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IMPROVEMENT CONFIGURATION OF EXTERNAL MOISTURE SEPARATORS AND REHEATERS IN THE SECONDARY CIRCUIT OF A PWR

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ABSTRACT: *This paper introduces the possibilities of efficiency improvement of a nuclear power plant secondary circuit. Impact of moisture separation and steam reheating parameters were tested by a model calculation. The calculations were made on a reference model with parameters block of the Temelín nuclear power plant. The reference model was modeled in the program GateCycle 5.51.0.r. The paper is summarized by analyzing the optimization calculation results and describing basic recommendations. These analyses demonstrate that it is beneficial to minimize the live-steam use for reheating in the separator-reheater.*
KEYWORDS: *PWR, secondary circuit, nuclear power plant, moisture separator reheater*

INTRODUCTION

Since new units of the Temelín nuclear power plant are planned for construction, a number of organizations work on conception of the new power plant secondary circuit. Compared to new fossil fuel power plants, where we are able to increase initial conditions (i.e. increasing efficiency) by using new materials, the initial conditions of nuclear power plants with the PWR are almost constant, and one of the possibilities to increase efficiency is optimization of a circuit configuration, such as moisture separation-reheating, and feed water heating.

Calculations carried out in the program GateCycle 5.51.0.r were focused on testing of the possibilities of the secondary circuit efficiency improvement, published in literature [1], [2], [3], [4]. The secondary circuit configuration with an external moisture separator and one-stage reheater, which corresponds to current nuclear power plants, was used as a reference model (Figure 1). In this case, a full-speed turbine was considered. The purpose of the paper is presentation of the obtained calculation results.

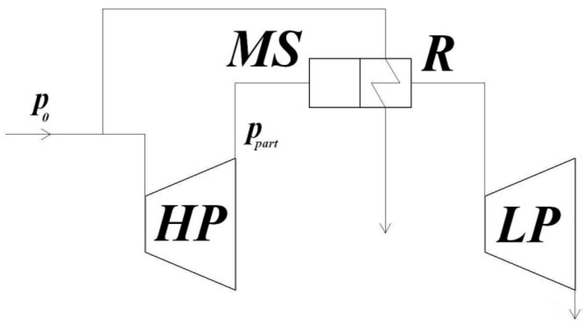

Figure 1. Configurations of wet steam turbines with external moisture separator (MS) and one-stage reheater (R)

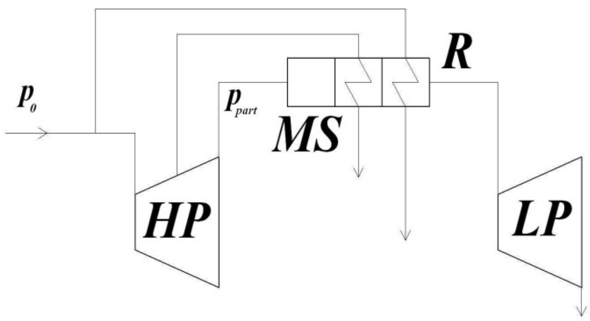

Figure 2. Configurations of wet steam turbines with external moisture separator (MS) and two-stage reheater (R)

At first we examined influence of separator-reheater characteristic properties changes in the reference cycle on overall efficiency. Particularly we were interested in changes of partition steam pressure (between HP and LP turbines), pressure drop in the separator-reheater, exit wetness from the separator, and terminal temperature difference of live steam and superheated exit reheater steam. The results of the last three influences are presented in Sections 2.1, 2.2, 2.3.

Since only a one-stage reheating was available in the reference model, we were also focused on determination of the overall efficiency improvement by a two-stage reheater (with both live and *extraction steam reheating). Therefore, we examined the influence of partition pressure and extraction pressure for the first reheater stage on the overall efficiency. The results of the last one are described in Section 2.4.*

SECONDARY CIRCUIT CONFIGURATION ANALYSES AND OPTIMIZATION

This section describes the results of the particular optimization calculations. In the most cases we examined the influence of certain parameters on overall efficiency of the secondary circuit. It is defined as a ratio of generated electric output to the heat that is supplied by the steam generator.

Influence of pressure drop in separator-reheater on overall cycle efficiency

The pressure drop in the separator-reheater is an important factor affecting the overall cycle efficiency (Figure 3). The pressure drop value for the whole configuration, which equals to a sum of drop in a pipeline, that connects the HP exhaust and the separator-reheater and is considered as $\zeta \cong 0.7\%$ [2] and drop in the whole separator-reheater, is for calculation simplification set only for separator as $\zeta = 4\%$.

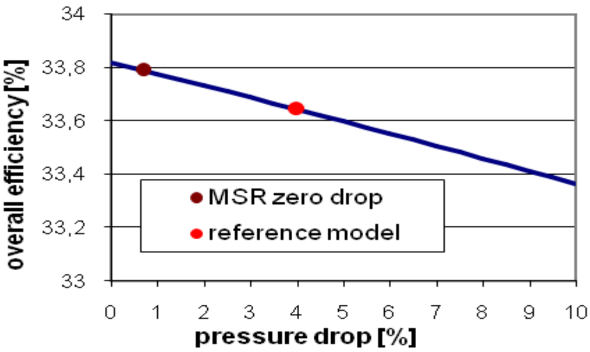

Figure 3. Influence of pressure drop in the separator-reheater to the overall cycle efficiency

Figure 3 shows that 1% of partition pressure drop from 0% to 10% decreases the overall efficiency of the cycle of approximately $\Delta\eta$= (0.04-0.05)%.

Influence of separator exit wetness on overall cycle efficiency

Figure 4 shows the dependence of the secondary circuit overall efficiency on the exit separator wetness. The reference value of the exit separator wetness is considered as 2.4% The figure illustrates that reduction of the exit separator wetness by one percent in range from 0% to 8% increases the circuit overall efficiency of about 0.1%. Obviously, reducing exit wetness enlarges the overall size of separators, that affects the separator pressure drops .

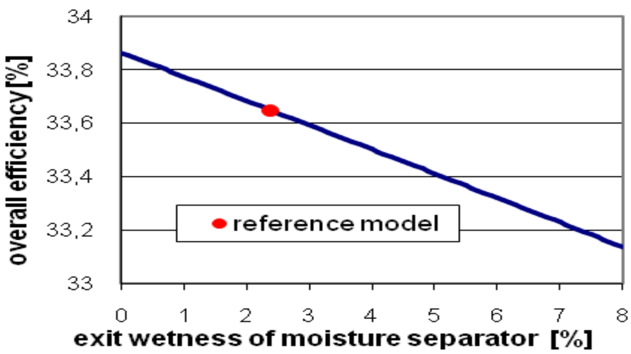

Figure 4. Influence of separator exit wetness to the overall cycle efficiency

Influence of separator-reheater terminal temperature difference on exit separator wetness and overall cycle efficiency

Figure 5 shows an influence of terminal temperature difference (TTD) between live-steam and exit superheated steam in the reheater with one stage reheating on the overall circuit efficiency and LP turbine exit wetness.

Figure 5 shows a significant increase of overall efficiency increasing TTD. This is reached due to the decrease of live-steam amount that is required for the reheater. Thus, the spared live-steam can be used in the HP turbine. The next advantage of the reheater temperature difference increase is reduction of the heat transfer surface. However, the TTD cannot be increased arbitrarily, since the exit wetness in the LP turbines increases proportionally.

If we select as a limit value for our LP turbine exit wetness y_{LPmin} = 10.7 %, maximum value of the reheater TTD =30.7 °C (Figure 5) can be obtained. It corresponds to the reference model. It is also noticeable to use a half-speed turbine at n=1500 rpm. In this case it is possible to set $y_{LPmin} \cong 14\%$ and the TTD can reach the value of 85.6 °C, that enables to increase the overall efficiency of $\Delta\eta$= 0.206%.

A slight increase of the efficiency in the area of TTD from 15°C to 0°C is caused by increase of condensate amount (from reheater) which is used in the regenerative system.

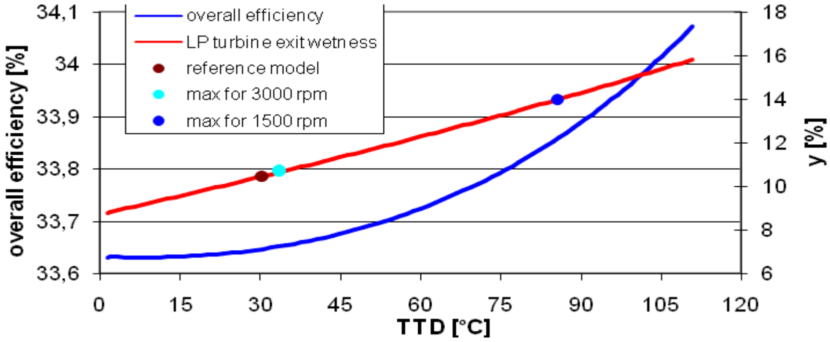

Figure 5 - The influence of Δt in the separator-reheater on LP turbine exit wetness and overall cycle efficiency

Two-Stage Reheating

The analysis of the influence of the second reheater stage addition on the overall efficiency assumes that the exit superheated steam temperature and partition pressure are constant. The value of the partition pressure p_{part} = 602 kPa is obtained from a partition pressure analysis. Within this analysis we apply a GateCycle macro that ensures setting a constant inlet steam generator temperature T = 220.4°C. The aim of this setting is to prevent effect of the exit reheater condensate, which is used in the regenerative system.

A comparison of three various temperature differences between extraction (bled) steam and first stage of reheater outlet steam Δt=10°C, Δt=20°C and Δt =30°C is presented in Figure 6. The inlet steam temperature to reheater is constant. Lower temperature differences are not considered due to the assumption of disproportional enlargement of reheater overall size. Figure 6 shows that the maximum efficiency is reached with smaller temperature difference Δt = 10 °C for the first stage extraction pressure p_e = 1790 kPa. This is primarily due to the reduction of a live-steam amount supplied to the second stage of the reheater, which can be used in the HP turbine.

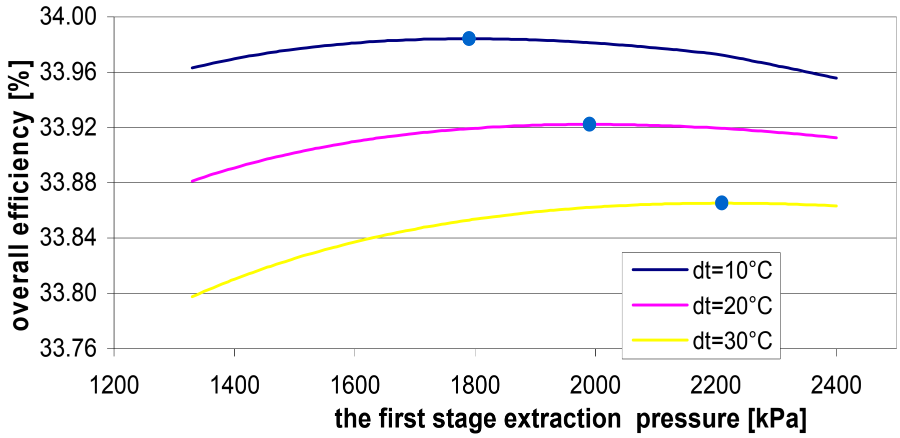

Figure 6 – Dependence of overall efficiency on extraction pressure for the first stage of reheating

CONCLUSIONS

We have made a number of nuclear power plant secondary circuit analyses and optimizations focused on moisture separation and reheating.

For secondary circuit design of a nuclear power plant with PWR these analyses demonstrate that it is beneficial to minimize the live-steam use for reheating in the separator-reheater. On contrary, application of the live-steam in a HP part of turbine can improve overall efficiency.

It can be achieved by using the two-stage reheating. Nowadays this solution, which obviously increases the overall efficiency, is commonly used at existing and new constructed nuclear power plants. Nevertheless, there are some nuclear power plants under construction that do not apply it. Within our analyses we have investigated that for two-stage reheating, taking into consideration the overall efficiency, it is profitable to increase steam temperature in the first reheater stage as high as possible.

In terms of influence of temperature difference between live-steam and superheated steam behind reheater on the value of wetness in the last stages of the LP turbine it is beneficial to use a half speed turbine (1500 rpm). In this case the increase of overall efficiency in the one stage reheating is $\Delta\eta$=0,206% in comparison to a full speed turbine (3000 rpm).

In case of using two-stage reheating for our reference circuit we are able to increase the overall efficiency of $\Delta\eta$=0,337% (for Δt = 10°C and for the first stage extraction pressure p_e = 1790 kPa). Another improvement is possible to achieve by the simultaneous use of a half-speed turbine.

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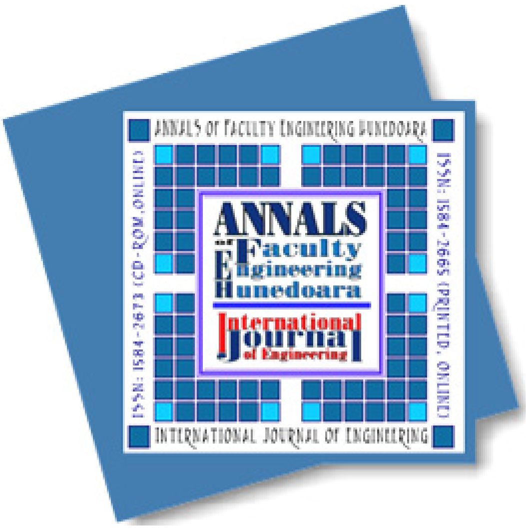

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