TECHNICAL REPORT

IEC TR 62140-1

First edition
2002-10

Fossil-fired steam power stations –

**Part 1:
Limiting controls**

Centrales à vapeur consommant des combustibles fossiles –

*Partie 1:
Régulations de limitation*

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FOSSIL-FIRED STEAM POWER STATIONS –

Part 1: Limiting controls

FOREWORD

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IEC 62140-1, which is a Technical Report, has been prepared by IEC technical committee 65: Industrial-process measurement and control.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
65/271/CDV	65/283/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the IEC/ISO Directives, Part 2.

IEC 62140 consists of the following parts, under the general title *Fossil-fired steam power stations:*

Part 1: Limiting controls

Part 2: Drum-level control

Part 3: Steam-temperature control

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual version of this Technical Report may be issued at a later date.

INTRODUCTION

This Technical Report is part of a series of Technical Reports which contain advice on the proper design and operation of control circuits in fossil-fired power stations. They are based on technical solutions used today by some member nations and provide also the background information necessary for proper understanding.

For the time being, all the different national documents tackling the subject are deemed to be at the same level. They always present or imply particular technical solutions which, although finally aimed at satisfying similar functional user needs, are different from country to country and often inconsistent among themselves. Such documents are considered to be real barriers to international trade.

The need for new standards formalizing an internationally agreed approach to express the functional need of fossil-fired power plant operators and suppliers is clearly identified by all the experts. Such documents could facilitate and develop the international business in this particular domain for the profit of the suppliers and the customers. The IEC 62140 series should consider the existing national documents presenting national solutions as a technical basis and should be consistent with them.

In the absence of an internationally agreed approach, this Technical Report is to be strictly considered as an example of particular technical solutions at a given time. It is only aimed at stimulating the debate in order to encourage the convergence of views on the subject and should not be transformed into an International Standard.

There are two types of technical reports within this series.

The reports of the first type refer to specific control circuits of steam generators, such as drum-level control or steam-temperature control and that under normal operational conditions.

The reports of the second type show special means to ensure proper operation also under restricted conditions, for example, during run-up and run-down or in the event of anomalous operating states, or they deal with super-ordinated control circuits, for example, load control or frequency control systems. These reports refer generally to the power station unit as a whole.

Each of the reports within this series is independent from each other; their contents, however, are largely coordinated. The series is to be supplemented.

FOSSIL-FIRED STEAM POWER STATIONS –

Part 1: Limiting controls

1 Scope

This Technical Report deals with limiting controls in fossil-fired steam power stations.

In their task and effect, limiting controls lie between the actual operating controls and the protective devices. Operating controls have the task of controlling the power generation process in such a way that the generated output always corresponds to the predetermined set point, and the individual subprocesses are thus carried out in accordance with economic and environmental criteria. Protective devices have the task of protecting human beings, the environment and the plant as well as its components against damage, principally by means of shut-down. Limiting controls are used to support the operating controls, and hence enable continued operation – possibly under restricted conditions – in the event of transient processes, for example, during start-up and shut-down, and in the event of anomalous operating states.

Limiting controls frequently make use of the actuators of the operating controls. They can be switched off in the same way as the operating controls. When they are switched off, however, the possibility no longer exists of early and automatic limiting of process values before the protective device is triggered. The limiting controls thus differ from the protective devices, which cannot be switched off and which mostly function with their own actuators. Operating controls and protective devices are not dealt with in this report.

The tasks for control of subprocesses may vary as a function of the operating state of the whole plant. Structure shifts are carried out to adapt the control to the various tasks. These are devices used to select structures

– between operating and limiting controls;
– within limiting controls;
– within operating controls.

Structure shifts are thus not independent control solutions to process tasks. They are dealt with in this Technical Report in connection with the limiting controls (see examples in Annexes A to G).

2 Terms, subscripts and abbreviations

2.1 Notations

m	mass
$\dot{m}$	mass flow, mass throughput
n	speed
p	pressure
$\dot{p}$	speed of pressure change
Δp	differential pressure
P	power
Q	quantity of heat
$\dot{Q}$	heat flux
t	time
ϑ	temperature

$\Delta\vartheta$ differential temperature
σ material stress
e control error
w reference variable
x controlled variable

2.2 Subscripts

ex external
op operation, operating
el electrical
i internal, inner (inner wall temperature)
m mean (mean wall temperature)
act actual value
max maximum
c centre
min minimum
ref reference
sp set point
target target
perm permissible
uL upper limit
lL lower limit

2.3 Abbreviations (also used as subscripts)

O outlet
F fuel
SG steam generator
I inlet
ECO economizer
D delivery (for example, p_D – delivery pressure)
LS live steam (main steam)
L limit value
HP high pressure
K constant
IP intermedium pressure
LP low pressure
FWT feed-water tank
FWP feed-water pump
FW feed water
C circulation
E evaporator
W reverence variable
RH reheater
HRH hot side of reheater
SPG set-point guidance
HPO high-pressure outlet

3 Function of limiting controls

The function of operating control and its relief by a limiting control is shown by way of example in Figure 1 using the change in a process variable (controlled variable) over time.

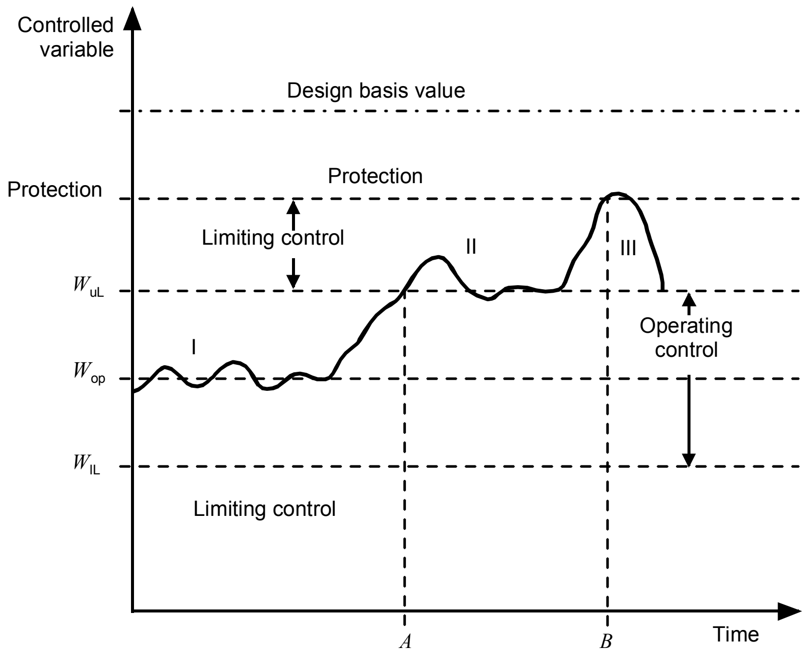

Figure 1 – Change in a controlled variable over time

Area I: The effects of faults of the plant, of a part of it or of the process are kept within the permissible limits by the operating control. The controlled variable is returned to the operating set point W_{op}.

Area II: The effects of faults can no longer be controlled by the operating controls: at time A, the limiting control intervenes and returns the controlled variable to a set point W_{uL} (upper limit value) or W_{lL} (lower-limit value), which deviates from the set point of the operating control. The control task may be transferred back to operating control

– by adjusting the set points, or
– by bringing the controlled variable closer to the operating set point.

This can be done manually or automatically.

Area III: The process fault leads to a change in the controlled variable which can be checked neither by the normal operating control nor by the limiting control. At time B, the protection intervenes, safely preventing the design basis value from being reached.

3.1 Values to be limited

Depending on the requirements of the process and its components, the following values may have to be limited:

– variables of state;
– their derivations and suchlike;
– the result of combinations of individual process variables.

This is done by specific limiting of

– reference variables;
– controlled variables;
– manipulated variables

of the operating control circuits.

The implementation of independent control circuits for limiting purposes is a further possibility.

3.2 Functional modules for limiting

As listed in 3.1, the limiting intervention can be carried out using two different methods.

a) Intervention directly into the structure of operating control.

   This can be carried out by means of the following:

   - switches which are triggered via a separate logic and hence change the control structure
   – by activating the limiting variable instead of the normal controlled variable,
   – by holding ramp rates,
   – by freezing integral action
   - selection circuits comprising combinations of extremity selector modules (MIN, MAX).

b) Implementation of a separate control circuit

   Data logging, controller and actuator are constructed independently and separately from the operating control. In this case, intervention is carried out directly into the process, and not by means of switching or selecting operating control signals.

4 List of limiting controls

Limiting controls which are important for the power station unit are listed below. In accordance with the construction of the individual function groups of the power station, only a part of these limiting controls is required; otherwise, additional limiting controls – which are not stated here – are to be provided for.

The most important limiting controls are listed in Table 1, and some selected examples are described in comprehensive fashion in Annexes A to G. The selection is made according to the importance and complexity of the control task.

Table 1 – List of limiting controls

Function group	Task	Control structure			Operating behaviour during			Additional comments
		Controlled variable	Reference variable	Manipulated variable	Start-up	Shut-down	Power change	
HP bypass device	Upper limiting of HP steam pressure	HP steam pressure	Maximum operational HP steam pressure (dependent on steam flow)	Position of the HP bypass valves	Not operative	Operative	Operative	Malfunction may lead to actuation of the safety valves or of special, additional devices of the HP bypass device. These additional devices of the HP bypass device lead to rapid opening and may thus take the place of the HP safety valves. Water injection to adjust the steam temperature behind the bypass device is necessary See Annex A for further details
HP pressure system	Lower limiting of HP steam pressure	HP steam pressure	Minimum required operational HP steam pressure (dependent on steam flow)	Position of the HP control valves of the turbine	Operative	Not operative	Operative	The HP minimum pressure control can also be used as an HP initial pressure control by switching over the reference variable with the speed/power control disengaged See Annex B for further details
Set-point guidance unit power	Limiting thermal stress in pressure-bearing components	Wall-temperature difference $\Delta\vartheta$ component σ thermal stress	Permissible wall-temperature difference perm$\Delta\vartheta$ component σ_{perm}	Feed-water flow, injection water flow, steam flow, fuel flow	Operative	Operative	Operative	Malfunction leads to premature material exhaustion and hence to lifetime losses. Special interlocks and protective shut-downs are not required for the steam generator See Annex C for further details
Feed water	Limiting evaporator flow to minimum value (lower limit value)	Evaporator (feed-water flow before ECO)	Required minimum evaporator flow	a) Feed-water pump speed (normal operation) b) Throttling with feed-water control valve (low power operation)	Operative	Operative	Operative (in re-circulation operation)	Malfunction may lead to unequal flow through and cooling of the parallel evaporator tubes, and thus to damage to the tubes Only required with forced flow steam generators. See Annexes D and E (E.1.5) for further details.

Function group	Task	Control structure			Operating behaviour during			Additional comments
		Controlled variable	**Reference variable**	**Manipulated variable**	**Start-up**	**Shut-down**	**Power change**	
Feed water	Limiting rate of pressure drop in the feed-water tank	Rate of pressure change in the feed-water tank	Permissible rate of pressure drop	Feed-water pump speed	Not operative	Operative (in very rapid shut-down)	Operative (in very rapid power re-ductions)	Malfunction may lead to damages to the feed-water pump (flashing in the suction pipe). In general, only required for exceptional operating states, for example, when sufficient vapour plating of the deaerator is not guaranteed See Annex E (E.1.4) for further details
Feed water	Limiting pressure in the feed-water header to a maximum value	Pressure in the feed-water header	Permissible maximum pressure	Feed-water pump speed	Not operative	Not operative	Operative in exceptional cases	Malfunction may lead to pipe damage See Annex E (E.1.7) for further details
Feed water	Limiting the differential pressure between the pump pressure and the HP steam-outlet pressure to a minimum value	Feed-water pump exit pressure	HP steam outlet pressure plus preset minimum differential pressure	a) Throttling with feed-water control valve (normal operation) b) Feed-water pump speed (low power operation)	Operative in ex-ceptional cases	Operative in ex-ceptional cases	Operative in exceptional cases	Malfunction may, particularly with natural circulation steam generators, lead to various feed-water pump extraction pressure or the injection water pressure being too low in certain operating cases See Annex E (E.1.6) for further details
Feed water	Preventing the feed-water flow to the evaporator from deviating from the guide value to an excessive degree during start-up and shut-down or pump change-over	Control error of feed-water pump controller, controlling at the time	Zero	Feed-water pump speed of the pump being start-up or down The transient of speed regulation is affected	Operative	Operative	Operative	Malfunction leads to over- or underfeed to the steam generator See Annex E (E.1.8) for further details.
Feed-water pump	Limiting the feed-water pump delivery to a minimum value	Feed-water pump delivery	Required minimum delivery	Reflux to the feed-water tank by opening the normally closed minimum flow valve	Operative	Operative	Not operative	Malfunction may lead to damage of the feed-water pump (for example, overheating) Limiting control is designed both as a control and as a continuous control See Annex E (E.1.1) for further details

Function group	Task	Control structure			Operating behaviour during			Additional comments
		Controlled variable	Reference variable	Manipulated variable	Start-up	Shut-down	Power change	
Feed-water pump	Limiting feed-water pump outlet pressure to a minimum value derived from the delivery flow	Feed-water pump outlet pressure	Function derived from delivery flow	Throttling with feed-water control valve	Operative	Operative	Operative in sliding pressure operation depending on design (for example, with half-load pumps)	Malfunction may lead to non-permissible axial loading of the feed-water pump (protective actuation) due to excessively low dynamic pressure compensation See Annex E (E.1.2) for further details (Figure E.3)
Feed-water pump	Limiting feed-water pump outlet pressure to a minimum value in accordance with the limit curve	Feed-water pump delivery flow	Control limit curve derived from feed-water pump pressure	a) Feed-water pump speed b) Feed-water control valve when minimum pump speed reached	Operative	Operative	Operative in sliding pressure operation depending on design (for example, with half-load pumps)	Malfunction may lead to non-permissible axial loading of the feed-water pump due to excessively low dynamic pressure compensation See Annex E (Clause E.4) for further details (Figure E.4)
Feed-water pump	Limiting feed-water pump outlet pressure to a minimum value	Feed-water pump outlet pressure	Preset minimum delivery pressure	a) Throttling by feed-water control valve (normal operation) b) Feed-water pump speed (low power operation)	Operative	Operative	Operative in sliding pressure operation depending on design (for example, with half-load pumps)	Malfunction may lead to wearing of the pump See Annex E (E.1.3) for further details
Fuel	Preventing the furnace thermal power of the steam generator burners from falling below a minimum value	Sum of fuel flow (furnace thermal power of steam generator)	Minimum furnace thermal power of the steam generator	fuel reference variables from feeder speed controller	Not operative	Not operative	Operative	See Annex F for further details
Fuel	Preventing the furnace thermal power of the burner group of a milling unit from falling below a minimum value	Fuel flow of the burner group of a milling unit	Minimum furnace thermal output of the burner group of a milling unit	Burner group controller position of speed divider device or control valve	Not operative	Not operative	Operative	See Annex F for further details

Function group	Task	Control structure			Operating behaviour during			Additional comments
		Controlled variable	**Reference variable**	**Manipulated variable**	**Start-up**	**Shut-down**	**Power change**	
LP bypass device	Upper limiting of RH steam pressure	RH steam pressure	Maximum operational RH steam pressure (load dependent)	Position of LP bypass valves	Not operative	Operative	Operative	To reduce the steam temperature, water may be sprayed into the bypass steam before it enters the condenser. The LP bypass device is subject to superimposed interlock which is able to bring about partial or complete closure of the bypass valve combination. The device is therefore unable to take on a safety-valve function
Turbo-generator group	Limiting of the minimum output of the turbogenerator	Generator output	Minimum generator output	Intervention occurs via the power set point of the turbine and thus on turbine inlet valves/steam flow	Operative	Operative	Operative	Malfunction lead via motoring to opening of the generator switch; in individual cases, this may lead to turbogenerator set trip
Turbine	Preventing turbine overspeed	Turbine speed	Maximum permissible speed (1,5 % below trip speed; this corresponds to ca. 108,5 % of nominal speed)	Intervention occurs via turbine inlet valves (HP part) and interceptor valves (IP part) steam flow	Operative	Operative	Operative	Malfunction may lead to turbogenerator set trip Acceleration limiting is provided to improve the intercept safety of the turbines
Turbine	Limiting thermal stress in turbine shaft/housing	$\Delta\vartheta$ component as a measure of thermal stress σ	Permissible stress σ_{perm}	Position of the live steam control valves and interceptor control valves	Operative	Operative	Operative	Malfunction may lead to turbogenerator set trip See Annex G for further details
IP pro-portional pressure control	Lower limiting of IP turbine exhaust steam pressure of extraction turbines	IP turbine exhaust steam pressure	Maximum pressure ratio from steam pressure in front of and behind IP turbine blading	Position of LP control valves in the crossover pipes to the LP turbine	Operative	Operative	Operative	The LP control valve is controlled by a minimum selection from the turbine control/extraction control

Annex A

Upper limiting of steam pressure of steam generators

A.1 Task

During shut-down of the unit and during normal operation, changes may occur in the high pressure and reheater pressure in the event of deviations between the generated steam flow and the steam flow taken up by the turbine. If a high pressure occurs which exceeds the preset upper limiting characteristic of the plant, the steam flow which is not taken up by the turbine is led off to the condenser. The latter can be carried out via the high-pressure bypass device if present, either directly to the condenser in the case of plants without reheaters, or, in the case of plants with reheaters, to the reheater first and from there to the condenser. Figure A.1 shows an elementary diagram.

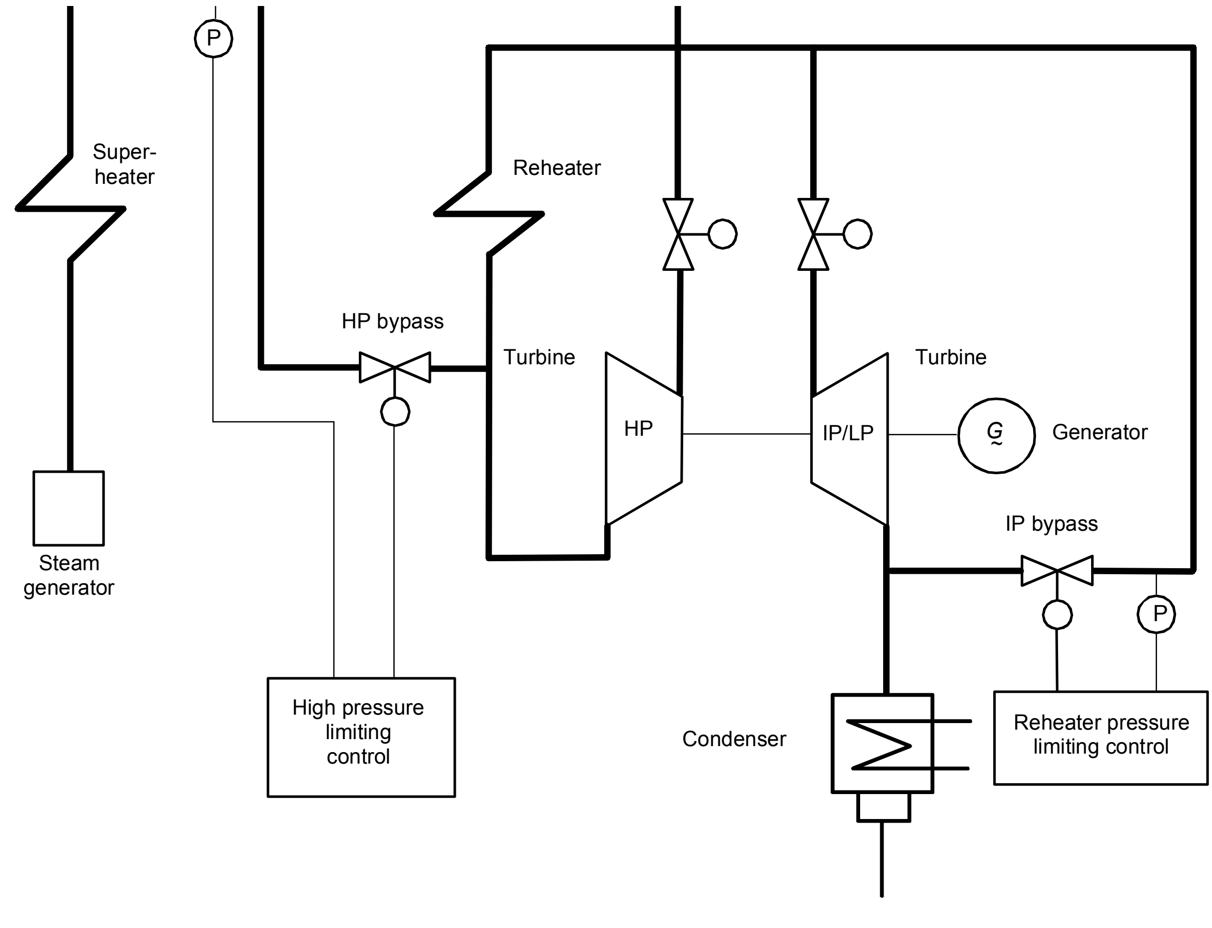

Figure A.1 – Plant circuit diagram for upper steam pressure limiting control using bypass devices

A.2 Description of the control structure

A.2.1 Controlled variable

The controlled variable for the high-pressure bypass device is the high steam pressure.

A.2.2 Reference variable

For limiting control, a control band is set around the operating characteristic, within which the controlled variable may vary within the context of normal operation. The diagram of pressure characteristics for modified floating pressure operation is shown in Figure A.2. Limiting control prevents the controlled variable from falling outside this control band. Only the upper limit of steam pressure is described in this example. The reference variable for the upper limit of steam pressure is formed by addition of a constant Δp to the value of operating characteristic. The value of Δp depends on the control behaviour of the steam generator (construction, firing, design characteristics). It is important here that there be sufficient distance between this new set point and the operating characteristic on the one hand and the value of the highest permissible operating overpressure on the other hand.

The elementary diagram of control of a steam bypass device for conventional power stations is shown in Figure A.3. The operating characteristic for normal operation is formed via a minimum select between the actual pressure value p_{act} and a function p_{target} of the steam mass flow. It runs from a lower limit value p_{min} to an upper value p_{maximum} The rate of change p_{perm} is adjusted using the set point control device. During start-up, the reference variable is formed using other influencing variables which become operative via the switch setting “start-up”. The bypass device, however, is not used as a limiting control actuator here.

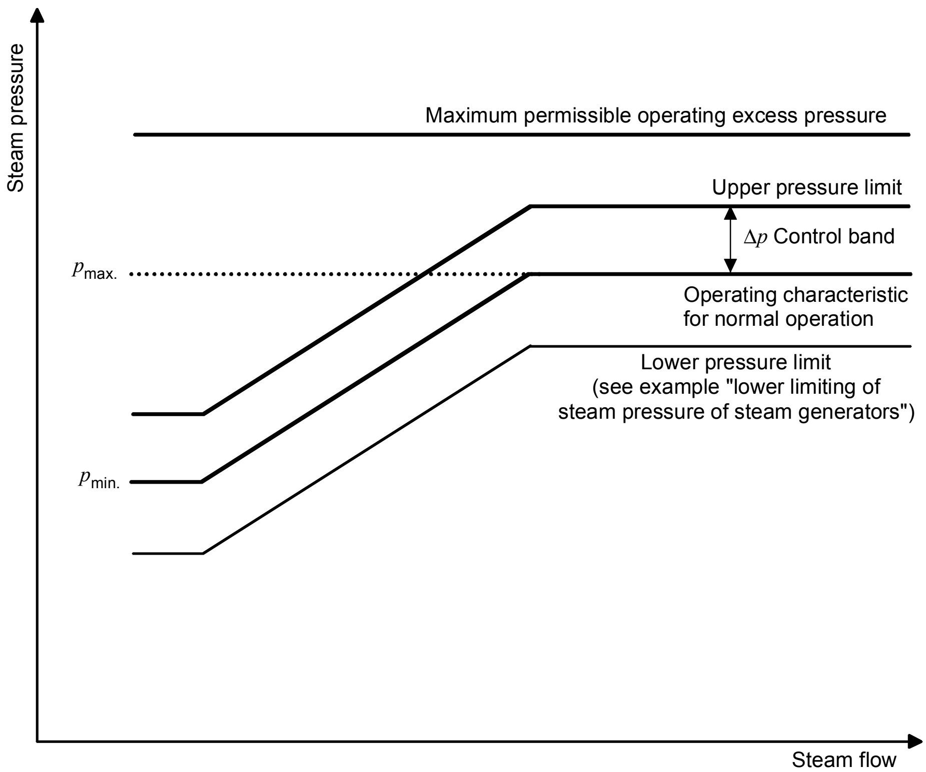

Figure A.2 – Pressure characteristics of a conventional power station unit, shown for modified sliding pressure

A.2.3 Manipulated variable

The position of the bypass device is the manipulated variable for the limiting control device.

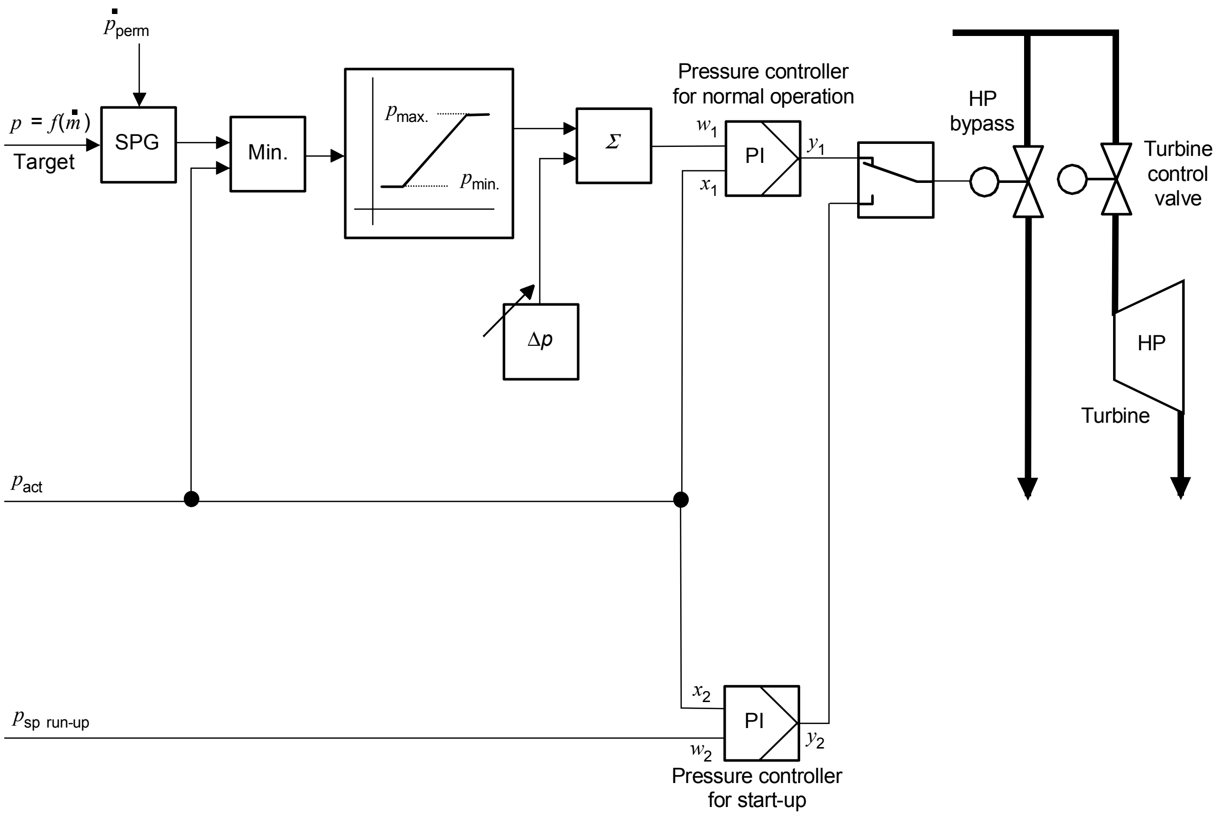

Figure A.3 – Function plan of master control of a steam bypass device for conventional power stations

A.3 Operating behaviour

A.3.1 Start-up

During start-up the control loop is not in operation as limiting control but is used for normal control of the steam pressure.

A.3.2 Shut-down

Limiting control ensures that, during shut-down, steam which cannot be processed through the turbine is led to the condenser. This avoids actuation of safety valves or safety functions of the bypass devices (Clause A.4).

In this way, independent operation of the steam generator and the steam turbogenerator unit is possible in the event of load shedding.

A.3.3 Load changes

The information contained in A.3.2 applies by analogy to downward load changes.

A.4 Supplementary information

With high-pressure bypass devices, it is necessary to adjust the steam temperature at the outlet of the bypass device to the temperature level which is permissible at this point by injecting water.

In addition to their function as a control actuator, high-pressure bypass devices frequently also have a safety function. In such cases, the high-pressure bypass device takes on the additional task of safety valves. The additional equipment for the bypass device which this necessitates consists of a multi-channel control of the drive which involves bypassing normal control. In order to improve the dynamics of the high-pressure bypass device, provision is usually made for the drive to have two different speeds. The faster stage becomes operative whenever the control difference exceeds a preset limit value in the event of particular incidents, such as load dump or turbine trip.

Annex B

Lower limiting of steam pressure of steam generators

B.1 Task

During start-up of the unit and during normal operation, changes may occur in the HP pressure and RH pressure in the event of variations between the generated steam flow and the steam flow taken up by the turbine. If HP pressure occurs which falls below the preset lower limiting characteristic of the plant, the steam flow into the turbine is reduced by throttling the HP governor valves in such a way that the required minimum pressure is complied with. As such minimum pressures are not required for reheaters, this limiting control is only used for the high-pressure side. Figure B.1 shows an elementary diagram.

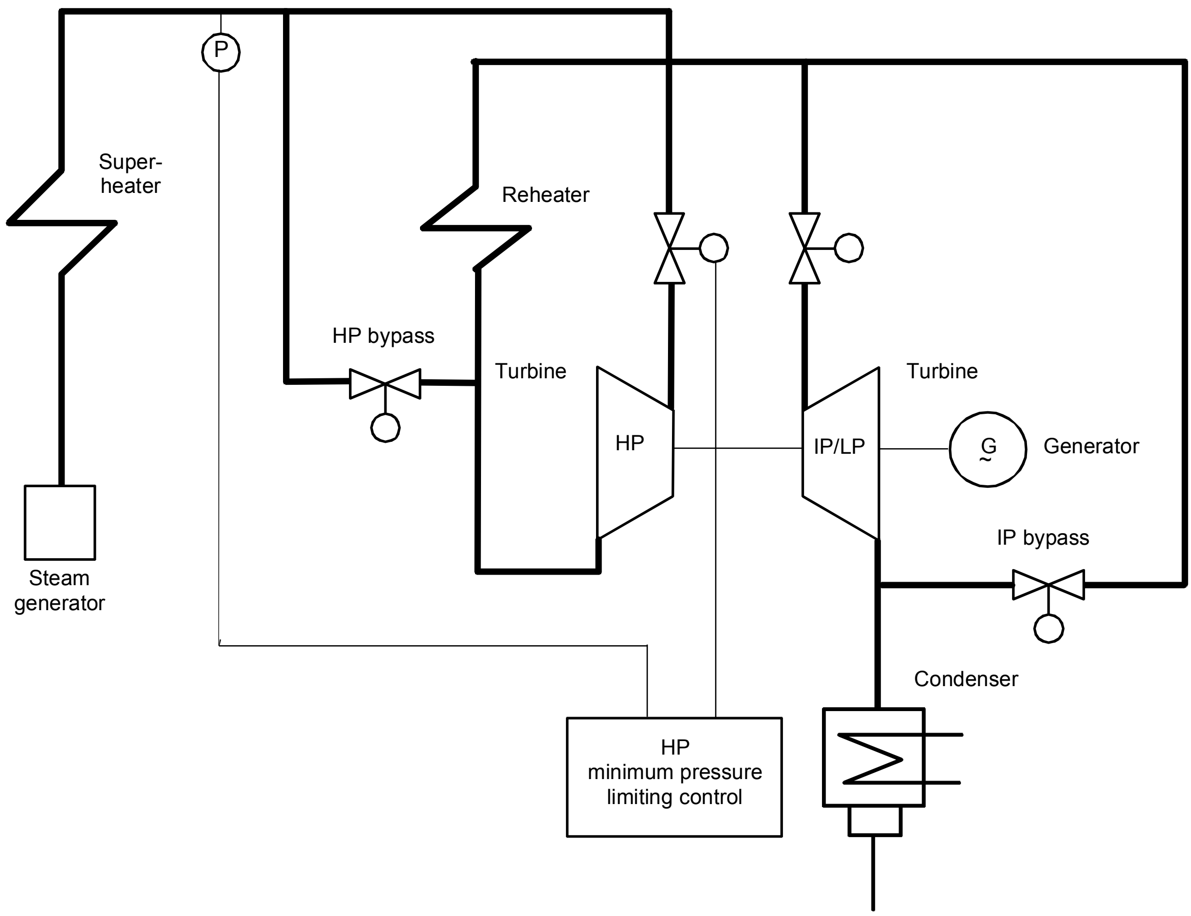

Figure B.1 – Plant circuit diagram for lower steam pressure limiting control

B.2 Description of the control structure

B.2.1 Controlled variable

The controlled variable for limiting control of the live steam minimum pressure is the HP pressure.

B.2.2 Reference variable

Analogous to the upper limit of HP pressure (Annex A), the reference variable for the lower limit of the HP pressure is derived from the operating characteristic, with a value Δp being subtracted from the operating set point (Figure B.2).

B.2.3 Regulated variable

The opening of the HP governor of the turbine is the manipulated variable for HP pressure minimum pressure control.

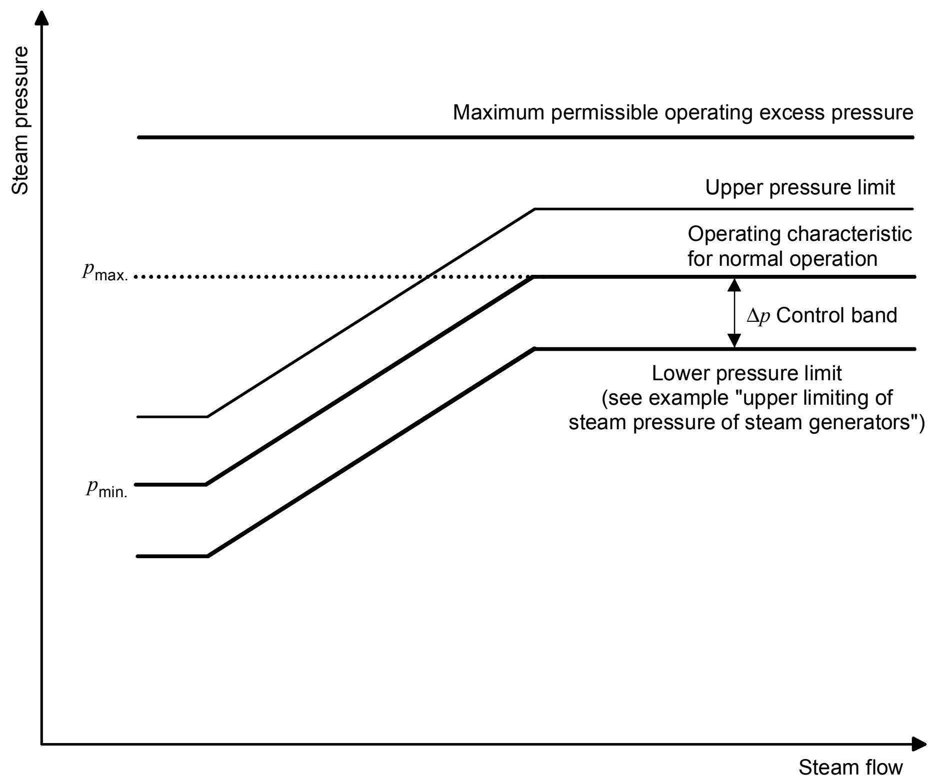

Figure B.2 – Pressure characteristics of a conventional power station unit, shown for modified sliding pressure

B.3 Operating behaviour

B.3.1 Start-up

This limiting control is not normally operative during unit start-up, as the steam pressure is controlled by the pressure control of the HP bypass device.

B.3.2 Shut-down

The information contained in B.3.1 applies by analogy to shut-down.

B.3.3 Load changes

During faster and greater load increases, the steam flow to the turbine is limited using the HP minimum pressure control in such a way that the pressure does not fall below the minimum HP pressure required for steam generation. Limiting is carried out by dint of the fact that the HP minimum pressure control guides the set point of the turbine opening control circuit via a minimum select with the speed/power control of the turbogenerator unit (Figure B.3).

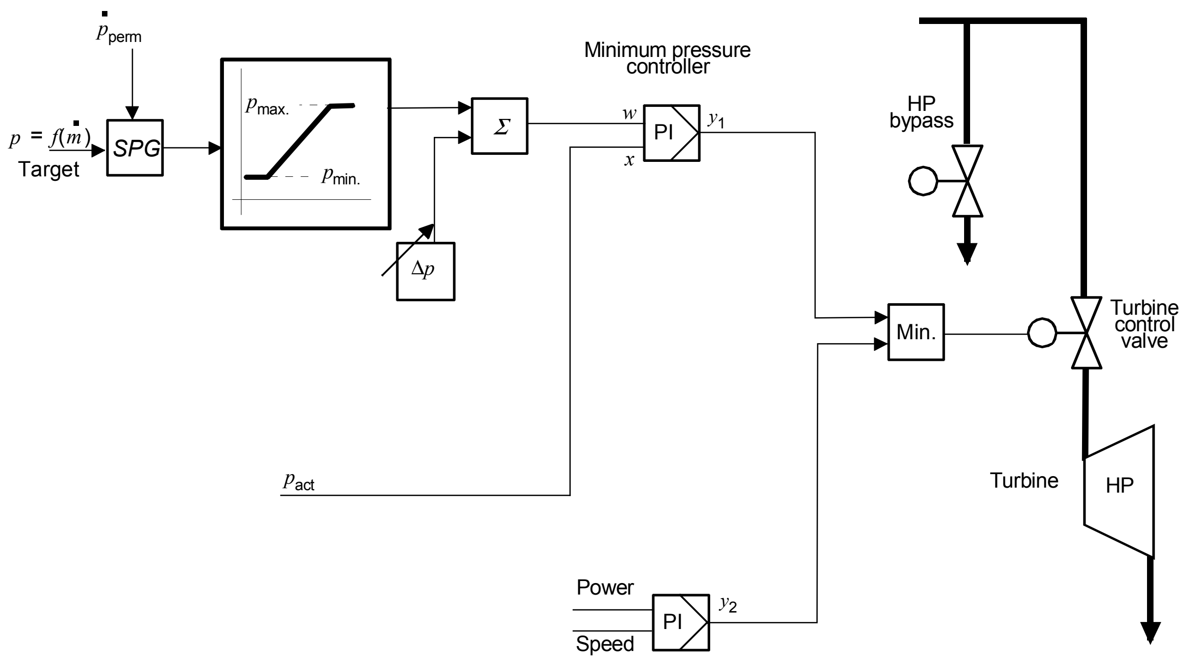

Figure B.3 – Function plan of master control of a high-pressure minimum pressure control for conventional power stations

B.4 Supplementary information

In addition to overcoming slowed steam production in unit operation, the HP minimum pressure control is also used to limit the steam generator stress in the event of erroneous opening of the HP bypass device.

The availability of the unit can be increased in the event of steam generator control problems, as the HP minimum pressure control offers the possibility of controlling HP inlet pressure with the turbine, with corresponding set-point guidance of the speed, power and pressure set point.

Annex C

Limiting control of thermal stresses in pressure-bearing components

C.1 Task

The pressure-bearing components of a steam generator are exposed to varying pressure and fluid temperature conditions due to operational load cycles. The tensile stresses and compressive strains which arise as a result lead to creep and cycling stresses, particularly with thick-walled components, and decreases the remaining life of the components. If the operational exhaustion exceeds the calculated design basis value, premature replacement of the component must be considered. Limiting controls are employed to prevent this. These are used to control the operating conditions so that the determined stress values do not exceed preset limit values. For this, the mechanical and thermal stresses are calculated continuously for selected components on the basis of national guidelines such as TRD 301, and their extreme values are compared with pre-calculated stress limits. If these limits are reached, further load increase is restricted and/or suitable regulated variables are activated, thus insuring that the stress limits are not exceeded. As the theoretical component exhaustion in accordance with national guidelines (for example, TRD 508 in Germany) is composed of cycling and creep stresses, an assessment of the overall component exhaustion is also required, strictly speaking, for the purpose of supervising the stress limits (Figure C.1). This assessment takes into consideration all completed stress cycles. It can be carried out after each stress cycle, or at less frequent time intervals (i.e. off-line). The results of this assessment provide the basis for correcting the stress limits in limiting control. If the calculated degree of component exhaustion lies below the design basis value, the stress limits can be raised. If the reverse is true, the stress limits must be reduced.

C.2 Description of the control structure

Selected components, which are under particular strain, are supervised at various points in the pressure part of the steam generator. The steam-bearing components of the high- and low-pressure zone are respectively combined into groups. The water/wet steam-bearing components, such as separator and circulating pump, form another group. Instantaneous wall-temperature differences are measured or calculated (Figure C.2). They are compared with permissible values which are established as limit value functions for each component on the basis of the calculation method used, for example, defined in national guidelines (TRD 301 in Germany). The allowance for each component (the difference between the limit value and the actual value) is converted into a permissible temperature transient. The smallest temperature transient of the component group is further processed to obtain a set-point guide. In the case of the water/wet steam-bearing components in the recirculation loop, the fluid temperature can only be influenced via the steam pressure and the fuel power. The temperature allowance is thus converted to a pressure/fuel allowance. The coupling between boiling temperature and saturation pressure in the wet steam zone is taken into account for the conversion of the temperature transient into a pressure transient. This value is used as a limit value for the pressure increase, and is further processed in the start-up pressure guidance of the high-pressure reducing station. If the relationship between steam pressure, steam flow and the valve opening of the reducing station is taken into account, a limit value for fuel increase can also be calculated using the permissible speed of pressure increase.

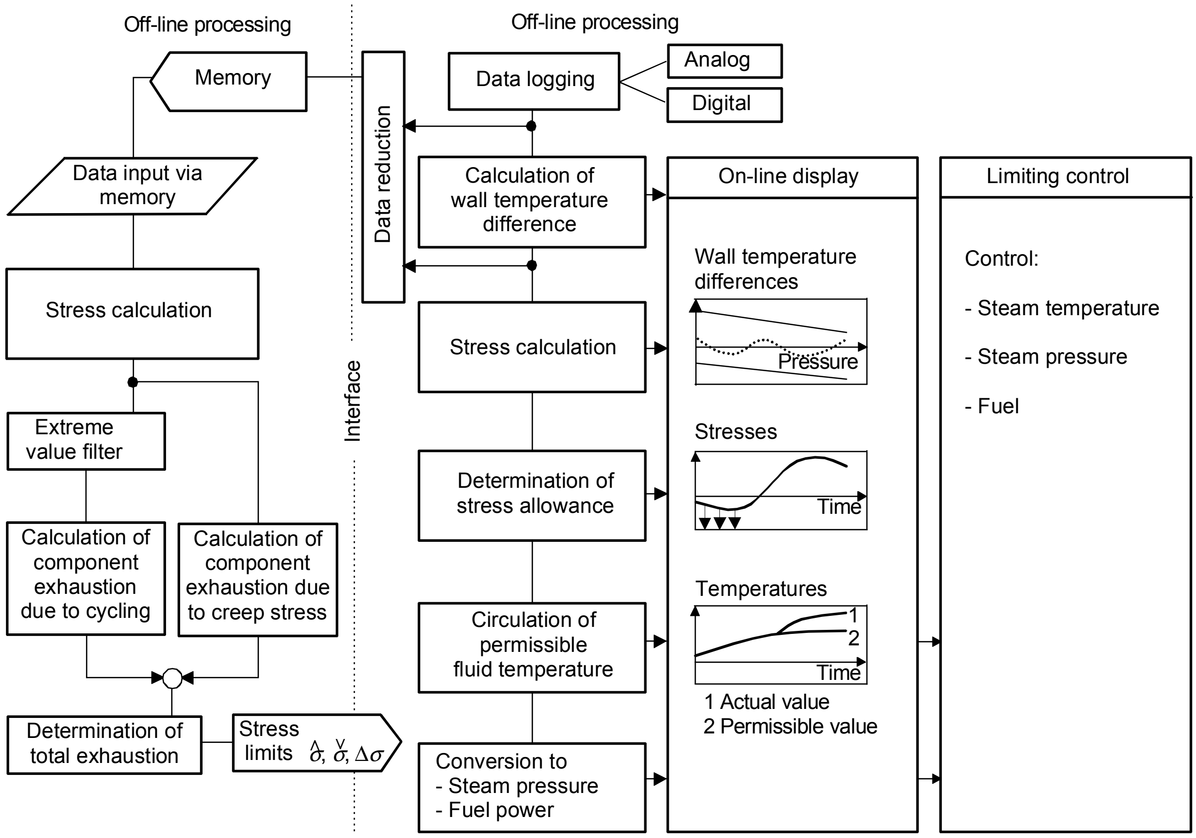

Figure C.1 – Data logging, calculation, display; documentation of a limiting control

C.2.1 Controlled variable

The controlled variables of limiting control are the measured or calculated wall-temperature differences of the pressure-bearing components in the water/wet steam zone and in the superheated steam zone of the steam generator which are to be monitored. The permissible fluid temperatures or the permissible fuel power levels are calculated from the permissible wall temperature differences. A selection circuit determines the most highly stressed component of a component group and limits the assigned manipulated variable.

C.2.2 Reference variable

The reference variables of limiting control are the maximum permissible wall-temperature differences of the assigned component. They are material and form specific and are dependent on the prevailing operating pressure and on the direction of temperature change (start-up = temperature increase; shut-down = temperature drop). Limit values for the subordinate control circuits of steam temperature, steam pressure and fuel control are formed from the difference (permissible minus measured wall-temperature difference = wall-temperature allowance) of a group of components. The maximum permissible fluid temperature change on the interior of the component is calculated from the wall-temperature allowance. The smallest temperature set point of a group of components gives the upper limit value, i.e. the reference variables for the steam temperature, the steam pressure and the fuel limiting control.

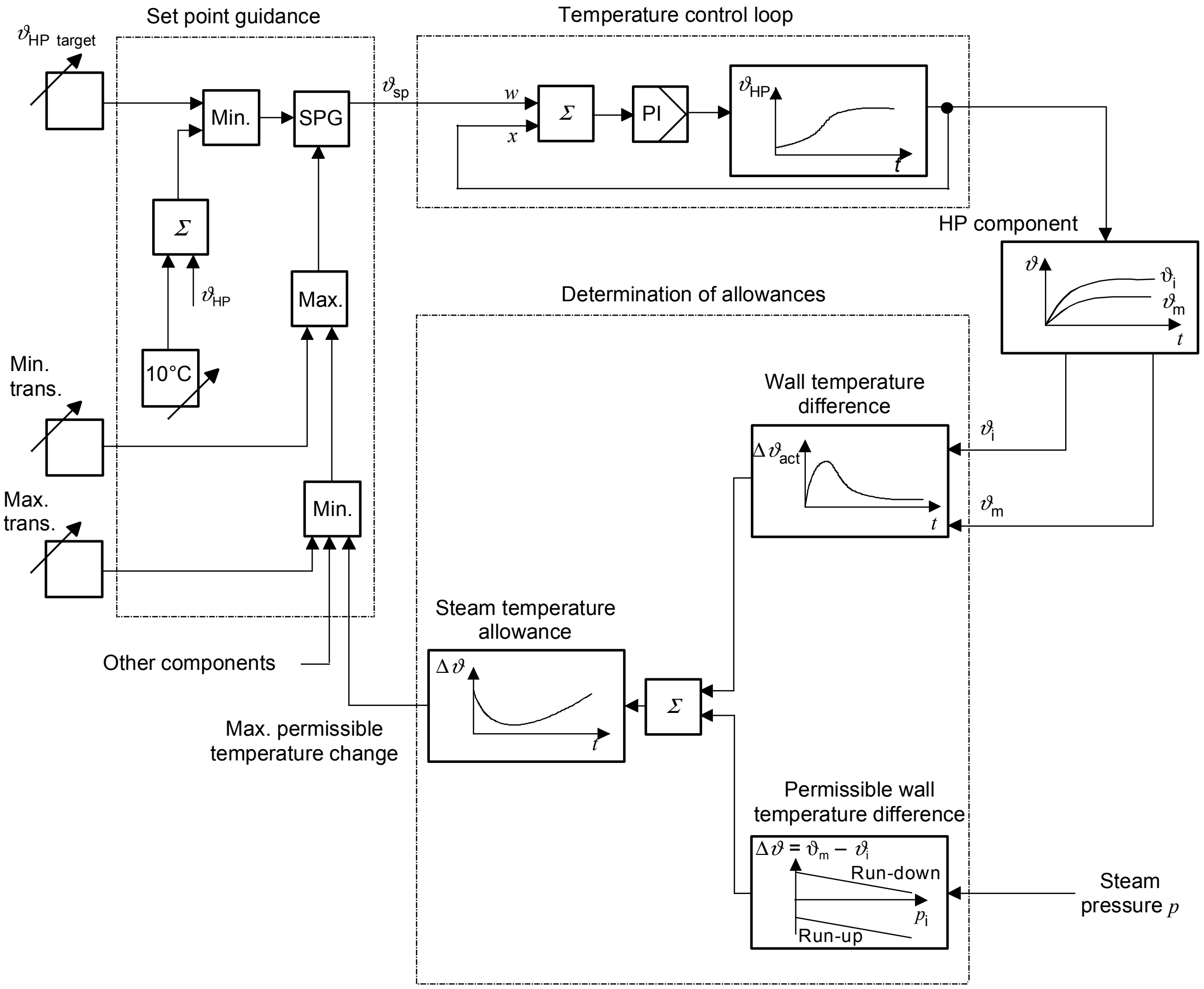

Figure C.2 – Set-point guidance of steam temperature

C.2.3 Manipulated variable

Several manipulated variables are used to limit wall-temperature differences. They vary, depending on the strategies selected to prevent excess stress, between feed-water control valves, injection water control valves, and pressure-reducing, turbine inlet and fuel control valves. In the case of components located in the water and wet steam zone, the actuators for adjusting the feed-water flow, fuel power and steam pressure at the steam generator outlet are used as manipulated variables. In the case of components located in the superheated steam zone, it is often sufficient to use only the injection water control valves. If the regulating range of the injection water control valves is exceeded, it may be necessary to use the fuel valves and pressure-reducing valves.

C.3 Operating behaviour

The component is usually designed for a preset load universe, made up of the following:

- number of cold start-ups
- number of warm start-ups
- number of hot start-ups
- number of large load changes

Sensible limiting control is also used for these load cycles.

C.3.1 Start-up

Component monitoring begins with the filling of the steam generator and the associated increase in component temperatures. The filling target value is limited as a function of the permissible temperature transient.

After ignition and the increase in fuel power, steam production begins, associated with an increase in pressure. Small pressure changes are associated with large temperature changes in the wet steam zone of the steam generator, particularly in the lower pressure range (cold start-up). During start-up and increase in fluid temperature, the thermal stress in the component acts as compressive strain, and the hole edge stress as a result of internal pressure acts as tensile stress. This means that only low permissible thermal stresses are available as an allowance in start-up at low pressures. Limiting control determines the maximum permissible steam temperature and the maximum permissible fuel power from the permissible wall difference temperature, and sets an upper limit for these values.

C.3.2 Shut-down

During shut-down, thermal stresses arise due to the reduction in pressure and fluid temperature which act both as compressive stress. The allowances for the temperature transients thus increase as the pressure falls. As a temperature reduction is associated with the pressure reduction in the boiling zone, a limiting of the steam pressure may already occur here. The same applies to a temperature reduction in the steam zone. If the reduction in the fluid-side temperatures is too rapid, the lower limit is set for the negative temperature transient via the maximum select.

C.3.3 Load change

No high stress cycles usually arise with load changes. If a power station is used in the mid-power range, the large number of load cycles may also necessitate limiting control. In this case, limiting has a restricting effect on the speed of load change.

C.3.4 Special operating situations

Special operating situations are operational faults which may lead to an increased component exhaustion at various points in the steam generator. Such operating situations include, for example, failures of units such as pumps, burners or consumers. Limiting controls of thermal stresses barely come into consideration for control of such incidents, particularly in the upper load range. Load limiting controls intervene here, which supersede the limiting controls of thermal stresses and render them inoperative.

Annex D

Lower limiting of evaporator flow for once-through boilers

D.1 Task

The limiting control "evaporator flow", like the limiting control "feed-water pumps", is part of the overriding feed-water delivery function group. It ensures during operation of the steam generator that sufficient feed-water is available to cool each of the parallel-flow heated evaporator tubes, and avoid excess temperatures, for example, due to film evaporation.

For this, the evaporator flow, with steam generators operated according to the forced flow principle, is limited to a minimum value. In low power operation, maintenance of the evaporator flow leads to an excess of boiling water, which must be recovered using additional control circuits and actuators in the water circuit. Some of these low power devices are shown in Figure D.1. In load operation with a variable evaporation end point, the feed-water flow to the evaporator is equal to the saturated steam flow. The adjusted set point is always higher than the limit value for the triggering of the evaporator protection. If the evaporator flow falls below the set protection criterion, this leads, after a preset time has elapsed, to the triggering of a fuel fault shut-off (firing emergency off). During the transition between variable and fixed evaporation point, the evaporator flow, in a load increase, is limited until the temperature control[1], or, in load decrease, the evaporator flow limiting, begins and the water-level control intervenes. The automatic transition of the two control structures, the balancing conditions and the criteria for the switching on and off of the circulating pumps are described in more detail in the clauses which follow.

D.2 Description of the control structure

The feed-water control frequently consists of a "temperature controller", which forms the set point of the evaporator flow, and an "evaporator flow controller", which acts on the actuators of the feed-water delivery (Figure D.2). In low power operation, the temperature control is superseded by the water-level control and balanced with the evaporator flow. Previous installed low power systems differ in particular in the type of limiting of the evaporator flow or the actuators used for this (Figure D.1). Simplified control diagrams for three of these variants are shown in Figures D.2, D.3 and D.4. The assignments of the individual values are brought together in Table D.1.

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1 The enthalpy in the slightly superheated zone (for example, after the separator) is frequently controlled instead of the temperature.

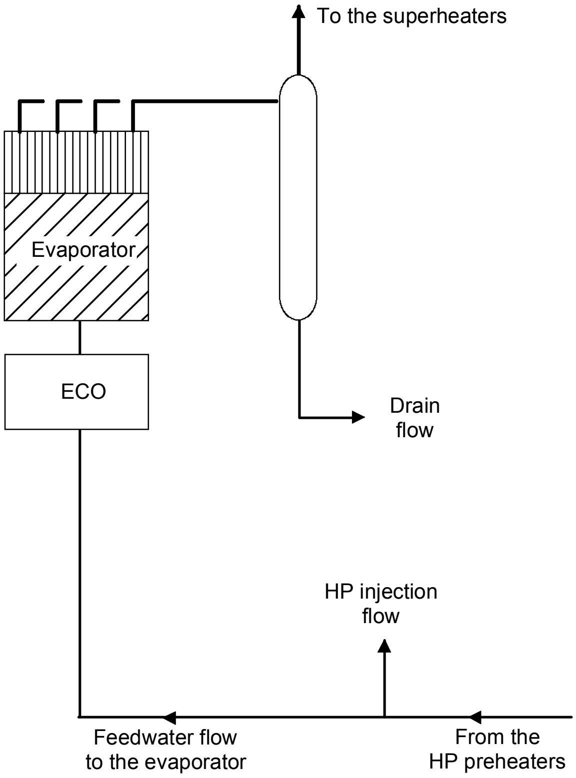


Figure D.1a - Forced flow steam generator with drain

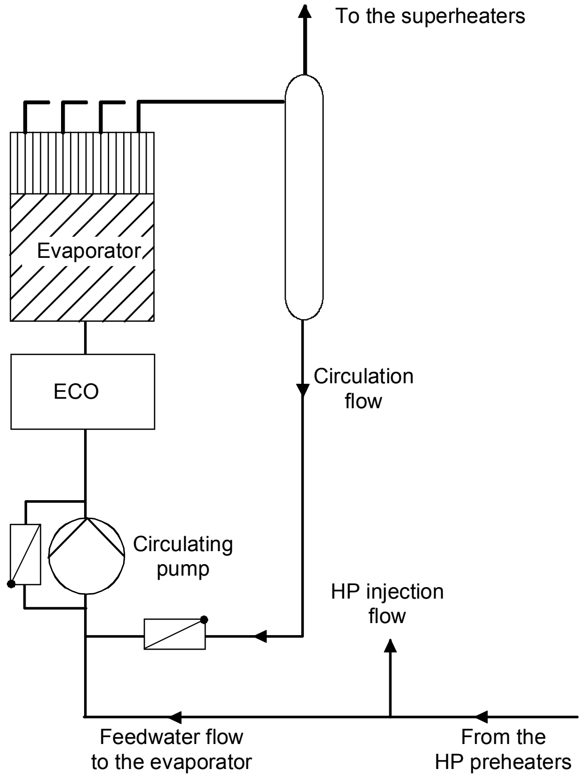


Figure D.1b - Forecd flow steam generator with circulating pump in main flow

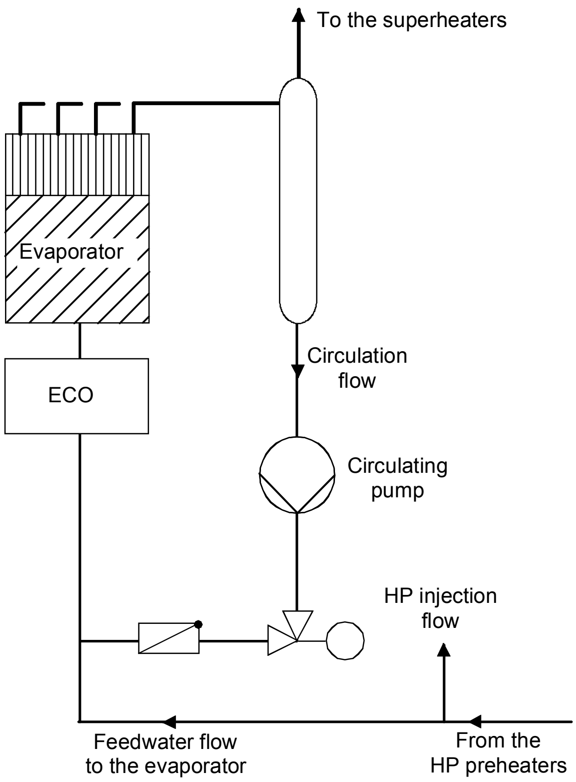


Figure D.1d - Forced flow steam generator with circulating pump in bypass flow

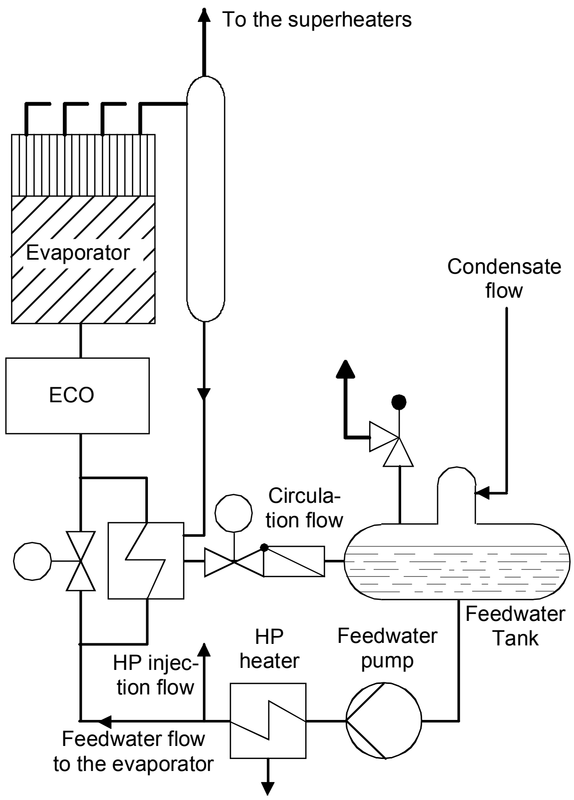
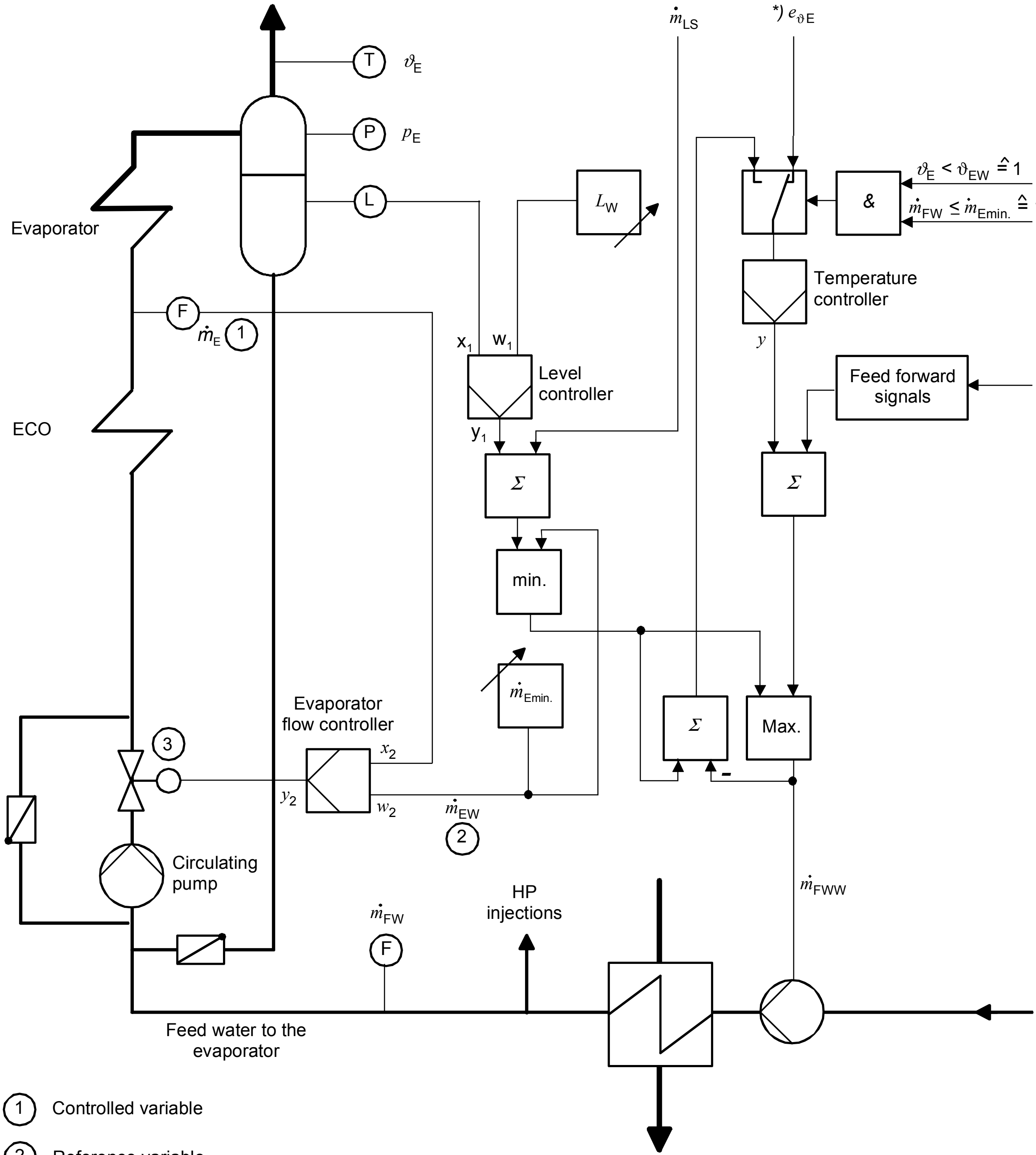


Figure D.1c - Forced flow steam generator with start-up heat exchanger

Figure D.1 – Start-up system for start-up low power operation



(1) Controlled variable

(2) Reference variable

(3) Final control element

*) e_{ϑ_E} is replaced by e_{h_E} in enthalpy calculation

Figure D.2 – Feed-water control with circulating pump in main flow (Table D.1b)

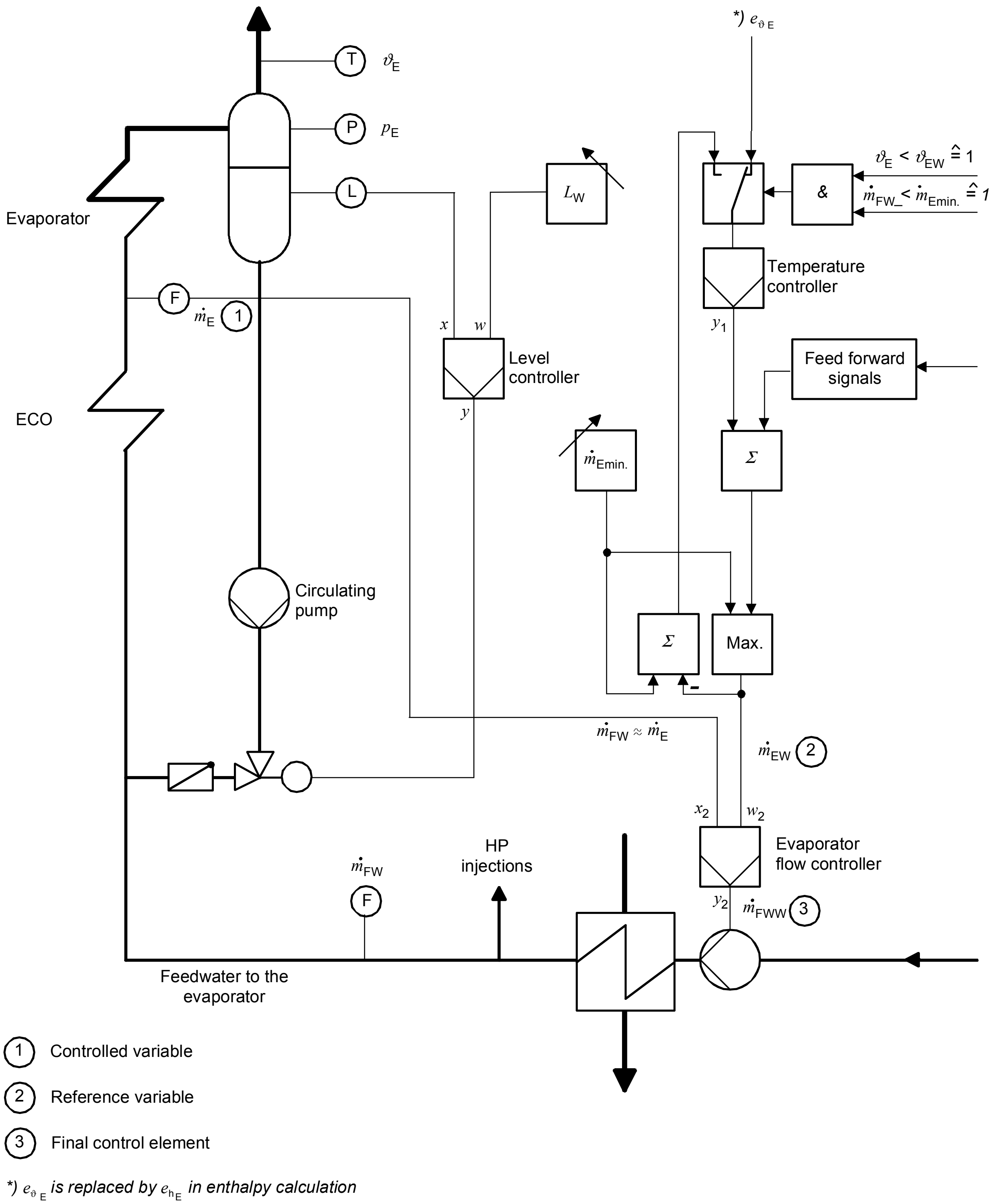
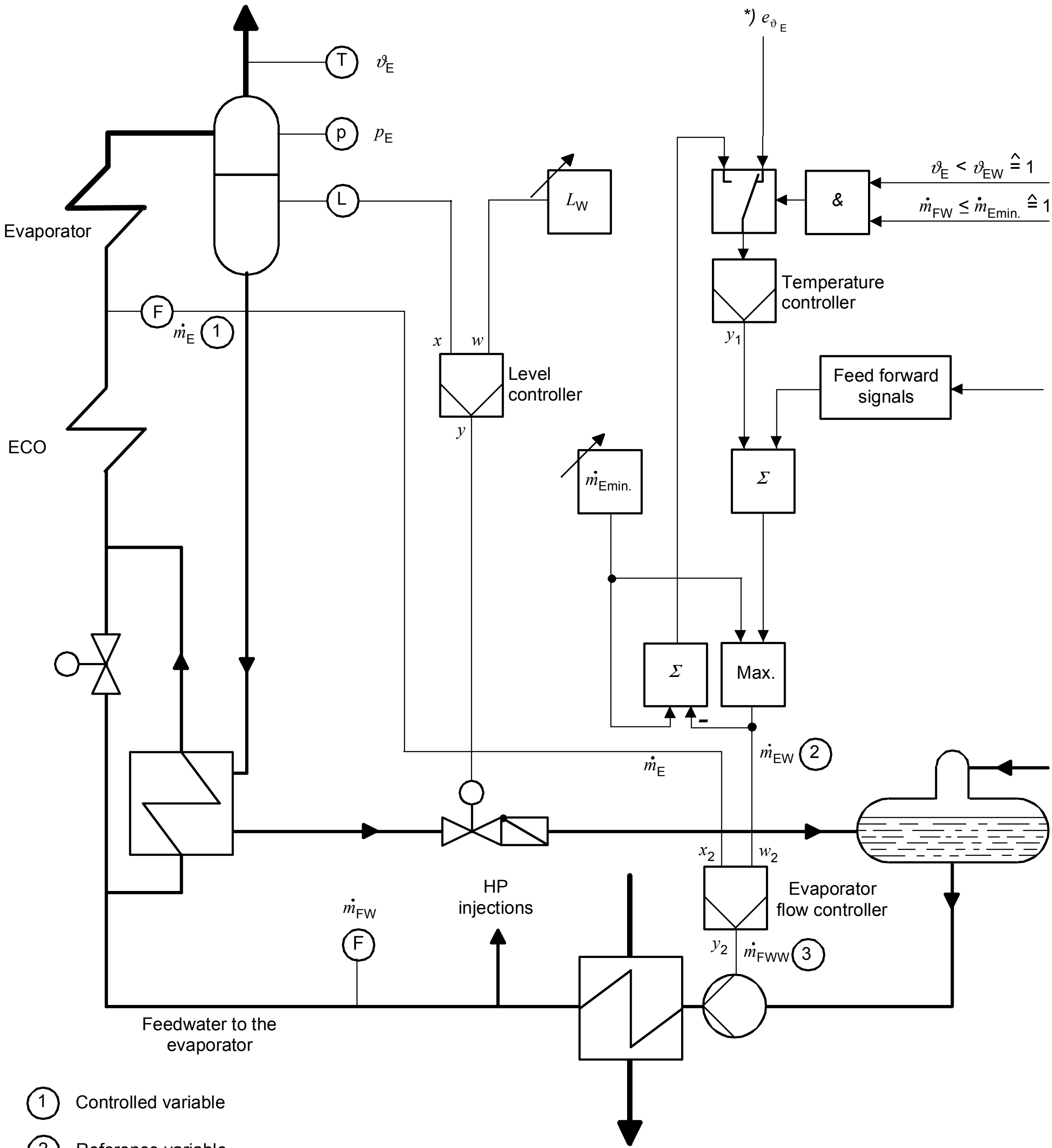


Figure D.3 – Feed-water control with circulating pump in bypass flow (Table D.1c)



(1) Controlled variable

(2) Reference variable

(3) Final control element

*) e_{ϑ_E} is replaced by e_{h_E} in enthalpy calculation

Figure D.4 – Feed-water control with circulating via feed-water pump (Table D.1d)

Table D.1

	Controlled variable	Reference variable	Manipulated variable	Actuator
Circulation via feed-water pump (Figure D.1a)	Evaporator flow	Required minimum evaporator flow	Feed-water flow	Feed-water pump or feed-water control valve
Circulation with pump in main flow (Figure D.1b, D.2)	Evaporator flow	Required minimum evaporator flow	Circulation water flow	Circulation control valve
Circulation with pump in bypass flow (Figure D.1c, D.3)	Evaporator flow	Required minimum evaporator flow	Feed-water flow	Feed-water pump or feed-water control valve
Circulation via feed-water pump (Figure D.1d, D.4)	Evaporator flow	Required minimum evaporator flow	Feed-water flow	Feed-water pump

D.2.1 Controlled variable

The measured evaporator inlet flow, known in short as the evaporator flow, is the controlled variable for limiting control in all four variants.

D.2.2 Reference variable

The reference variable is a lower limit value of the evaporator set-point flow $\dot{m}_{\mathrm{Emin}}$ which acts via a maximum select.

D.2.3 Manipulated variable

During low power operation, two different manipulated variables are possible in the area of the feed-water and circulation flow control. Either the feed-water or the circulation-water flow is used to control the evaporator flow. The second regulated variable is used to control the water level.

D.3 Operating behaviour

D.3.1 Start-up

The evaporator flow limiting control intervenes when the set point of the feed-water flow is less than, or equal to, the required evaporator flow. Figure D.5 shows the progress over time of the feed-water and evaporator flow as a function of fuel increase during start-up. In phase I, the water level and the evaporator flow are controlled simultaneously. As soon as, at time (1), the feed-water flow gives the required evaporator minimum flow without saturated water reflux, a structure shift to temperature control is possible. This structure shift takes place automatically in phase II. Further details are described in D.3.3. The temperature is controlled in phase III. The feed-water flow increases, as the fuel power increases, above the evaporator minimum flow and ends the intervention of the limiting control.

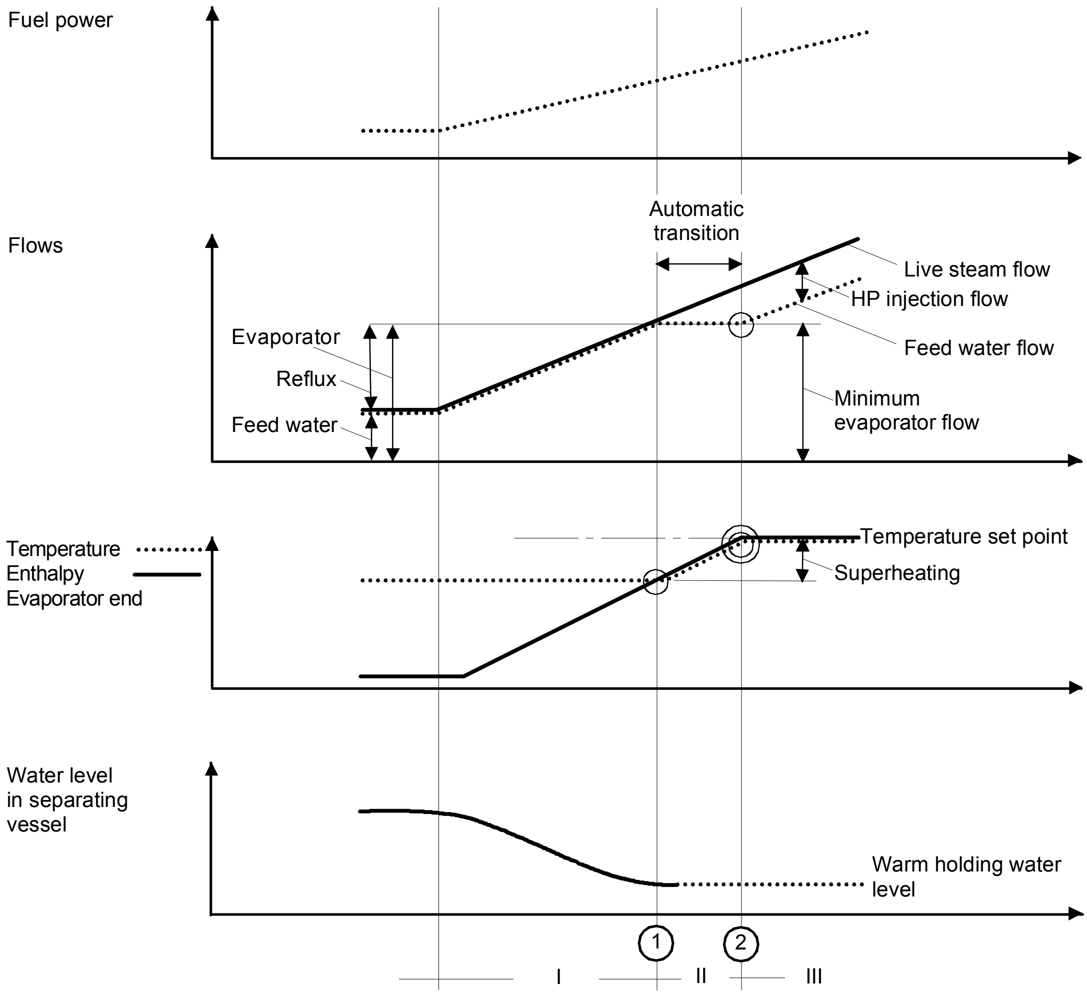


Figure D.5 – Limiting of evaporator flow during load increase

D.3.2 Shut-down

The fuel power is reduced during shut-down. The temporal changes in feed-water and evaporator flow shown in Figure D.6 are associated with this. The evaporator flow limiting control becomes operative when the evaporator flow has reached its lower limit value at time (1) in Figure D.6. Further reduction of the feed water is prevented in phase II until the superheating behind the evaporator has fallen and the water level in the vessel of the separator is sufficient to start the circulating pump, or the control valve for discharge of the water arising has intervened. The structure shift occurs automatically in this second phase. In phase III, the evaporator flow limiting control returns to continuous intervention.

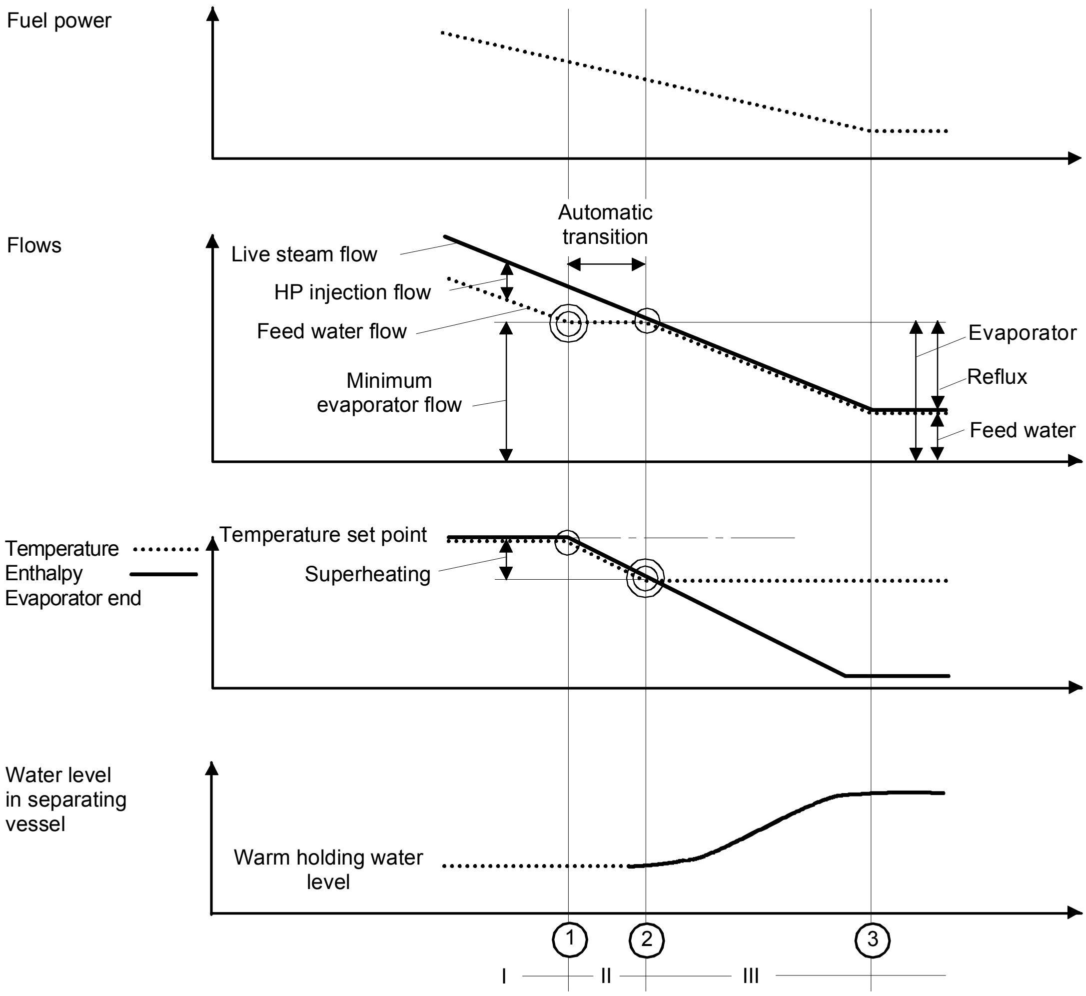


Figure D.6 – Limiting of evaporator flow during shut-down

D.3.3 Load changes

Evaporator flow limiting intervenes in the event of load changes when the steam generator is run in recirculation operation in the lower load range. It may happen here that the evaporator flow limiting control and the temperature control intervene reciprocally.

As the power falls, the evaporator flow is initially reduced via feed forward control in the transition from forced once-through to forced circulation operation until the evaporator target flow reaches the minimum evaporator flow and is limited. The superheating of the steam is reduced as a result of the limiting of the evaporator flow. The temperature controller remains operative until the evaporator outlet temperature has fallen below its set point and the following criteria are fulfilled:

$$\vartheta_E < \vartheta_{EW} \wedge \dot{m}_{FW} \leq \dot{m}_{Emin}$$

The temperature controller must then be balanced with the evaporator flow and rapidly followed up. Figures D.2 to D.4 show this balancing process.

The increased arising of boiling water fulfils the switch-on conditions for the circulating pump and/or brings the water-level control into operation. The follow-up conditions of the temperature controller shown in Figures D.2 to D.4 always, i.e. even when the limiting control intervenes, allow an increase in the evaporator target flow. The balancing of the temperature controller with the limit value minimum evaporator flow is always interrupted if some evaporator tubes are subjected to excess superheating as a result of heating changes and the measured controlled variable ϑ_E is greater than its reference variable ϑ_{EW}. Even in the event of planned load increases, the set point of the evaporator feed forward flow may rise above the evaporator minimum flow by means of feed forward controls in spite of insufficient superheating. This must be prevented by balancing with the limit value. In both cases, the limiting of the evaporator flow is immediately superseded by the overriding temperature control. This makes reciprocal intervention of the water level, temperature and evaporator flow limiting possible in the transition zone

D.3.4 Special operating situations

In order to avoid actuation of the protection criteria “evaporator flow below minimum”, even extreme operational faults must be controlled. In the event of failure of a circulating pump, the feed-water flow must be increased to the lower limit value of the evaporator flow.

With the variant in Figure D.1 c, this occurs automatically, as the control deviation of the evaporator flow acts on the manipulated variable feed-water flow. With the variant in Figure D.1b, the set point of the feed-water flow must be increased to the limit value of the evaporator flow.

Annex E

Limiting controls on the feed-water function group

E.1 Task

The task of the feed-water function group is to supply the steam generators with feed water. This must be fed to the steam generator, continuously variable, in the range 0 % to 100 % (related to nominal capacity) depending on the steam generator capacity. Figure E.1 shows the plant overview of a typical feed-water function group.

The task of the control device is as follows:

- to control the feed-water flow to the evaporator in accordance with the preset reference variable, whereby throttling losses should be avoided as far as possible;
- where several feed-water pumps are operating in parallel, to guarantee their load synchronization;
- to ensure controlled loading and unloading in run-up and run-down of the pumps, and load transfer from one pump to another;
- to take into consideration boundary conditions, which arise for fluid mechanics, design and operational reasons and which require specific operational structures depending on the type of boundary conditions which are relevant in each case (see Figure E.2).

Such boundary conditions are listed below, whereby the boundary conditions given in E.1.1 to E.1.4 arise from operating specifications of the feed-water pumps, and the operational requirements given in E.1.5 to E.1.8 arise from the steam generator or the piping system.

E.1.1 To avoid overheating of the feed-water pumps, the delivery water flow may not fall below a specific minimum, (Figure E.2; $\dot{m}_{\mathrm{D}} \geq \dot{m}_{\mathrm{Dmin}}$) or keep them at specified minimum flow by using minimum flow valves.

E.1.2 To avoid non-permissible axial forces on pump rotors as a result of insufficient dynamic thrust compensation, the pump outlet pressure may not fall below the limit pressure, which is dependent on the delivery (Figure E.2; $p_{\mathrm{D}} \geq p_{\mathrm{DL}}$).

E.1.3 To facilitate automatic, i.e. controlled, start-up and shut-down operation, even at very low feed-water requirements (down to zero values), the pump outlet pressure may not fall below a specific minimum pressure (Figure E.2; $p_{\mathrm{D}} \geq p_{\mathrm{Dmin}}$), as otherwise there is a danger of grazing the rotor blades' rubbering.

E.1.4 To avoid cavitation damage in the feed-water pumps due to partial evaporation in the suction pipe, the rate of pressure decrease in the feed-water tank must be limited to a maximum value $(-\dot{p}_{\mathrm{FWT}} \geq \dot{p}_{\mathrm{FWTmax}})$.

E.1.5 To avoid flow instabilities in the parallel evaporator tubes of forced flow steam generators, the evaporator flow may not fall below a specific minimum $(\dot{m}_{\mathrm{E}} \geq \dot{m}_{\mathrm{Emin}})$. This limit is dealt with in detail in Annex D, in particular in relation to various steam generator low power circuits. It is only included in this example in that it falls within the feed-water function group together with the other limits referred to here.

E.1.6 To ensure an adequate injection water pressure, principally with natural circulation steam generators, the pressure may not fall below a preset differential pressure between the high-pressure steam outlet pressure and the pump outlet pressure $(p_{\mathrm{D}} \geq p_{\mathrm{HPD}} + \Delta p_{\mathrm{min}})$.

E.1.7 To protect the piping system, the pump outlet pressure must be prevented from exceeding a permissible pressure p_{Dmax}, which is conditioned on design grounds (see Figure E.2).

E.1.8 To prevent the feed-water flow to the evaporator from deviating excessively from the set point during start-up and shut-down or load transfer, the transient of the pump to be run up or down must, under certain circumstances, be restricted (shown in Figure E.4 and described in Clause E.4).

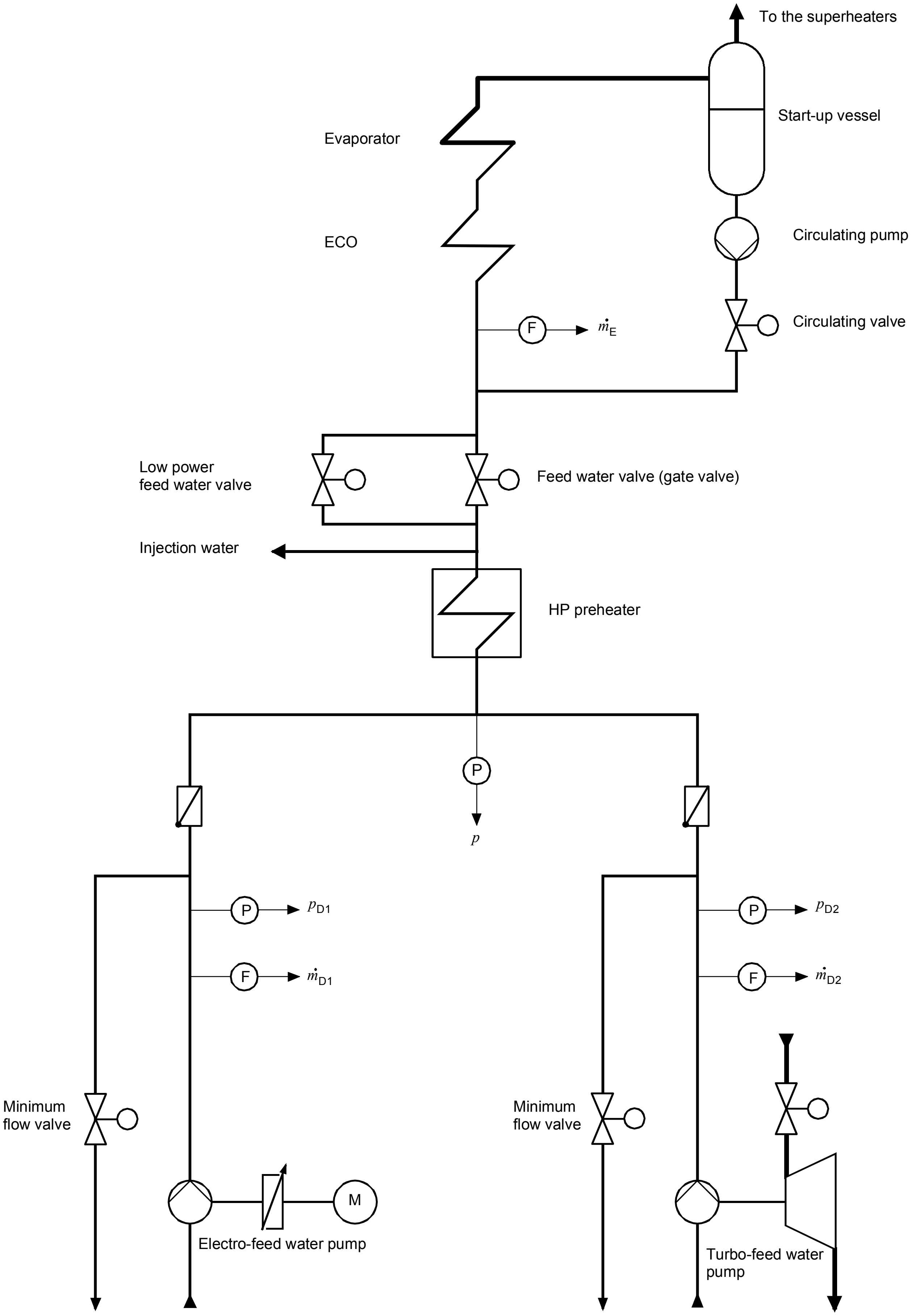


Figure E.1 – Plant overview of feed-water function group

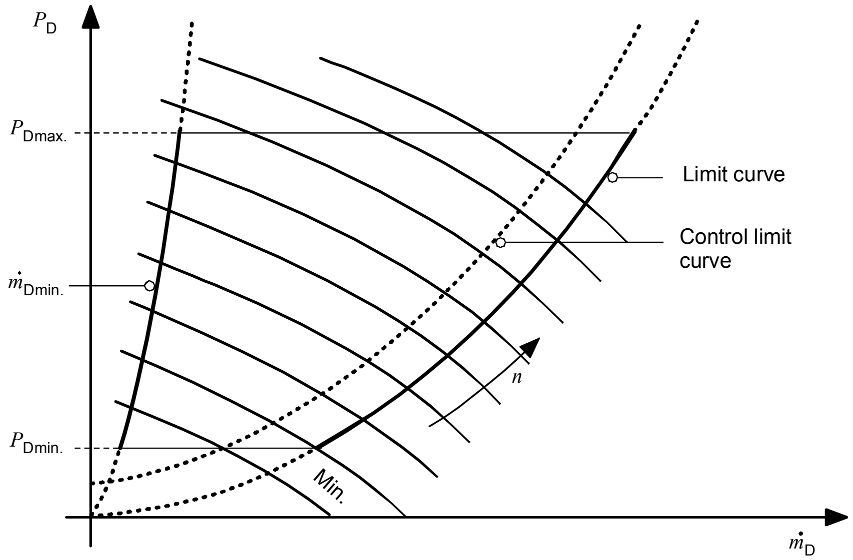


Figure E.2 – Feed-water pump characteristics with limit curves

E.2 Description of the control structure

Figure E.3 shows the functional diagram of the control system. To aid understanding, considerable simplifications are used, both on the whole feed-water pump system and the control circuit. For example, only one feed-water pump (and not two, as in Figure E.1, or three), one feed-water valve (and no separate low power valve) and one evaporator system are assumed.

The problems of adapting different pump drives and pump sizes, taking into account single- and multi-pump operation and the transitions between them, the problems of recirculation operation and the adaptation of the feed-water flows of several evaporator lanes to different heatings are not taken into consideration in the following. The "minimum flow control" of the feed-water pumps is also not described (boundary conditions E.1.1). In addition, the pressure drop between the feed-water pump outlet and the feed-water control valve are also disregarded, and only the pump outlet pressure p_D is used as the pressure-controlled variable for the purposes of simplification (see Table E.1). All the devices for signal adaptation and gain adjustment are also disregarded.

In accordance with the task according to Clause E.1, the following assignments of controlled, reference and regulated variables arise.

Table E.1 – Assignment of controlled references and regulated variables

Controlled variable	Reference variable	Manipulated variable
Feed-water flow to the evaporator $\dot{m}_E$	a) Output signal $\dot{m}_{EW}$ of the feed-water master controller (if no recirculation operation) b) Minimum value $\dot{m}_{Vmin}$ (if recirculation operation)	a) Feed-water pump speed (if $P_W > P_C$ or $P_D = P_{DL}$) b) Throttling with feed-water control valve (if $p_W \leq P_C$)
Feed-water pump delivery pressure p_D	a) $p_D = p_{DL}$ b) $p_{HPO} + \Delta p_{min}$ (if recirculation operation) c) p_{Dmin} (via maximum select, see Figure E.2) d) p_{Dmax}	Throttling with feed-water control valve (if $P_W > P_C$ or $p_D = p_{Dmax}$) Feed-water pump speed (if $P_W > P_C$ or $P_D = P_{DC}$)
NOTE P_W is the reference variable for the steam generator capacity; P_C is the transfer point for the assignment from controlled variable to manipulated variable. It is dependent on the design of the feed-water pumps: it must not be confused with the transition from recirculation to once-through operation.		

E.3 Operating behaviour

While each of the two controllers shown in Figure E.3 is assigned to its manipulated variable on a fixed basis, the controlled and reference variables, along with the controllers, are assigned automatically in accordance with the table, depending on the operating conditions. This is described below.

E.3.1 Upper power range ($P_W > P_C$)

The right input into minimum select 1 is negative. The output of the minimum select is thus also negative. Limiter 2 limits this signal to zero. The output signals of limiters 3 and 4 also remain zero independently of the value of their input signals (the control difference e_{mE} and e_{pD} or e_{pDmax}). Control error thus goes unchanged into the feed-water pump speed controller 5; this means that this controller regulates the evaporator flow $\dot{m}_E$ at the value $\dot{m}_{EW}$ formed by the feed-water master control, provided that this is greater than the evaporator minimum flow $\dot{m}_{Emin}$, which is generally the case at power levels $P_W > P_C$ (maximum select 7, boundary condition E.1.5), provided that the pump outlet pressure is less than p_{Dmax} (minimum select 9, boundary condition E.1.7) and provided that the rate of pressure drop in the feed-water tank is not greater than – p_{FWTmax} (minimum select 9, boundary condition E.1.4).

In accordance with the task set, the feed-water control valve should be fully opened if possible in this load range to avoid throttling losses, i.e.:

- provided that a sufficient differential pressure Δp_{min} is available between the pump outlet pressure p_D and the high pressure outlet pressure p_{HPO} (boundary condition E.1.6)
- provided that the pump outlet pressure p_F lies above the limit curve $p_{DL} = f(\dot{m}_D)$ (boundary condition E.1.2)
- and provided that the pump delivery pressure p_D is greater than the desired minimum delivery pressure p_{Dmin} (boundary condition E.1.3).

As the control difference e_{pD} is negative in the assumption that none of these boundary conditions is reached, controller 6 will fully open the feed-water control valve in accordance with the task.

If the pump delivery pressure p_D reaches or falls below the greatest of these limit values (maximum select 8) because of particular operating conditions, the control difference e_{pD}, which has previously been negative, becomes zero or positive, and controller 6 will throttle the feed-water control valve such that a permissible pump outlet pressure p_D arises via the feed-water flow control using controller 5.

E.3.2 Low power range ($P_W < P_C$)

In the load range below P_C, the control tasks of the feed-water pump and the feed-water control valve should be exchanged for operation in the upper load range, i.e. the control difference $e_{\dot{m}E}$ shown on the right in the diagram must be supplied to controller 6, and the control error e_{pD} shown on the left in the diagram must be supplied to controller 5. This structure shift takes place in analogue or quasi-analogue fashion using the limiting device shown in the centre of the diagram, which, in contrast to binary shift, facilitates a smooth, overlapping transition.

The process is as follows.

With falling power, the right input signal into minimum select 1, which has previously been negative, becomes positive. (The left input signal normally has a greater positive value, as the limit value derived from the high-pressure outlet pressure is higher than the pump limit curve, and it is therefore eliminated in minimum select 1.) This positive signal is accepted by limiter 2 and opens limiters 3 and 4 in both directions to the extent that the power set point P_W falls. If the control differences $e_{\dot{m}E}$ and e_{pD} are now smaller than or equal to the signal derived from the difference $P_C - P_W$, they are eliminated at the controllers assigned to them and supplied to the other controller in each case instead. By selecting the gain of limiter 2, the overlap band width is obtained, in which the structure transition occurs. This overlap not only brings about a completely smooth transition, but also assists control behaviour in the event of considerable and rapid changes, for example, in the event of faults, as in these cases both actuators support each other. As the pump limit curve is formed as a function of the pump delivery $\dot{m}_D$, a positive feed-back effect would occur, if the pump pressure were to be controlled via controller 5 by setting the feed-water pump speed. The control structure which is otherwise reserved for the upper power range must therefore also be operative in the low load range in the case of the pump limit curve being reached. This is brought about by the left input signal into the minimum select 1 becoming zero in the case of the pump curve being reached, and thus closing the limiters 3 and 4 independently of the value of the right input.

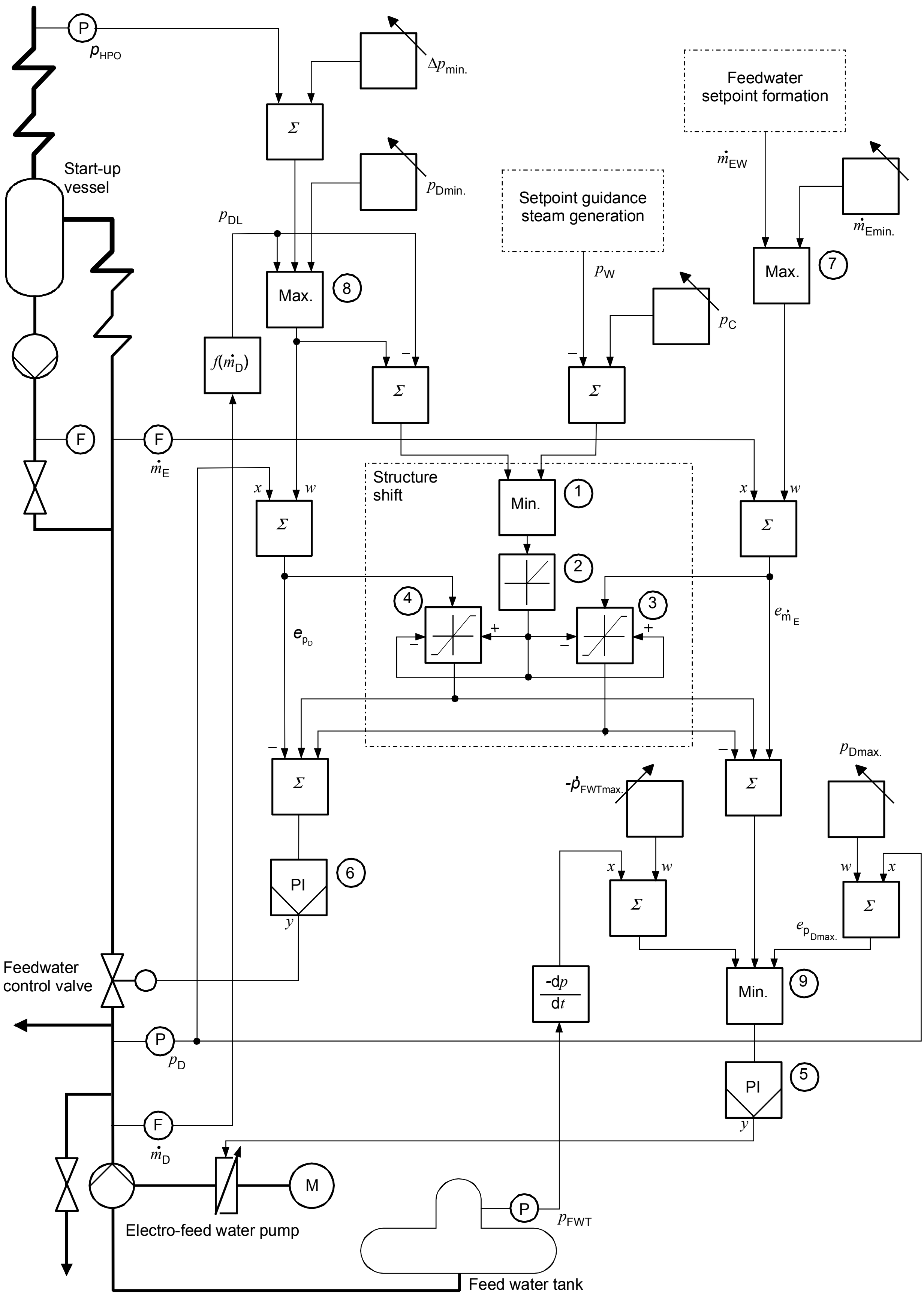


Figure E.3 – Simplified function plan of a feed-water control with limiting and structure shift

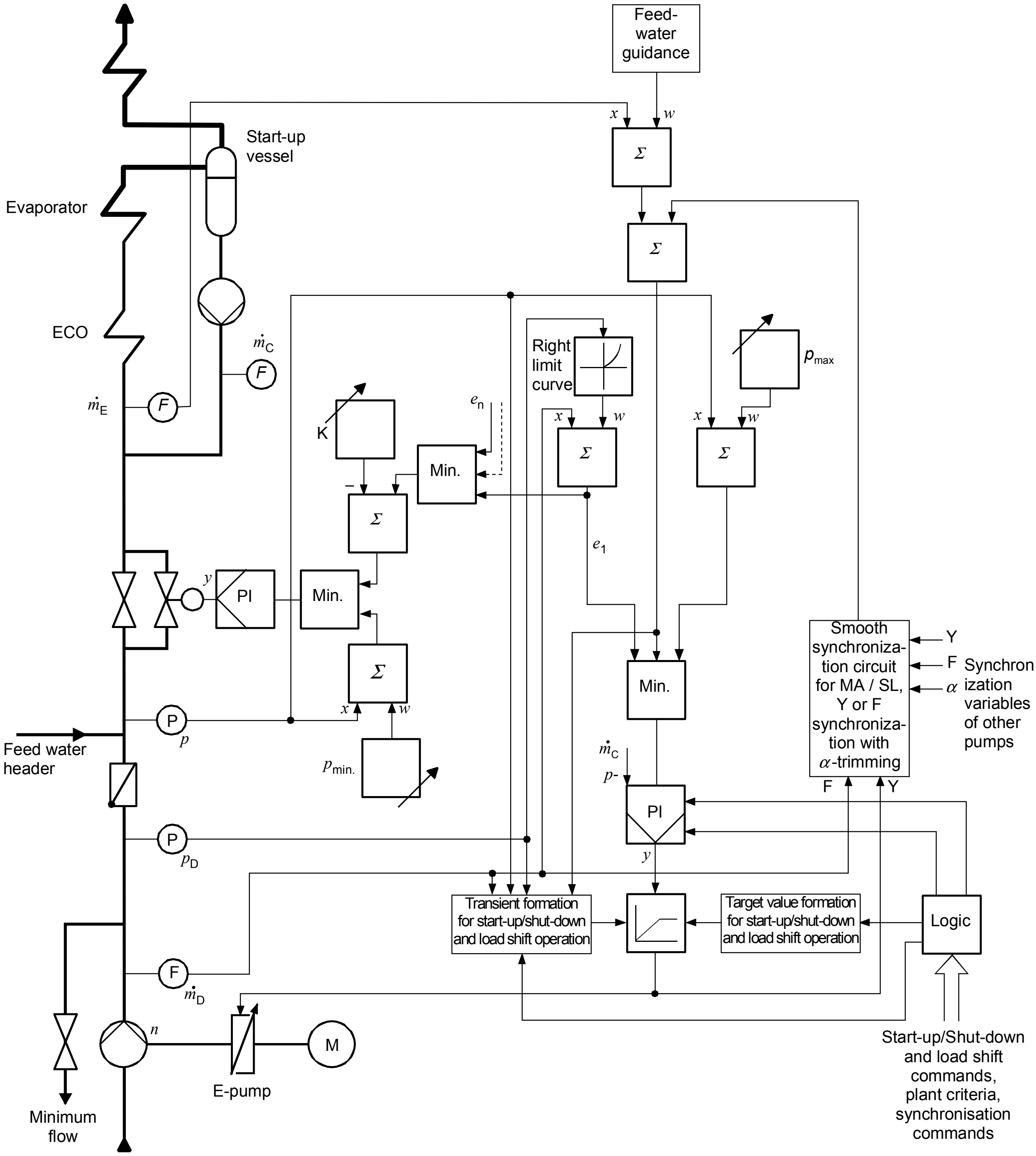


Figure E.4 – General plan of feed-water control with speed-controlled E-pump and low power control valve

E.3.3 Load changes

The limiting controls are generally only operative in start-up and shut-down operation, in the lower partial load range, particularly in sliding pressure operation, and where the feed-water pumps are designed as partial load pumps. In the upper power range, no limiting can be expected in fault-free operation.

E.4 Further control structures

Figure E.4 shows, as a variant to Figure E.3, a functional diagram, in which the flow control is always carried out – even in the low power range – by changing the pump speed. The following assignments of controlled, reference and manipulated variables result (see Table E.2).

Table E.2 – Assignment of controlled references and manipulated variables

Controlled variable	Reference variable	Manipulated variable
Feed-water flow to the vaporator $\dot{m}_E$	Output signal of the feed-water control device (corresponds to the minimum flow $\dot{m}_{Emin}$ in recirculation operation)	Feed-water pump speed n
Feed-water delivery of the pump $\dot{m}_D$	Feed-water pump pressure p_D with downstream limit curve	Feed-water pump speed when n_{min} feed-water control valve is reached
	Required minimum delivery as flow recirculation $\dot{m}_{Dmin}$ or limit curve $\dot{m}_{Emin.} = f(p_D)$	Feed-water minimum volume valve
Feed-water pressure *p*	Feed-water minimum pressure p_{min}	Feed-water control valve
	Feed-water minimum pressure p_{max}	Feed-water pump speed

The whole circuit, with the exception of the feed-water guidance device and the feed-water control valve drive, is present for each pump. The core is a PI controller which adjusts the speed-control device of the pump. The controller receives the smallest of three control differences as an input. The control error between the feed-water set point and the actual feed-water flow is normally to the fore. However, if the operating point approaches a limit characteristic (see Figure E.2), the corresponding control error takes over, as it then becomes the smaller. For the right limit curve, which is derived from the feed-water pressure using a function generator, there are, in the event of convergence, preselector stages which intervene to varying degrees, in order to protect the pump in any circumstances, i.e. to prevent the limit curve from being exceeded. The control device will first of all try to keep to the control limit curve, and the pump is switched off only when the actual limit curve is reached. To keep to lower limit curve, the low power control valve is brought into play if required, in order to obtain a pressure increase by throttling.

If there is a danger that the maximum limit pressure will be exceeded, the corresponding control difference kicks in on the minimum select device and reduces the pump speed via the PI controller. If several pumps are in operation, a smooth synchronizing circuit ensures the required synchronization of pumps. A choice is possible here between master/slave operation or position synchronization/flow synchronization. Trimming is possible.

Another programme part ensures orderly start-up and shut-down of the pump, or load transfer from one pump to another. A controllable follow-up device behind the PI controller obtains the target value and transient and outputs the corresponding regulating signal.

After switching on, the pump is initially running up, using a relatively small start-up transient, to a set speed. If the “load” order then comes from the function group, start-up continues with a correctly sized load transient, until the differential pressure across the non-return valve (= pressure behind valve minus pressure in front of non return valve) has fallen below a set positive value. The load transient is then reduced as a function of the control error between feed-water flow and set point, and switched over smoothly to normal automatic operation when a certain discharge flow is reached. Shut-down takes place in reverse order. Load transfer involves the corresponding combination of the two.

Annex F

Lower limiting of furnace thermal output, using as an example direct-firing pulverized coal furnace

F.1 Task

The following explanations relate to a direct-firing pulverized fuel furnace, i.e. a furnace in which the fuel, after processing to pulverized coal, is fed direct from the mill to the burners (Figure F.1). The mixture of pulverized coal and gas delivered by a coal mill consists of the pulverized coal prepared in the milling unit, drying gases (mill air in case of black coal and flue gas in case of lignite) and the vapours and gases (exhaust vapours) released from the coal during drying. Additional combustion air is fed in before the burners. Heat is released during combustion of the coal. The combustion process proceeds via the stages of degassing, ignition and combustion of the volatile matter and the residual coke. An inflammable mixture, a sufficient ignition temperature (ignition energy) and ignition speed are preconditions for ignition.

The task of fuel control is to adapt the coal dust flow to the required power, whereby fault-free fuel ignition conditions at the individual burners must be guaranteed at all times. For safe operation of the furnace, therefore, it is necessary to set a lower limit for the pulverized coal flow, so that it does not fall below the minimum furnace thermal output. This is the task of the limiting control. The minimum furnace thermal output is the lowest furnace thermal output at which safe operation of the furnace is ensured. It is specified either by the supplier or by local or international standards, for example, TRD 413 (September 1991, points 2.10 and 2.12) in Germany.

The furnace thermal output, and hence also the minimum furnace thermal output, results from the total fuel and air mass flow at the burners, and is influenced in its behaviour by the following operationally variable parameters:

a) lower calorific value of the fuel;

b) proportion of volatile matter in the fuel;

c) milling fineness;

d) temperature of fuel-air mixture;

e) dust concentration at the burner;

f) fuel-air ratio at the burner;

g) the nature of any support firing which may be present (oil/gas) or the burning output of adjacent burners, in so far as they influence the ignition conditions of the burner under consideration.

Parameters a) and b) are long-term varying operational boundary conditions (this may include point c), depending on the type of milling unit). Only points c) (or d)) to g) can be influenced by the automation system. If the furnace thermal output falls below the permissible minimum, the pulverized coal furnace is switched off by a safety system.

The aim of the limiting control is to prevent this from happening. In the individual operating states, the lower limit of furnace thermal output has the following tasks.

- In stationary operation, and in load changes, the furnace thermal output should be controlled in such a way that the furnace thermal output is prevented from falling below the minimum value. This applies also for every mill.

- When the coal burners are put into operation, the support firing (oil, gas or adjacent coal burner) should be controlled or adjusted so that the resulting furnace thermal output does not fall below the minimum furnace thermal output of the burner group to be started up.

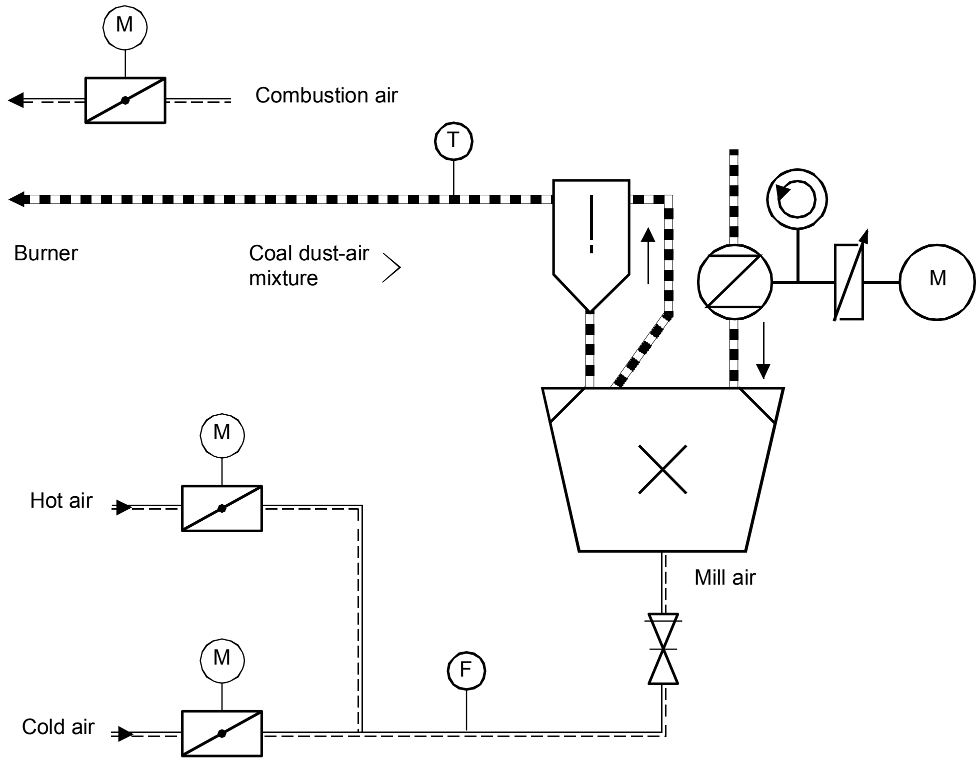
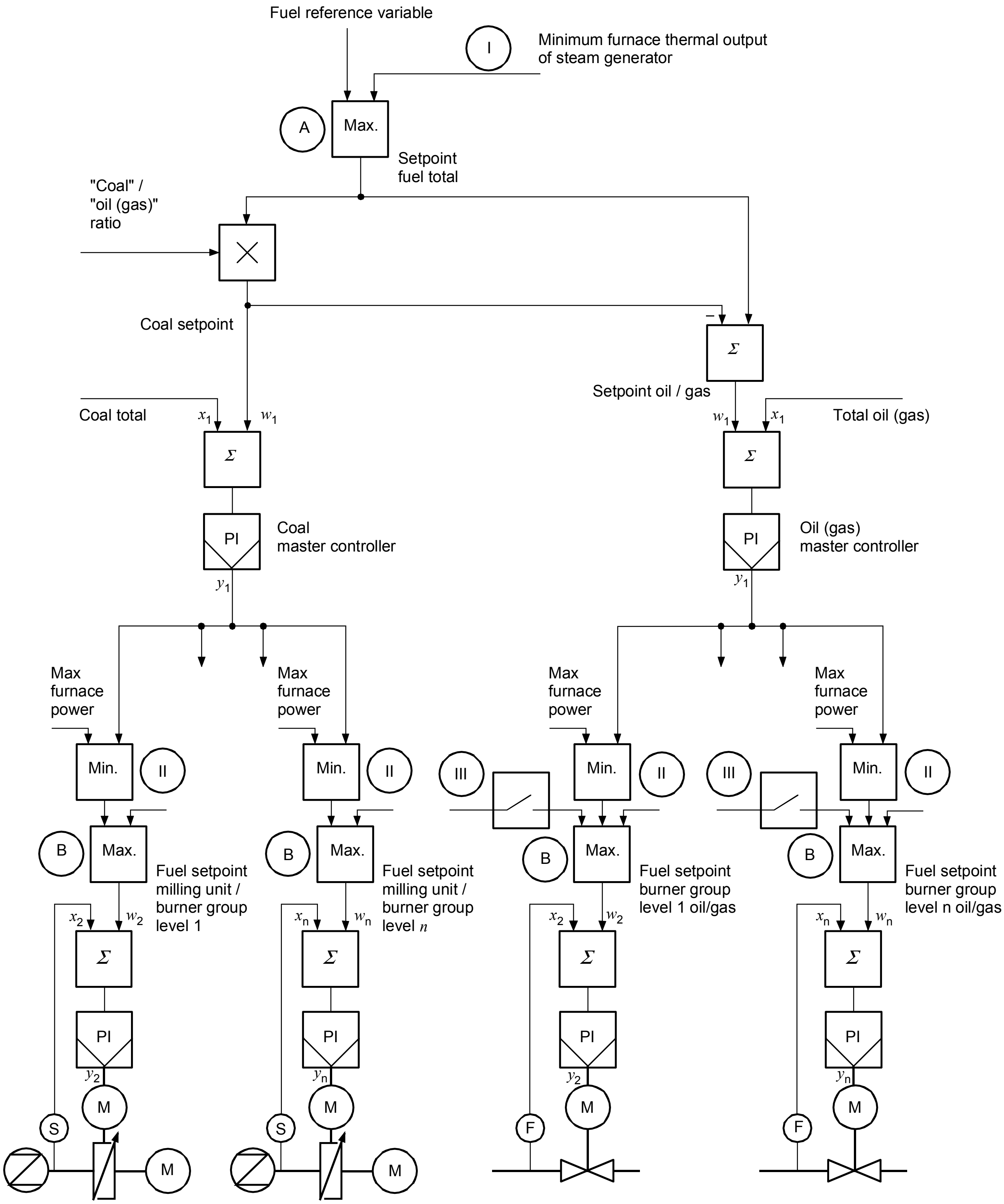


Figure F.1– Plant connection diagram of a milling unit



I Minimum furnace thermal power of steam generator

II Minimum furnace thermal power of milling unit/burner group

II Minimum furnace thermal power of ignition coal burners

A Limiting of fuel reference variable

B Limiting of fuel guidance signals to the milling units/burner groups

Figure F.2 – General plan of limiting control of minimum furnace thermal power

F.2 Description of the control structure

The construction of the control structure is shown in Figure F.2. The fuel reference variable which comes from the superimposed unit control acts on the master controller of the individual fuel types. Upper and lower limits are operative within the control structure. This example deals with the lower load limit of the furnace. The fuel sum set point is divided, according to an adjustable ratio, into a coal sum set point and an oil/gas sum set point. The output signal of the coal master controller is divided, and forms the fuel set point for the individual burner groups or milling units. This set point has a lower limit for each milling unit. This lower limit represents the minimum furnace thermal power of the burner groups or milling units. The minimum furnace thermal power of the steam generator is dependent on the number of milling units or burner groups in operation and their mutual supporting effect. The minimum furnace thermal power of the steam generator is usually less than the sum of the minimum furnace thermal power of the milling units/burner groups.

F.2.1 Controlled variable

The controlled variable for limiting control of the steam generator is the sum of the fuel flows (coal and oil/gas) as a value for the furnace thermal power. The controlled variable for the limiting control of the individual burner groups/milling units is their associated fuel flow.

The furnace thermal power cannot be assessed accurately in measuring terms, so that the weighted feeder speed is used as a substitute value.

F.2.2 Reference variable

The reference variable of limiting control is the minimum furnace thermal power of the steam generator (signal I on maximum select A in Figure F.2) or, for the milling units, the lower limit values behind the coal master controller (signal II on maximum select B in Figure B.2).

F.2.3 Manipulated variable

The manipulated variables of limiting control for the minimum furnace thermal power of the steam generator are the output values of the coal or oil/gas master controller. They correspond to the fuel reference variables of the subordinate feeder speed or burner group controller. The manipulated variables of limiting control for the minimum furnace thermal power of the individual milling units or burner groups are the positions of the feeder speed actuating devices or the valve positions of the burner group controller.

F.3 Operating behaviour

F.3.1 Start-up

During start-up of a milling unit, the burner combination necessary for ignition is selected manually *or* using a sequence control. Set point III in Figure F.2 sets the required furnace thermal power for ignition of the pulverized coal + flow in the oil/gas control. Figure F.3 shows the typical start-up process of a milling unit. Start-up operation of a milling unit is complete when the minimum furnace thermal power is reached. In order to obtain adequate controllability of the furnace, the set point of the minimum furnace power of the milling unit during start-up is somewhat higher than its specified minimum furnace thermal power.

F.3.2 Shut-down

During shut-down of a milling unit, its firing power is reduced until the limit of the minimum furnace thermal power intervenes, and the coal feeder is then switched off. If additional oil/gas firing or adjacent coal firing is in operation, the milling unit may be blown through using the mill air, and the pulverized coal remaining in the mill may be burnt. Figure F.4 shows a shut-down process, in which the oil firing is in operation.

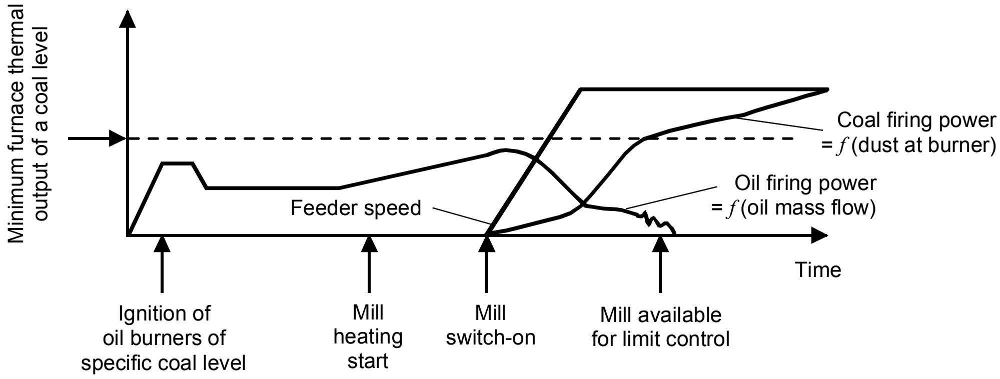


Figure F.3 – Example of start-up of a milling unit with oil support. Oil ignition power (for ignition coal) minimum oil power. The furnace thermal output of the steam generator is met using other burner groups.

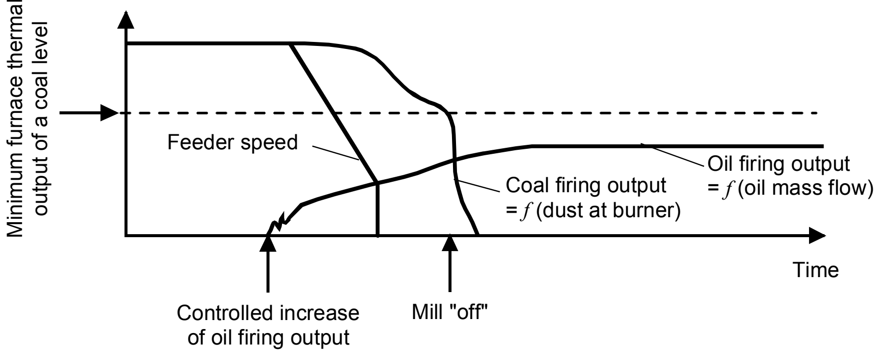


Figure F.4 – Example of shut-down of a milling unit. The minimum furnace thermal output of the steam generator is met using other burner groups

F.3.3 Load changes

In load changes, the furnace thermal power of the steam generator or of a milling unit/burner group may at no time fall below the minimum thermal power.

As can be seen in Figure F.2, the limiting control acts on two levels within the control structure. On the upper level, a maximum select A sets a lower limit for the fuel reference variable, so that no reference variables of the superimposed unit control can become operative which are lower than the minimum furnace thermal power of the individual milling units/burner groups.

F.3.4 Special operating situations

F.3.4.1 Start-up of a milling unit without specific support firing

If a burner group is supplying sufficient firing power, an adjacent burner group with its milling unit may be brought into operation without additional oil/gas support firing in order to guarantee ignition of the coal dust of that adjacent burner group with its milling unit. It is not necessary to switch on set point III (in Figure F.2).

F.3.4.2 Shut-down of a milling unit without supplementary firing

During shut-down of a milling unit without oil or gas firing or adjacent coal firing, its firing output is reduced until the limiting control intervenes. When the feeder and the mill air are switched off, the limiting control of furnace thermal power is no longer operative. The furnace monitoring prevents blow-through of the milling unit.

Annex G

Permissible turbine thermal stresses

G.1 Task

Temperature changes in the steam flowing through the turbine lead to unsteady temperature differences in the turbine components and hence to additional thermal stresses due to obstructed expansion. This is particularly decisive in relation to the thick-walled components of the turbine, such as the following:

– turbine shaft

– housing, inlet section

during start-up and shut-down, and during load changes on the turbogenerator set.

To obtain the optimum loading and unloading speed of the turbogenerator, the thermal stresses are recorded by means of temperature measurements and compared with the permissible stress; the result has a limiting effect on turbine control in the event of the stress allowance, i.e. the difference between permissible and actual stress, reaching zero at the point recognized as critical.

G.2 Description of the control systems

G.2.1 Controlled variable: thermal stress (indirectly recorded)

The thermal stresses cannot be measured directly; they can, however, be determined approximately from the temperature difference between

– surface temperature, and

– temperature in the centre of the component.

A direct temperature measurement on the rotor, as a rotating component, is not operationally possible. Instead of the surface temperature of the rotor, a substitute temperature is measured at a point with a steam stress equal to that of the rotor. The relationships relating to steam/metal heat flux and heat transmission can be taken into consideration in particular by using a specially formulated substitute temperature measuring point.

The corresponding temperatures at the surface and in the shaft of the rotor ($\vartheta_{\mathrm{i,rotor}}$) can be calculated from the substitute temperature (ϑ_{sub}), giving the decisive temperature differences ($\Delta\vartheta_{\mathrm{i,rotor}}$) for the thermal stresses (σ) :

$$\vartheta_{\mathrm{sub}} \rightarrow \vartheta_{\mathrm{i,rotor}} \rightarrow \Delta\vartheta_{\mathrm{i,rotor}}$$

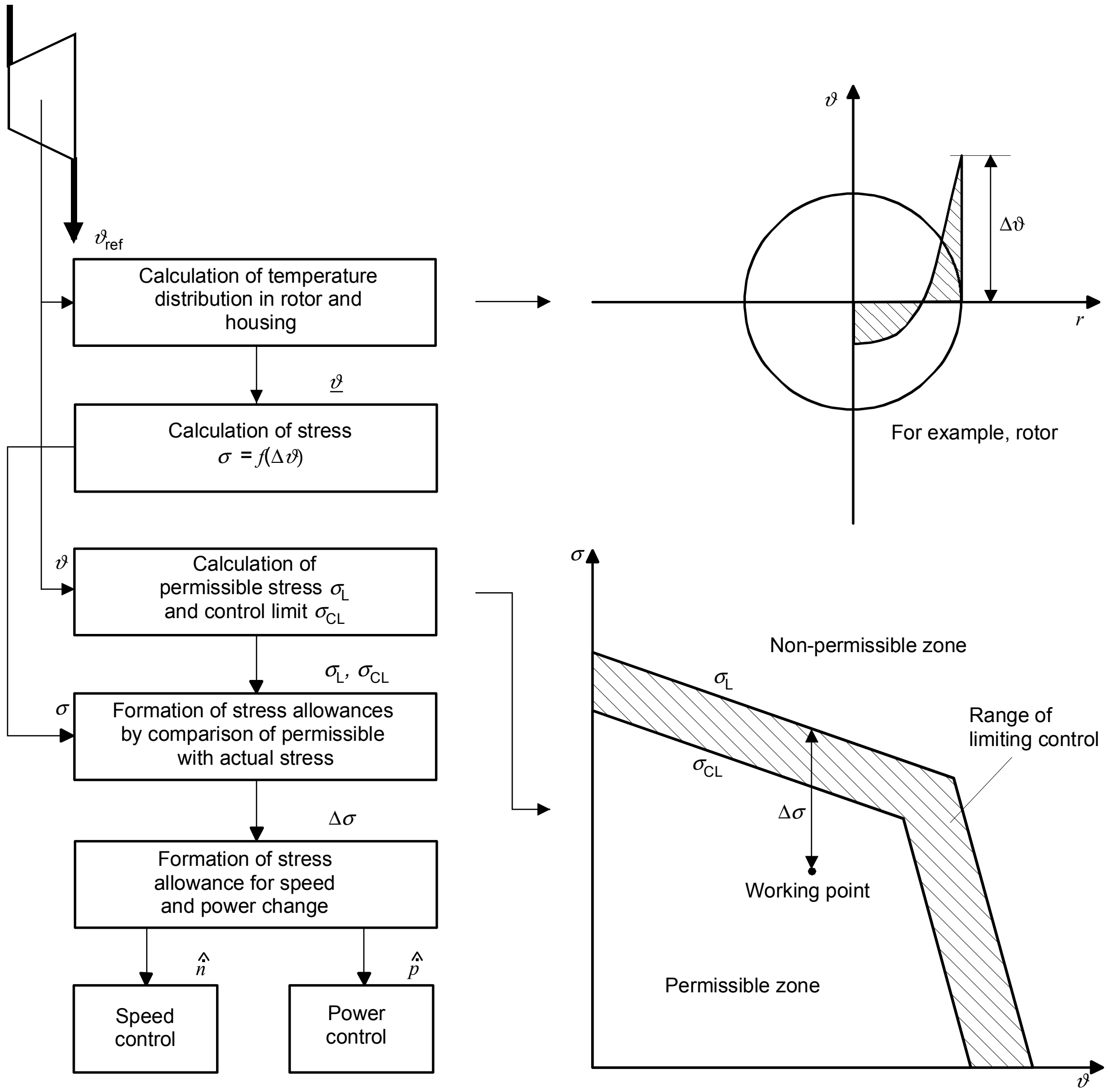


Figure G.1 – Formation of stress allowance

The thermal stresses determined in this way are then combined with the mechanical basic stresses, which arise principally due to internal pressure (housing) and centrifugal forte (rotor), to give a comparative stress, which represents the stress equivalent of the multi-axis state of stresses. Figure G.1 shows an overview of the instrumentation and control system necessary for determining stresses.

The temperature differences can be measured directly on the other highly-stresses components, such as turbine housing and valve housing, should this be required because of the design of the components.

$$\Delta\vartheta_i \text{housing} \rightarrow \sigma$$

Depending on the design and operating state of the turbine, the point at which the highest stress is to be expected varies – for example, rotor or inlet section of the high-pressure or medium-pressure housing. This point can be determined in advance by means of calculations or measurements, so that the measurement can usually be limited to a single point with the highest stress in both the HP and IP parts of the turbine. The stress calculated for this point, as a decisive controlled variable, thus adequately covers all other points. However, a greater number of measuring points or components to be monitored may also be established, from which the most highly stressed component is then determined continuously by means of a selection circuit (minimum select of allowances).

G.2.2 Reference variable: permissible stress

The reference variable for limiting control is the permissible stress on the material used at the prevailing temperature. In accordance with Figure G.1, the yield point ($\sigma_{0.2}$) is decisive as a reference curve in the lower temperature range, with the creep limit decisive in the upper temperature range. The controlled limit is established at a certain distance from this reference curve.

G.2.3 Manipulated variable

Position of the HP governor valves and the intercept valves.

G.3 Operating behaviour

G.3.1 Start-up

If a limiting controller intervenes during speed start-up, it acts to limit the rate of change of the speed set point, if the allowance becomes too small. Correspondingly, the rate of change or even the speed set point itself is then reduced. Further start-up of the turbo group after synchronizing takes place as described in G.3.3.

G.3.2 Shut-down

Outside power operation of the turbine, intervention of the limiting control is neither useful nor appropriate. The turbine is usually run cold and uncontrolled after separation from the network.

G.3.3 Load change

The limiting controller acts on the rate of change of the power set point and, where applicable, on the power set point.

Distinction should be made between two cases here:

– power increase: if the allowance becomes small, the rate of change is first of all;
– reduced gradually to zero: if the allowance becomes negative, the turbine is disengaged;
– power reduction: if the allowance becomes small, the rate of change is reduced gradually to zero.

In the case of turbines with bypass devices, a largely mutually independent loading of the HP- and IP-turbine in accordance with the thermal stress is possible until this device is closed. The manipulated variable for the intercept valves, with corresponding stress on the IP turbine, is limited by the associated allowance of the IP turbine, while the HP turbine can be further loaded if a corresponding allowance is available.

G.4 Supplementary information

In the event of a malfunction, a warning occurs and the speed and power set-point guidance is automatically switched to manual to prevent turbine trip.

The calculated actual stresses may, in addition, be used for continuous lifetime monitoring (life counter).

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