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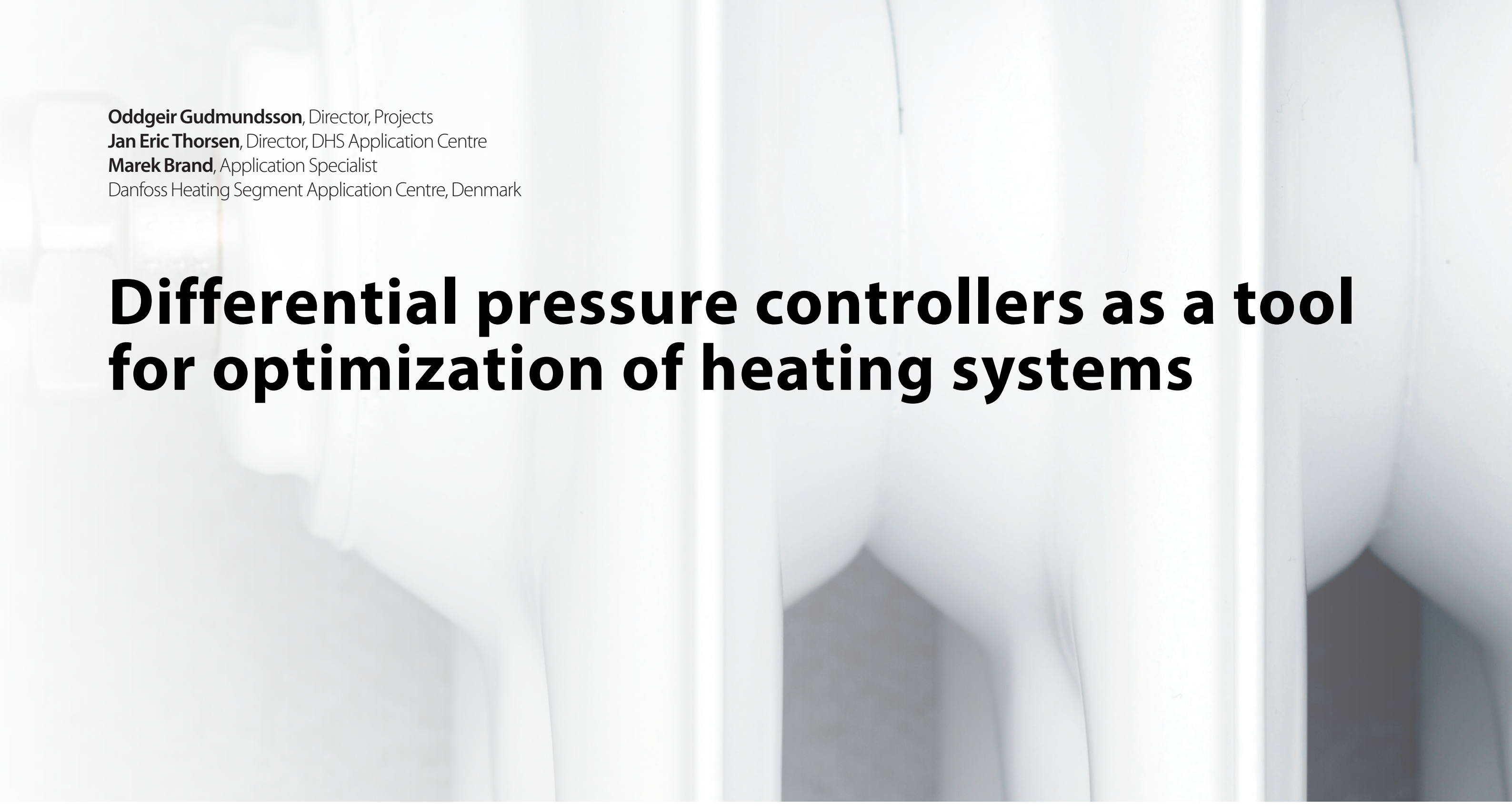

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Differential pressure controllers as a tool for optimization of heating systems

In general district heating (DH) systems are designed with a main pump at the heat source. The role of the main pump is to provide sufficient pressure (head) to move the water from the plant to the consumers, operate the consumer interfaces (substations) and back to the plant. The head is therefore used to compensate for the frictional losses when the water moves through the pipe network and the substations. In general the required pressure is determined such that the most critical consumer has just enough pressure difference between the supply and the return pipe line available to operate the substation. The control strategy of the main pump is to ensure the critical consumer has this certain minimum differential pressure. This is achieved by monitoring the available differential pressure at the critical consumer. This implies that all other consumers located closer to the heat source will have higher differential pressure available to operate their substation, to compensate for the higher differential pressure at these consumers the control valves operate with less opening degree. The side effect of this is reduced control stability of the substation.

Additionally, as all modern district heating systems are based on variable flow in the network reflecting the actual demand at a certain point of time and at a certain location there will inevitably be pressure variations in the distribution network. These variations are mainly due to varying heat consumption by the consumers. The effect of the varying network pressure is that the available differential pressure across the consumer substation can vary significantly over a short period of time and hence alter the condition the control equipment is operating under. These pressure variations can have, if not considered during design, negative impact on the controllability of the substation, leading to discomfort for the consumers and reduced lifetime of the control equipment. In order to achieve stable and accurate control it is therefore recommended to apply differential pressure controllers (dP controller). In fact, one of the preconditions for a well-functioning control of a district heating (DH) network is to have stable differential pressure across the substations in the network.

DIFFERENTIAL PRESSURE CONTROLLERS

Application

DP controllers are mainly used to create a constant differential pressure across the substation, independent of the variation of the differential pressure in the supply net, e.g. due to consumption level of other consumers in the DH system. DP controllers are also used to create a hydronic balance in a network.

The general applications for dP controllers are:

- Control of differential pressure across district heating house substations to ensure hydronic balance
- Pressure and differential pressure control in district heating networks
- Balancing in building space heating and building domestic hot water (DHW) installations

These benefit end-users of the house substation as well as the DH utility company.

End-user advantages

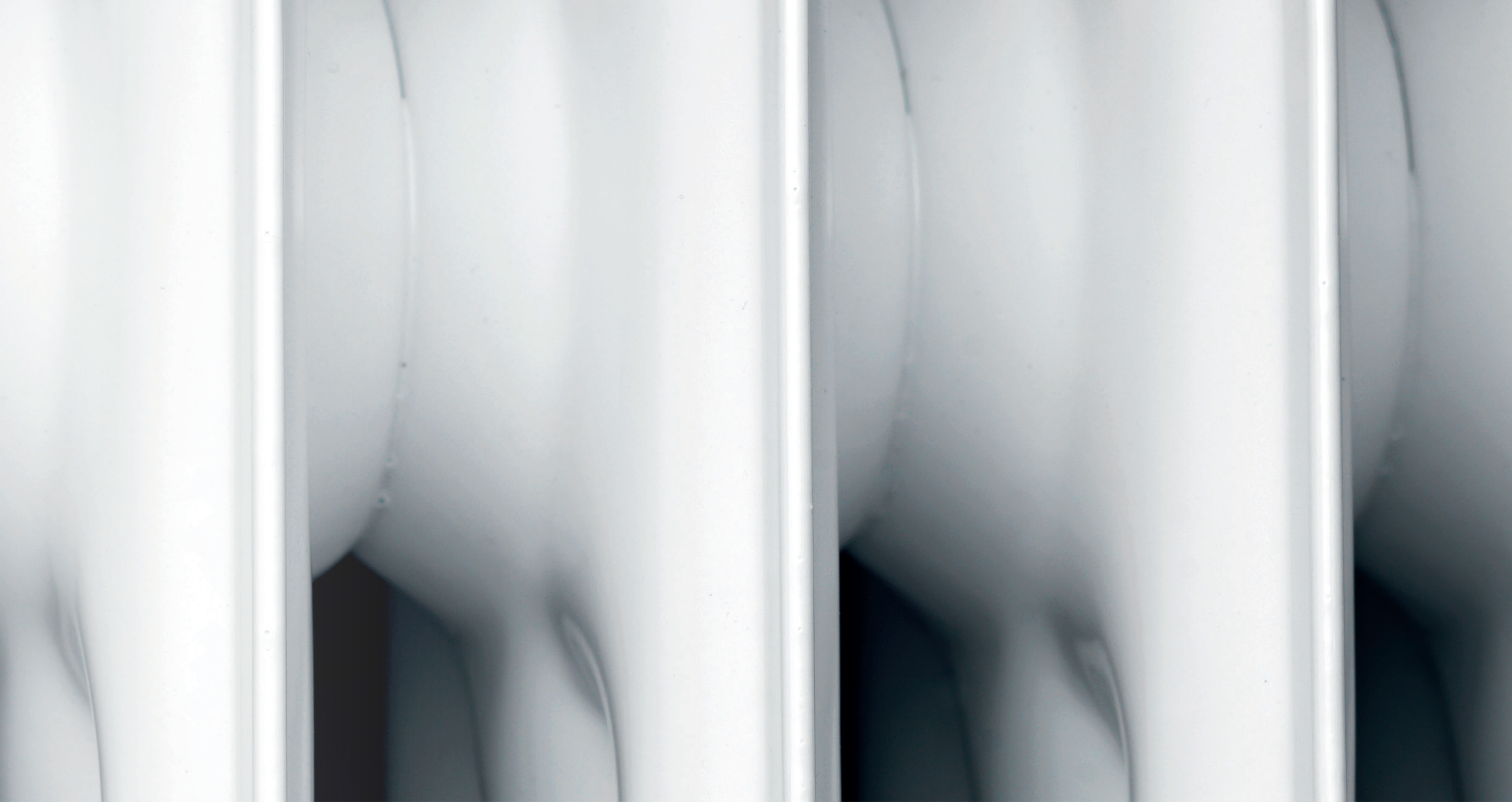
Applying a dP controller enables the exact sizing of the control valve. This again offers improved control conditions for the control valve, which gives the following advantages for the end-user:

- Stabilization of the temperature control. (Better control valve authority and lower system gain range)
- Simple adjustment of the substation
- Prolonged lifetime of the control equipment

DH Utility company advantages

Use of dP controllers in substations and in the district heating network will maintain a hydronic balance in the network. This means:

- Good distribution of water in the supply network at all conditions (all customers get the heat they need in all conditions)
- The designed differential pressure level in the substation is achieved. This will achieve stable control of the substation and consequently reduce risk of pressure or hydronic oscillation in the network
- The optimum operation of the substation will allow for increased temperature difference between the supply and the return line, see [1]
    - Reduced quantity of circulating water in the network (reduced pump electricity consumption for water circulation)
    - Possibilities of either or both decreased supply and return temperatures due to more efficient substation operation



- Reduced network heat losses due to lower operating temperatures
- Each individual substation is independent on network changes whether the distribution network size is increased or reduced. Further on it makes the control independent and efficient in a situation where the energy is supplied from various heat sources at different locations

It is therefore clear that applying dP controllers in the network brings important benefits to the overall network operation. In the following sections the theory and benefits of the dP controller will be explained.

BASICS AND THE BENEFITS OF THE DP CONTROLLER

This section describes the influence a dP controller has on the functioning of a DH substation.

In order to understand the benefits of the dP controller, knowledge of the following topics is essential:

1. Control valve sizing
   1.1. Sizing of a motorized control valve
   1.2. Sizing of a differential pressure controller
   1.3. Control ratio
   1.4. Control valve authority
   1.5. Comfort concerns
2. Commissioning of the substation
3. Hydronic balance in the supply network
   3.1. Flow limitation
   3.2. Accuracy of the flow limitation

1. Control valve sizing

In order to achieve stable temperature control it is important to select the most appropriate control valve, both for space heating as well as for (DHW) applications.

As control valves come in discrete sizes it is important to choose the most appropriate control valve for a given condition. By considering the water as incompressible and having limited property change within the normal DH operating pressure and temperature range the simplest way is to use an control valve capacity equation for a standard condition. In data sheets the control valve capacity k_{vs}, is given for the fully opened control valve under standard condition of 1 bar pressure drop across the control valve and temperature between 5-30°C. The equation for control valve capacity, see Eq. 1, is derived from the Darcy-Weisbach [2] equation which relates the pressure loss to the flow rate of the fluid through a flow channel.

$$k_v = Q/\sqrt{\Delta P_v} \tag{1}$$

Where:

k_v = capacity of the control valve under the given operational conditions (valve position) [m^3/h]
Q = the required flow rate through the control valve [m^3/h]
ΔP_v = differential pressure across the control valve [bar]

The required control valve size is chosen such that the calculated k_v value for the peak demand is as close to, but still lower, than the k_{vs} value of the chosen control valve, where the k_{vs} is the capacity of the control valve fully opened under standard condition.

Equation (1) can be rearranged to calculate the expected water flow through the control valve for a given ΔP:

$$Q = k_v\sqrt{\Delta P_v} \tag{2}$$

and the expected pressure drop across the control valve for a given flow rate:

$$\Delta P_v = (Q/k_v)^2 \tag{3}$$

Further on the ratio

$$k_v/k_{vs} \tag{4}$$

can be used to indicate how much of the control valve stroke is being used for the given k_v value, or in other words how much of the capacity is utilized compared to the maximum capacity.

The following examples are given for sizing of control equipment for a substation supplying both space heating and DHW to a multi-family building, see Figure 2 and Figure 3. Due to analogous calculations the same capacity requirements and primary side cooling are considered. The assumptions are:

- Minimum differential pressure across the substation guaranteed by the DH utility, ΔP_{supply} = 1 bar
- Primary temperature profiles for the substation design:

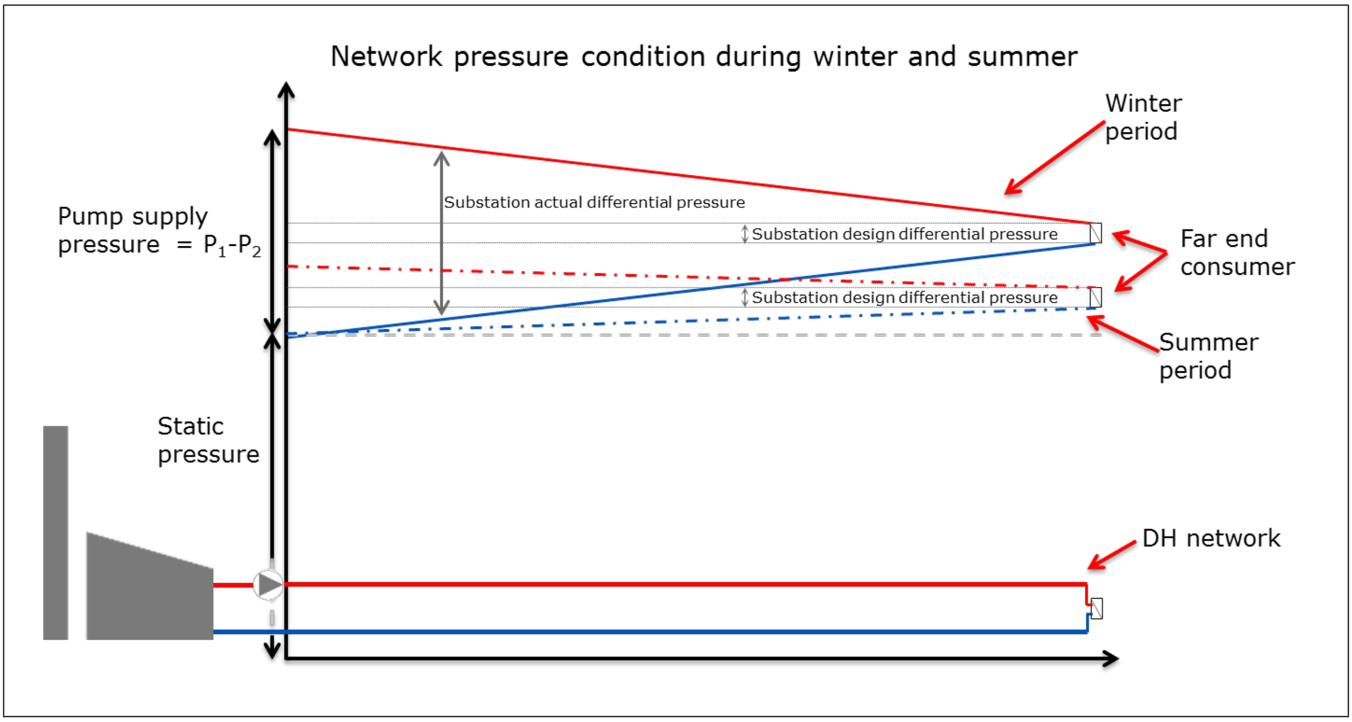


FIGURE 1: Pressure profile in district heating networks during winter and summer

- Heating: Supply of 100°C and return of 50°C
- DHW: Supply of 70°C and return of 20°C

Space heating

- Peak heating demand of 250 kW
- Flow requirements from the DH network given the design condition (winter) is a flow rate of 4.31 m³/h for heating

Domestic hot water

- Peak DHW demand of 250 kW
- Flow requirements from the DH network given design condition (summer) is flow rate of 4.31 m³/h for DHW

To discuss the benefits towards the substation and the district heating system by applying a dP controller, two design examples are calculated. The first example considers heat exchanger control without a dP controller and the second examples considers heat exchanger control with a dP controller.

Here it is important to note that these design conditions are seldom achieved. For example the minimum differential pressure may only be achieved at the most critical consumer, all other consumer will have higher differential pressure due to the network layout principle, as can be seen in Figure 1 which is displaying the typical pressure profile in a district heating network.

Under operation of the DH system there are numerous things that can cause pressure variations in a DH network. These can, among others, be:

- Startup after night set back
- Change in heat consumptions, due to flow changes to the radiators or DHW tapings
- Temperature changes in the network
- Equipment failure

During startup after night set back the valve are fully opened which causes high flow draw off, resulting in increased system pressure and potentially hydronic unbalance in the network if no dP controllers are installed.

1.1 Sizing of a motorized control valve (MCV) without a dP controller

The applications being considered for space heating and DHW preparation, are as shown in Figure 2.

As mentioned above the equation for the control valve capacity, Eq. (1), is used to calculate the minimum required control valve capacity for fulfilling the heating demand. Before the required control valve capacity is calculated, it is needed to know how much differential pressure is required for operating other components in the substation. In this example the only additional components considered are the heat exchanger. However it should be kept in mind that usually there is also heat meter and other auxiliary equipment.

Available min. $\Delta P_{min} = 1$ bar 100 kPa (1 bar)

ΔP_{other} across other equipment 30 kPa (0.3 bar)

Available differential pressure for the control valve $\Delta P_v = \Delta P_{min} - \Delta P_{other}$ is 70 kPa (0.7 bar)

It's important to stress that the available differential pressure for the control valve has been calculated for the design case, however the DH substation is seldom being operated under design condition. Under normal operation the differential pressure will, as mentioned above, vary. Depending on the location in the network it can easily vary by factor 3-6, which will have significant influence on the operation of the control valve. The consequence of the varying differential pressure will be considered in a later section of the paper.

Once the needed flow, Q = 4.31 m³/h, and the minimum available differential pressure for the control valve, $\Delta P_v = 0.7$ bar, has been calculated it is possible to calculate the minimum required k_v value of the MCV using Eq. 1.

$$k_v = \frac{Q}{\sqrt{\Delta P_v}} = \frac{4.31}{\sqrt{0.7}} = 5.15\ m^3/h$$

For this case a control valve of DN25 with a $k_{vs} = 6.3$ m³/h will fit the conditions.

Since the k_{vs} value of the chosen control valve is larger than the required and calculated k_v value the control valve will only use part of its full capacity, which is correlated to the utilization of the stroke. In this particular case it will at design or peak demand only use $k_v/k_{vs} = 5.15 / 6.3 = 82\,\%$ of its maximum capacity. In the main part of the operation time it will operate at a much lower capacity or stroke.

For elaboration, the calculation is repeated for the case of high differential pressure (5 bar) across the substation, representing the same substation just in the proximity of main pump. In this case the pressure drop across the control valve will be 4.7 bars and the required k_v value will be:

$$k_v = \frac{Q}{\sqrt{\Delta P_v}} = \frac{4.31}{\sqrt{4.7}} = 1.99\ \mathrm{m^3/h}$$

Under this condition the chosen control valve would only use $k_v/k_{vs} = 1.99/6.3 = 32\%$ of its maximum capacity, at part load it will be less.

Figure 4 shows how the control valve capacity usage changes with increased differential pressure across the control valve, both in case with and without a dP controller.

1.2 Sizing of a differential pressure controller

As explained above, the condition of the network is seldom as specified for the design condition. This will inevitably affect the operation of the control valves installed in the network. However by installing a dP controller the design condition, regarding differential pressure, can be guaranteed for the control valve at all times.

Following is the example from above, calculated again but now by installing a dP controller as well, see Figure 3.

As before the operational conditions are:

Available min. $\Delta P_{min} = 1$ bar 100 kPa (1 bar)

ΔP_{other} across other equipment 30 kPa (0,3 bar)

Peak flow demand 4,31m³/h

At this stage the maximum differential pressure across the control valve has to be decided, in general it is recommended to have at minimum 50% of the available pressure drop allocated to the control valve and the remaining over the dP controller. In this example the maximum differential pressure across the control valve is chosen to be 60% of 70 kPa, that is $\Delta P_v = 42$ kPa (0.42 bar). By using Eq. (1) the minimum required k_v value can be calculated.

$$k_v = \frac{Q}{\sqrt{\Delta P_v}} = \frac{4.31}{\sqrt{0.42}} = 6.6\ \mathrm{m^3/h}$$

For this case a control valve of DN25 with a $k_{vs} = 8$ m³/h will fit the conditions.

The next step is to choose the dP controller. The dP controller should be chosen such that the maximum stroke utilization of the control valve is achieved. For that it is needed to calculate the pressure drop required to achieve 4.31 m³/h with the valve fully open.

$$\Delta P_v = \left(\frac{Q}{k_{vs}}\right)^2 = \left(\frac{4.31}{8}\right)^2 = 0.29\ \mathrm{bar}$$

The next step is to calculate the available differential pressure for the dP controller

Using Eq. (1) the minimum k_v value for the dP controller can be calculated.

$$k_v = \frac{Q}{\sqrt{\Delta P_{dP}}} = \frac{4.31}{\sqrt{0.41}} = 6.7$$

In this situation a dP controller of DN 25 and a $k_{vs} = 8$ m³/h can be chosen.

The aim of the dP controller will be to keep the differential pressure across the control valve as close to the set point as possible. The dP controller achieves this with a small deviation (X_p deviation, which is a result of the applied proportional control principle for the dP controller) as the differential pressure varies in the distribution network. As an example this particular control valve will have approximately 5 kPa variations across the control valve when the ΔP_{supply} increases from 1 bar to 5 bars, which is practically a stable differential pressure compared to the case when no dP controller is used.

1.3 Benefits of a differential pressure controller

One benefit of the dP controller is that it allows the control valve to practically use its maximum stroke independently on the pressure variations in the distribution network. Figure 4 compares the maximum control valve capacity or stroke usage for a substation with and without a dP controller when the differential pressure across the substation increases from 1 bar to 5 bars. As can be seen from Figure 4, the dP controller allows the control valve to utilize almost the full range of the stroke independently on a) the differential pressure in the distribution network at a given location or b) varying differential pressure across the substation at a given time.

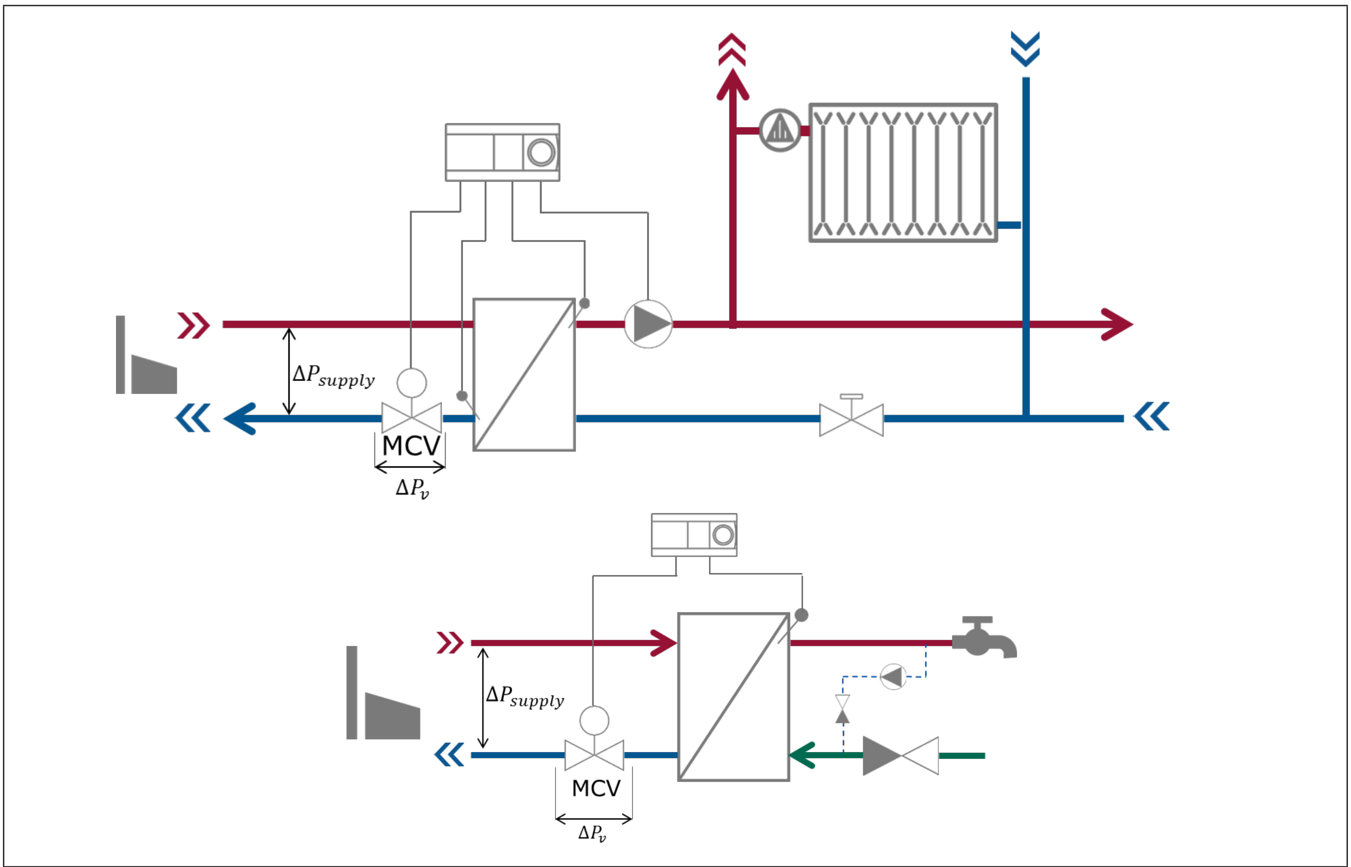


FIGURE 2: Space heating application above and DHW application below. Both applications are controlled by a MCV

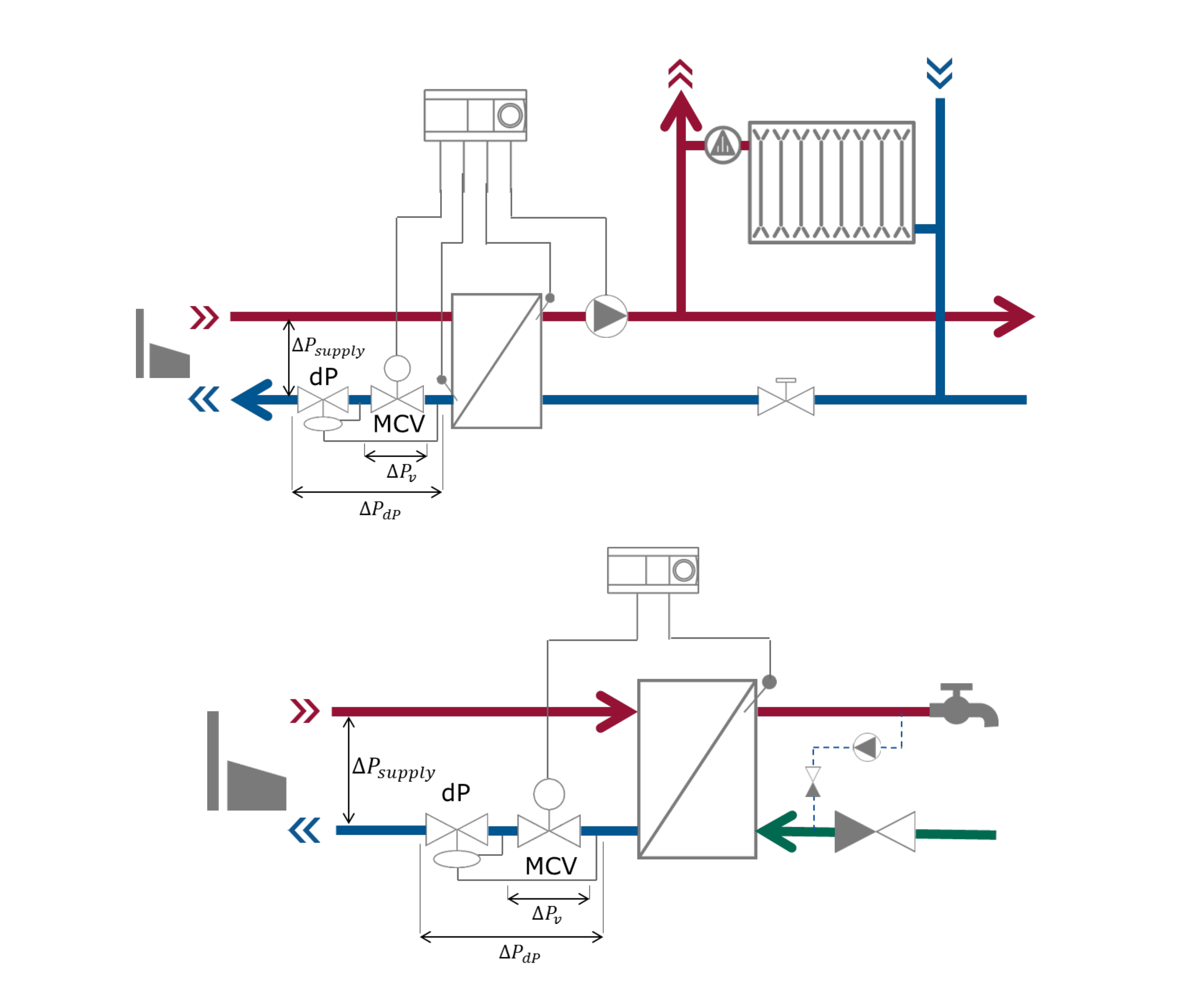


FIGURE 3: Space heating application above and DHW application below. Both applications are controlled by a motorized control valve and a dP controller

The stroke usage in the case of no dP controller is significantly less compared to using a dP controller. If the substation would run under part load at the same time as there is high differential pressure, there is a risk that substations without dP controllers will operate under the minimum recommended control valve capacity and hence risking oscillations. In this analysis it's assumed the minimum control valve capacity is 1,5 % of the maximum valve opening. If the opening is less than the specified minimum opening for stable operation, the risk of oscillations increases. However there are other factors that need to be considered to ensure stable operation such as

- Setting of the PI parameters for the electronic controller
- Type of control valve characteristics
- Control ratio and control valve authority of the control valve

Controller setting

The setting of the control parameters for the electronic controller is critical in regards to avoiding oscillations. The setting can be simplified by selecting a controller with functions such as auto tuning and motor protection [3].

Control valve characteristics

A control valve must have characteristics adapted to the operating actuator and the application. For room heating and DHW systems, a split characteristic will be the optimum choice, see Figure 5. The split characteristic is developed to allow stable temperature and flow control at very low flow rates compared to linear control valves, see [4] and [5].

1.4 Control ratio

The German standard VDI / VDE 2173 states the rules of defining the control ratio of a control valve. The control ratio is defined as the ratio between the k_{vs} and the k_{vr} value of the control valve. The definition of the control ratio R is:

$$R = k_{vs}/k_{vr} \qquad (5)$$

k_{vs} is the maximum capacity of the given control valve, m³/h.

k_{vr} is the lowest capacity of the control valve at which the slope of control characteristic is within 30 % compared to the basic form of the control valve characteristic.

Figure 5 shows an example of a control valve with split characteristic. In the figure the k_{vr} is marked in the lower left corner. It can be seen, as the control valve stroke passes the k_{vr} point it goes on a steep path to zero. This steep path is the important part as it indicates that with small changes in the control valve opening (stroke) a relative large flow change will occur. This indicates the gain in the control loop (flow rate change pr. stroke change) will be relatively high compared to the normal operating range of the control valve. This means the capacity corresponding to the capacity at k_{vr} normally is the lowest degree of opening at which a stable control can be expected.

As a result, the temperature control under low openings, corresponding opening below k_{vr}, becomes more demanding and might cause oscillation of the controlled temperature.

Definition: Effective control ratio.

The effective control ratio is the control ratio of the control valve given for the calculated max k_v value under specific differential pressure across the control valve divided by the k_{vr} of the control valve.

As explained above it is seldom that the available control valves fit exactly to the real situation, hence compromises are required and larger than required control valves are selected. This will reduce the effective control ratio from the theoretical max, as defined in the VDI/VDE 2173 standard. If the differential pressure increases compared to the design condition, it will lead to the control valve to operate on a lower operating capacity, as is shown in Figure 4. This fact will push the upper end of the operating range of the control valve closer to the k_{vr} value and hence reduce the effective control ratio for the given control valve. This can become an issue if the substation is operating at high differential pressure in combination with part load.

Considering the examples above and using the k_{vr} corresponding to the minimum recommended control valve stroke usage, as is shown in Figure 5, the effective control ratio of the control valve is calculated under various differential pressure conditions, see Figure 6.

To ensure good and stable temperature control it is important to have as high control ratio as possible. This can only be achieved if the pressure drop across the control valve is independent of the differential pressure across the substation and this can only be achieved by utilizing a dP controller, as clearly represented in figure 6.

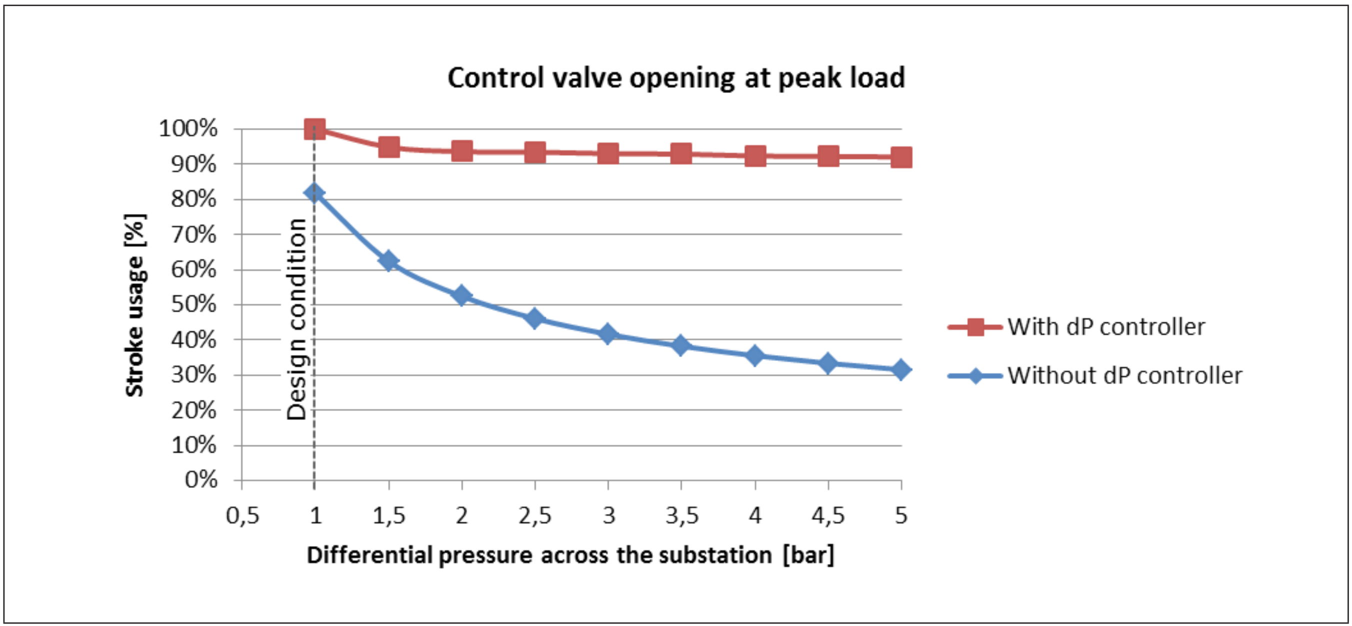


FIGURE 4: Control valve stroke usage related to the differential pressure across the substation with and without dP controller

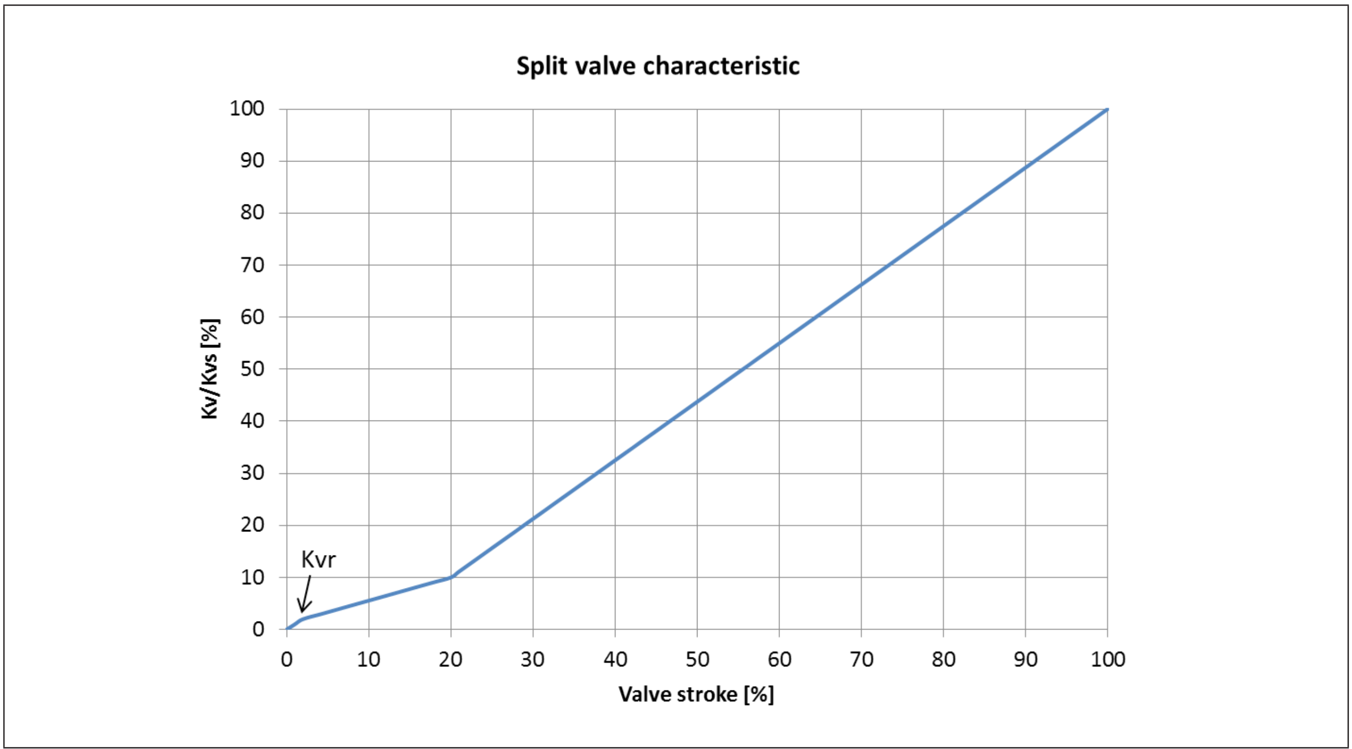


FIGURE 5: Example of the split characteristic of a control valve and the relation between the K_v / K_{vs} and the valve opening

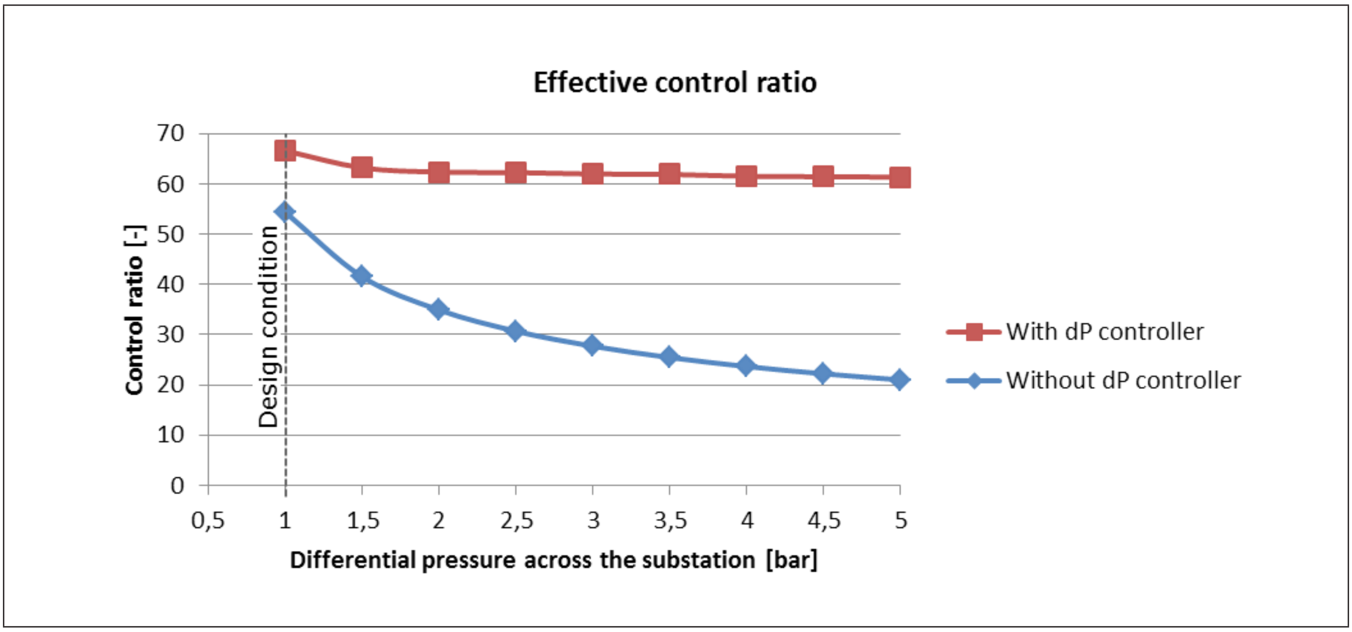


FIGURE 6: Effective control ratio of the chosen control valve under various differential pressure across the substation

1.5 Control valve characteristic and authority

Control valve characteristic:

When considering the valve characteristic of a control valve for controlling a heat exchanger, the valve characteristic must comply with the dynamics of the heat exchanger, the control principle and control signals used.

Typically the control signal used is the secondary flow temperature. The actual temperature is compared to a desired set point temperature and a control error is calculated. In principle this error of e.g. 1°C results in a certain movement of the motor valve or change in valve position or capacity. If the flow temperature is too high the motor valve moves a certain stroke in the closing direction or in case the flow temperature is too low the motor valve moves a certain stroke in the opening direction. The amount of stroke the motor valve is opening or closing is depending on the settings for the electronic PI controller. If the setting of the PI controller results in too large stroke changes, say primary flow changes for a certain error, the result will be oscillating secondary flow temperatures.

Looking at the heat exchanger, a certain flow change on the primary side results in a certain change of the secondary side flow temperature. Here it is important to keep in mind that the secondary side flow temperature change is depending on the operational condition of the heat exchanger, say temperatures and flow levels. For example, in case the primary flow is 100 l/h, and the motor valve is increasing the flow by 100 l/h due to a certain temperature error, then this will have big influence for the secondary temperature, leading to potential oscillations. In case the heat exchanger is operating at a higher primary flow, for example 1,000 l/h and the flow is increased by 100 l/h due to the same temperature error, then the impact on the secondary flow temperature is much smaller and oscillations are probably avoided. Since the PI controller moves the motor valve a certain stroke for a certain error, not knowing the valve position, the dynamic nonlinearity of the heat exchanger has to be compensated somewhere else. This is achieved by the valve characteristic. Basically at low primary flows, meaning at low stroke positions the flow change for a certain stroke travel is small. At higher flows, meaning higher stroke positions the flow change for a certain stroke travel is big. See Figure 7 for a typical valve characteristic. By realizing the valve characteristic in this manner, the example from above would lead to similar secondary flow temperature changes whatever the heat exchanger is operating at a primary flow of 100 l/h, resulting in a flow of 110 l/h, or 1,000 l/h, resulting in a flow of 1,100 l/h, for a given error. In this way the heat exchanger can have a better control, including faster secondary temperature recovery times, lower peaks and avoiding temperature oscillations. For further information about control of heat exchanger see [4].

Valve authority:

However as shown in Figure 8 the flow rate through the control valve depends on the control valve authority (Va). The control valve authority is defined as how well the control valve follows its designed characteristics, generally it can be said the control valve should have at least 50% control valve authority to achieve proper control. The control valve authority further on depends on the differential pressure across the application, which as discussed above can vary during operation. By applying a dP controller it is possible to ensure constant differential pressure across the control valve and high control valve authority. A constant differential pressure across the control valve means the control valve authority is optimized and that the flow rate to the consumer installation can be controlled with minimum effort, which maximizes the lifetime of the control valve and the actuator.

The control valve authority is defined as the pressure drop across the control valve divided by the total pressure drop across all components in the system loop. The control authority is calculated with the following equation:

$$V_a = \frac{\Delta P_{\text{v100\% open}}}{\Delta P_{\text{v0\% open}}} \tag{6}$$

If a dP controller is installed the system loop is considered as everything that is located between the impulse tubes, see Figure 3, of the dP controller. In the case the impulse tubes are connected only across the control valve the control valve authority is calculated as:

$$V_a = \frac{\Delta P_{\text{v100\% open}}}{\Delta P_{\text{v100\% open}} + X_p} \tag{7}$$

Where $X_p = \Delta P_{\text{v0\% open}} - \Delta P_{\text{v100\% open}}$ is the control deviation of the dP controller during operation. It should be noted that X_p is a small value. Therefore the control valve authority will be close to 100 %.

Additional benefits of a constant differential pressure across the control valve are: 1. the control valve can use its whole operating range and 2. reduced control valve position changes and hence long lifetime for valve and actuator.

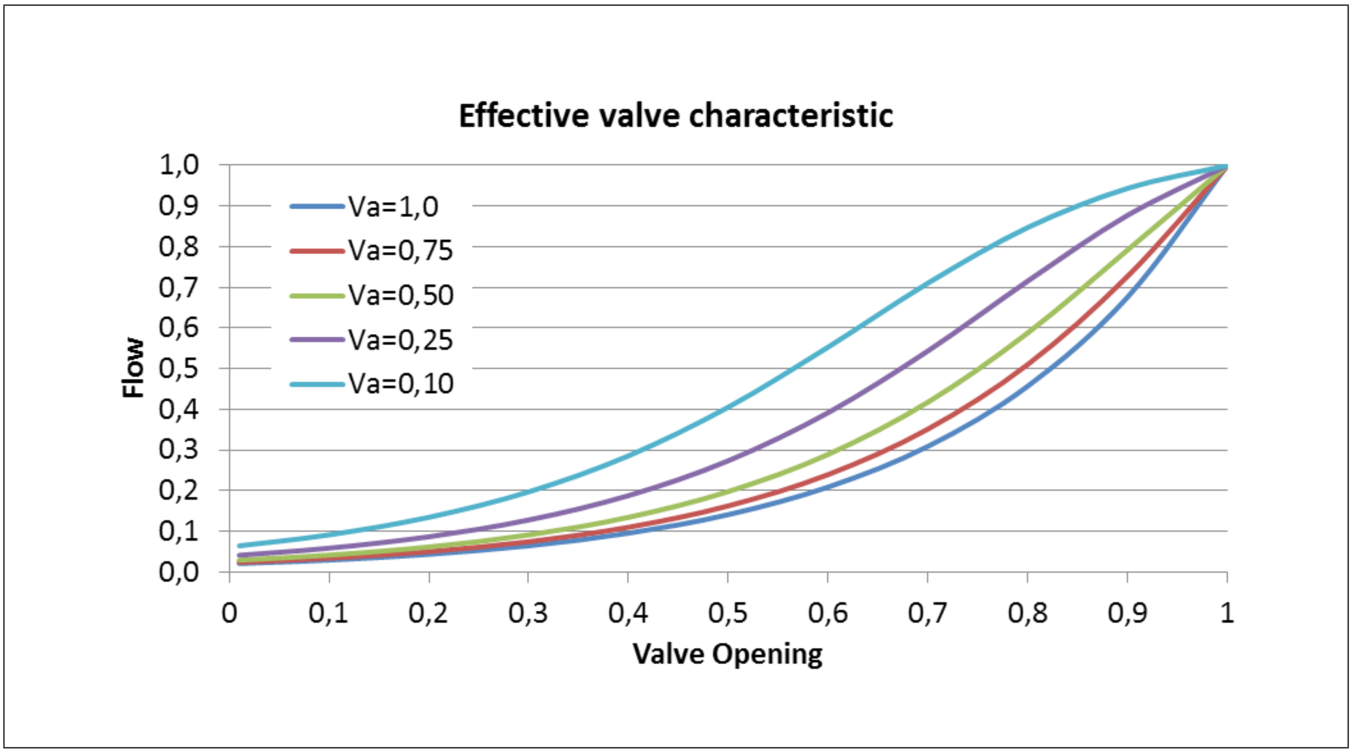


FIGURE 7: Control valve authority of a control valve

1.6 Comfort concerns

For comfort reasons the temperature in a DHW system has to be very stable. This is especially an issue for instantaneous DHW systems, as the control valve has to be able to maintain a stable temperature at high dynamics of DHW flow. This is less of an issue in space heating due to the high time constant of buildings and the low dynamics of the heating flow.

This can be considered in relation to a person taking a shower. During the shower, the expectations to the DHW system are that the water temperature is maintained stable throughout the shower. This is especially important during the heating season due to the higher network temperature profiles and likelihood of varying pressure levels. In general there are two types of instantaneous DHW systems which need to be considered, parallel and two-step systems, see Figure 8. For the parallel system the DHW is connected parallel to the heating system while in the two-step system the cold water is pre-heated by the return flow from the space heating system. The main difference between these two systems is in the demanded primary side flow rate during the heating season. Due to the pre-heating of the domestic cold water in the two-step system there is reduced demand to the primary side flow rate compared to the parallel system, which has no pre-heating of the domestic cold water. However as the DHW system is designed under summer condition, when no pre-heating is assumed, the same control valve would be chosen for both cases.

Figure 9 shows the minimum controllable flow for a given system differential pressure across the substation for the two-step system mentioned. The minimum control performance is based on the flow level corresponding to k_{vr}. It is clear in case of a two-step system a dP controller is required, even at design conditions of 1 bar differential pressure. In case of a parallel system, see Figure 10, a stable control can be achieved up to 2,2 bar differential pressure, for higher differential pressure a dP controller should be applied to ensure stable DHW temperature. Here it is important to note that it is not unusual that the differential pressure in a DH system has variations from 1-5 bars.

From Figure 9 it can be seen that two-step systems without dP controller should not be used, and even parallel system will quickly face challenges when the differential pressure increases, given that no dP controller is applied, see Figure 9.

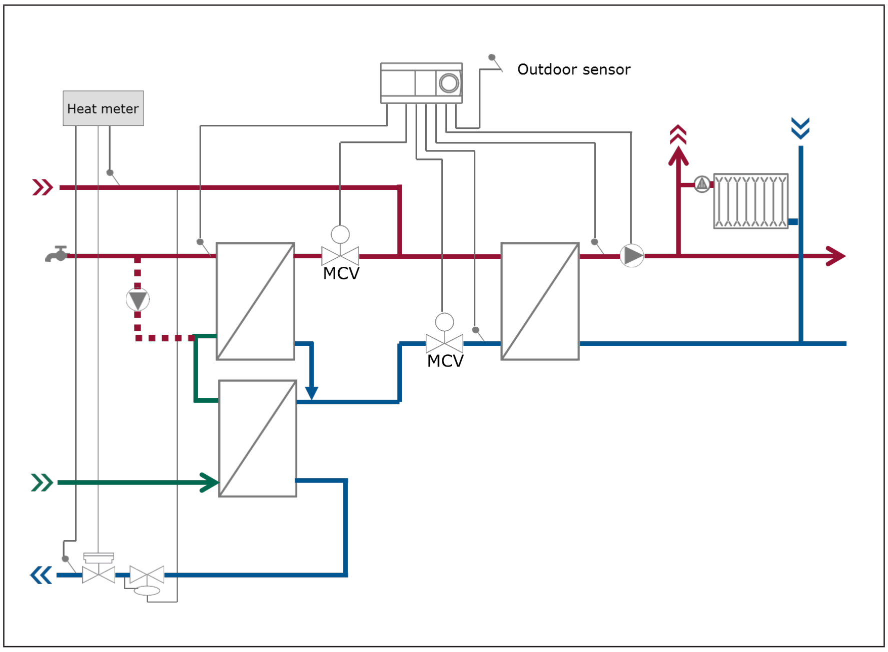


FIGURE 8: Schematic of a two-step system

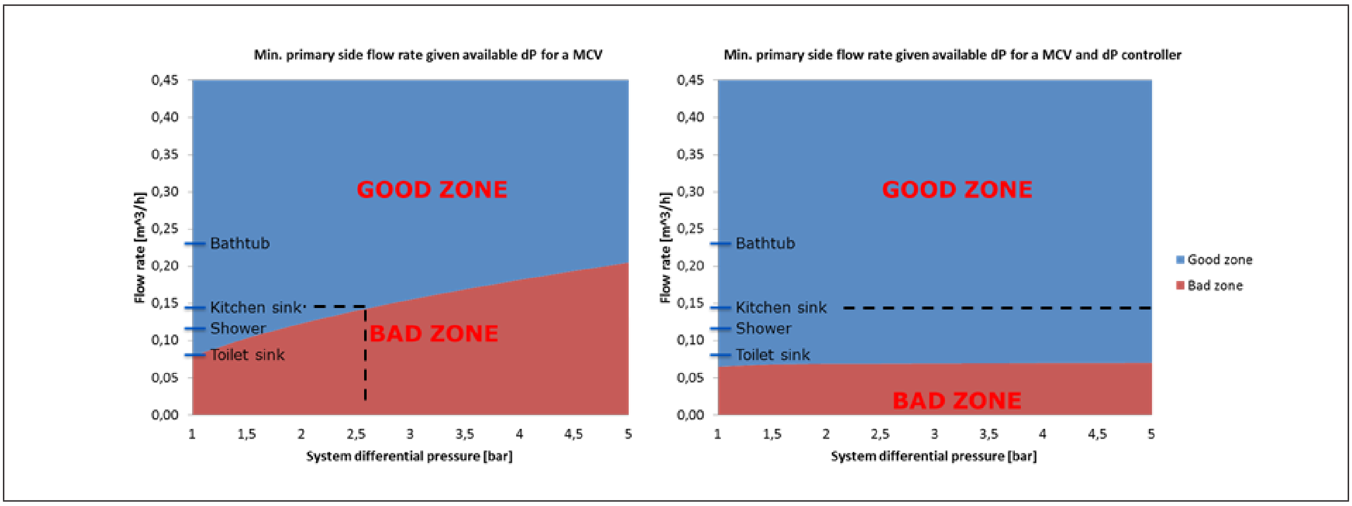


FIGURE 9: Minimum controllable flow rate given available differential pressure across a two-step substation. Figure to the left is for application without dP controller and to the right with dP controller. The dotted lines show how the minimum system temperature for stable control can be read out from the graphs

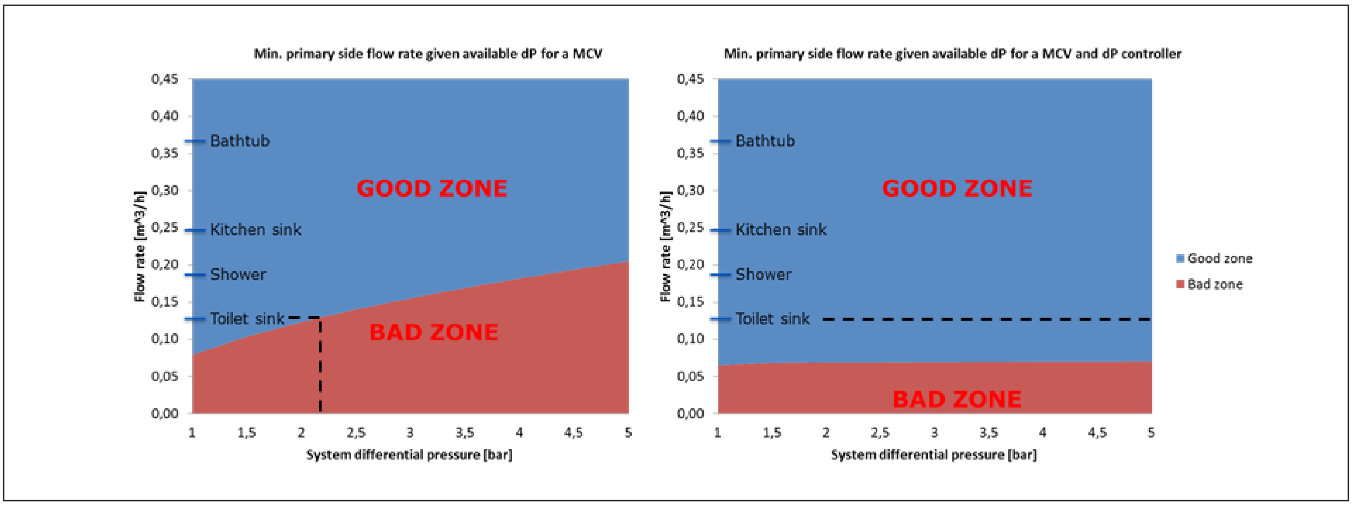


FIGURE 10: Minimum controllable flow rate given available differential pressure across a parallel substation. Figure to the left is for application without dP controller and to the right with dP controller. The dotted lines show how the minimum system temperature for stable control can be read out from the graphs

2. Adjustment of the system

It is a prerequisite for a well-functioning system that all of it is components are properly commissioned. It is therefore very important that the substation is correctly adjusted to the operational situation. This includes ensuring the control valve is opening to the highest possible degree at 100% load.

The best temperature control is achieved when the control valve operates in the entire range of the control valve characteristic.

If a dP controller is used in a system, the pressure drop across the control valve can be adjusted in a simple and easy way to ensure at peak load the whole capacity of the control valve is used, see Figure 6.

The adjustment procedures are:

- Use Eq. (3) to calculate the required pressure drop, ΔP_v given the design flow through the chosen control valve. The calculated ΔP_v is then the setting differential pressure of the dP controller.
- Monitor the flow rate through the energy meter at fully open control valve and adjust the set point of the dP controller until the demanded flow rate is acquired.

3. Hydronic balance in the supply network

A district heating system is in hydronic balance when the water flow to the individual consumers is exactly what they need, no more and no less while achieving the desired cooling of the supply, for both space heating and DHW preparation.

If a system is not in a hydronic balance, there could be the following reasons:

- The consumption is not according to specification
- No possibility of adjusting the flow, e.g. due to missing control equipment
- The substation has not been properly adjusted or commissioned
- The operator/customer has selected unfavorable controller settings, e.g. a too high temperature set-point

According to the specification, hydronic balance means that individual consumers get exactly the water volume they need to fulfill their heating requirement while achieving designed cooling of supply.

3.1 Flow limitation

In addition to all mentioned benefits of dP controllers, they as well provide an efficient mean to limit the maximum flow individual consumers can draw from the network. The flow limitation is effectively achieved when the allowable pressure drop across the control valve is set on the dP controller.

The setting of the dP controller can be calculated by Eq. (3):

$$\Delta P_{set} = \left(\frac{Q_{max}}{k_v}\right)^2$$

ΔP_{set} = the setting of the dP controller [bar].

Q_{max} = Flow rate in the substation at 100% load [m³/h].

k_v = k_v value of the control valve that is being considered [m³/h].

If more than one control valve is installed in parallel within the control loop, say between the impulse tubes, the sum of the k_v values should be used to determine the setting of the dP controller. If the dP controller only controls the differential pressure across one control valve, as is the case in Figure 3, the k_{vs} value of the control valve is to be used.

Under the precondition, the dP controllers are used in substations and that they are adjusted according to the maximum allowable flow rate, they will automatically establish a hydronic balance in the network under design condition. This means the flow rate in the substation is limited according to the maximum allowable flow rate.

3.2 Accuracy of the flow limitation

The expected accuracy of the flow limitation depends on the controlled differential pressure variation in the part of the substation between the points where the impulse tubes are connected.

The dP controller is a proportional controller. The controlled differential pressure variation is defined as ΔX_p deviation, see Appendix.

The flow difference, ΔQ, for varying differential pressure across the substation can be calculated by:

$$\Delta Q = Q_1 - Q_2 = Q_1 - k_v\sqrt{\Delta P_{set} - \Delta X_p} = \\ = Q_1 - \frac{Q_1}{\sqrt{\Delta P_{set}}}\sqrt{\Delta P_{set} - \Delta X_p} \qquad (10)$$

Where $\Delta X_p = X_{p\,design} - X_{p,actual}$, i.e. ΔX_p is the change in the X_p deviation between the designed condition and the actual condition. The equation can be rewritten as:

$$\frac{\Delta Q}{Q_1} = 1 - \frac{\sqrt{\Delta P_{set} - \Delta X_p}}{\sqrt{\Delta P_{set}}} \qquad (11)$$

From the Eq. (11) it can be seen that the flow variation $\Delta Q/Q_1$ depends on ΔP_{set} and ΔX_p. As the X_p value is generally small compared to ΔP_{set} the flow accuracy is high. Figure 11 shows the calculated accuracy of the flow limitation of a dP controller for various ΔP_{set} and ΔX_p values, from the figure it can be seen that the higher the ΔP_{set} or lower the ΔX_p is the higher accuracy is achieved. This is due to the fact that the higher the pressure drop across the control valve is the less effect the ΔX_p deviation will have on the flow through the control valve. This explains the minimum recommended split of the available pressure drop between the control valve and the dP controller mentioned above.

The maximum X_p for a differential pressure controller is typically 10 kPa, reflecting the range from full open to full closed dP controller valve, in practical operation the X_p band is much smaller.

CONCLUSION

From the discussion above it is clear the dP controller is an essential part of modern substations. The dP controller not only guarantees a good and efficient control of the district heating substation it also opens up the possibility to utilize the full stroke of the control valve, resulting in more accurate and stable temperature control for the secondary side of the substation, to the comfort benefit of the customers.

The benefits of applying dP controllers can be summed up by:

1. Effectively ensuring maximum allocated flow rate for the substation is not exceeded.
2. Allows the control valve to operate independently of other consumers in the network.
3. Ensure optimal control performance with stable temperature control.
4. Increases the lifetime of the control valve by ensuring stable operating condition for the control valve.

In other words, the dP controller ensures a well adjusted and well functioning substation fulfilling the demands for a modern district heating substation.

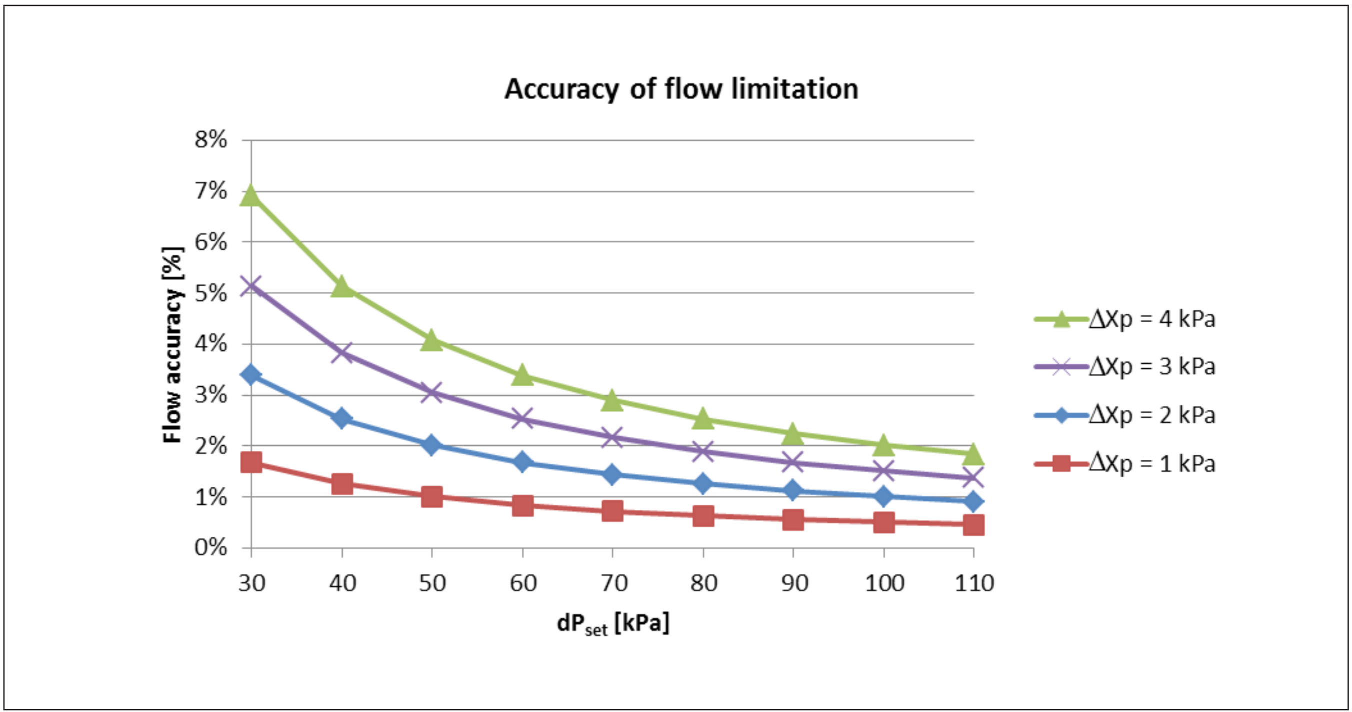


FIGURE 5: Example of the split characteristic of a control valve and the relation between the K_v/K_{vs} and the valve opening

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