable of communicating with each other via the redundant SUB-NET bus system. Access to the SUB-NET is based on the Flying Master principle. Subprocessors or I/O modules can be replaced during operation without any adverse effect on the system. The system can be configured during online operation and the user configuration can be documented graphically.

In addition to its simultaneous processing capability, the AE 4012 has a high arithmetic capacity and thus allows short signal scans and output update cycles. Process-specific redundant circuits can be implemented on different processors.



AE 4012 programmable controller with multifunction processing

Typical cycle times of the AE 4012 programmable controller:

- Speed control < 5 ms
- Function group control circuits ≤ 20 ms
- Drive control ≤ 20 ms
- Multi-loop feedback control circuits with complex arithmetic functions ≤ 20 ms
- Visual/acoustic alarm system ≤ 20 ms
- With time stamp at the signal source ≤ 1ms

Subprocessors and I/O modules with process bus interface can be inserted at any position in the subracks. This allows complete integration of arithmetic, closed-loop control, alarm and monitoring functions required for efficient turbine control.

The multifunction processor modules are equipped with Pentium processors to cater for the high 32-bit computing accuracy required for analog value processing. The I/O bus connects the subprocessors with the I/O modules.

All subprocessors and I/O modules have their own onboard power supply unit.

Criterion Transmitter Signal Conditioning

The K16IN binary signal conditioning modules process the binary signals coming from the process, e.g., from pressure and temperature switches, level switches, etc..

Input characteristics:

- Isolated electronic protection (self-healing) for each contact or initiator
- Input filter for contact debouncing, 5 ms typ.
- Transmitter simulation or disconnection via simulation pins
- Overload protection of input stages and transmitter supply outputs by means of overvoltage protection and rupture joints
- 11 discrete diode-decoupled outputs of the contact-type inputs for separate protection and interlocking
- 24 V or 48 V input contact scan
- Wire break monitoring of the inputs with 100 kΩ resistors
- Wire break monitoring can be individually configured for each input
- Transmitter input status indication by means of one LED per channel
- Simulation indication through LED or simulation pins
- All inputs interrupt-controlled, alarm and time stamp capable, accuracy: 1 ms
- Supply and scan of 2-, 3- and 4-wire initiators of PNP design
- Protection against overload, short -circuit and polarity reversal
- Minimum load current at contact scan 4 mA at 24 V or 8 mA at 48 V
- Indirect input scans for the generation of the contact complementary signal (virtual changeover contact)
- Configurable valence monitoring of the changeover contact inputs

Analog Signal Conditioning

The AE16 analog signal conditioning modules communicate with the field units and are used as coupler elements between transducers and subprocessors. Up to 16 transducers can be connected to each AE 16 module.

Hardware structure:

- Non-floating analog signal inputs, nominal range: 0 to 20 mA
- Analog-digital converter with 12-bit signal resolution
- Separate 24 V voltage supply with monitored fusing
- Separate short-circuit proof transducer supply for each input channel
- 24 V DC / 4 W, minimum current and undervoltage monitoring
- Input low-pass filter, 24 Hz transition frequency
- Load resistors (250 Ω) for the injection of FSK signals to reduce power loss; only connected during HART protocol transmission for the SMART measuring transducer concerned
- CPU for signal preprocessing
- Test sockets on faceplate for measuring the input signals (0/4 to 20 mA), without measuring circuit isolation
- Static-dynamic 24 V group alarms
- I/O bus interface
- Redundant signal conditioning of analog signals to different AE16V modules with signal isolation via an AV24P module

Input characteristics:

- Connection of standard and SMART transducers
- Transducer supply 24 V, 2-wire and 4-wire
- Measuring range 0/4 to 20 mA, linear up to an overload of 11 %
- Measuring accuracy ± 0.2 % with regard to the upper range value
- Measuring value acquisition 1 ms approx. for each channel, 2 analog-digital converters, resolution: 12 bits
- Input load at normal operation 100 Ω, overload protection
- Measuring range input can be configured and standardized
- Configurable input filter PT1, average value, low pass for signal filtering
- Limit value indication and time stamp
- Remote parameter setting and diagnosis of SMART transducers using HART protocol, max. distance: 2000 m

Information Exchange

The information is transmitted by the standardized analog signal of the transducer and by the frequency-modulated digital signal of the HART protocol using the measuring circuit as the common electrical connection.

The analog signal transmits the measuring value and the information required for measuring circuit diagnosis. The measuring circuit is monitored for:

- Wire break
- Overload
- Plausibility
- Failure of the auxiliary supply voltage

The digital information transmitted by the HART protocol is used for centralized parameter definition and diagnosis of the field units via the ME-DRP system. Due to the low transmission rate of 2 measuring values per second the digital measuring value is not used in the process control system.

Interface Module AEAA8 00AF for Continuous Servo Drives

This module is used for the interface connection of continuous actuator and servo drives. All signal types required are implemented on a passive module that offers a direct connection between its processor and the I/O bus. This makes the AEAA8 00AF module suitable for the use in servo loops with very fast response times (cycle time <5 ms).

To achieve a high degree of processing reliability the analog inputs and outputs are provided with electronic switches. These allow the field units (transducers, actuators) to be connected to two interface modules simultaneously without having to fear any conducted interferences and without any additional effort in the configuration work. The UMFPR 60HF processing unit controls the standby changeover on both interface modules so that always one module is in standby mode.

The same applies to the module’s opto-decoupled binary inputs and the diode-decoupled binary outputs. Independent supply stages on each module ensure that the transducer auxiliary power, too, is supplied through redundant circuits.

A true plausibility check of the actuating commands issued by the module is performed by picking off the signal directly at the analog signal output and carrying out a feedback measurement on the module.

The module has its own fuse-protected auxiliary power supply unit.

Design of the AEAA8 00AF Process Interface Module

Analog Signal Conditioning
Hardware structure:

- 8 non-floating analog inputs, nominal range: 0-20 mA
- Analog-to-digital converter with 12 bit signal resolution
- Separate short-circuit proof transducer supply for each input channel, 24 V DC / 4 W, minimum current and undervoltage monitoring
- Input low-pass filter, transition frequency 24 Hz
- I/O bus interface
- Redundant signal conditioning of analog signals on different modules without additional configuration work and hardware through redundant monitoring, and disconnection of the inputs of the failed module

Input characteristics:

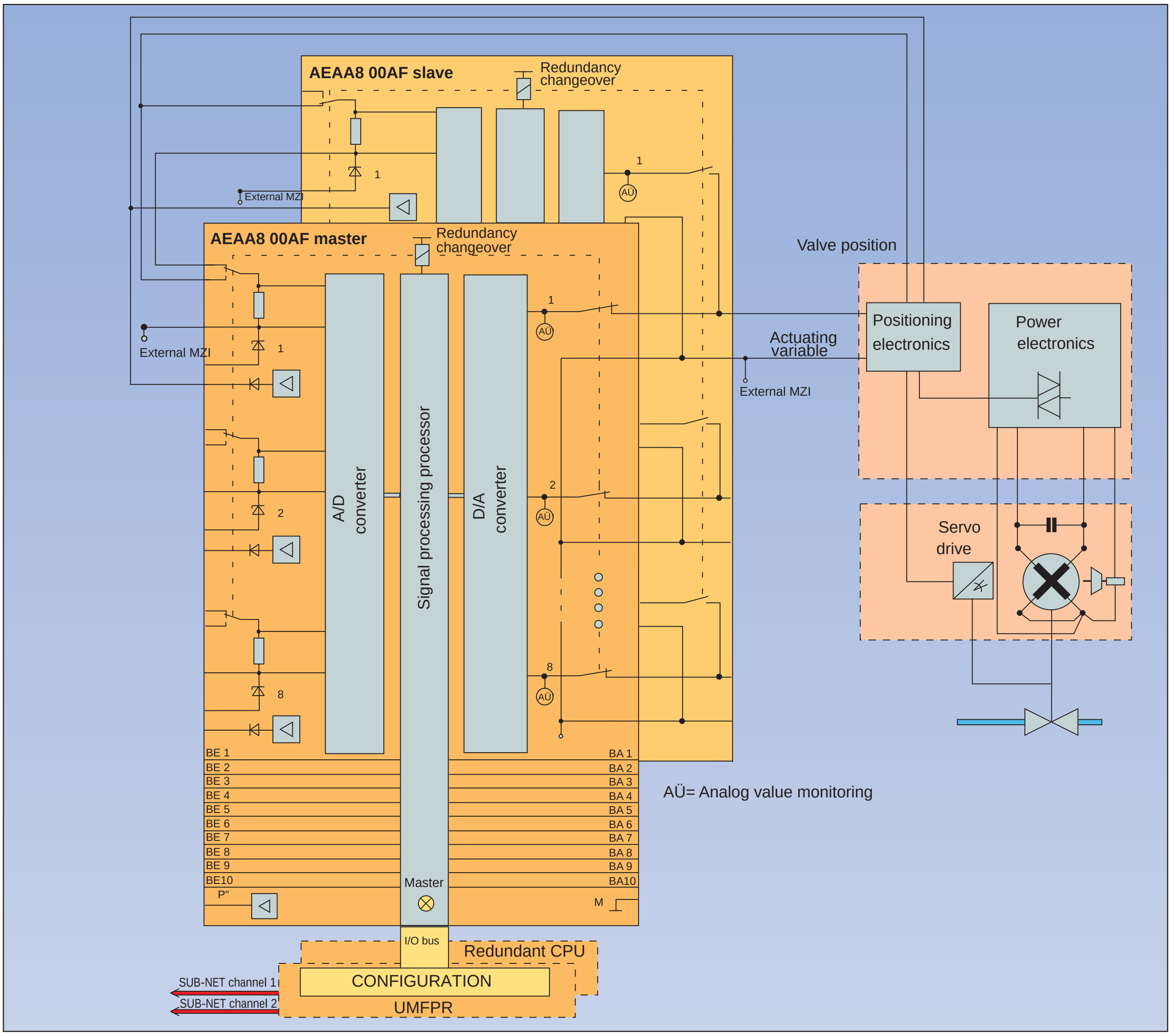
- Transducer supply 24 V, 2-wire and 4-wire
- Measuring range 0/4-20 mA, linear up to an overload of 11 %
- Measuring accuracy ± 0.2 % with regard to the upper range
- Measuring value acquisition approx. 1 ms for each channel, 2 analog-digital converters, resolution: 12 bits
- Input load at normal operation 100 Ω, overload protection

Analog Signal Output
Hardware structure:

- 8 analog signal outputs, 0-20 mA, common isolation
- I/O bus interface
- Self-diagnosis for signal output disconnection in the event of faults
- Redundancy capability

Output characteristics:

- Signal level 0/4-20 mA up to 110 %
- Signal output load: 600 Ω
- 8 short-circuit proof output channels, common isolation
- Resolution: 12 bits, accuracy: ± 0.1 % with respect to the upper range value
- Outputs can be disconnected in the event of faults



Binary Signal Input/Output
Hardware structure of the expansion module:
- 10 outputs, single-pole circuit
- 10 contact-type inputs ± 24 V DC
- Module supply 24 V DC with monitored fusing
- I/O bus interface
- Supply stage + 24 V DC, 50 mA for the isolated, monitored transmitter supply

Output characteristics:
- Signal level + 24 V DC, 50 mA, overload and short-circuit protection, isolated for ohmic, inductive and capacitive loads

Input characteristics:
- Contact circuit ± 24 V DC, 3.3 mA for all input channels
- Signal delay 5 ms typ. (debouncing)
- Isolated by means of opto-couplers
- Surge strength acc. to DIN EN 60870-2-1:97-07, Class VW3

Drive Control

F6 ATR modules inserted in the AE 4012 programmable controller implement the drive control level. These I/O modules are designed to control 1, 2 or 3 independent drives. The required functions for solenoid valves, motors or actuating drives are selected in the configuration interface provided by the associated multifunction processor. All modules are equipped with the necessary stages for contact scanning and protection.

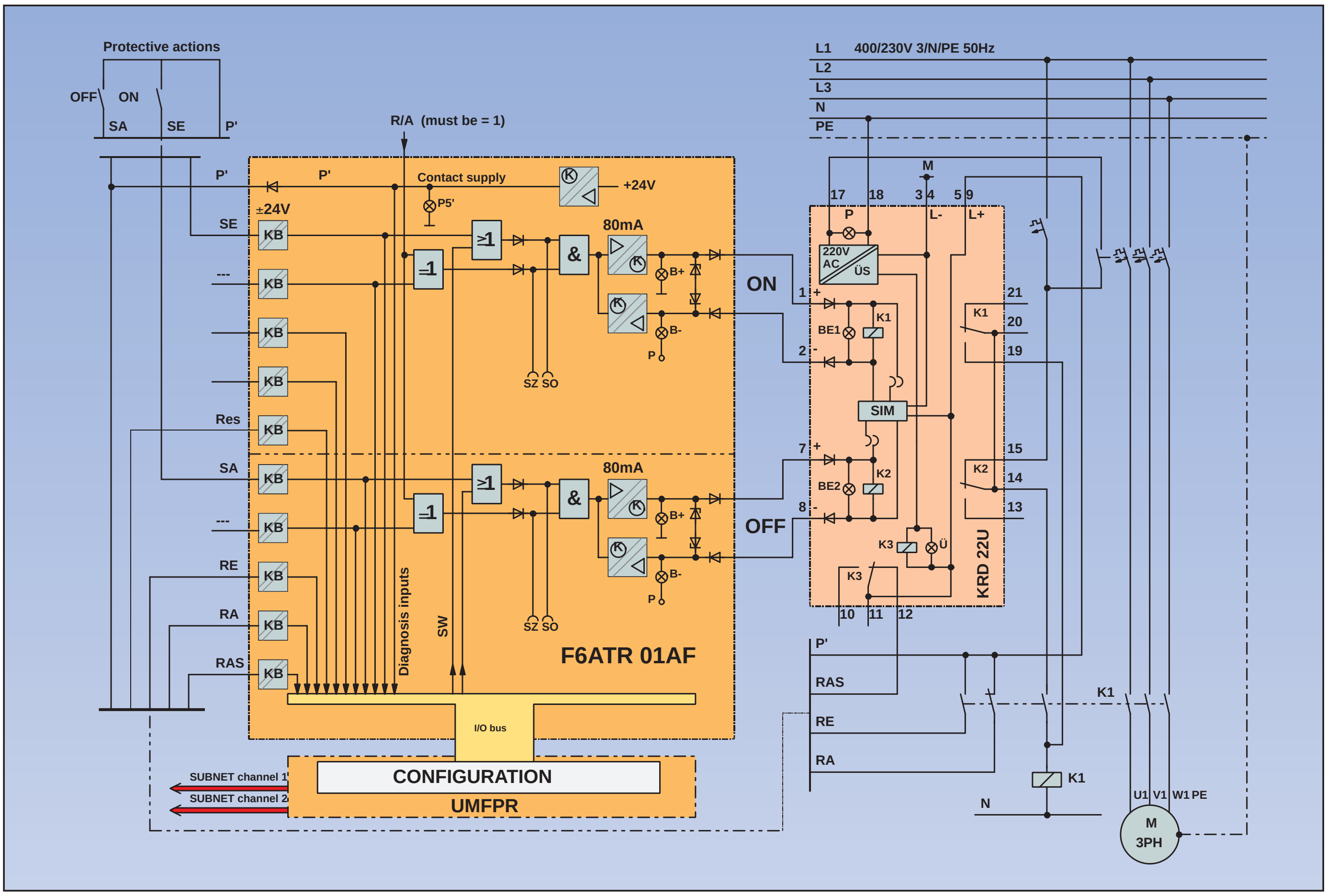
Protection and Interlocking Logic

The protective criteria of the individual drives are preprocessed on the F6 ATR drive control modules and then processed on the associated multifunction processor. Signals transmitted over the SUB-NET bus can also be processed. Additional hardware inputs with wire break monitoring (K16IN) can be connected to the F6ATR module (parallel-wire connection). Extensive interlinking possibilities are available.

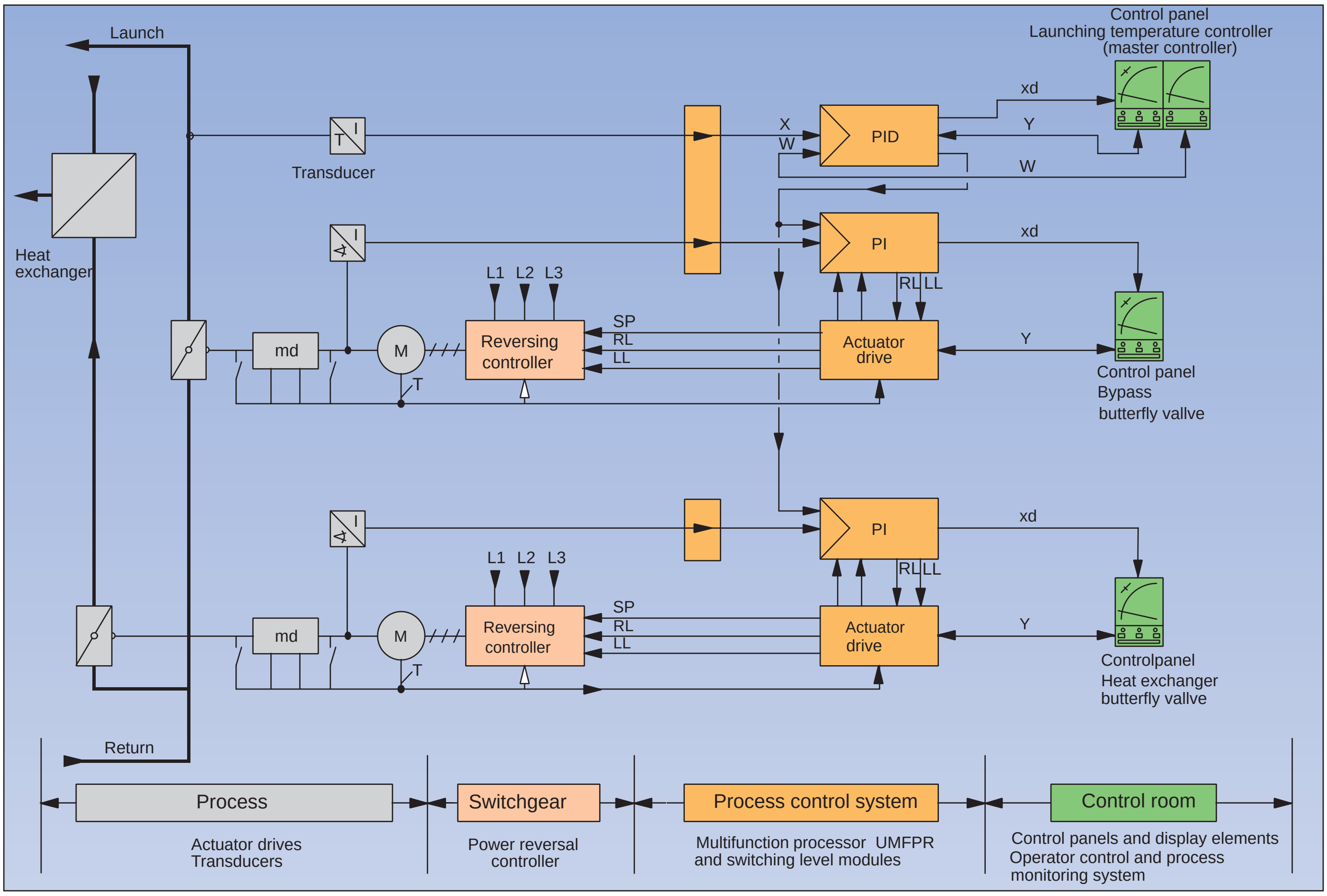
In the event of a CPU malfunction, the criteria 'Protection ON' and 'Protection OFF' can be directly connected to the output stages. This increases the availability and reliability of the drive control.

Signal Scan Monitoring

In order to further increase availability for a multiple connection with drives the module is equipped with 6 current-limiting contact supply stages. These monitor the overall loop resistance in long transmission lines. Due to their high-ohmic inputs a short circuit to frame off the contact scan loops can be safely detected which could not be done with fine fuses. Scanning the inputs from the process and switchgear sections is thus drive-specific.



Multifunction processor programmable controller AE 4012



Vertical level hiearchy with process, switchgear, process control system and control room

Process Control

Information Processing and Actuator Connection
Closed-loop control and arithmetic functions are executed by the same multifunction subprocessor. A maximum of 3 step (S) servo drives or 8 continuous (K) servo drives is allocated to one I/O module to ensure a high degree of decentralization.
To enhance the safety of K-type control loops (i.e. continuous-action servo drives), the analog actuating signal outputs can be transmitted via redundant analog outputs, with the failed channel being disconnected, in the event of a hardware failure.
Standby processors provide redundancy to increase availability in cases where the active processor transmits a doubtful actuating signal, e.g., due to a CR error or watchdog time-out.
The multifunction controllers can be used as continuous-action controllers with continuous output of y = 4 to 20 mA, or as three-step controllers with discontinuous output for the activation of contactless thyristor power controllers.

Visual/Acoustic Alarms

Message generation takes place in the programmable controllers of the ME 4012 system where all out-of-range and trip signals, fault and switchover criteria are available or generated. The subprocessor modules provide each process message with a time stamp before sending it to the ME-VIEW operator control and process monitoring system for display.

SUB-NET Interface

All subprocessors can exchange information over the redundant SUB-NET process bus on the basis of the Flying Master principle, and independent of a bus coordinator. This offers the following possibilities:

- Operator control and monitoring of all control loops, drives and signals, even in the event of an error
- Connection and disconnection of individual modules during online operation without adverse effects
- Distributed installation, even outside of a programmable controller (field bus, maximum distance: 2 km)

Interfacing to Third-Party Systems

The SPCMD subprocessor module handles the serial data exchange between the AE 4012 programmable controller and the process control systems of other manufacturers. Standard transmission procedures 3964 R or Modbus are provided.

Power Controllers for Continuous Servo Drives

Depending on the actuating force required, the power controllers are designed as single-phase electronic controllers (plug-in units) or as three-phase electronic controllers and installed in separate power controller cubicles. Activation from the AE 4012 programmable controller and position feedback to the AE 4012 programmable controller is by means of 4-20 mA signals.

Power Controllers for Step-Action Servo Drives

Actuating times of ≤ 30 seconds are often sufficient to achieve the required control quality and dynamic process behaviour. In these cases, servo drives with thyristor-controlled three-phase a.c. motors are the first choice. The robust and cost-effective three-phase a.c. motors produce high actuating torques which allows a simplified valve design without complex pressure relief systems .

Please note:
When using simple reversing contactor arrangements for the activation of the servo drives, they must be designed for the SA4/S5 -25 % ED operating mode (operations per hour: 1,200 c/h max.). The power contactors must comply with the utilization category AC 4 (AC 4 lays down the startup, plug braking, reversing and inching specifications for squirrel-cage motors). Under these conditions the power contactors have a lifetime of about 300,000 operating cycles. However, a number of about 10 million operating cycles per year may be necessary to achieve the required control quality, depending on the dynamic disturbance of the control loop and the defined control parameters. Due to the high maintenance requirements and the resulting reduced availability we therefore do not recommend the use of reversing contactors.

Electro-Hydraulic Power Controller (E/H Converter)

Due to the relieved valves only low actuating forces are required. Therefore servomotors are capable of operating with low fluid and spring forces.

In modern turbines, every inlet valve has its own hydraulic servomotor using oil pressure to overcome the seating thrust. Electric 4-20 mA signals drive the servomotor. The failsafe protection system triggers emergency tripping, i.e. the shut-off valves. The control valve servomotors, however, are additionally driven by the electric positioning control loop implemented in the turbine controller (cycle time ≤ 2 ms). As a result, only one 4-20 mA signal is sent to the power amplifier of the E/H converter.

To ensure smooth seating of the valve plugs even at rapid closing the servomotor piston enters a damping chamber at the end of the stroke which delays the last part of the stroke.

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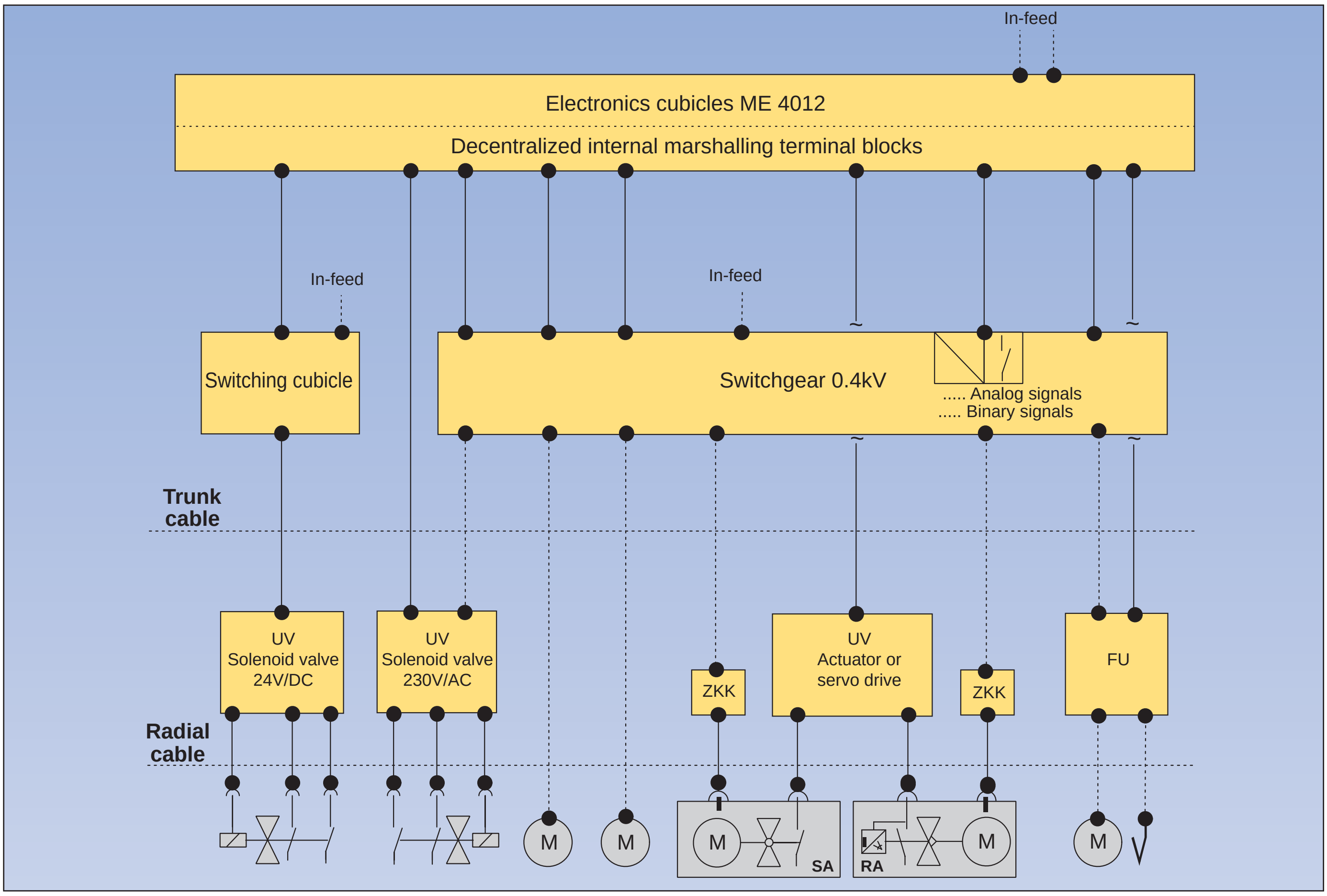
Control Valves and Servo Drives

The control valves are designed according to the valve specifications supplied by the turbine supplier.

Cabling

The cable systems of the individual process sections are installed according to the cabling diagram shown below. The cables for the power section and the supply of the electronic equipment cubicles must be supplied, installed and connected by the customer (except the power cables to the servo drives).



Cabling concept for a typical turbo generator set installation

System Cubicle Layout

The turbine controller cubicle is totally enclosed, has double-wing doors at the front and the back, and is mounted on a swivel frame. The bottom is open. Cable entry can be from the bottom or the top. The connection terminals are located behind the swivel frame and are accessed by opening the swivel frame and the rear double-wing door. The swivel frame accepts 4 subracks for the installation of the turbine controller hardware.

The top tier (subrack 0) contains the master/slave turbine speed controllers and the open-circuit protection channels 1 and 2 (i.e. for energize-to-trip protection). The tier below (subrack 2) contains the turbine protection channel 3 and the control system of the HP/IP bypass stations.

The failsafe protection system (i.e., for deenergize-to-trip protection) of the HP and IP bypass stations and the Turbine Temperature and Power Reference Control Unit (TPR unit) are installed in subrack 4. Subrack 6 contains the DW modules of the failsafe turbine protection and also the electrical failsafe power electronics that is common for new turbine plants.

The protection and central monitoring modules are installed in the X-subrack.

The cubicle mains infeed is connected via the Z-subrack.

I/O Connections

External signals are connected by means of 8 x 25 terminal blocks mounted at the rear of the cubicle.

The connection on the I/O wiring side is made by maxi-termipoint or soldering (0.5 mm^2 max.).

All distribution wiring is carried out internally between two rows of terminal blocks (1800 connections max.).

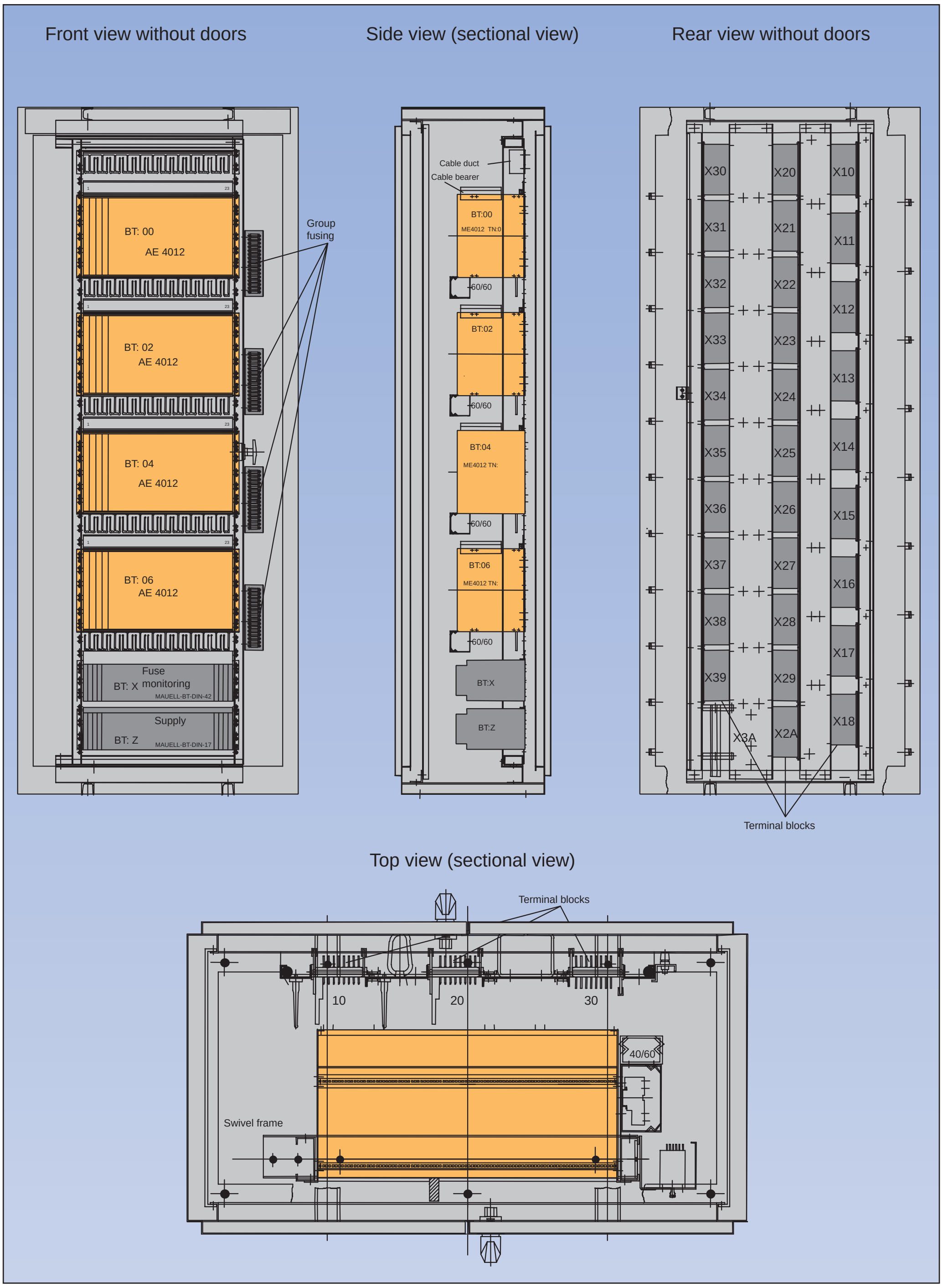
Prefabricated system cables connect the marshalling terminal blocks and the system modules of the turbine controller.

Power Supply and Cubicle Mains Infeed

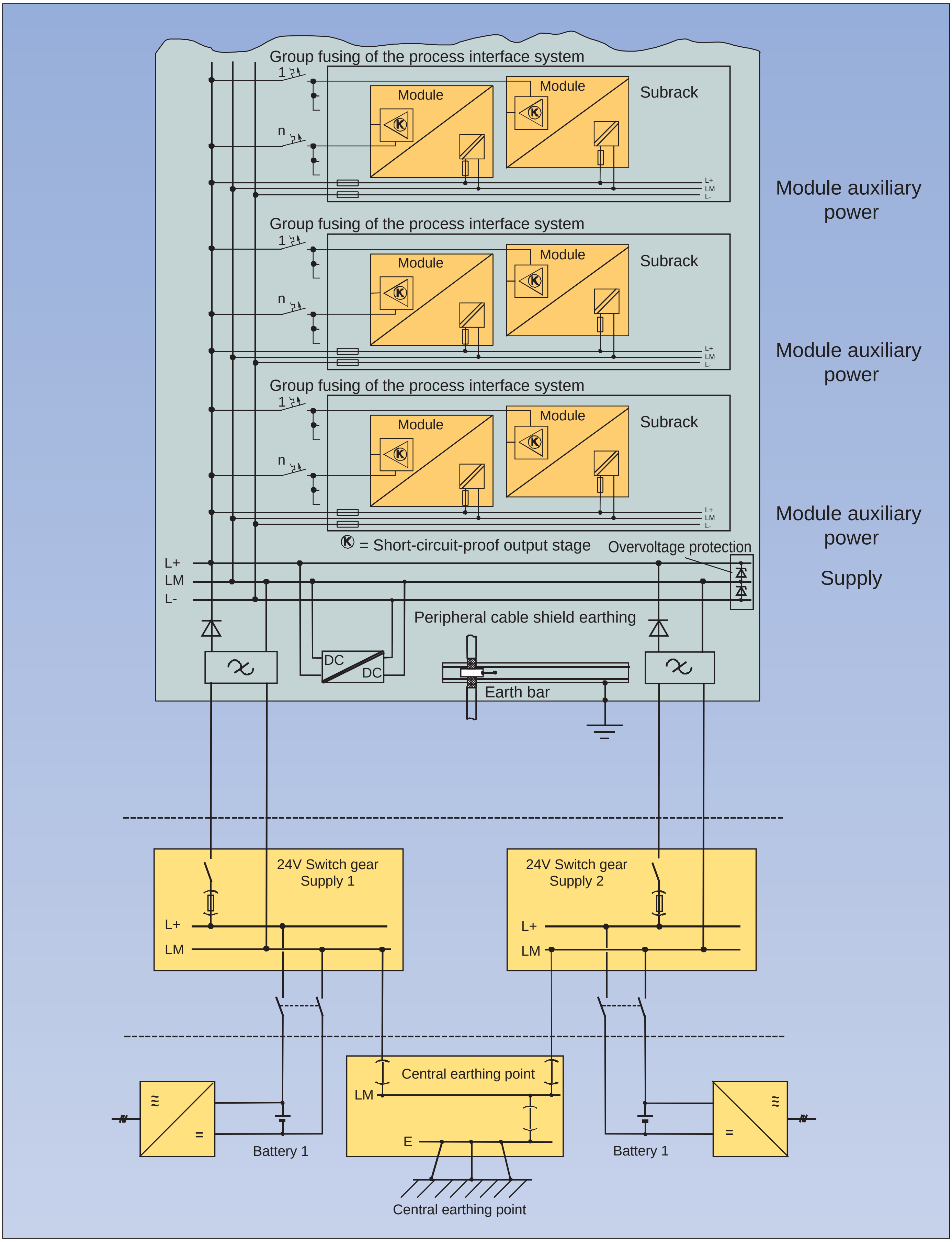
The system cubicle of the turbine controller are designed for a redundant supply from two independent 24V sources. The de-coupled voltages (L+), the reference potential (LM) and the shielding potential are fed to busbars. The group fuse is connected from this point, keeping the distance short.

Group fuses and individual fuse protection are implemented on plug-in modules. Each group fuse protection is followed by individual section fuses.

The restriction to low currents for group protection minimizes the risk of inductive overvoltages in the event of short circuits. Overvoltage protection is ensured by fast suppression diodes.



ME 4012 system cubicle with space for two-source mains infeed, 4 subracks and terminal blocks for 1800 process signals and 1800 distribution wiring connections



Voltage supply, internal distribution and protection for an ME 4012 system cubicle (example)

Cubicle Signalling System

The cubicle signalling system processes all messages caused by the monitored criteria and the hardware functions of the system cubicle and generates a resulting group message. This group message is indicated by the cubicle lamp. The individual messages are displayed by the LEDs of the protection and monitoring subrack. The following criteria are monitored:

- Overvoltage of the internal 24V distribution (supplied by a redundant power supply)
- Supply voltage L + 24 V
- Hardware faults in the individual subracks
- 24 V supply < 19.2 V
- Supply of the external signalling-circuit voltage
- Miniature circuit breaker tripping of the internal group protection
- Door contacts
- Internal overtemperature
- Smoke detector for smouldering fire monitoring (if applicable)

Auxiliary supply L+

Rated voltage	24 V DC
Permissible range	19.2 V to 28.8 V
Permissible ripple	< 5 %
Overvoltage	< 40 V, < 1 ms
Permissible interruption without malfunction	< 1 ms typ.
Working voltage limit	30 V
Current feed per cubicle	15 A max., 10 A typ.
Permissible limit voltage before cubicle supply	30.5 V

Auxiliary supply L-

Only required for 48V contact scanning voltage.

Rated voltage	- 24 V DC
Permissible range	- 19.2 V to - 28.8 V
Current feed per cubicle	3 A
Overvoltage	< 40 V, < 1 ms

Power dissipation

Inside the system cubicle, a power dissipation of 75 watts must be anticipated for each subrack. A fully equipped system cubicle will therefore generate an internal power loss of 300 watts. Additional power losses caused by peripheral equipment, such as switchgear and transducers and by the cables depend on the equipment installed.

Ambient conditions for system cubicles without internal ventilation and forced ventilation

Temperature	0 °C to 40 °C up to 1000 m above sea level
Upper limit temperature for subrack	70 °C
Permissible relative humidity	< 75% without dew
Storage temperature range	- 40 °C to + 85 °C
Relative humidity during storage	< 85 %

Peripheral Interface Signal Level

Binary signal Definition (with respect to M-potential)

Inputs	
Supply	24 V or ± 24 V (48V)
Low signal "0"	0 V to + 5 V
Highsignal "1"	+ 15 V to + 28,8 V
ON and OFF delay	5 ms typ.
Input currents	2 mA at 24 V (binary signal scan) 3 mA at 48 V (signal scan) 8 mA at 48 V (criteria conditioning) Input loop resistance monitoring for < 150 Ω (short circuit monitoring)
Outputs	
Amplifier output	Short circuit- and overload-proof
Output voltage	24 V DC
Output currents	0-50 mA / 0-100 mA

Analog signal definition (with respect to measuring earth MZ)

Input signals	0-20 mA or 4-20 mA 0-10 V or 2-10 V
Nominal input resistance	100 Ω at 20 mA
Analog-to-digital conversion	12-bit
Accuracy	0.25 %
Sensor inputs	Resistance thermometer, thermocouple
Output signals	0-20 mA or 4-20 mA
Rated burden	> 350 Ω
Digital-analog conversion	12-bit
Accuracy	0.25 %

Cubicle characteristics

Dimensions (W x H x D)	900 x 2200 x 500 mm^3
Material	Zincor sheet steel, 2 mm
Body	Fully welded
Doors	Zincor sheet steel, 1.25 mm, fully welded, easily removable, opening angle 180° (free-standing)
Door lock	Espagnolette lock
Operation, optional with	- Double-bit mandrel (standard 3 mm mandrel) - Knob - Knob, lockable
Colour	Textured enamel both inside and outside RAL 7032 (pebble grey) Special coating on request
Top rail	Light grey RAL 7035 both front and rear, black lettering
Cubicle lamp	One lamp, front top rail centre

Cubicle weight	
With mounting frame, empty	140 kg approx.
Equipped and wired	300 kg approx.
Complete with cabling	400 kg approx.
Additional equipment	Thermostat, adjustable up to 45 °C Door contacts (open door monitoring)
Type of protection	
With ventilation slots	IP 20
Closed cubicle	IP 42

Electromagnetic Compatibility Test

Interference test

Test standards: DIN EN 50082-2.96-02/VDE 0839 Part 82-2

The following tests are carried out:

Test	in accordance with:
ESD	DIN EN 61000-4-2.96-03
EM-HF field	DIN EN 61000-4-3.97-08 IEC 1000-4-3.1995 VDE 0847-4-3
EM-HF field generated by digital mobile phones	DIN EN 61000-4-3.97-08 IEC 1000-4-3.1995 VDE 0847-4-3
Burst	DIN EN 61000-4-4.96-03
Surge	DIN EN 61000-4-5.96-09
HF interference	DIN EN 61000-4-6.97-04
50 Hz magnetic field	DIN EN 61000-4-8.94-05
AC voltage fluctuations	DIN EN 61000-4-1.95-04
DC voltage fluctuations	Factory specifications

Noise emission test

Test standards: DIN EN 50081-2.94-03 VDE 0839 Part 81-2.

The following measurements are carried out:

Test	in accordance with
Radio interference voltage	DIN EN 55011.97-10, VDE 0875-11, Class A, Gr. 1
Noise emission	DIN EN 55011.97-10, VDE 0875-11, Class A, Gr. 1

EC Conformity Declaration with CE Label

The conformity of our devices and systems guaranteed by the CE label complies with the legal specification no.89/336/EWG.

Planning and Documentation

For a new turbine plant, the turbine supplier is in charge of all the planning and technical specifications of the turbine control functions, whereas Mauell GmbH is responsible for the implementation of these functions, i.e., the design and configuration of the control system and the development of the circuit diagrams.

In retrofitting and modernization projects, function planning is based on the "as built" documentation and the integration of Mauell's latest technological know-how.

The project documentation covers all components and services supplied by Mauell GmbH and complies with the documentation standard for German Power Stations (HW and function planning acc. to VGB R-I70-C). The documentation is written in German and forwarded to the customer in form of the original data file and three printed paper copies. The following documents are supplied:

- Plant scheme
- Control schemes with description
- Function description with section level and single control level
- Signalling lists, lists of measurement points and drives
- Circuit diagrams
- Cubicle layout diagram
- Terminal connection diagram

Coherent Computer-Aided Design and Configuration (ME-DRP)

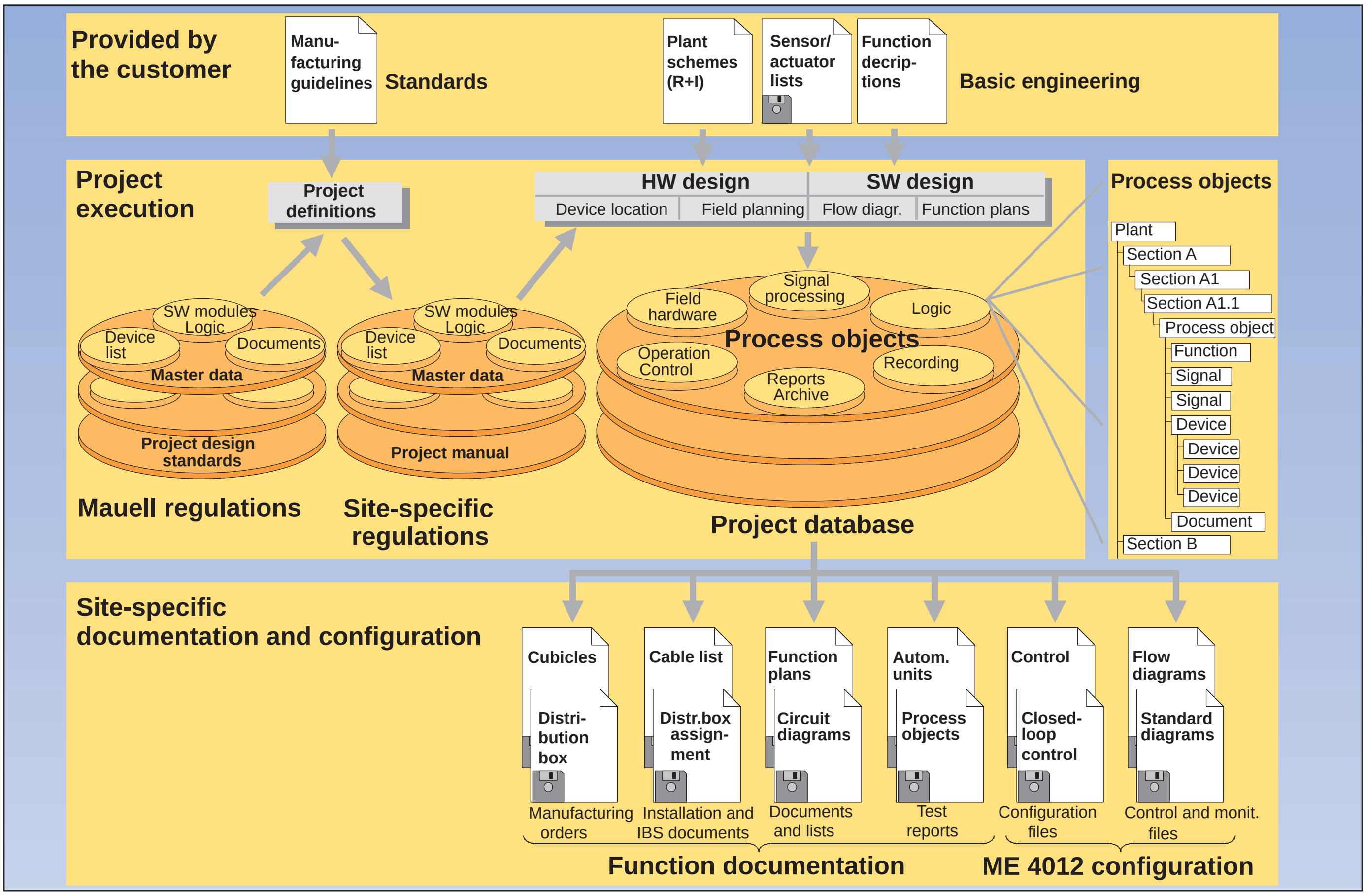
The project is configured and documented using a state-of-the-art CAE tool that is object and database oriented. The diagram on page 54 illustrates the information flow during project planning, development and documentation.

Factory Test

All turbine control equipment is designed and manufactured by Mauell GmbH. The turbine control system as a whole is thoroughly tested with the help of a turbine simulator. To ensure a realistic system environment and precision testing of all system hardware components and of the overall configuration, all incoming process signals are simulated by means of appropriate hardware. Signal outputs are initiated on plug-in test consoles that allow the definition of input quantities. The turbine simulator checks the turbine control loops for correct functioning and optimum response.

Signals that come from higher-level function areas and cannot be simulated by hardware I/O equipment, are simulated by setting the relevant flags. The decentralized marshalling terminal blocks installed in the system cubicles allow the thorough testing of all distribution wiring. After the test, terminal block connections and distribution wiring are corrected as necessary. During the final manufacturer's quality test, the test engineers step by step work through the function description, and test and monitor the following functions on the monitor of the configuration system under online conditions..

- Binary and analog input signals,
- Results of binary and analog logic operations,
- Runtimes, memory contents and flag settings, selection circuits,
- Output signals, commands, feedback signals, actuating variables, arithmetic results.



Flow of information in the computer-aided design and configuration tool ME-DRP

Installation

The installation is carried out by the turbine supplier or by Mauell GmbH.

Device Designation and Labelling

All plant components delivered by us are designated according to the KKS standard (KKS = German Classification System for Power Stations).

Commissioning

The plant components delivered by us can be commissioned by adequately trained personnel of the turbine supplier. During ”cold” commissioning, the individual functions and setting values are tested and the results are documented.

During ”warm” commissioning, the turbine control system is optimally adapted to the dynamic and other operating conditions of the overall plant.

The client’s operating personnel takes part in the commissioning to get acquainted with the system.

Mauell engineers can support the commissioning engineers of the turbine supplier upon request. The commissioning of retrofitting and modernization projects is carried out by Mauell.

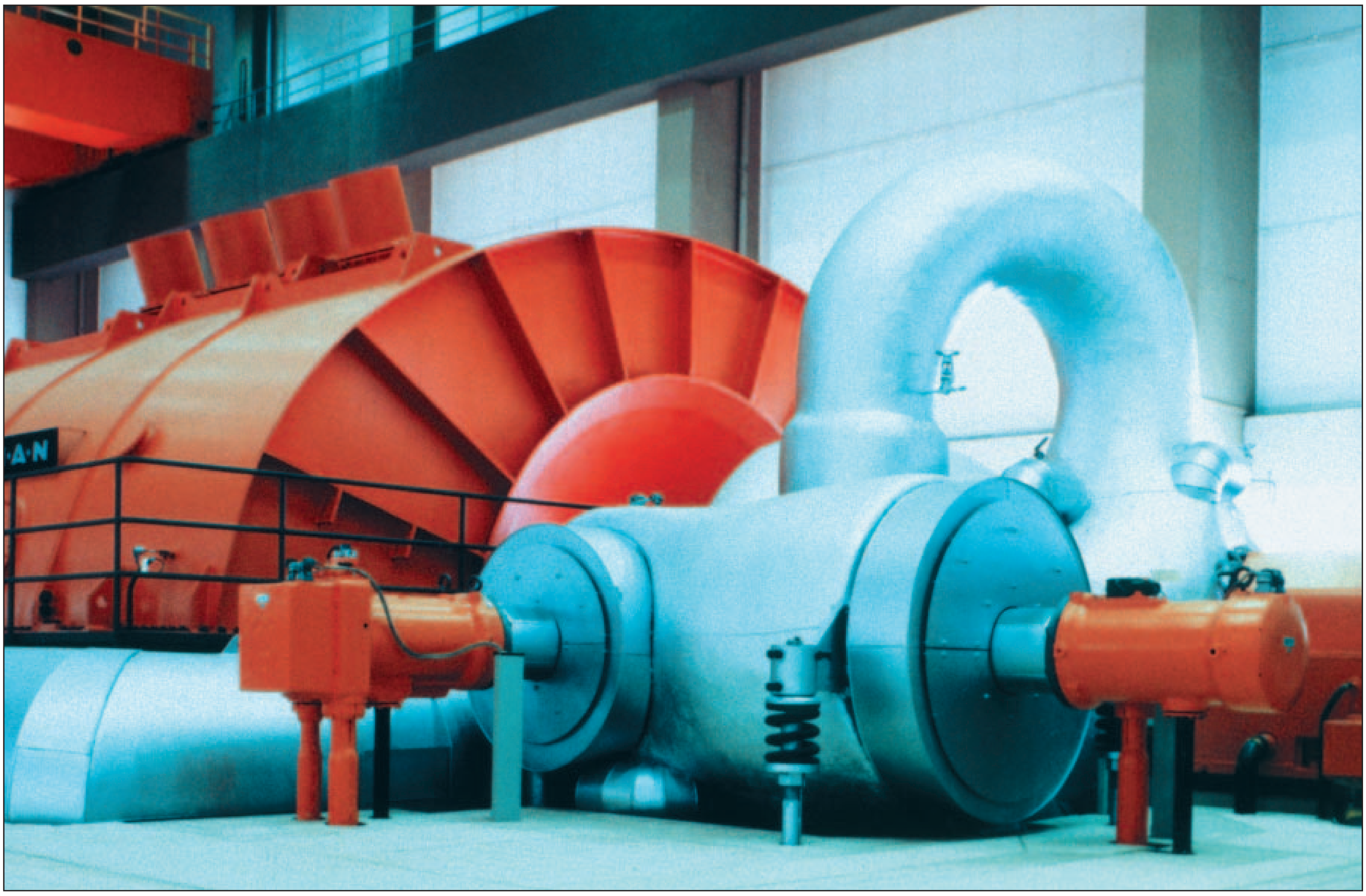
Service and Diagnosis

The modules of the turbine controller are equipped with status LEDs for comprehensive on-site fault diagnosis. They indicate the status of essential binary data, such as

- Input variables,
- Intermediate results of logic operations,
- Output variables.

Analog values coming from the I/O equipment or going to the valve position controllers can be measured on the module frontplate without any disturbance to the other signals. All process states (binary and analog) can be monitored online with the ME-DRP configuration system. It is also possible to simulate signals. If required, the system can be equipped with an interface for remote diagnosis.
The ME-DRP configuration sysem also allows the generation of updated graphical project documentation that integrates all current parameter settings. This updated description of the user configuration can be printed out on a laser printer, even in graphical form, to ensure that one "as built" documentation is always available.

Owing to the larger format (A4 landscape) of the printed documentation, the IDs, plain text descriptions and hardware addresses of inputs and outputs can all be displayed on the same printout. The printout is sorted according to the function areas which are indicated by the appropriate title block. The printed document is automatically provided with page numbers and the date of printing.



HP shut-off valve and HP control valve


Reference example: VEAG Kraftwerk Jänschwalde with 6 turbo sets (500 MW each) and the ME 4012 turbine control system

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Helmut Mauell GmbH
Am Rosenhügel 1-7
D-42553 Velbert
Germany
Tel. +49 (0)20 53 1 30
Fax +49 (0)20 53 1 34 03
E-Mail info@mauell.com

Helmut Mauell B.V.
Postbus 89
NL-3840 AB Harderwijk
Netherlands
Tel. +31 (0)3 41 41 15 80
Fax +31 (0)3 41 41 15 81
E-Mail info@mauell.nl

Helmut Mauell GmbH
Nová 967
CZ-28522 Zruc nad Sázavou
Czech. Republic
Tel./Fax +420 (0)3 27 93 42 80
Mobiltel. 06 02 38 97 70
E-Mail mir-v@cboc.cz

Werk Weida
Papiermühlenweg 10
D-07570 Weida
Germany
Tel. +49 (0)3 66 03 4 80
Fax +49 (0)3 66 03 4 83 10
E-Mail kle@mauell.com

Mauell GmbH
Brown-Boveri-Straße 8/12
A-2351 Wiener Neudorf
Austria
Tel. +43 (0)22 36 2 11 01-0
Fax +43 (0)22 36 2 11 01-30
E-Mail fje@mauell.at

Helmut Mauell GmbH
SULTAN INTERNATIONAL
P.O. Box 3486
Abu Dhabi U.A.E.
Tel. +9712 6 22 44 11
Fax +9712 6 22 44 55
E-Mail farag@emirates.net.ae

Mauell AG
Furtbachstraße 17
CH-8107 Buchs
Switzerland
Tel. +41 (0)1 847 42 42
Fax +41 (0)1 844 44 56
E-Mail info@mauell.ch

Mauell Ltd.
P.O. Box No. 183
GB-Calne, SN11 9BZ
Wiltshire/Great Britain
Tel. +44 (0)12 49 81 20 46
Fax +44 (0)12 49 81 70 96
E-Mail mauell@globalnet.co.uk

Mauell Corporation
31 Old Cabin Hollow Road
Dillsburg PA 17019
USA
Tel. +1717 4 32 86 86
Fax +1717 4 32 86 88
E-Mail gms@mauell-us.com

Helmut Mauell do Brasil Ltda.
Estr. Est. Salvador de Leone, 2998
06850-000 Itapecerica
da Serra São Paulo / Brazil
Tel. +55 (0)11 79 47-17 77
Fax +55 (0)11 79 47-17 74
E-Mail mauell@mauell.com.br

To obtain our latest list of branch offices and
sales representatives in both Germany and abroad:

visit us at: **www.mauell.com**
email us at: **info@mauell.com**
or call us: **+49 (0) 20 53 - 13 405**

please adress technical inquiries to:
vertrieb@mauell.com

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