THE WAY OF DISTRICT HEATING OUTPUT CONTROL BY MEANS OF HYDROTHERMAL POWER SYSTEMS

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Abstract: The paper deals with brief description of **three modifications** of the way of control of hot-water piping heat output at simultaneous operation of qualitative and also quantitative parts of control. The separate modifications are as follows:
1. Qualitative – quantitative way of control of hot-water piping heat output using prediction of the course of daily heat supply diagram in district heating systems.
2. Adaptation of qualitative – quantitative way of heat supply control for the case of using part of the piping for heat accumulation.
3. Algorithm of qualitative – quantitative way of control of hot-water piping output with using hot-water boilers as heat sources.
Modifications of the way of control are different due to possibility of implementation into specific conditions in separate localities of district heating systems.

Keywords: district heating, control algorithms, control applications, transport delay, prediction

1. DEFINITION OF THE PROBLEM

District heating system has to ensure supply of energy to all heat consumers in quantity according to their requirements variable in time. Energy supply has always to comply with prescribed quality index (Reetz and Halmdienst, 2002), (Linderberger and Bartels, 2002). In case of hot-water piping it means to maintain prescribed temperature of hot water in intake piping.
Algorithm of so called qualitative-quantitative method of control using prediction of the course of heat supply daily diagram in hot-water systems of district heating enables to eliminate influence of transport delay between the source of heat and consumption of heat by relatively concentrated consumers. Transport delay depends on the speed of flow of heat-carrying medium (hot water) and on the length of feeder piping. The new method of hot-water piping output control consists in simultaneous and continuous acting of two manipulated variables influencing transferred heat output and in utilization of required heat output prediction in the specific locality. The newly designed method of control was considered for a specific case when the transport delay was supposed to be in the range of six up to twelve hours depending on consumed heat output by all consumers.
The following three methods of application of qualitative-quantitative method of hot-water piping output control are elaborated at present namely according to technologic equipment of the source of heat.
I Basic method – it is created for the case of heat supply from the exchanger at power and heating plant as the source of heat – the principle:
Qualitative-quantitative method of control of hot-water piping heat output using prediction of the course of heat supply daily diagram in district heating systems.

It is created for the case of heat supply from the exchanger at power and heating plant at the source of heat. Technologic scheme is presented on Fig.1. It enables to eliminate the influence of transport delay between the source of heat and relatively concentrated heat consumption of all consumers.

II Modification of the basic method:

<u>*Adaptation of qualitative-quantitative method of control of heat supply by hot-water piping for the case using part of the piping for heat accumulation.*</u>

The method of control is created for the case when part of the feeder piping can be used for heat accumulation and enables to eliminate influence of transport delay between the source of heat and relatively concentrated heat consumption by all consumers. At combined production of heat and electric energy it enables to use heat accumulation for heat supply for combined heat and power purposes aside from the time interval of peak supply of electric energy. It is created for the case of heat supply from power and heating plant exchanger at the source of heat but with the configuration according to Fig. 3.

III Modification when grate hot-water boilers are sources of heat:

<u>*Algorithm of qualitative-quantitative method of output control with grate hot-water boilers as sources of heat.*</u>

The algorithm enables the method of control of technological string "production – transport+ distribution" of heat in radial or circular hot-water network. It enables to eliminate the influence of transport delay between the source of heat (hot-water grate boilers) and relatively concentrated heat consumption by all consumers (see Fig. 4).

2. THE PRINCIPLE OF CONTROL METHOD

Algorithm of so called qualitative-quantitative method of control with utilization of prediction of the course of heat supply daily diagram in hot-water systems of district heating enables to eliminate the influence of transport delay between power and heating exchanger at the source of heat and relatively concentrated heat consumption by all consumers (Balátě, 2003). The transport delay depends on the speed of flow of heat-carrying medium (hot water) and on the length of feeder piping. *The new method of output control of hot-water piping consists* ***in simultaneous and continuous acting of two manipulated variables*** *influencing transferred heat output and in utilization of required heat output prediction in the specific locality.* The new designed method of control was considered for a specific case when the transport delay was supposed to be in the range of six up to fourteen hours depending on consumed heat output by consumers.

The designed method is a solution of heat output control method at the source of heat.

The present common method of heat output control of heat supply by hot-water piping utilizes usually dependence on water temperature in intake piping of the heat feeder or also even dependence on outdoor air temperature. Two manipulated variables are available for the control of hot-water piping heat output from the source of heat:

- the change of water temperature difference in intake and return piping of hot-water piping realized in practice by changing heat input at intake into power and heating plant exchanger, so called qualitative method of heat output control;
- the change of mass flow of hot-water by means of changing speed of circulating pump, so called quantitative method of heat output control.

The above mentioned manipulated variables are usually used as separately acting, namely only one of them. If both are used it would be a case when qualitative method of control is the main method of control and quantitative method is used by starting and stopping pumps with different transported mass flow. These quantitative changes have been used once at change of season (summer, transient season, winter). For this purpose usually two or three sizes of circulating pumps have been used.

Disadvantage of the described methods of control is the fact that they do not cover completely dynamic properties of the controlled plant. Transport delay in the intake branch of heat feeder and delay of inertial members of power and heating plant exchanger are omitted. If the output consumed in some place of the hot-water network changes, then the corresponding output of sources (production) controlled by the classic qualitative method adjusts itself though with considerable delay even if there occurred self-controlled change of hot-water mass flow due to self-controlling properties of static characteristic of transport pump caused by the change of operating point of the pump.

The change of heat output consumption is realized by acting of autonomous controllers of temperature in secondary networks of consumers´ transfer stations. Thus some of the requirements on the prescribed quality indexes of heat-carrying medium are not fulfilled.

2.1 Analysis of dynamic properties of the hot-water piping.

Technologic scheme of hot-water piping equipment is principally presented on Fig.1. On the displayed case the circulating (transport) pump is included at the end of return piping before the exchange station.

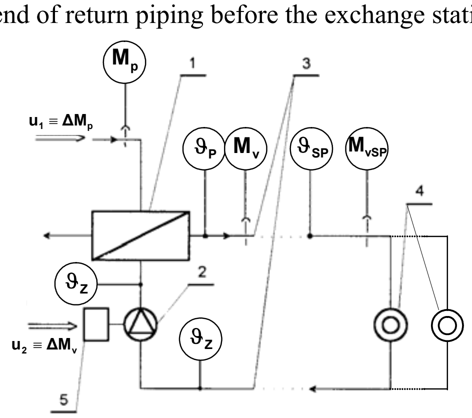

Fig.1 Principal scheme of hot-water piping

Heat output is supplied according to the following relation:

$$P_T = M_v \cdot c \cdot \Delta\vartheta \qquad (1)$$

Quantitative metod of control ↑ ↑ Qualitative metod of control

where: P_T *[W]* is heat output of hot-water piping, M_v*[kg.s^{-1}]* is mass flow of heat-carying medium, $\Delta\vartheta$*[°C]* is temperature difference, c *[J.kg^{-1}.K^{-1}]* is specific heat kapacity.

Behaviour of controlled plant at qualitative method of control. At qualitative method of control the hot-water piping behaves as a proportional system with inertia of higher grade with transport delay, expressed by transfer function (2)

$$G_v^{kval}(s) = \frac{\Delta\Theta_{SP}(s)}{\Delta M_p(s)} = \frac{k^{kval}}{1 + T_1 s + T_2^2 s^2 + T_3^3 s^3} \cdot e^{-sT_d} \qquad (2)$$

where: T_1, T_2 and T_3 are parameters of transfer function describing the behaviour of heat exchanger situated in heat exchange station, T_d – transport delay.

Behaviour of controlled plant at quantitative method of control. Quantitative method of control realizes the change of circulating water mass flow by converter of speed of circulating pump and thus also the change of supplied heat output (1). It includes inertia of speed converter and contains also a time constant of piping, which affects the time necessary for acceleration or possibly deceleration of circulating mass of incompressible heat carrying medium. The hot-water piping itself behaves as a proportional system without inertia. The specified properties can be expressed by transfer function $G_S^{kvant}(s)$

$$u_2 \equiv G_s^{kvant}(s) = \frac{\Delta M_{vSP}(s)}{\Delta M_v(s)} = \frac{k^{kvant}}{1 + T_1' s + T_2'^2 s^2} \cdot \frac{1}{1 + T_3' s} \doteq 1 \qquad (3)$$

where inertia time parameters of speed converters T_1' and T_2' are defined by the kind of converter (hydraulic clutch, electric speed-changing device), time constant T_3' is defined by the length of piping, speed of heat-carrying medium and transport height of circulating pump. They are generally much smaller (seconds, tens of seconds) than time parameters in the relation (2) i.e. than time constants of heat exchanger in power and heating plant (tens of minutes). T_3' is the time which hot-water needs for achievement the speed c_{max} from *zero* speed. This speed corresponds to maximum mass flow M_{vmax} by acting of the transport height H_{max} of the pump.

2.2 Elimination of transport delay at heat output control of hot-water piping.

It is possible to eliminate influence of transport delay at control of heat output of hot-water feeder **by simultaneous and uninterrupted control by two manipulated variables.** This algorithm is shown on the Fig.2

Key to Fig.2: c- specific heat capacity, l- length of intake branch of heat feeder, RT- real time (time in which manipulated variable of qualitative method of control is acting on exchanger in power and heating plant), S- cross section of intake branch of feeder, T- time in which acting of manipulated variable of quantitative method of control shows itself at locally concentrated consumers, T_d - transport delay, T_d^p - presupposed transport delay, T_{pr}- time advance, T_{prech}- time of transition of exchanger in power and heating plant at action of manipulated variable, T_{VZ} - period of sampling (approx. 15 minutes), M_v- mass flow of circulating water, $M_{v,RT}^s$ - real mass flow of circulating water in time RT, $M_{v,T}^s$ - real mass flow of circulating water in time T, P_T - heat output of hot-water piping, P_T^p - presupposed heat output read from

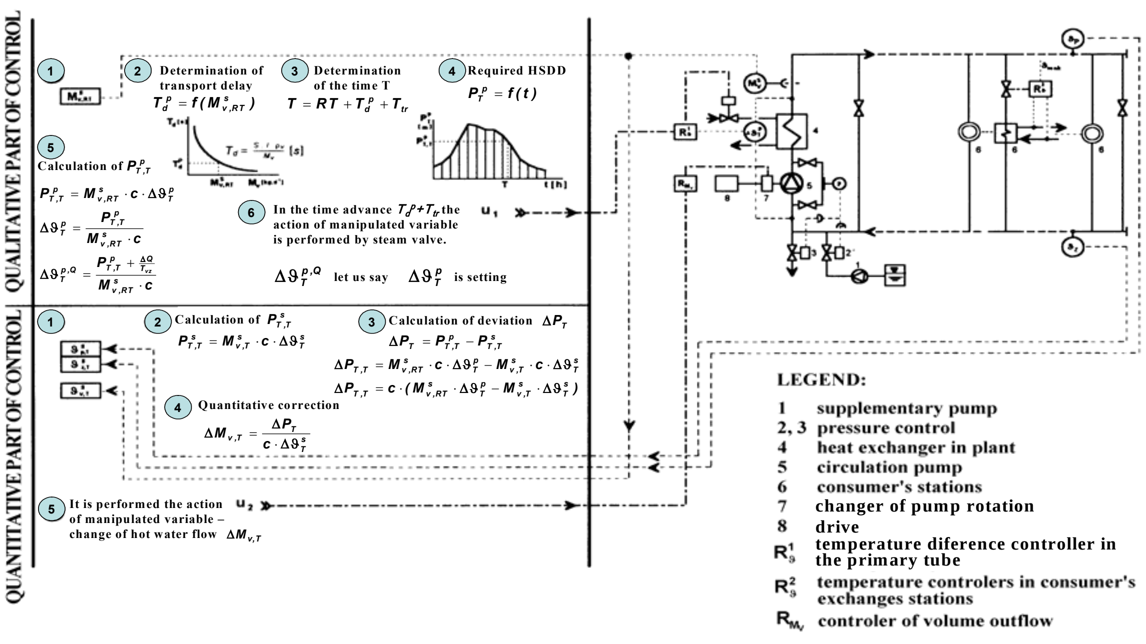

Fig. 2 Algorithm of qualitative-quantitative method of control of heat supply by heat supply by hot-water piping

predicted daily diagram of heat supply *(DDHS)*, $P^p_{T,T}$ - presupposed heat output in time *T*, $P^s_{T,T}$ - real measured (calculated) heat output in time T, $\vartheta^s_{P,T}$ - real temperature in intake branch of feeder at consumers in time *T*, $\vartheta^s_{Z,T}$ - real temperature in return branch of feeder at consumers in time *T*, $\Delta P_{T,T}$ - deviation between presupposed and real consumed heat output in time *T*, $\Delta M_{v,T}$- quantitative correction, i.e. change of mass flow of circulating water, ΔQ- change of heat content in intake branch of feeder caused by quantitative correction, $\Delta\vartheta^s_T$ - real temperature difference at consumers in time *T*, $\Delta\vartheta^p_T$ - presupposed temperature difference on exchanger in power and heating plant in time *T* which is calculated from $P^p_{T,T}$ and which is manipulated variable of qualitative method of control, $\Delta\vartheta^{p,Q}_T$ - presupposed temperature difference on exchanger in power and heating plant in time *T* which includes correction of heat content in intake branch of feeder ΔQ. It is necessary to bring in this heat or possibly to decrease heat admission by it in dependence on sense (sign) of quantitative correction $\Delta M_{v,T}$, ρ_v- specific mass of circulating water in intake branch of feeder.

3. MODIFICATION OF THE ALGORITHM OF CONTROL AT UTILIZATION OF A PART OF HEAT FEEDER FOR HEAT ACCUMULATION

It is necessary to adapt the above described algorithm at possibility of utilizing a part of piping for heat accumulation in intake branch of heat feeder for the purpose of utilizing economically justified combined production of electric energy and heat in power and heating plant. In this case for qualitative part of control it is necessary to utilize mixing of hot water from piping determined for heat accumulation and cooled water in return branch of hot-water piping (see Fig. 3).
Presupposed heat output in time T (see analogically to the key to Fig. 2) is

$$P^p_T = M_{v,II,RT} \cdot c \cdot \Delta\vartheta^p_T \qquad (4)$$

$$\boxed{M_{v,II,RT} = f(\Delta p_{min})} \qquad \boxed{\begin{aligned}\Delta\vartheta^p_T &= \vartheta_{P,II,T} - \vartheta_{Z,II,T} \\ \Delta\vartheta^p_T &= f\left(M^{SMES,\,p}_{v,RT}\right)\end{aligned}}$$

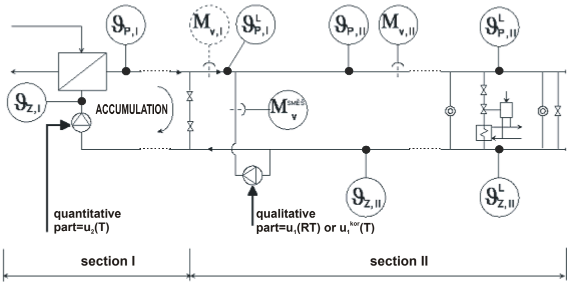

Fig. 3 Principal scheme of heat output control of hot-water piping by mixing

4. ALGORITHM OF QUALITATIVE – QUANTITATIVE METHOD OF OUTPUT CONTROL OF HOT-WATER PIPING WITH HOT-WATER BOILERS AS HEAT SOURCES

The algorithm enables control method of technological string **production – transport+ distribution of heat** in radial or circular hot-water network (Balátě, *et al.,* 2003).
The philosophy of the method of control utilizes prediction (of part) of daily diagram of heat supply in particular locality (DDHS) *at simultaneous and continuous acting of two manipulated variable* i.e. **qualitative part of control** (*by controlling temperature gradient at intake and return branch of hot-water piping or possibly at hot-water boiler*) and **quantitative part of control** (*by controlling mass flow of heat carrying medium – hot water* by means of circulating (transport) pumps) so that it would be enabled **to eliminate transport delay** of really consumed heat output by consumers from really produced heat output at hot-water boiler, which has been produced in advance. The presented method of control enables supply of heat output with variable temperature at intake into hot-water network in dependence on presupposed heat consumption. Prediction of the course of DDHS is based on the analysis of development history of time series (Box – Jenkins method).
Sequence (algorithm) of qualitative – quantitative method of output control of hot-water piping with hot-water grate boilers as heat sources is described by realization of the following steps according to Figure 4:
1. Calculation of prediction of DDHS
2. Covering of predicted heat supply daily diagram – produced heat output $P^{p,DOD}_T$, selection of operational assembly of collaborating boiler houses and determination of separate boilers of these boiler houses for separate time periods of the daily diagram of heat supply in the course of 24 hours. It concerns 4 time periods: $u = 1,2,3,4$.
3. Optimization of operation of sources for $P^{p,DOD,u}_{T,RT}$ in current time period of DDHS (time period is denominated by *u*)
4. Dividing the load into collaborating sources:
Qualitative part of control: $u_{1,RT}$
5. Measurement (or possibly completed by calculation) of immediate heat consumption i.e. in time *T*: $\sum P^{spotř}_{T,T}$
6. Determination of working point of hot-water network $\Delta p_{čerp}=f(\Delta p^{ref})$ where Δp^{ref} is pressure difference in reference point of circular hot-water network.
7. Calculation of transport delay in reference point hot-water network $T^{ref}_{d,T}$ in time *T*.
8. Calculation of time back-prediction (i.e. prediction to the past), i.e. output of production units in time *RT*.
9. Quantitative part of control: $u_{2,T}$
It concerns correction of mass flow of hot water in time *T* at circulating pumps $\Delta M_{v,T}$:

10. Correction of qualitative part of control i.e. of boilers output Δu_I in time T (correction of original output adjustment $u_{I,RT}$).

Calculation of individual steps is not so complicated but it is assumed right knowledge of function (operation) and behaviour of technolog. equipments.

Key to Fig. 4: c – specific heat capacity, *l* – length of intake branch of feeder in power and heating plant, *RT* – real time (time in which manipulated variable of qualitative method of control at hot-water boiler is acting), *S* – cross section of intake branch of feeder, *T* – time in which acting of manipulated variable of qualitative method of control shows itself at locally concentrated consumers, T_d – transport delay, $T_{d,T}^{ref}$ – transport delay at reference point of hot-water network in time *T*, Δt^Z – time of prediction to the past (time by which it is necessary to change manipulated variable of boilers in advance so that change of heat output of hot-water boiler by qualitative method of control shows itself in time *T*), t_K – transition time of output control of boiler, $t_{k\ st\check{r}ed}$ – medium transition time of output control of the whole boiler house, T_{VZ} – period of sampling, $P_T^{p,DOD}$ – prediction of daily diagram of (produced) heat output supply – DDHS, *u* – number of the time period of DDHS, $P_{T,RT}^{p,DOD,u}$ – presupposed supplied (produced) heat output in time *RT* and in time period *No. u*, $P_{T,Vj,RT}^{u}$ – heat output of boiler house *No. j* in time *RT* in time period *No. u*, $P_{T,Kj.i}$ – heat output of hot-water boiler *No. i* in heating plant *No. j*, $\Delta\vartheta = \vartheta_P - \vartheta_Z$ – temperature difference in intake ϑ_P and return ϑ_Z piping of hot-water network, $M_{pol,\ Vj}$ – heat output in fuel of heating plant *No. j*, $\Delta\vartheta_{RT}^{p}$ – temperature difference predicted in time *RT* corresponding to predicted produced output of boilers, $\sum P_{T,T}^{spot\check{r}}$ – heat output consumed by all consumers in time *RT*, $\Delta p^{\check{c}erp}$ – pressure difference of circulating pump in hot-water network, $\Delta M_{V,\ T}$ – correction of mass flow of hot-water in time *T*, $P_{T,Vj,RT}^{p}$ – predicted heat output of hot-water boilers of boiler house *No. j* in time *RT*, $P_{T,RT}^{p,DOD}$ – predicted heat output produced in time *RT*, $P_{T,Kj.i,RT}^{p}$ – predicted heat output of boiler *No. i* of boiler house *No. Kj*, $M_{v,RT}^{p}$ – predicted mass flow in time *RT*, $\Delta\vartheta_T^{p,Q}$ – correction of heat input in delivered fuel at hot-water boiler in time *T* including correction of heat content in intake branch of feeder and at the same time also in fuel on grate of hot-water boiler, ϑ_P^{SP} – temperature of hot water in intake piping in consumers' network, ϑ_Z^{SP} – temperature of hot water in return piping in consumers' network.

5. BENEFITS

- minimization of primary fuel consumption by adjustment – control of heat output of sources on the base of knowledge of immediate heat consumption by consumers,
- minimization of pumping work of circulating pumps for transport of hot water at hot-water piping with continuous control $\Delta p^{\check{c}erp.\ min}$,
- minimization of heat losses of hot-water piping with continuous control of temperature in feeder intake branch ϑ_p in dependence on predicted course of DDHS.

6. FINAL SUMMARY

Three presented ways of application of qualitative-quantitative method of output control of hot-water piping generalize the original idea described in chapter 1 **Qualitative-quantitative method of heat output control of hot-water piping with utilization of prediction of the course of heat supply daily diagram in district heating systems.**

This access to solution of control, so called ADVANCED CONTROL ALGORITHMS, is quite unique in the field of district heating. In the course of time further requirements appeared on the algorithm namely according to **technological equipment of the source of heat**. Thus the modification II came into being which enables to utilize parts of intake piping of feeder for **accumulation of heat**.

Modification III was initiated by the requirement of application of qualitative-quantitative method of heat output control of hot-water piping on hot-water system of district heating **where hot-water boiler houses are sources of heat** and therefore on the base of good equipment of hot-water system by information system for measuring heat at consumers it is possible to control the technological string **production – transport+distribution of heat as the whole**.

It is the matter of complex access to solution of given task and the solution is original and quite unique.

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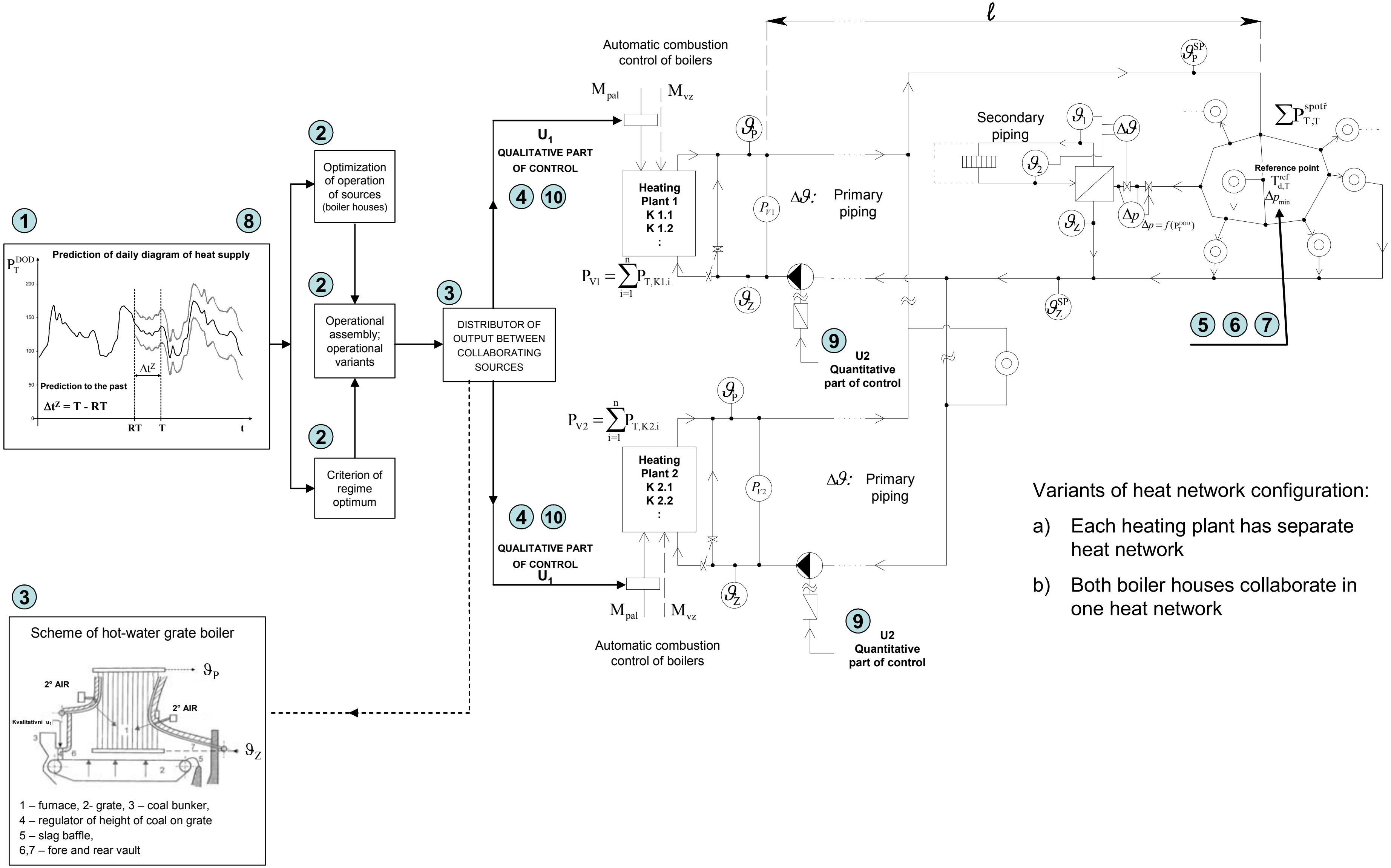

Fig. 4 Algorithm of qualitative – quantitative method of output control of hot-water piping with hot-water grate boilers as heat sources