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Heat metering and water quality

Comparing heat measurement accuracy of a new adaptive algorithm with existing heat meters in accordance to the Swedish test standard

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Abstract:
Heat measurement errors cause revenue discrepancies in the district heating industry. Some of these errors are caused by the uncertainty in the sensors them selves but the most contributing error source is the dynamic load such systems are subject to, as in the case of an irregular warm water tapping.
A new adaptive algorithm, that adjusts its estimation frequency depending on the flow rate, has been implemented to reduce the heat measurement error due to the dynamics of the system.
Simulations of the adaptive algorithm subject to the Swedish standard test program FVF F:111 have been made in order to compare the heat measurement accuracy of the adaptive algorithm with existing heat meters.
The heat meters used were also tested according to the Swedish standard test FVF F:111 by both the Swedish District Heating Association and the Swedish National Testing and Research Institute (SP).
The results of the simulations show that the adaptive algorithm gives a better heat energy estimation than most of heat meters tested.

Keywords: district heating, heat meter, sensors, measurement, heat.

1 Introduction:

The district heating technology was introduced in the USA around 1870-80 [1]. It is a technology that distributes heat energy produced in a central production facility to city districts or hole cities. The heat energy is delivered through a distribution network where water is often used as a carrier.
The heat energy transfer between the distribution network, often referred to as primary circuit, to the building network, or secondary circuit, occurs in district heating substations and more specifically in heat exchangers. Heat meters are located in these substations.
The energy consumption can be divided into space heating and tap water usage. The tap water consumption varies as users consume hot water when they, for example, take a hot shower or wash hands.
A typical heat meter consists of a set of two resistive temperature sensors, usually Pt-500 sensors, a flow meter and an integrating unit, which estimates the energy consumed by the household [1].
Heat meters are often battery operated and their battery power consumption is proportional to their estimation frequency, which is constant or flow, rate dependent. Heat meters with a flow rate dependent frequency are based on volume-flow meters, such as turbine flow meters. Such heat meters have a longer battery life thanks to their lower estimation frequency. They are therefore widely used in district heating.

A modern substation responds well to sudden changes of the heat demand or dynamic loads. However, the metering of the transferred heat has not evolved to address such variations.
The measurement error in traditional heat meters based on volume-flow meters is proportional to the frequency and amplitude of the tap water load. A low tap water load results in a higher measurement error [2].
A new adaptive algorithm is proposed to increase the heat measurement accuracy while keeping the battery life relatively long.
The Swedish District Heating Association has developed the test program FVF F:111 [3] to test the ability of heat meters to cope with the dynamic load such substations are subject to. Heat meters from well known manufacturer such as Enernet [4], Kamstrup [5][6], ABB [7], Siemens [8] and Actaris [9] have been tested by the Swedish District Heating Association and the Swedish National Testing and Research Institute (SP).
A Simulink model of the adaptive algorithm has been made. This model has been used as part of a Simulink model of a district heating substation [10] subject to the test program FVF F:111 [3] proposed by the Swedish District Heating Association. Results from this simulation were then compared to real life results from the heat meter testings made by the Swedish District Heating Association and the Swedish National Testing and Research Institute (SP).
The results of the simulation show that the adaptive algorithm gives a better heat energy estimation than most of heat meters tested.

2 Theory

The district heating substation, connects the district heating network and house, while separating the two household circuits, namely the space heating and the tap water circuits. The district heating circuit is referred to as the primary circuit and the household circuits are the secondary circuits. A heat meter measures how much heat energy was transferred from the primary circuit to the secondary circuits. It is commonly comprised of a flow meter, two resistive temperature sensors and a computing unit. The temperature sensors measure the supply and return temperatures of the primary circuit. The flow meter measures the flow rate of the primary circuit.

The heat energy Q [J] consumed by the household during a period of time $\Delta t = t_1 - t_2$ is given by the following continuous time integral [1]

$$Q = \int_{t_1}^{t_2} \dot{m}\, \overline{c_p(t_R, t_S)}\, \Delta T\, dt = \int_{t_1}^{t_2} V\, k\, \Delta T\, dt \quad (1)$$

where

$$k(T_r, T_s) = \rho(T_r)\overline{c_p(T_r, T_s)}$$

$$\Delta T = T_s - T_r$$

$$V = \frac{\dot{m}}{\rho}$$

and

T_r : The measured return temperature $[{}^oK]$

T_s	:	The measured supply temperature	$[^o K]$
$k(T_r, T_s)$	:	The heat coefficient	$[J/^o Km^3]$
$\dot{m}$	:	The mass-flow rate	$[kg/s]$
V	:	The volume-flow rate	$[m^3/s]$
$\rho(T_r)$	:	The fluid density at T_r	$[kg/m^3]$
$\overline{c_p(T_r, T_s)}$	:	The average heat capacity at T_r and T_s	$[J/^o Kkg]$

Modern heat meters do not compute continuous events; they use the following discrete approximation of equation (1) to compute the heat energy consumed by the household

$$Q = \sum_{i=0}^{N} k_i V_i \Delta T_i \Delta t_i \quad (2)$$

where $\Delta t_i = t_{i+1} - t_i$ is the time elapsed between two consecutive measurements, k_i, V_i, and ΔT_i are measured at t_i.

2.1 Heat meters based on volume-flow meters:

This method has its origin in old turbine flow meters. Such flow meters are powered by the flow. The turbine drive a mechanism that provides a pulse after a certain amount of fluid has past by.
The flow rate dependent heat measurement is triggered by a series of pulses from the flow meter. The flow meter emits a pulse when a fixed volume of water has passed through it. The time between two consecutive pulses are often called *the integration time* and is flow dependent. When a pulse is emitted, the integration unit measures the return and supply temperatures and the integration time [1].

The heat integrator computes the heat energy consumed for each iteration i with the average flow rate during the integration time V_i, temperature difference ΔT_i and the heat coefficient $k(T_{r_i}, T_{s_i})$. The obtained value is then accumulated onto the total heat energy consumed according to equation (2).
The measurement error in such heat meters depends on many factors [2]. The largest source of error originates from the flow meter. It only enables us to estimate an average flow rate under the integration time. The real flow rate may drastically vary during the integration time without being detected by the heat meter.

2.2 Heat meters with a constant estimation frequency:

Such heat meters estimate the heat energy consumed by the household at constant time intervals varying between 4 and 30 seconds.

They measure the flow rate V_i and the temperatures difference ΔT_i between the supply and return pipes of the primary circuit then estimate the heat

energy consumed using equation (2).
These heat meters often give a more accurate value of the heat energy consumed by the household but they consume more battery power than heat meters based on volume-flow meters.

2.3 Adaptive algorithm:

The measurement error of heat meters based on volume-flow meters is dependent on the frequency and amount of tap water demand as mentioned in [2].
Under normal flow rates, the estimation frequency of traditional heat meters based on volume-flow meters is fast enough to obtain an acceptable heat measurement accuracy, since it is proportional to the flow rate [2]. The problem occurs at low flow rates, when the time between tow flow meter pulses is longer. The measurement frequency in this case is too slow to cope with fast and short heat energy changes in the system. Heat meters with a constant estimation frequency are not affected in the same way by low primary flow rates since their measurement frequency can be set to be high enough to avoid this problem, but again at the cost of the battery's life expectancy.
The adaptive algorithm measures the heat energy with a flow rate dependent estimation frequency at high flow rates in the primary circuit. However, if the flow rate drops below a certain transition threshold, the heat meter measures the energy with a constant estimation frequency. This implies that the sampling frequency at low flow rates will be higher than the one in heat meters with a flow rate dependent estimation frequency.
The adaptive algorithm is a hybrid algorithm that adjusts its estimation frequency depending on the flow rate. It combines two existing heat measurement algorithms to give a higher accuracy measurement.

Manufacturer	**Model**	**Flow meter type**	**Error in test 1 (%)**	**Error in test 2 (%)**	**Power supply type**	**Measurement frequency**	
						Constant (s)	Flow dep. (l/pulse)
Kamstrup	Multical Compact	Ultrasonic	-1.5	-13.8	Battery	30	-
Kamstrup	Multical 66C92F0312	Ultrasonic	-0.6	-10.8	Battery	-	1
Enermet	10EVL	Inductive	-1.05	-3.8	220V	-	1
ABB	F3	Ultrasonic	-1.97	-2.59	220V	-	2.5
Siemens	2WR5	Ultrasonic	-2.8	-35.35	220V	30	-
Actaris	CF Echo	Ultrasonic	-1.95	-8.06	Battery	-	1
Adaptive alg.	-	-	-0.26	-3.6	Battery	10	1

Table 1: Results of several heat meters subject to standard test program FVF F:111

3 Method

In order to test the measurement accuracy of heat meters subject to daily dynamic heat energy load, the Swedish District Heating Association has established a standard test program called FVF F:111 [3]. A test rig has been built to test heat meters against this standard. The rig is equipped with reference temperature sensors and flow meter in order to have a reference heat measurement. The reference temperature, flow rate and heat energy measurement uncertainties are estimated to ±0.1%, ±1.5% and ±1.6% respectively.
The standard test program FVF F:111 consists in a series of two tests.

- Test 1: Both space heating and hot tap water loads are taken in account in this test. The space heating load is set to 10-20 kW/h. The hot tap water load is cyclic as shown in figure 1 and the table below. The cycle is 19 minutes long and repeated until the reference heat meter measures 100 kWh.

Time(s)	60	120	180	180	30	300	150	30	90
Flow (l/s)	0	0.1	0.2	0.1	0	0.2	0	0.2	0

- Test 2: Only hot tap water load is taken in account in this test. No space heating is set. The hot tap water load is cyclic as shown in figure 1 and the table below. The cycles are 5.5 minutes long and are repeated until the reference heat meter measures 20 kWh.

Time (s)	300	30
Flow (l/s)	0	0.2

Heat meters from known manufacturers such as Enernet [4], Kamstrup [5][6], ABB [7], Siemens [8] and Actaris [9] have been tested in this rig. The results of theses tests are summarized and shown in table 1.
Simulations of the adaptive algorithm subject to the hot tap water loads stated in test 1 and 2 were conducted to compare its accuracy against well known heat meters present in the market today.

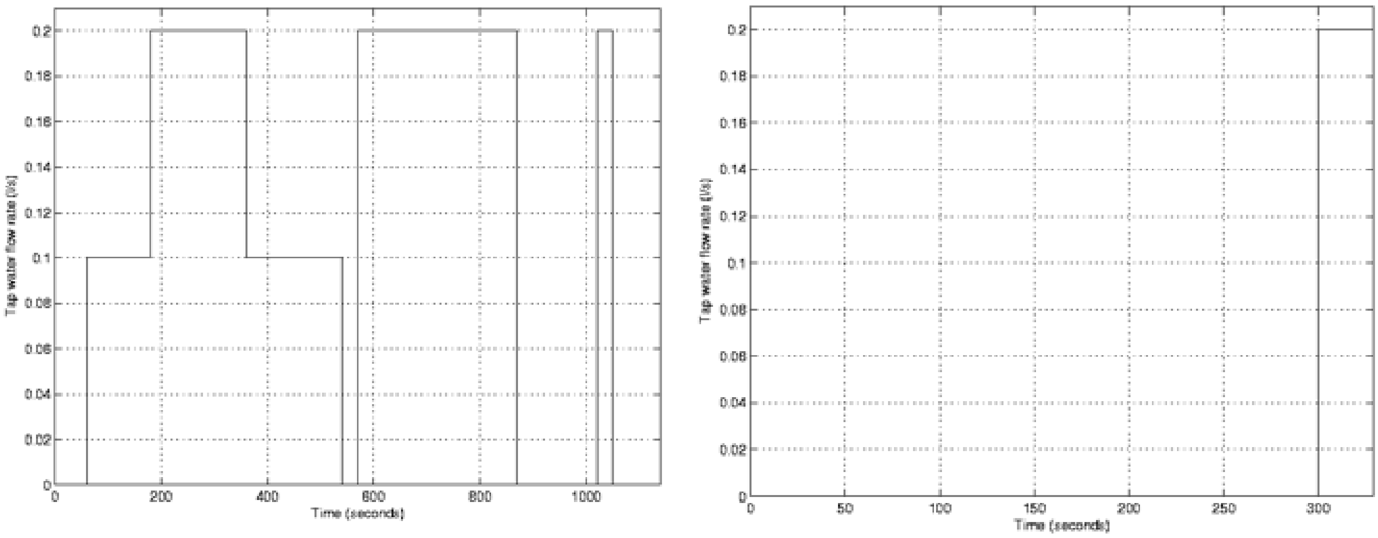

Figure 1: Tap water load in test 1 and 2 respectively.

4 Results and discussion

It has been shown in these simulations that the adaptive algorithm has higher measurement accuracy than most heat meters tested against the Swedish standard FVF F:111. The results of these tests are shown in table 1 and the graphs of the average error rate of the adaptive algorithm subject to test 1 and 2 are plotted in figure 2.

The adaptive algorithm has an average error rate of -0.26% in test 1 which is lower than the error shown by other heat meters subject to the same test. The average error rate of the adaptive algorithm in test 2 was measured to -3.6% where only ABB F3 [7] heat meter had a higher measurement accuracy.

The results of test 1 show that the adaptive algorithm has higher measurement accuracy when both the space heating and tap water consumption dynamics.

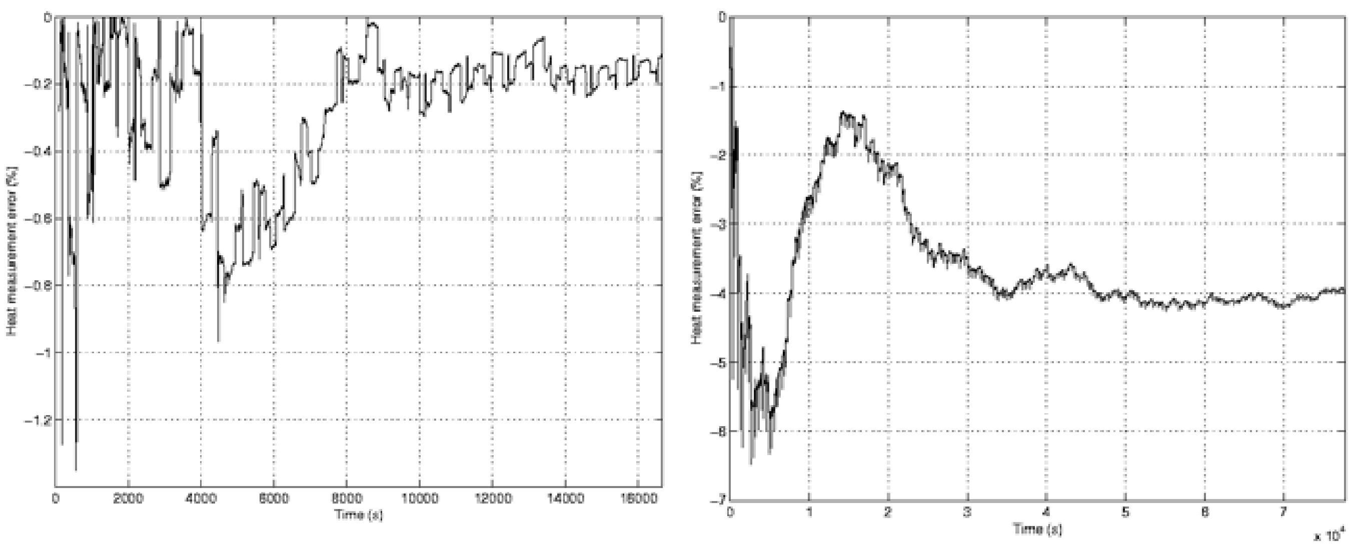

Figure 2: Heat measurement error in test 1 and 2 respectively.

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