HaBIDES - Heat and Battery Integrated Domestic Energy Storage

Kristoffer Lorentsen

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1 Summary

HaBIDES is to become a model of a combined battery and hot water energy storage solution for domestic use. This document will explore the potential of such an energy storage solution and explain how the model works.

I have started this project for numerous reasons. These include:

- Investigate the potential in the energy storage solution

- Try to develop a mathematical model of a real-world problem

- Learn how to program a model in Python

- Learn how to use LaTeX (formulas, graphs, refrencing, indexing)

- Have a reason to investigate the future of Smart Grid and demand side response

Note: I strive to make the information in this document and repo as accurate and true as possible, but it has not been reviewed by others than me. You can use it for whatever you want, but I can not guarantee that it is correct.

2 Potential

The potential for a combined hot water and battery energy storage is defined by its capability to shift loads from peak-hours to times of lower demand. Norways (and the rest of the worlds) electricity demand varies throughout the day. Residential electricity use has two peaks in Norway, one at 9:00, and one between 18:00 and 23:00, depending on time of year [4]. The price of electricity rises with demand, therefore the user will benefit from a lower energy bill in the future when all measurements of energy use is done hourly [3]. The grid operator will experience a lower peak which in turn might mitigate/replace future investments/upgrades.

Integrating a capability to sell energy to the grid at peak hours will allow for further economic benefit for the end user. It will allow the system to buy at low price and sell at peak hours. Further introducing energy generation, in terms of solar PV, will add more benefit. In the future, such functionality will be added to the model.

The rest of this chapter will provide the reader of background information about the energy storage potential.

2.1 Hot water energy storage potential

The amount of energy contained within a hot water tank is limited by the amount of water and its temperature. Formula 1 gives this relation.

$$U(m, \Delta T) = m \Delta T C_W \tag{1}$$

- m - mass of water [kg]

- ΔT - Adjustable temperature difference [$^\circ C$]

- C_W - Heat capacity of water - 4184 [$J/^\circ kg$]

The volume of a hot water tank - and subsequently the mass of water - varies depending on model and make. The model will investigate what a optimal volume will be.

2.1.1 Available temperature difference in a hot water tank

The available temperature difference in a hot water tank is limited by three factors:

1. Maximum design temperature and pressure

2. Minimum temperature for mitigating legionella bacteria growth

3. The working temperature range of the thermostat

OSO's Super 8 hot water tanks safety thermostat is set at 98 $^\circ C$ and the hot water tank is designed for temperatures up to 99 $^\circ C$. The thermostats working range is 60-90 $^\circ C$. The Norwegian health authorities define minimum temperature for mitigating legionella bacteria growth as 65-70 $^\circ C$ [1]. Assuming that the thermostat will be replaced by a new one in the system, the available temperature span is 70-95 $^\circ C$, resulting in a temperature difference (ΔT) of 25 $^\circ C$. Average energy use for a hot water tank i Norway is 3,066 kWh/day and new heaters heat loss is less than 70 W amounting to a maximum of 1,68 kWh/day [2].

Using equation 1, available heat storage capacity in a hot water tank of 200 l is 20,91 MJ or 5,81 kWh. In theory, this allow us to heat the water to 95 $^\circ C$ at night when electricity is cheap and abundant and use it during the day when electricity is expensive.

A hot water tank will usually use energy after the consumer uses hot water - to bring the temperature in the tank to its set level. Assuming that consumers shower and use hot water in the morning, this energy use will take place during the first daily electricity load peak. This simple calculation demonstrates the potential of the hot water storage solution.

2.1.2 Hot water distribution and consumption

Increasing the temperature of a hot water tank increases the risk of scalding. To ensure that this is not a problem, a thermostatic mixing valve (TMV) is usually used to blend hot water with cold water to create a constant and safe shower and bath outlet temperature. In this model and paper it is assumed that a self-contained TMV unit is used to keep the temperature of hot water in the distribution pipes and outlets at a constant, safe value.

Hot water consumption is defined by a consumption volume flow rate, $\dot{V}_C$ [l/s]. The rate of energy used is defined by the volume flow rate and the consumption temperature, T_C [$^\circ C$]. The model must therefore accept consumption as a function of $\dot{V}_C$ and T_C.

2.2 Model of hot water tank

In this chapter, I will develop a mathematical model for a hot water tank. I will develop the model under the following assumptions.

- The contents (water) is idealy stirred.

- The heat loss varies with the temperature of the water

- Environment temperature is constant

- Inflow and outflow will be equal

The energy balance is given in equation 2. Equations 3, 4, 5, 6 and 7 can be used to simplify and specify the model of the water tank. The following list denotes all symbols used in the equations.

$$\frac{dE}{dt} = \dot{E}_i - \dot{E}_o + \dot{Q} \tag{2}$$

$$\dot{Q} = \dot{Q}_E + \dot{Q}_L \tag{3}$$

$$E = K + U + P \approx U = V\gamma_W C_W T \tag{4}$$

$$\dot{E} = \dot{K} + \dot{U} + \dot{P} \approx \dot{U} = \dot{V}\gamma_W C_W T \tag{5}$$

$$T_o = T \tag{6}$$

$$V_o = V_i \tag{7}$$

- E - Energy in a mass [J]

- $\dot{E}$ - Energy flow [J/s]

- K - Kinetic energy - in our case neglectible

- U - Thermal energy [J]

- P - Potential energy - in out case neglectible

- T - Temperature in the tank [$^\circ C$]

- T_i - Temperature in the inflow water [$^\circ C$]

- V - volume of tank [l]

- $\dot{V}_i$ - volume flow into the tank [l]

- γ_W - Specific weight of water - 1 [kg/l]

- $\dot{Q}_E$ - Energy inflow from heater element [W] = [J/s]

- $\dot{Q}_L$ - Energy heatloss from tank [W] = [J/s]

Using the equations, we can formulate the energy balance for the tank, as shown in equation 8. Equation 9 can be used to calculate temperature T from the accumulated energy E. The model can be used to study the behavior of a hot water tank. To enable the consumption to be given as $\dot{V}_C$ and T_C, equation 10 can be used.

$$\frac{dU}{dt} = (T_i - T)\dot{V}_o\gamma_W C_W + \dot{Q}_E - \dot{Q}_L \tag{8}$$

$$T(U) = \frac{U}{\gamma_W C_W V} \tag{9}$$

$$\dot{V}_o(T_C, \dot{V}_C) = \dot{V}_C \frac{T_C - T_i}{T - T_i} \tag{10}$$

2.3 Heat loss from the water tank

Heat loss from the tank is assumed to be varying with temperature. OSO gives their heat loss as [kWh/day]. For the model we need the heat loss to be [W] as a function of temperature inside (T) and outside (T_e) the tank as shown in equation 11. I assume that there is a heat loss constant (C_L) for each individual water heater that can be calculated using equation 12. T_f is the factory temperature setting. Q_D is the given daily heat loss in [kWh/day]

$$Q_L(T, T_e) = C_L(T - T_e) \tag{11}$$

$$C_L(T_f, T_e) = \frac{Q_D 1000}{24(T_f - T_e)} \tag{12}$$

3 Model test case

To test the model, the following test case will be used.

- Tank volume is 200 l

- Inflow water temperature is 10 [$°C$]

- A shower is assumed to be

- Standard tank temperature is 70 [$°C$]

References

[1] Folkehelseinstituttet. Forebygging av legionellasmitte – en veiledning. *Folkehelseinstituttet*, 2009.

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[4] B. Halvorsen T. Ericson. Hvordan varierer timeforbruket av strøm i ulike sektorer? *SSB*, 2008.