POSSIBLE EFFICIENCY IMPROVEMENT BY APPLICATION OF VARIOUS OPERATING REGIMES FOR THE COOLING WATER PUMP STATION AT THERMAL POWER PLANT BITOLA

by

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Thermal power plant Bitola is the largest electricity producer in the Republic of Macedonia with installed capacity of 691 MW. It is a lignite fired power plant, in operation since 1982. Most of the installed equipment is of Russian origin. Power plant’s cold end comprised of a condenser, pump station and cooling tower is depicted in the article. Possible way to raise the efficiency of the cold end by changing the operating characteristics of the pumps is presented in the article. Diagramic and tabular presentation of the working characteristics of the pumps (two pumps working in parallel for one block) with the pipeline, as well as engaged power for their operation are also presented in this article.

Key words: power plant, pump, cold end, operating regime, cooling water

Introduction

Two pump stations for circulation of cold water from the condensers through cooling towers are used at the plant. One pump station is mutual for blocks 1 and 2, while the other one is for block 3 with the possibility to serve for future enlargement with another block. Block is comprised of steam generator, turbine, electric generator, condenser, and cooling tower. Pumps are of axial type, vertical, with variable geometry of the working blades. Two pumps, working in parallel, are used on each block. There’s a third (auxiliary) pump that serves both working pumps whenever needed.

Cold water from the cooling tower basin, through open channel that later transforms into two underground pipes (with DN2400 each) is transported into pump station’s open basin (chamber). From this basin, water is taken by the pumps and further transported through one-way valve into main distributive pipeline DN2400. From this pipeline, water flow is divided on two pipes (DN1600) leading to both condenser halves, fig. 1 [1].

Cooling water flows from the condenser, where it is heated up for 9 to 12 °C, through return pipeline (DN1600) and enters the main return pipeline (DN2400). Main pipeline further on, splits on two pipelines (DN1600 each) and enters cooling tower through pipelines DN1800, up to cooling tower’s fill.

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Pump OPV Z-87 MKE is of axial type, one-step, vertical with variable geometry of the blades. It has the following technical characteristics: water volume flow – 3.25 m³/s, specific energy engaged – 206 J/kg, rotation speed – 730 per minute, maximum engaged power – 880 kW, and optimal pump efficiency (η) – 81.5%.

Natural draught cross-flow hyperbolic cooling tower with fill made of asbestos plates is part of the cold end. Numerical calculation of moist air properties [2], and cooling tower theory and performance [3], are partly used in the analysis performed in this article.

Operating regimes should match the recommended operating area of the pump, which is shown with bold line on fig. 2.

Six working blades are mounted on pump’s rotor. The angle of the blades can be changed according to needs, mostly to meet variations in heat load. Change of the angle of working blades can be made manually, while the pump is not in function, or from distance (control room for each block). There are five different angle positions of the blades. This means that each pump has five different working characteristics. Blade angles are: −4°, −2°, 0°, +1°30’, and +4°. Parallel work of two pumps gives the possibility of 15 achievable operating points for each block.

Operating characteristics

Operating characteristics for every pump (according to the angle of the blades) are:

− angle of blades: −4°

\[ e_{p,-4°} = -1731.76 + 1498.49712 q_v - 289.422 q_v^2; \quad \eta_{p,-4°} = -0.3165 q_v^2 + 1.7404 q_v - 1.5983 \] (1)

− angle of blades: −2°

\[ e_{p,-2°} = -363.568 + 472.116 q_v - 95.1688 q_v^2; \quad \eta_{p,-2°} = -0.1754 q_v^2 + 1.0823 q_v - 0.8595 \] (2)

− angle of blades: 0°

\[ e_{p,0°} = -148.17 + 309.6428 q_v - 62.54856 q_v^2; \quad \eta_{p,0°} = -0.164 q_v^2 + 1.0539 q_v - 0.8792 \] (3)
– angle of blades: $+1^\circ 30'$

$$e_{p, +30'} = -472.469 + 510.08 q_v - 90.7424 q_v^2; \quad \eta_{p, +30'} = -0.1482 q_v^2 + 0.9957 q_v - 0.8513 \quad (4)$$

– angle of blades: $+4^\circ$

$$e_{p, +4^\circ} = -385.1995 + 435.54438 q_v - 74.069424 q_v^2; \quad \eta_{p, +4^\circ} = -0.1782 q_v^2 + 1.2181 q_v - 1.2584 \quad (5)$$

where $e_p$ is the specific engaged energy, $q_v$ – the volume flow of water, and $\eta_h$ – the optimal utility pump efficiency.

![Characteristics of OPVZ-87 MKE](image)

**Figure 2. Operating characteristics of axial pump OPVZ-87 MKE operating at TPP-Bitola**

Operating characteristics of the pipeline cooling tower – circulation pump station – condenser – cooling tower equals [4]:

$$E = 256.49226 - 42.183 q_v + 4.598928 q_v^2 \quad (6)$$

*Two pumps working in parallel with same angle of the blades*

Operating characteristics of two pumps working in parallel and with same angle of the blades on both pumps:

$$-4^\circ (2 e_{p, -4^\circ})_{par} = -1731.76 + 749.248 q_v - 72.355617 q_v^2 \quad (7)$$

$$-2^\circ (2 e_{p, -2^\circ})_{par} = -363.568 + 236.058 q_v - 23.7922 q_v^2 \quad (8)$$
\[ 0^\circ \left( 2 e_{p,0^\circ} \right)_{\text{par}} = -148.17 + 154.82 q_v - 15.637 q_v^2 \]  
\[ +1^\circ 30' \left( 2 e_{p,1^\circ 30'} \right)_{\text{par}} = -472.469 + 255.04 q_v - 22.6856 q_v^2 \]  
\[ +4^\circ \left( 2 e_{p,4^\circ} \right)_{\text{par}} = -385.1995 + 217.77219 q_v - 18.517356 q_v^2 \]

The resulting intersection point between the pipeline characteristic and operating characteristics of both pumps working in parallel is the operational characteristics of equivalent pump.

Operational characteristics of the pumps and operational characteristic of the pipeline along with intersections are shown in fig. 3.

![Figure 3. Operating characteristics of two pumps with equal angle of the blades, working in parallel and operating characteristic of the pipeline cooling tower – circulation pump station – condenser – cooling tower](image)

Parameters for the operating points of both pumps in parallel connection and with equal angle of the blades are given in tab. 1.

<table>
<thead>
<tr>
<th>Combination</th>
<th>Volume flow</th>
<th>Specific energy usage</th>
<th>Power usage N [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 2 e_{p,-4^\circ} )_{\text{par}}</td>
<td>5.92</td>
<td>21310</td>
<td>167.984</td>
</tr>
<tr>
<td>( 2 e_{p,0^\circ} )_{\text{par}}</td>
<td>6.37</td>
<td>22940</td>
<td>174.506</td>
</tr>
<tr>
<td>( 2 e_{p,1^\circ 30'} )_{\text{par}}</td>
<td>6.79</td>
<td>24450</td>
<td>182.109</td>
</tr>
<tr>
<td>( 2 e_{p,4^\circ} )_{\text{par}}</td>
<td>7.16</td>
<td>25790</td>
<td>190.350</td>
</tr>
<tr>
<td>( 2 e_{p,4^\circ} )_{\text{par}}</td>
<td>7.59</td>
<td>27310</td>
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</tbody>
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Two pumps working in parallel with different blade's angle

In this case, the combination of two pumps working in parallel, with different angle of the blades on every pump, results in 10 different operating characteristics [5]. The operating characteristic of the pipeline remains unchanged.
Operating characteristics of both pumps, working in parallel with different angle of the blades together with pipeline characteristic are presented on fig. 4.

Parameters of the operating point for both pumps working in parallel while with different blades angle is given in tab. 2.

Relation power plant cold end – climatic curve

From the values of the climatic curve for Bitola [6], for the months of October, November, December, January, February, and March and for a volume flow of water to/from the cooling tower of 27310 m$^3$/h (2 pumps operating in parallel with +4$^\circ$ angle of the blades – maximum power-maximum flow) for certain values of cooling range, dependence of water temperature leaving the cooling tower and wet-bulb air temperature is presented, $t_{w2} = f(t_{m})$. These values are shown in tab. 3.

Values of water temperature leaving the tower indicate that the cooling tower performance is correct. Having in mind that the projected cooling range (temperature difference of water entering and leaving the cooling tower) is 9.2 K [6], we count the number of appearances of cooling range values presented in tab. 3 (10-13 K, respectively) for the cold months of the year (from October till March) and for three values of electric power on the power plant’s generator (215, 220, and 225 MW, respectively). Number of appearances shows how many times certain cooling range matched certain power output, for months October-March and for years 1999-2001 [7-9]. Engaged time in hours shows the operation time of the

\[
-4^\circ \hspace{1cm} -2^\circ \hspace{1cm} (e_{p,-4} + e_{p, -2})_{\text{par}} = -802.09 + 399.13 q_v - 39.165 q_v^2 \\
-4^\circ \hspace{1cm} 0^\circ \hspace{1cm} (e_{p,-4} + e_{p, 0})_{\text{par}} = -581.86 + 312.24 q_v - 30.358 q_v^2 \\
-4^\circ \hspace{1cm} +1^\circ 30' \hspace{1cm} (e_{p,-4} + e_{p, 1^\circ 30'})_{\text{par}} = -985.51 + 437.82 q_v - 39.69 q_v^2 \\
-4^\circ \hspace{1cm} +4^\circ \hspace{1cm} (e_{p,-4} + e_{p, 4^\circ})_{\text{par}} = -837.96 + 397.34 q_v - 33.716 q_v^2 \\
-2^\circ \hspace{1cm} 0^\circ \hspace{1cm} (e_{p,-2} + e_{p, 0})_{\text{par}} = -257.22 + 194.34 q_v - 19.476 q_v^2 \\
-2^\circ \hspace{1cm} +1^\circ 30' \hspace{1cm} (e_{p,-2} + e_{p, 1^\circ 30'})_{\text{par}} = -458.75 + 257.05 q_v - 24.001 q_v^2 \\
-2^\circ \hspace{1cm} 4^\circ \hspace{1cm} (e_{p,-2} + e_{p, 4^\circ})_{\text{par}} = -377.66 + 226.37 q_v - 20.847 q_v^2 \\
0^\circ \hspace{1cm} +1^\circ 30' \hspace{1cm} (e_{p, 0} + e_{p, 1^\circ 30'})_{\text{par}} = -299.91 + 202.29 q_v - 19.024 q_v^2 \\
0^\circ \hspace{1cm} +4^\circ \hspace{1cm} (e_{p,0} + e_{p, 4^\circ})_{\text{par}} = -227.02 + 177.06 q_v - 16.554 q_v^2 \\
+1^\circ 30' \hspace{1cm} +4^\circ \hspace{1cm} (e_{p, 1^\circ 30} + e_{p, 4^\circ})_{\text{par}} = -379.17 + 223.35 q_v - 19.721 q_v^2
\]
pumps for each pair “cooling range – power”. Number of appearances, sorted by power and range are shown in tab. 4.

Table 2. Operating parameters of both pumps working with different blade angles

<table>
<thead>
<tr>
<th>Combination</th>
<th>Volume flow $Q_v$ [m³/s]</th>
<th>Specific energy usage $e_v$ [J/kg]</th>
<th>Height $H$ [m]</th>
<th>$\eta_{p1}$ [%]</th>
<th>$\eta_{p2}$ [%]</th>
<th>Power usage $N$ [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>($e_p,-4,+e_p,2$)</td>
<td>6.15</td>
<td>22150</td>
<td>171.076</td>
<td>17.44</td>
<td>78</td>
<td>82</td>
</tr>
<tr>
<td>($e_p,-4,+e_p,0$)</td>
<td>6.38</td>
<td>22970</td>
<td>174.547</td>
<td>17.79</td>
<td>78</td>
<td>80</td>
</tr>
<tr>
<td>($e_p,-4,+e_p,10$)</td>
<td>6.57</td>
<td>23650</td>
<td>177.753</td>
<td>18.12</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td>($e_p,-4,+e_p,4$)</td>
<td>7.82</td>
<td>28150</td>
<td>207.424</td>
<td>21.14</td>
<td>79</td>
<td>30</td>
</tr>
<tr>
<td>($e_p,2,+e_p,0$)</td>
<td>6.58</td>
<td>23700</td>
<td>178.296</td>
<td>18.18</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>($e_p,2,+e_p,10$)</td>
<td>6.77</td>
<td>24370</td>
<td>181.443</td>
<td>18.49</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>($e_p,2,+e_p,4$)</td>
<td>6.99</td>
<td>25130</td>
<td>186.275</td>
<td>18.99</td>
<td>81</td>
<td>78</td>
</tr>
<tr>
<td>($e_p,0,+e_p,30$)</td>
<td>6.97</td>
<td>25090</td>
<td>185.848</td>
<td>18.95</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>($e_p,0,+e_p,4$)</td>
<td>7.18</td>
<td>25850</td>
<td>190.750</td>
<td>19.44</td>
<td>81</td>
<td>79</td>
</tr>
<tr>
<td>($e_p,10/+e_p,4$)</td>
<td>7.37</td>
<td>26550</td>
<td>195.466</td>
<td>19.93</td>
<td>82</td>
<td>77</td>
</tr>
</tbody>
</table>

* Combination is not possible since $\eta_p$ of the second pump is outside of recommended operating area.

Table 3. Dependence of $t_{a2}$ = $f(t_{a1})$ for $Q_v = 27310$ m³/h

<table>
<thead>
<tr>
<th>$t_{a1}$ [°C]</th>
<th>$-15$</th>
<th>$-10$</th>
<th>$-5$</th>
<th>$0$</th>
<th>$5$</th>
<th>$10$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta t_w$ [°C]</td>
<td>10</td>
<td>21.8</td>
<td>23.2</td>
<td>24.6</td>
<td>26.0</td>
<td>27.4</td>
</tr>
<tr>
<td>11</td>
<td>23.2</td>
<td>24.4</td>
<td>25.5</td>
<td>26.7</td>
<td>27.9</td>
<td>29.0</td>
</tr>
<tr>
<td>12</td>
<td>24.1</td>
<td>25.4</td>
<td>26.6</td>
<td>27.8</td>
<td>29.0</td>
<td>30.2</td>
</tr>
<tr>
<td>13</td>
<td>25.1</td>
<td>26.2</td>
<td>27.4</td>
<td>28.5</td>
<td>29.6</td>
<td>30.7</td>
</tr>
</tbody>
</table>

Required volume flow of cold water for reaching the mentioned power of the plant and cooling ranges is presented in tab. 5.

In order to achieve the required volume flow of water to match the electricity production, we propose using of one combination (out of 15 possible combinations) for parallel connection of pumps. To cover the entire range of values for volume flow of water presented in tab. 5, possible combinations of pump’s connections are shown on tab. 6 with the corresponding electricity consumption of the pumps (engaged power).

Table 4. Number of appearances/pump’s engaged time in hours, for six months of the year and for corresponding power on the generator shaft

<table>
<thead>
<tr>
<th>$N$ [MW]</th>
<th>$\Delta t_{a1}$ [K]</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>215</td>
<td>10/132</td>
<td>30/397</td>
<td>30/397</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>220</td>
<td>4/53</td>
<td>55/728</td>
<td>50/662</td>
<td>10/132</td>
<td></td>
</tr>
<tr>
<td>225</td>
<td>0</td>
<td>62/423</td>
<td>37/490</td>
<td>30/397</td>
<td></td>
</tr>
</tbody>
</table>

Results and discussions

From the values presented in tab. 4 and tab. 6, we can determine the consumption of electricity in the period of 6 months.
Possible improvements of energy efficiency are obvious and easily achievable since, from technical point of view, it is very easy to change the angle of the blades even when the pumps are in operation.

However, the analysis presented in the chapter Relation power plant cold end – climate curve showed that one combination of pump’s parallel operation \( (e_{p,+4^\circ}, e_{p,+4^\circ}) \) is not possible since the optimal pump efficiency of the pump with angle of blades \(+4^\circ\) is far outside recommended operating area of the pump and hence will require greater engaged power.

**Conclusions**

Two axial pumps, working in parallel transport cooling water for each block’s cold end at TPP Bitola. By varying the angle of the blades on any of the pumps, a total of 15 different operating characteristics are possible. This means 15 different operating points (cross points between the curves of pump’s operating characteristics an characteristic of the pipeline) can be achieved. As a result, water flow can range from 5.92 m³/s to 7.59 m³/s, while the power consumption varies from 1274.96 kW to 1907.83 kW, respectively. Since TPP Bitola became fully operational (more than 25 years ago), the only working combination of the pumps is the one with same angle of the blades \(+4^\circ\), with maximum volume flow and maximum power consumption. As a logical conclusion of everything said above, there is a space for efficiency improvements at plant’s cold end, related to pump station’s optimal operating regime, mainly by matching the required volume flow through adjustments of the angle of the pump's blades. That would lead to substantial savings in own electricity consumption, especially in “colder” months of the year.
Nomenclature

\( E \) – pipeline characteristics, \([\text{Jkg}^{-1}]\)
\( e_p \) – specific engaged energy
\( N \) – engaged power, \([\text{kW}]\), \([\text{MW}]\)
\( N_p \) – electricity usage of the pump, \([\text{kW}]\)
\( n \) – rotation speed of pump, \([\text{min}^{-1}]\)
\( q_v, Q_v \) – volume flow of water, \([\text{m}^3\text{s}^{-1}]\), \([\text{m}^3\text{h}^{-1}]\)
\( t_{vt} \) – wet bulb temperature of the ambient air, \([\text{°C}]\)
\( \Delta t_w \) – temperature difference between of water entering/leaving the cooling tower, \([\text{K}]\)
\( t_{w1} \) – temperature of water entering the cooling tower, \([\text{°C}]\)
\( t_{w2} \) – temperature of water leaving the cooling tower, \([\text{°C}]\)
\( \eta_p \) – optimal pump efficiency, \([\%]\)

References

[5] ***, Guarantee and Normative Measurements of the Cooling Towers for Block-I and Block-II of TPP Bitola (in Macedonian), Faculty of Mechanical Engineering, Skopje, 1985

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