Seasonal and Daily Operation of Nuclear Based District Heating System with Varying Energy Demand

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ABSTRACT

Operation of nuclear based district household heating relates to several challenges. These challenges mostly reflect two aspects. The first aspect is reflecting daily based changes of heat consumption with morning and evening demand peaks. Second aspect relates to huge difference in summer and winter demand, where summer demand (mostly for district hot water production) is usually about 10 % of winter nominal consumption. Nuclear reactors usually prefer stable operation on nominal power, without fast changes and are not designed for rapid power changes. In this study we would like to introduce a concept of a nuclear district heating station, for real situation with realistic heat consumption profile. We will address changing heat consumption on daily and seasonal basis.

1 INTRODUCTION

As electricity production in Europe is moving towards renewable sources of electric energy, deploying wind and solar (photovoltaic and concentration) powerplants, current district heating still heavily relies mainly on coal, gas, and oil sources with some minor addition of biomass and waste incineration plants. Achieving new goals for decrease of CO_2 production is strongly depending on finding of new innovative technologies [1].

With increasing number of small modular reactors (SMR) aimed for industrial and district heating, as DHR400 or TEPLATOR®, a thermal energy storage (TES) seems to be an interesting system feature [2].

Nuclear reactors are generally not designed for rapid power changes, as they are usually connected with unwanted phenomena as xenon poisoning or increased mechanical stress to fuel cladding caused by pellet – cladding interaction. Nuclear reactors are generally better to operate at nominal power, what is easy to do with base load electricity production for large electric grid but may cause several issues in generally smaller district heating grids with more variable consumption profile (Figure 1).

TEPLATOR is an industrial concept of central supply of heat/cold using spent nuclear fuel from light water reactors. Combining this new concept of heat production for district heating with Thermal Energy Storage (TES) could bring more flexibility and more safety to TEPLATOR operation and could have significant economic value.

This innovative concept for district heating could benefit from having a robust heat energy storage for compensation of 1) TEPLATOR power fluctuations, 2) compensation and smoothing of the demand curve and 3) can serve as an emergency and safety heat sink.

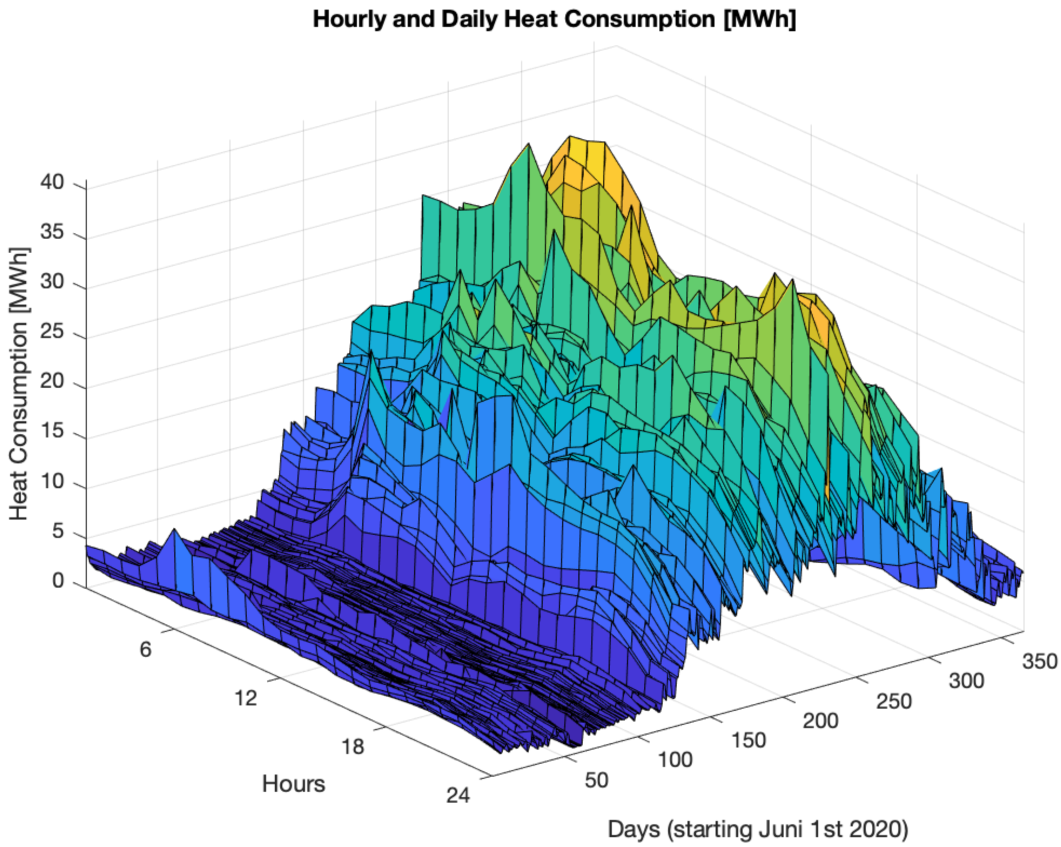

Figure 1: Real data of daily and hourly heat consumption

2 SEASONAL AND DAILY EQUALIZATION

The unevenness in heat consumption is considered from two directions – daily and seasonal basis (see Figure 1).

2.1 Seasonal equalization

Seasonal operation consists of two main parts heating season and non-heating season (usually summer when only domestic hot water for direct consumption is generated). Heating season is usually defined by law and depends on date and daily average temperature. Daily heat demand during of season is constant without significant consumption peaks. On the other hand, heat consumption curve has significant peaks (morning and evening) during heating season. Peaks sharpness caused by end user behaviour. For TEPLATOR serving as heat only source of DH (District Heating) and DHW (Domestic Hot Water) and operation following predefined operation curve is proposed. It is presumed that summer season DHW consumption will be covered with additional source, as a low power operation seems to be too costly in comparison with cheap renewables, which available in summer season (mostly solar).

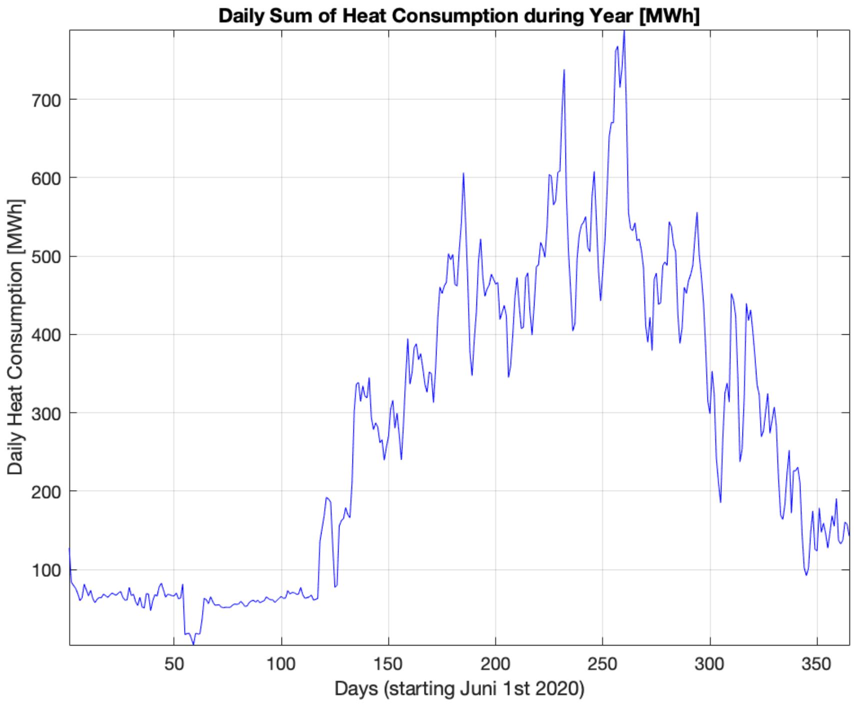

Figure 2 – Sum of daily heat consumption over a year

For seasonal equalization a daily sum of heat consumption was used (see Figure 2). This data was then filtered with moving average filter simulating short term equalization with TES free capacity and DHS network capacity. Filtering with 4-day average proves to be sufficient (see Figure 3). Second order polynomial approximation was used for calculation operation curve for heating season. Polynomial operation curve serves as a steppingstone for further discretization simulating real nuclear reactor operation. Example of such discretization with 2 MW step is on Figure 3.

Final adjustment of heat production and actual heat demand will be realized by varying step size according to actual situation. This rough regulation is limited by safe reactor operation, which does not allow quick reactivity and power changes. For final precise adjustment other means (listed below) will be used.

Other means of equalization for overproduction is:

- Dissipation of heat to the surroundings when the excess heat is removed by the cooling tower. This is an uneconomical option when the heat leaves the surroundings without benefit. However, this is a simple and easy-to-apply measure.
- Storage tank charge, excess heat is removed to the heat storage tank. Can only be applied if the tank has free capacity.

Other means of seasonal equalization for underproduction is:

- Connecting an alternative source. In this case, the missing heat is supplied by a backup source.
- Tank discharge when the heat accumulated in the tank is discharged.

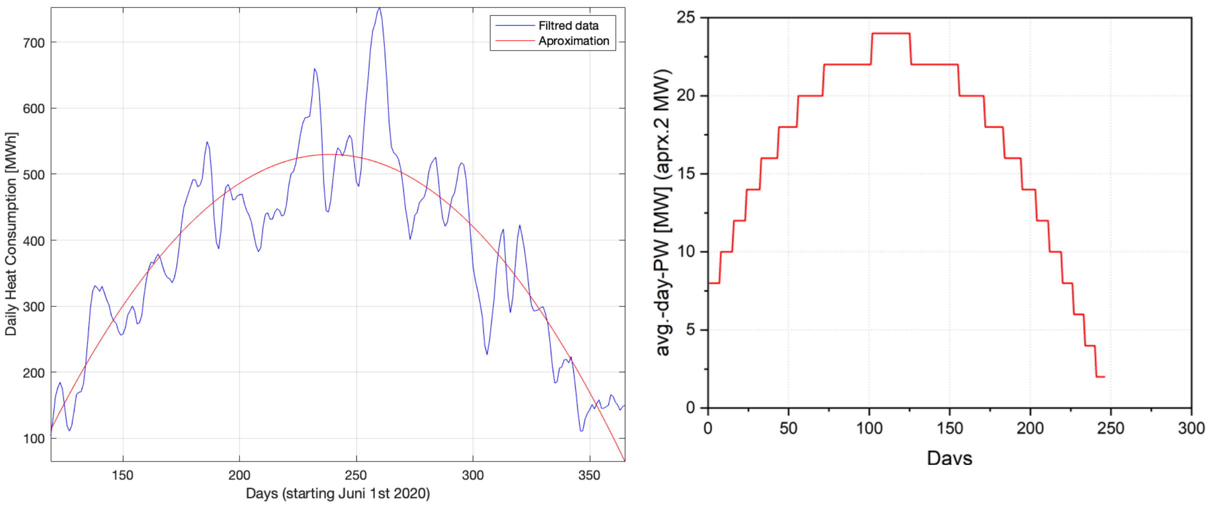

Figure 3 – Reactor operation curve with discretisation

2.2 Daily equalization

During daily operation two peaks (morning and evening) generally appear in heating season. Heat consumption (composed only from DHW) is nearly constant during off season. TES used for peak compensation as TEPLATOR operation is considered being constant. TES is charged in period with low heat consumption and discharged in periods with high energy demand. Peak shaving algorithms should be used for optimal sizing of TES. Example of such an algorithm and visualization of TES operation is on Figure 4. Red marked are where TES is discharged and green where TES is charged. This case shows typical winter day in existing CHP with optimal TES size (complete charge and discharge).

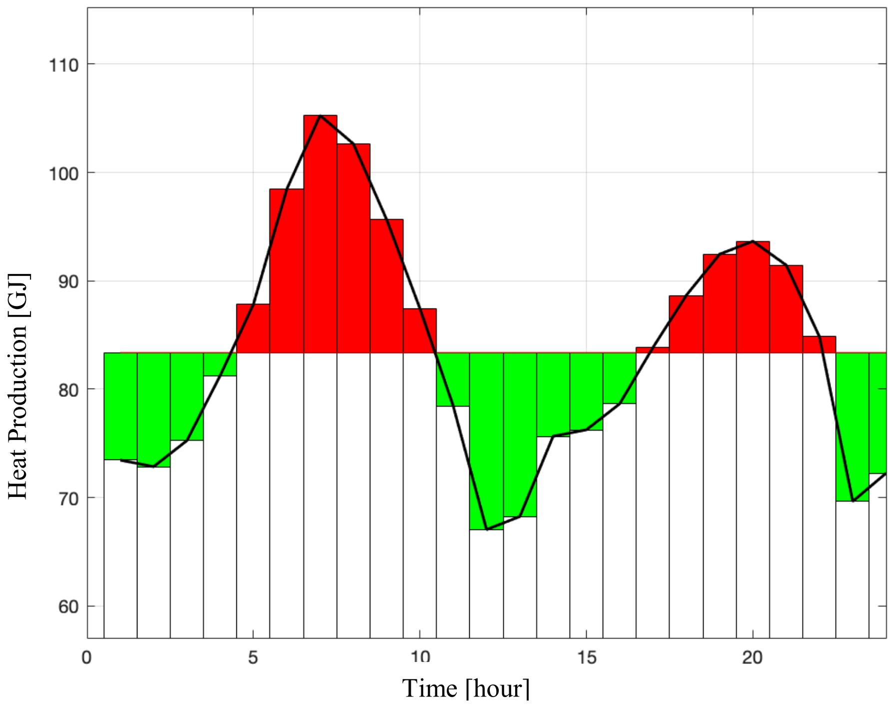

Figure 4 – TES operation, sizing, and peak shaving algorithm.

3 CONCLUSIONS

Two types of equalization are required for nuclear reactor as a source for DH - daily and seasonal equalization.

Daily equalization can be achieved by TES.

Seasonal equalization needs more sophisticated approach:

- TEPLATOR will operate along operation curve, this compensates highest heat consumption in winter and lower heat consumption is spring and autumn.
- Several other means have to be deployed for mid-term equalization including, energy storage, excess heat dissipation and use of additional / backup heat source.

ACKNOWLEDGMENTS

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