A NEW NON-INVASIVE AIR-COOLED CONDENSER MONITORING METHODOLOGY TO INCREASE PERFORMANCE

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Abstract
Air-Cooled Condenser performance can significantly affect WTE plants bottom-line. Most of the possible ACC performance improvement solutions require some important capital costs (fin tubes replacement, fans blades or motor upgrade, additional ACC cells, addition of preventive air re-circulation panels, etc...). A new low cost tool and methodology is now allowing to gain a very detailed understanding of ACC behaviours and to optimize ACC operations and cleaning schedules. This article is illustrated by the case-study of a WTE located in the south of France (equipped with a 5.5 MW GE condensing turbine), where the facility performance was strongly limited by its ACC, and where additional turbine generator output of more than 1 MW were achieved.

1. Introduction
The reference plant is equipped with a 35 t/h, 5.5 MW GE condensing turbine. In 2003, the average production of the unit was 2.58 MW (while the unit was on-line). This is less than 50% of the design capacity. The maximum hourly production achieved in the course of the year was 4.1 MW (fig. 1). One of the main limiting factor for increasing power generation was the 17 year old Air-Cooled Condenser unit, that was designed for a 0.45 b.a. pressure at 25°C outside temperature. The air cooled condenser is equipped with four fans that constantly operate at high blades pitch conditions.
As a result, the turbine load was most of the time in the 20-25 t/h range, far below the design turbine capacity of 35 t/h. This was the main cause for the low turbine output.

2. ACC modeling

2.1 Theory
A simulator of the turbine – ACC module was built.

ACC modeling
A simplified assumption was made (and later verified against actual plant operations): the air flow was considered as constant (all 4 fans are running all the time at high blades pitch). With this assumption made, the following equations were used to model the ACC:

- \((T_{sat} - T_{air \; inlet}) \times e^{NTU} = (T_{sat} - T_{air \; outlet})\)
- \(Q_{steam} \times H_{steam}(T_{sat}) \times X_{steam}(T_{sat}) = Q_{air} \times C_{air} \times (T_{air \; outlet} - T_{air \; inlet})\)

Turbine modeling
The turbine was modelled according to the isentropic efficiency method.

2.2 Modeling tools
The theory described above was automated in a computerized program. The program computes expected T/G output and Condenser Vacuum values when provided with outside air temperature, turbine steam flow and ACC cleanliness factor.

First, the model is configured and tuned to reflect the actual plant operations. The model was tested against field values in numerous test runs. The results from one test run are presented in the table below:

<table>
<thead>
<tr>
<th>Actuals</th>
<th>Model</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/G output</td>
<td>3.188 kW</td>
<td>3.193 kW</td>
</tr>
<tr>
<td>Vacuum</td>
<td>0.46 b.a.</td>
<td>0.458 b.a.</td>
</tr>
<tr>
<td>Outside air temperature</td>
<td>29.2 °C</td>
<td>29.2 °C</td>
</tr>
<tr>
<td>T/G flow</td>
<td>24.6 t/h</td>
<td>24.3 t/h</td>
</tr>
<tr>
<td>Condenser cleanliness</td>
<td>N/A</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 1: Model vs. Actuals test results
Nota: Models inputs are in blue. Models output are in red. Directly available measures are in violet. Computed values from other field measures are in green.

Once the program has been configured, it is used to:
1) compute the cleanliness factor of the ACC (with an iterative methodology).
2) and then to forecast the T/G output under different operating scenarios. For example, the program can compute the achievable T/G output with a different operating procedure or with a cleaned ACC.

3. ACC operations analysis

2.2 Rise in outside air temperature
The impact of a 10°C ambient temperature rise on the plant operation was assessed for the following initial operating conditions:
- Vacuum: 0.5 b.a
- Outside temperature: 25°C

The rise in outside temperature can translate into:
- A rise of the condenser pressure if the turbine steam flow remains identical, or
- A lower turbine steam flow if the condenser vacuum remains unchanged, or
- Any combination of these two situations.

The actual impact on the T/G output was:
- A loss of production of 1200 kW for a constant vacuum operation (which correspond to a steam flow reduction of 7.5t/h).
- A loss of production of 450 kW for a constant steam flow operation (which correspond to a 0.28b increase in condenser vacuum).

There is a 750 kW difference between the two different operating modes.

The conclusion of this study is that the priority must be given to the maximisation of the turbine flow at the expense of vacuum. Vacuum can be optimised when there is no trade-off with steam flow, ie when the maximum turbine capacity is reached.
2.3 Upgrade of the operating procedure
A new operating procedure was implemented. The idea was to run at a higher vacuum value, in order to maximize the flow into the turbine and to increase T/G output. The ACC rupture disk rating and turbine trip vacuum value were checked and found to be above 1.2 ba. The high vacuum alarm on the DCS was increased to 0.8 b.a and operators were asked to allow the turbine to run around 0.7 b.a. These settings still allowed for the failure of an ACC fan without any risk of tripping the turbine or blowing the ACC rupture disk.

The new procedure, that had been established with the help of the computerized model was field tested under close scrutiny before actual implementation. Test results were identical to simulation results.

2.4 Benefits of the new operating procedure
The benefits of the new operating procedure are very dependent on the quality of the procedure implementation in the field. $180k a year in increased electrical revenues could be gained with the new procedure being constantly followed by operators. Actual results for the 2 first months showed a production increase of 500 MWh per months (700 kW average increase).

4. ACC cleanliness monitoring

2.2 Non invasive cleanliness factor monitoring
The modelling tools allow to use widely available parameters to estimate the ACC cleanliness. It is a non-invasive method that is very reliable and that does not require expensive test instrumentation to be installed. The key of the system is that the monitoring tool uses transfer functions that translate as-is plant instrument readings into actual T/G output. Even if the instrumentation is not precisely calibrated, the tool provides correct values of:
- T/G output,
- Condenser vacuum
- Condenser cleanliness.

The list of the required plant instrumentation readings to compute the condenser cleanliness is short and widely available in any plant:
- air temperature (or circulating water temperature for water cooled condensers),
- turbine steam flow and inlet steam temperature,
- major parameters to estimate turbine extraction flows such as DA pressure

The first step is to convert these readings to a relative condenser cleanliness factor, and to monitor the cleanliness factor.

Different scenarios of condenser cleanings can then be assessed to established the optimum cleaning schedule. The tool provides T/G output and condenser vacuum estimation for each scenario. The cost of a condenser cleaning and the benefits of increased T/G production can then be balanced to establish the best cleaning schedule. non-invasive and

2.2 Implementation of an in-house cleaning program
When applied to the reference plant, the cleanliness monitoring program gave the following results:
- Initial cleanliness was computed at 0.54 (against 0.9 design cleanliness)
- It was decided to implement an in-house ACC pressurized water cleaning program and to monitor the results of this cheap and easy to implement program before assessing contracted cleaning methods such as acid cleaning. Pressurized water cleanings were done during T/G downtime or during periods of reduced T/G load when a fan could be turned off. The wash was done from below, with a great care taken in keeping the cleaning water flow perpendicular to fins to avoid any bending.
- Pressurized water cleaning is able to bring the condenser cleanliness factor up to 0.68, which correspond to an increase of 1100kW at 20°C and 0.4b vacuum.

2.2 Benefits of the cleaning program
A summary of the first six months of the condenser cleaning program is shown in fig 3.

Total benefits of the cleaning program were estimated between $160k and $290k per year.

Fig. 3 Cleaning Program Benefits

<table>
<thead>
<tr>
<th>Date</th>
<th>Efficiency factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 2003</td>
<td>0.54</td>
</tr>
<tr>
<td>June 12 2004</td>
<td>0.64</td>
</tr>
<tr>
<td>June 18 2004</td>
<td>0.68</td>
</tr>
<tr>
<td>July 7 2004</td>
<td>0.65</td>
</tr>
</tbody>
</table>

$180k a year in increased electrical revenues could be gained with the new procedure being constantly followed by operators. Actual results for the 2 first months showed a production increase of 500 MWh per months (700 kW average increase).
5. Conclusions

Thanks to a good understanding of the ACC behaviour and to a non-invasive cleanliness monitoring, total yearly benefits of approximately $400k are on the verge to be achieved in the reference plant. No capital investment was required to implement two high impact performance improvement solutions that allowed to gain more than 1 MW on the output of a 5.5 MW turbine:

- An in-house ACC pressurized water wash program
- A new turbine/ACC operating procedure.

References
