Efficiency mark of the two-product power complex of nuclear power plant

V A Khrustalev¹, V M Suchkov²
¹ Yuri Gagarin State Technical University, Saratov, Russia
² Yuri Gagarin State Technical University, Saratov, Russia

E-mail: dante92@bk.ru

Abstract. The article discusses the combining nuclear power plants (NPP) with pressurized water reactors and distillation-desalination plants (DDP), their joint mode of operation during periods of coating failures of the electric power load graphs and thermo-economical efficiency. Along with the release of heat and generation of electric energy a desalination complex with the nuclear power plant produces distillate. Part of the selected steam “irretrievably lost” with a mix of condensation of this vapor in a desalination machine with a flow of water for distillation. It means that this steam transforms into condition of acquired product - distillate. The article presents technical solutions for the return of the working fluid for turbine К-1000-60/1500-2 и К-1200-6,8/50, as well as permissible part of low pressure regime according to the number of desalination units for each turbine. Patent for the proposed two-product energy complex, obtained by Gagarin State Technical University is analyzed. The energy complex has such system advantages as increasing the capacity factor of a nuclear reactor and also allows to solve the problem of shortage of fresh water. Thermo-economics effectiveness of this complex is determined by introducing a factor -" thermo-economic index". During analyzing of the results of the calculations of a thermo-economic index we can see a strong influence of the cost factor of the distillate on the market. Then higher participation of the desalination plant in coverage of the failures of the graphs of the electric loading then smaller the payback period of the NPP. It is manifested more clearly, as it's shown in the article, when pricing options depend on time of day and the configuration of the daily electric load diagram. In the geographical locations of the NPPs with PWR the Russian performance in a number of regions with low freshwater resources and weak internal electrical connections combined with DDP might be one of the ways to improve the competitiveness of NPPs, especially for foreign coastal areas.

Today, the absolute growth of water consumption in the world, the depletion of water resources poses the task of large-scale distillate production for industry, and after conditioning and for consumption purposes. Therefore, it is rational to use relatively cheap nuclear energy (nuclear power plants) for water desalting using desalination plants, which positively proved themselves (c. Shevchenko, NPP with BN-350). At the present time desalination of water on the nuclear power plant basis has not yet received wide development.
As a result of joining to the selection of the power unit turbine of the nuclear power plant with PWR reactors with pressure from 1.0 to 5 bar of the DDP HEU unit (distillation-desalination plants with horizontally-film evaporation units under vacuum), two market products can be obtained: electricity and high quality distillate. Moreover, since the distillate can be stored for a long time without deterioration under certain conditions, such a dual-purpose nuclear power unit can be a consumer-regulator for the daily load diagrams in the United Power Systems (UES) with a growing share of nuclear power plants. This is especially true for hot countries with mainly coastal areas of nuclear power plants and the existing shortage of fresh water.

The following system benefits are achieved:
- The RIU of the nuclear reactor is increased (on thermal power) with the simultaneous participation of the NPP power unit in covering the variable part of the load schedule (daily and weekly);
- On the basis of the heating stream the distillate is produced and the losses in the condenser are reduced;
- The power plant is dual-purpose, with the possibility of deregulation of distillate production and therefore it can work practically according to the given current consumer electric load schedule with a short update period of the dispatching task (highly maneuverable);
- Power plant of NPP with DDP HEU can have increased technical and economic indicators in areas with high cost of fresh water, where it will be in demand and highly competitive.

Below in Table 1 the technical characteristics of the DDP HEU are illustrated by the example of low, medium and high output of the produced series.

| Table 1. Technical characteristics of DDP HEU (RF production) |
|---------------------------------------------------------------|
|                  | DDP-50 | DDP-200 | DDP-700 |
|-------------------|--------|---------|---------|
| DISTILLATE        |        |         |         |
| Productivity, m³/h| 50     | 200     | 700     |
| Mass concentration of salts, mg/l | 1-10 | 1-10 | 1-10 |
| Pressure, MPa     | 0,4    | 0,4     | 0,6     |
| STEAM             |        |         |         |
| To carry out desalination: |        |         |         |
| Pressure, MPa     | 0,15-1 | 0,15-1,4| 0,15-1,4|
| Consumption, t/h  | 3,5    | 14,0    | 45,0    |
| To create and maintain a vacuum: |        |         |         |
| Pressure, MPa, not less than | 0,6    | 1,0     | 1,0     |
| Consumption, t/h  | 0,3    | 1,0     | 3,3     |
| DIMENSIONS OF THE INSTALLATION |        |         |         |
| Length, m         | 15,0   | 9,0     | 38,0    |
| Width, m          | 5,0    | 10,0    | 26,0    |
| Height, m         | 7,4    | 16,5    | 28,0    |

Figures 1 and 2 show the technical solution for connecting desalination plants on the basic thermal schemes of turbines K-1000-60/1500-2 and K-1200-6,8/3000. Some of the selected steam is "irretrievably lost" when mixing the condensate of this steam in a desalination plant with a stream of water for distillation, so in the final analysis, the part of the working fluid in the quality of the product - distillate. The quality of the distillate obtained in most cases is high enough that it can be used back in the cycle after possible additional preparation in the chemical plant. At the same time, the balance of the working fluid remains (figure 1.2). Such application of the DDP was described in the patent specification of the SSTU [1] on the method of blowing the spray pool of nuclear power plants. However, the loss of steam in
this case would have to be compensated with water from the chemical plant, since the DDP will work with the technical water of the reactor compartment with specific properties (low radioactivity).

Figure 1. Principle heat scheme K-1000-60/1500-2 with DDP HEU

Figure 2. Principle heat scheme K-1200-6,8/3000 with DDP HEU, A - use the selection at the outlet of separator reheater with the mode of operation of the turbine below 80 %N, B - used 5 steam extraction of the low-pressure cylinder.
When calculating turbines K-1000-60 / 1500-2 and K-1200-6,8/300 0 for daily loading schedules, the power consumption characteristics were constructed in conditions of connection to desalination plants. In calculations, the change in the NPP unit efficiency was taken into account for various given energy and thermal loads. Let's consider an example (figure 3) of combining the daily schedule of electric load with the desalination load-producing fresh water in the non-deficit hours of the schedule. At the same time, not only the "schedule" of the heat capacity of the reactor is "filled", but also the economics of electricity generation in the night period improves, partially realized on thermal consumption.

In SSTU named after Gagarin Y.A. [2] a method was proposed for estimating the economic efficiency of two and multi-product as well as bi-fuel energy complexes using the "thermo-economic index". This indicator is more logical to apply in situations where the main volume of capital investments is already separately known (to the power unit of the nuclear power plant and the DDP), but an analysis of the effectiveness of their joint use is of particular interest and influence on the result of the systematic and cost factors. The general formula of the thermo-economic index to the case under consideration:

$$\eta_{mf} = \frac{\bar{r}_{np}(N_{np}I_{pr}^{pp} + z(D_0 - D_n)I_{pr}) + \bar{r}_{bas}N_{bas}I_{bas}}{(Q_{bas}\bar{r}_{bas} + Q_{pp}\bar{r}_{np})I_{pr}/q_{a} + D_nz_{yu}}$$

Here $\bar{r}_{np} + \bar{r}_{bas} = 1$ are the relative periods (per 1h) of the power unit operation of the nuclear power plant with the DDP HEUs ($\bar{r}_{np}$) included (for electricity generation only); ($\bar{r}_{bas}$); $I_{pr}^{pp}, I_{bas}^{bas}$- vacation tariffs for electricity from the nuclear power plant's tires in the failed and base period, rub/MWh; $N_{np}, N_{bas}$- electric power of the turbine in the hours of failure and in the base mode, respectively, MW; $D_0$; - production of distillate DDP, t/h; $D_n$- the amount of steam to be taken to the DDP, t/h; $I_{pr}$-selling price for distillate, rub/t; $I_{pr}$-cost of nuclear fuel, rub/ kg UO2; $q_{a}$- calorific value of nuclear fuel, MW * h / kg UO2, taken on the basis of fuel burnup data B (MW d./kg UO2) in the reactor; $z_{yu}$- Specific expected costs in the preparation of the working fluid (distillate) in the chemical plant; Z - the number of desalination plants, pcs. The calculation of the thermo-economic index for the conditions of the heat load schedule of the reactor with a fixed configuration of electrical output for figure 3 is shown in figure 4.

| Number of desalination plants | 5   | 10  | 14  |
|-----------------------------|-----|-----|-----|
| 1200                        | 12,851 | 6,425 | 4,589 |
| 1600                        | 17,134 | 8,567 | 6,119 |
| 2200                        | 23,560 | 11,780 | 8,414 |

Table 2. Selling price for distillate under the boundary conditions, rub/t
Figure 3. The schedule of mode operation of the turbine K-1200-6.8/3000 with the selections with a combined daily schedule rigidly specified by the consumer.

Figure 4. Diagram of changing of thermo-economical index depending on the distillate and electricity's price.
The presented thermo-economical method of analysis does not contradict the further calculation of the known indicators of BHD, CO, ID, etc. in the presence of reliable dynamics of the initial data on the calculation horizon. It is seen from figure 4 that the value of the thermo-economic index $I_{thw}$ has a significant effect, remaining practically indefinite. However, the trend $I_{thw}$ towards growth and, especially, in shallow areas, in places with brackish water resources, observed today in the world by no one of the researchers is contested. In practice, today's $I_{thw}$ values are up to 5000 rubles per ton of water, but in the proposals for limited (packaged) sales volumes, prices up to 10-15 thousand rubles per 1 ton are encountered.

As a result of the accession to the turbine of the NPP with DDP, dual-purpose energy complexes can not only contribute to solving the problem of the world deficit of clean water, but also significantly improve the technical and economic performance of nuclear power plants with water-cooled reactors.

References

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