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Small Modular Reactors in Industrial and District Heating Combined with Thermal Energy Storage System

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ABSTRACT

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. 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 more or less 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. On the other side are an industrial (stable with better prediction) consumption or district household heating with variable and less predictable consumption profile. Industrial and district heating systems has different requirements for dynamic response varying from immediate, short term full power delivery (e.g. for finishing already started batch of product before forced manufacturing line cool-down) to long term delivery with more relaxed parameters (e.g. for residual area district heating).

In this study we would like to introduce a concept of a thermal energy storage as a dynamic system connecting SMR and district heating, considering different requirements on both sides with different dynamic system response.

1 INTRODUCTION

As electricity production in Europe is moving towards renewable sources of 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 CO2 production is strongly depending on finding of new innovative technologies. 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 also 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.

2 TEPLATOR DESIGN AND VARIANTS

2.1 General TEPLATOR design

TEPLATOR is a channel type reactor using 55 VVER-440 fresh or used fuel assemblies, moderated and cooled by heavy water. Coolant circulation is forced during standard operation; during emergency core cooling and residual heat removal natural convection to heat storage is anticipated. TEPLATOR layout includes 3 circuits (Figure 1). The primary circuit includes calandria, a core, three heat exchangers each with its own pump. The core is made from zirconium alloy channels in which the fuel is based. The space between the channels is filled by the moderator, heavy water. The coolant flows in the channel around the fuel and then it flows through a system of pipes at the outlet of which there is a collector. Three pipes are led out of this collector, each of which is led into one heat exchanger. The coolant passes through the primary side of the heat exchanger and returns to the fuel channels through the pump and the lower distribution chamber [1]. Three primary heat exchangers with heat transfer surface 520 m^2 each. Each heat exchanger is able to cool 100 % of the power, in case of failure of the others [2].

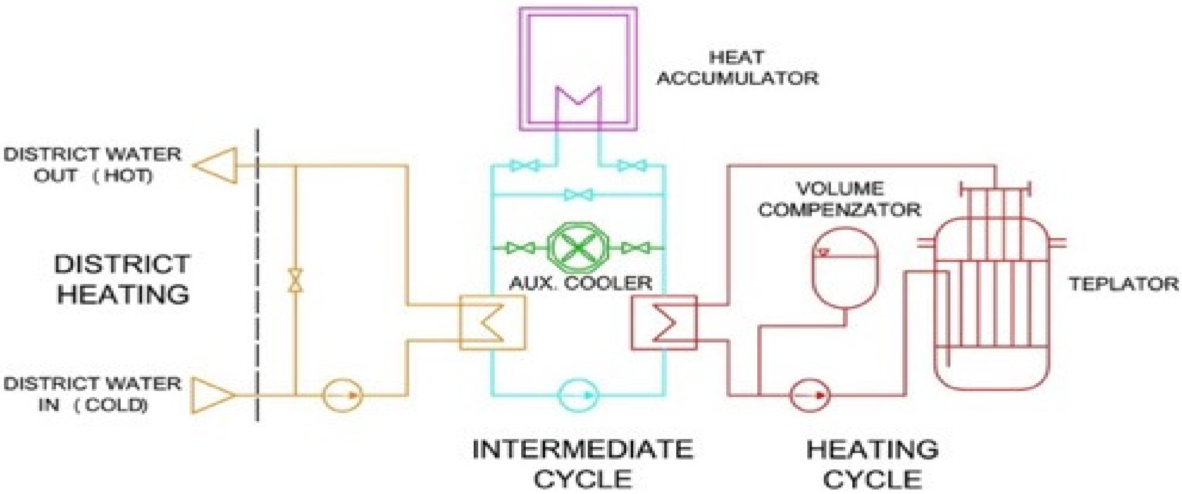

Figure 1: TEPLATOR 3 circuit design [2]

Design variants of TEPLATOR are summarized in (Table 1). There are three variants considered DEMO and FULL uses heavy water as a primary circuit coolant. These two variants are designed for district heating. HIGH TEMP variant is designed as a heat source for industrial heating, this variant uses Santowax as primary circuit coolant.

Table 1: TEPLATOR – design variants

TEPLATOR type	DEMO	FULL SIZE	HIGH TEMP
Power output [MW_t]	50	150	150
Output temp. [°C]	98	200	400
Coolant	Heavy water	Heavy water	Santowax

Secondary circuit heat transfer fluid (HTF) (Table 2) depends mainly on required output temperature for district heating or industrial heat production. Water is purposed for lower temperature range and molten nitride salt for higher temperature range. The HTF transfers heat from the primary circuit to the heating circuit itself via the secondary exchanger. The intermediate circuit includes two storage tanks (or one in case of Thermocline design) serving as a thermal energy storage for covering demand peaks. Storage tanks are able to simultaneously dissipate and store heat from the residual power of the fuel, therefore they can be used as residual heat removal system for safety purposes [1].

Table 2: Secondary circuit heat transfer fluids (HTF)

TEPLATOR type	DEMO	FULL SIZE	HIGH TEMP
Secondary circ. HTF	Water	Water / salt	Molten salt
Energy storage type	Thermocline	Therm. / 2-tank	2-tank
Storage media operation range	0-120°C	0-120 / 140-650°C	140-650 °C

The tertiary or heating circuit is then a set of secondary exchanger and pipes, which distribute the heat to the end customer either as steam or hot water, depending on installed distribution network [2].

2.2 Heat distribution, consumption and storage

All CHP (Combined Heat and Power) plants are unique, combining different heat sources and fulfilling different requirements. Hence, a universal approach, considering all parameters and variables is hardly to develop. Some approaches has been described [3],[4],[5], but usually considering only local systems. For sizing of nuclear reactor as HS (Heating Station) or CHP and sizing of TES these circumstances has to be considered:

a. *District heating* is usually for large number of households. Transportation for longer distances is no exception. Consumption is generally more variable following typical daily profile with respect to current weather and other conditions. Small changes are in heat properties (like lower temperature) are not significant for end customer.

b. *Industrial heating* for one or more large industrial complexes located usually in close proximity of heating plant. Consumption is generally less variable – usually heat consumption is defined in advance, on the other hand industrial processes are more dependent on reliability of heat supply and stable heat properties.

c. *Seasonal operation* is generally better for household district heating, where heat consumption is at 10-30 % of winter heat consumption. In this case is better to design TEPLATOR for winter operation only and summer consumption cover with another (ideally some “must have” source like waste burning plant) heat source. In this scenario TEPLATOR operates at full power and variability in consumption is compensated with TES.

d. *Daily operation* is generally better for industrial heating, where consumption profile is already given by industrial processes. This allows full operations during whole year with lower demands on TES. TEPLATOR maintenance and full exchange has to be connected with full-stop or decrease in industrial production.

Other gamechangers, which can strongly affect economics and operation of TEPLATOR are:

1. *Electricity storing (power to heat)* – in times of negative electricity price (caused by overproduction of renewables) some energy could be stored in form of heat and then used later.

2. *Grid stabilization services* – again in times of electricity overproduction – some electricity can be transformed into heat. Economic benefit is not in stored amount of heat, but it is flat pay service for grid operator.

3. *MES (multi energy systems)* mainly combination with solar, biomass and waste burning plants, renewable electricity overproduction and gas in many cases only available high potential heat source, or use of high protentional waste heat as another heat source (e.g. blast furnace waste heat…) with all these a complete mish-mash is created.

3 CONCLUSIONS

Thermal energy storage could provide enough capacity to allow full power operation of nuclear HS or CHP while covering the changes in heat consumption. Construction and design of TES is strongly dependent on primary circuit temperatures as well as on operation temperatures at district heating grid.

Sensible heat storage with molten salt as heat transfer / storing fluid is optimal for operation above 140 °C and stratified hot water storage tank optimal for temperatures below 120 °C.

- Difference in winter / summer consumption has to be solved by design and heating plan / cogeneration plant design.

- Difference in daily consumption (morning and evening peaks) has to be solved using thermal energy storage.

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