Power Efficiency Improvement of Heating Substation Using Pump Motor Speed Rate Regulation

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Abstract-The paper presents district heating substation power efficiency improvement method. The method of circulation pump’s motor speed regulation by variable frequency drive let us cut down electrical energy consumption and significantly improve regulation characteristics during dynamical heating load change.

I. INTRODUCTION

Recently heating system designers have not taken into account electrical efficiency of circulation pump, meanwhile pumps motor speed regulation by variable frequency drives have been effectively and widely used in water supply systems. Several research activities in the field of variable frequency drives integration into heating systems and their results show, that circulation pump’s motor speed rate control can effectively change electrical power consumption. For instance integration of the inverter technology into district boiler heating system could result in up to 32% economy of electrical energy [1]. Most of the works describe district heating system improvement by inverter integration in it [2], and less attention is paid to electrical power savings in substations. The paper evaluates efficiency, electrical energy saving potential and methods of regulation of substation circulation pump’s motor control.

II. HEATING SYSTEM SUBSTATION

Basically district heating substation’s electrical system consists of heat exchanger, weather compensation controller, outdoor and flow temperature sensors, circulation pump and motorized control valve[3] (see Fig. 1).

Fig. 1. Principal scheme of heating substation.

Weather compensation controllers control heating system flow temperature on dependence of outside temperature. Controllers calculate the flow heat agent temperature’s set-point from current outside temperature and control a motorized valve by changing valve position from totally opened with maximum flow to totally closed position with minimum flow thus automatically controlling the temperature. Valve motor is controlled discrete by mean of thyristors or analogue control signals.

Heating system circulation pump’s nominal power is calculated to compensate the coldest five-day-period average temperature [4], for Riga temperature is -20.7°C. The duration of heating season in Riga time is 203 days and air temperature can go up to +7.0°C. Meanwhile heating system circulation pump is loaded on its nominal electrical power all heating season long, and existing heating systems do not take into account circulation pump electrical power saving potential.

III. PUMP REGULATION BY THROTTLING

Pump and heating system curves describe the relation between pump’s and system’s flow rate (Q) and head or pressure (H), curves intersection display pump actual operation point (see Fig. 2). Pump’s electrical power consumption is defined by the formula:

\[ P = \frac{Q \cdot H \cdot g \cdot \rho}{\eta \cdot 3.6 \cdot 10^6}, \text{ kW.} \]  (1)

where \( \eta \) – efficiency grade, \( g \) – gravity (9.81) m/s², \( \rho \) – density of fluid, kg/m³, 3.6*10⁶– conversion factor for kW

Modern heating systems include regulation valves, for instance heater thermostatic valves and balancing valves. Thermal inertia of building and zones’ (rooms’) different set-point temperatures result in heating load dynamical change. When zones’ set-point temperatures are reached regulation valves are closed, heating load and thus the flow are decreased, and this regulation method can be described as throttling. During throttling the flow is reduced from \( Q_{\text{max}} \) to \( Q_{\text{red}} \) by creating head losses \( \Delta H \) on valves, thus shifting the curve, and changing pump’s performance point from A1 to A2 and it is obvious, that on totally closed valve power losses are maximal and pump’s power consumption due to losses
remains practically close to maximum. During throttling pump’s electrical power is consumed inefficiently.

Fig. 2. Pump and heating system curves at throttling.

IV. PUMP REGULATION BY MOTOR SPEED CHANGE

Effective circulation pump’s electrical power regulation method is rotation speed rate control. Circulation pump has asynchronous motor and its rotation speed rate (n) can be controlled by electrical frequency (f) [5]:

\[ n = \frac{60 \times f \times (1 - s)}{p}, \text{ rpm} \]

where \( p \) – pole number, \( s \) – slip, which is about 0.02-0.05

On Fig. 3 the relation between head \( (H) \) and flow rate \( (Q) \) at variable speed regulation of pump’s motor, i.e., at changing of frequency, is presented.

Fig. 3. Flow control by motor’s frequency change.

If frequency is lower, then \( H \) and \( Q \) are both decreased. Pump’s power consumption change can be expressed as [6]:

\[ \frac{P_1}{P_2} = \left( \frac{n_1}{n_2} \right)^3 \]

where \( P_1 \) – power at higher speed \( n_1 \), \( P_2 \) – at lower speed \( n_2 \)

For instance, if we change pump’s speed rate from 1500 rpm to 1350 rpm, i.e., speed of a pump decreased by 10 %, then the electrical power decreases by 27 %. Figure 5 describes connection between electrical power saving potential \( (W) \) by pump’s motor speed decrease rate from nominal ones \( n_1/n_2 \) (see Fig. 4). Due to the fact, that motor speed rate decrease below 70% affects pump’s motor complex efficiency grade, maximum power saving is defined as 60% (see Fig. 4).

Fig. 5. Head reduction at frequency control by flow rate compared to the one at throttling.

At regulation asynchronous motor magnetization current must be kept constant, i.e., to keep frequency proportional to
voltage on stator winding. That is why essential to change voltage, when changing the frequency, i.e., to keep $U/f$ constant.

V. FREQUENCY CONTROL BY TEMPERATURE DIFFERENCE

Dynamical heating load change by regulation of valves throttling affects heating system flow rate. Efficient regulation method is circulation pump’s frequency control from heating system flow rate, pump’s performance point A3 (see Fig. 5). The evaluation of power savings ($\Delta W$) by frequency converter integration into heating system and head reduction by pump’s frequency change from flow rate change can be described as (4):

$$\Delta W = (1 - \frac{H_2}{H_3}) \times 100\%, \quad (4)$$

where $H_2$ – pump’s head after heating load change at frequency $f_{\text{max}}$, $H_3$ – pump’s head after frequency reduction

Frequency control by flow rate change requires flow-meter integration into system, complicates and raises the price of heating system.

Momentary heating load change can be described as difference between feed and return temperature ($\Delta T$). That is why more efficient method would be the pump’s frequency control by $\Delta T$ (see Fig. 6).

CONCLUSION

1. Existing district heating substation circulation pump is loaded on its nominal electrical power all heating season long. Substation consumes electrical energy inefficiently.
2. Heating system substation regulation by frequency control results in electrical power consumption rate reduction in up to 60% on dependence of speed decrease rate.
3. The most efficient control method of substation heating circulation pump is control by feed and return temperature difference $\Delta T$.

REFERENCES

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