



Investigating to Improving the Air-Cooled Condensers Performance (ACC) in Behbahan C.C.P.P

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ABSTRACT

Combined cycle power plants are among the most efficient methods of electricity generation, utilizing a combination of gas and steam cycles to enhance energy efficiency. A crucial component in these power plants is the air-cooled condenser (ACC), which plays a significant role in cooling and converting the exhaust steam from the steam turbine back into water. However, the efficiency of air-cooled condensers is highly influenced by environmental conditions, particularly air temperature, humidity and wind speed, which can lead to a reduction in the overall efficiency of the power plant. This paper examines methods for improving the performance of air-cooled condensers in combined cycle power plants. It first addresses the challenges associated with the design and operation of these condensers under varying environmental conditions. Next, innovative solutions such as changing the angle of the blades, creating water spray paths at the inlet of the blades, and the washing of fin tubes and the evaluation of wind speed reduction methods are analyzed. The findings indicate that by adopting these strategies, it is possible to enhance the thermal efficiency of the power plant, reduce water consumption, and minimize operational costs. Recommendations for future research in the optimization and development of cooling technologies are also provided.

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1. Introduction

Combined cycle power plants are among the most efficient methods for electricity generation, utilizing both gas and steam cycles to optimize energy use. A key component in these power plants is the air-cooled condenser (ACC), which plays a critical role in cooling the steam exiting the steam turbine and converting it back into water. While air-cooling systems offer significant water-saving advantages, especially in arid regions, their performance tends to decline under specific climatic conditions, particularly during high temperatures and strong winds (Bekker et al. 2022).

The air-cooled condenser of the Behbahan combined cycle power plant, operational since 2015, is designed to function within a temperature range of -4°C to 50°C and performs well under normal ambient conditions. However, over time, rising temperatures and strong winds have caused the vacuum pressure in the condenser to increase up to 400 mbar, leading to a reduction in the steam unit's power output. Similar to other power plants with air-cooled condensers, this performance degradation has affected the overall efficiency of the plant (Behbahan CCPP Documents).

Numerous studies have demonstrated that air-cooled condensers experience performance losses when exposed to crosswinds, particularly in areas with high wind speeds. It is evident that the performance of the fan array fluctuates with changing wind conditions, as the inflow and outflow of air through the fans are determined by these external factors. Consequently, both the heat transfer capacity between the turbine exhaust and the ambient air, as well as the back pressure of the power plant, are affected (Duvenhage and Kröger 1996). Due to this sensitivity to wind conditions, the performance of direct air-cooled power plants often deviates from the design specifications during adverse wind conditions. Therefore, it is crucial to investigate the impact of wind on power plant performance and understand the

underlying principles of this influence (He et al. 2013 , Marincowitz et al. 2023).

In recent years, to enhance the efficiency of these systems, the use of water spray cooling systems has been proposed as a simple and cost-effective solution (Zeng et al. 2023). This approach, particularly during hot summer days, helps to increase steam turbine efficiency and mitigate the issues associated with high ambient temperatures.

In this paper, to identify an effective and optimal solution for improving the performance of the air-cooled condenser at the Behbahan combined cycle power plant, we investigate the implementation of water spray cooling and fin tube cleaning systems. The results are compared with performance curves, and the economic feasibility of these solutions is evaluated based on the specific conditions of the power plant.

This study aims to enhance the efficiency and stability of electricity generation in combined cycle power plants operating under similar climatic conditions.

2. The Impact of Inlet Airflow Behavior on Cooling System Performances

One of the critical parameters affecting the cooling capacity of the ACC cooling system is the behavior of the air drawn into the ACC fan inlet. While the inlet should be designed to minimize flow separation and ensure uniform distribution, the amount of airflow disturbance increases as wind speed rises. Given the importance of this issue, various studies have been conducted to enhance the cooling capacity of the ACC system by examining the losses in the fan inlet section and analyzing the airflow behavior.

Wind flow (Figure 1) can significantly reduce fan efficiency, leading to a decrease in megawatt output and lowering the reliability of key mechanical components, such as the gearbox, in the moving fans.

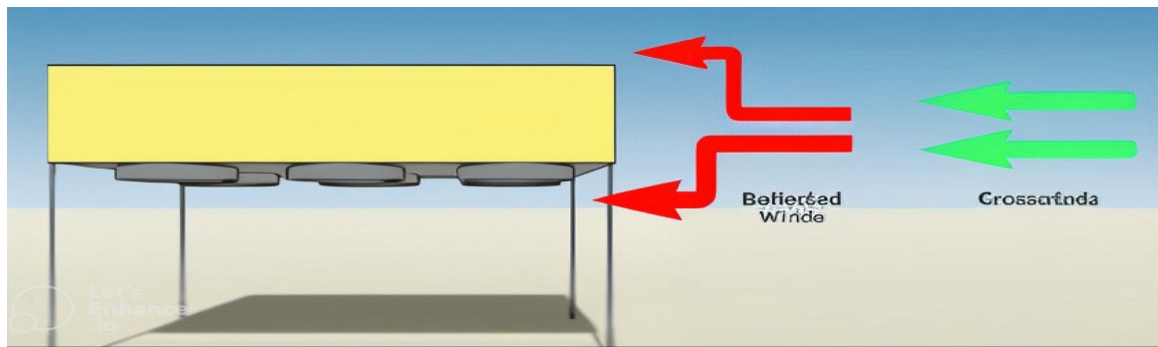


Figure 1. Cross Wind & Deflected Wind

Wind speed fluctuations can cause deviations in airflow, leading to an increase in the acceleration of wind flow. This acceleration causes flow separation at the fan inlet, resulting in an asymmetric distribution of airflow. As wind speed increases, the airflow becomes more turbulent, and the likelihood of the fan experiencing the stall phenomenon rises. Typically, fans are installed at a height of 35 to 40 meters above the ground, and wind power increases with height. For example, when wind speed is 3 meters per second at ground level, it can reach 12 to 15 meters per second at a height of 30 meters.

During normal fan operation, air enters around the fan blades and exits vertically. However, when the fan operates in high wind conditions, the inlet pressure decreases due to the wind

direction, reducing the airflow through the fan. This results in increased mechanical stress on the fan and gearbox assembly. As the airflow through the fan decreases, the cooling capacity of the fan and consequently the condenser also diminishes. If wind speeds increase further, they can raise the back pressure, reducing the pressure at the fan inlet and impeding airflow. In severe cases, the airflow through the fan can drop to zero, leading to a stall, which can damage the fan and its mechanical components.

In the diagrams below, the operation of the fan is shown under normal conditions (Figure 2), in high wind conditions (Figure 3), and in strong wind conditions (Figure 4). As depicted in (Figure 4), airflow through the fan reaches zero due to strong winds, causing a stall and potential mechanical failure (Maulbetsch and DiFilippo 2008).

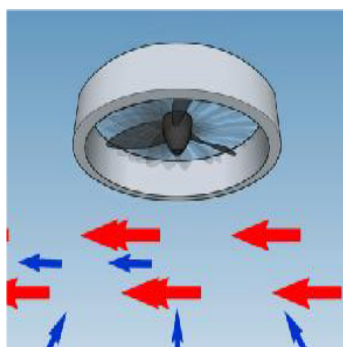


Figure 4- Strong Wind

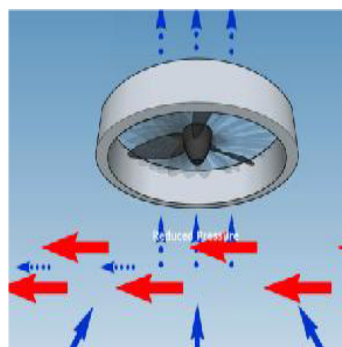


Figure 3- High Wind

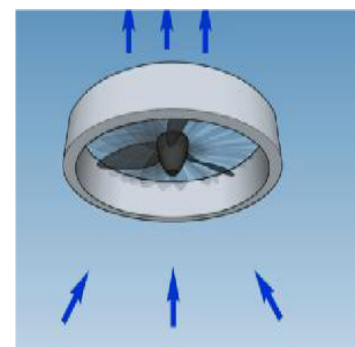


Figure 2- Normal State of the Fan

One solution to mitigate the effects of wind in the ACC system is the use of wind screens (Figure 5). These screens act as barriers against wind flow, reducing wind speed and ensuring a more even distribution of airflow at the fan

inlet. Wind screens can be installed in two types: fixed and mobile. Due to their economic viability, wind screens are currently installed in many power plants around the world.

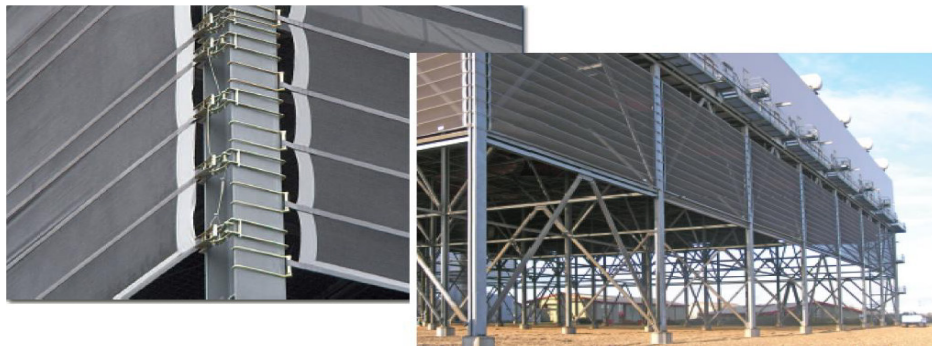


Figure 5. Molle wind Screen Implemented in some European Power Plants

As you can see in the (Figure 6), the back-pressure changes of the condenser are shown in two modes with and without the wind screen in Kings Lynn and Corryton power

plants in England. For example, at a wind speed of 14 meters per second, the wind creates a difference in the back pressure of the condenser of approximately 20 millibars.

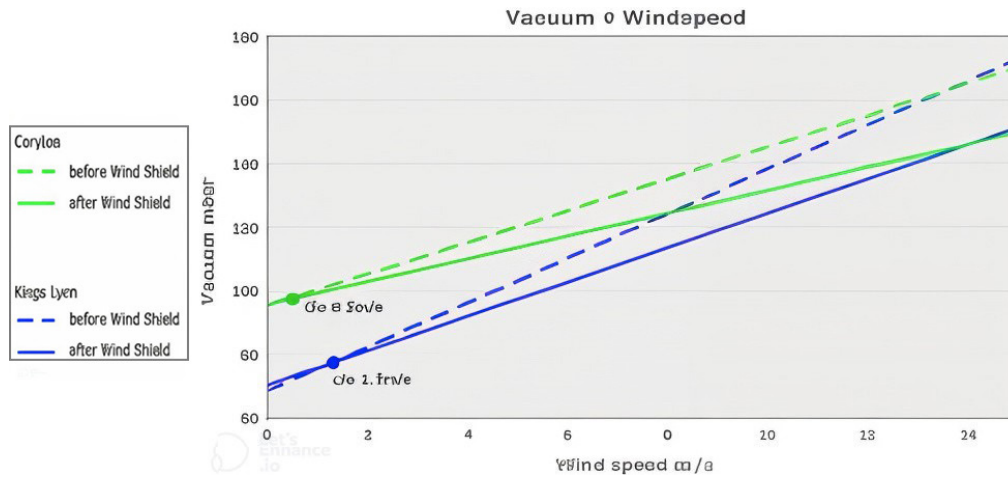


Figure 6. Two Modes for Back-Pressure Changes with and without the Wind Screen

Reducing the effects of increasing wind speed by installing a guide, as mentioned, is one of the major factors affecting the performance of the air condenser system (wind speed and direction), generally, the wind will have a negative effect on the performance of the condenser.

According to (Figure 7), this phenomenon increases the temperature of the air entering the fan, leading to a decrease in the cooling system's performance due to the recirculation of hot air back into the fan. The most significant negative impact of this phenomenon occurs on the fans positioned downstream of the wind flow, particularly along the side walls of the

deltas (Yang et al. 2011). Therefore, to enhance the performance of the fans against this issue, the implementation of a retaining wall or guide, as shown in (Figure 8), is recommended.

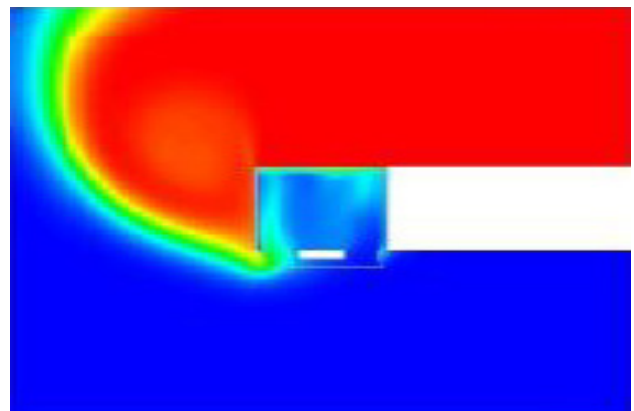


Figure 7. A View of the Thermal Effect on the Fan

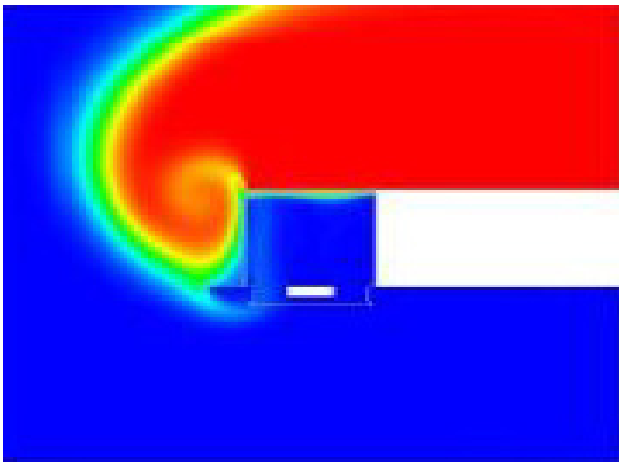


Figure 8. A View of the Thermal Effect on the Fan with a Retaining Guide

3. Comparison of Condenser Performance with the Back-Pressure Curve

As the ambient temperature rises, the subcooling temperature (the difference between the steam input and condensate output temperatures) decreases, leading to a reduction in condenser efficiency. For instance, in (Table 1), the actual operating conditions of the system are compared with the Back-pressure performance curve at 110% of the cycle (where the warranty conditions at 110% of the cycle are set at 12 kPa). Additionally, the gas units are operating in Base Load mode to maintain the steam flow as close as possible to the design conditions.

Table 1. Comparison between Actual Condenser Vacuum and Performance Curve

Deviation of the Vacuum from the Curve	Back Pressure Curve(mbar)	Condenser Vacuum (mbar)	Wind Speed m/s	Temperature	Hour	Date
OK	170	177	2.6	33	08:35	01/09/2021
OK	210	207	1.3	38	10:50	01/09/2021
30 mbar deviation	180	216	5	35	03:10	02/09/2021
50 mbar deviation	300	352	8.3	45	10	27/07/2021
50 mbar deviation	330	386	13	48	12	27/07/2021
30 mbar deviation	270	306	4.8	44	12	26/07/2021
Run Back	300	405	10	45	16:30	04/09/2021

Based on the recorded data and plotting it on the power plant performance diagram (Figure 9) (Behbahan CCPP Document), it is observed that under normal conditions, when the system operates with a wind speed below 4 meters per

second, it follows the expected performance curve. However, as wind speed increases, the system's behavior becomes unpredictable, leading to conditions that approach the runback set point (400 mbar) (Li et al. 2018).

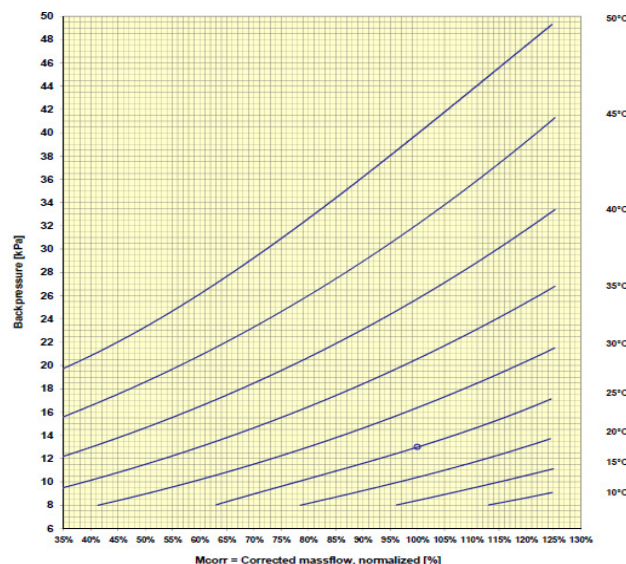


Figure 9. Behbahan CCPP Performance Curve

4. Checking the Implementation of the Water Spray Plan

Due to issues with the main cooling system during hot seasons and specific weather conditions, optimization suggestions were made. One of these suggestions was the implementation of a misting system, which was applied to twelve counterflow fans. This proposal was examined and analyzed from mechanical, electrical, water consumption, and financial perspectives. After performing the necessary calculations, a preliminary design was prepared, and it was decided to implement the misting system on one of the fans using 100 nozzles, each with a size of 0.4 mm.

Upon installation and testing of these 100 nozzles, it was found that at a pressure of 50 bar, the water consumption was approximately 9 liters per minute (Figure 10). Since the ACC washing skid was used for the misting system and this skid could generate a pressure of 50 bar with a flow rate of 180 liters per minute, it was decided to increase the number of nozzles from 100 to 200 and change their size from 0.4 mm to 0.7 mm.

After the misting system was implemented on twelve counterflow fans and tested, the following data (Table 2) were obtained for the system's flow rate and pressure.

Table 2. Water Consumption for the Implementation of the Fogging Plan

Water pressure (bar)	Water consumption (lit/min)
40	130
45	155
47	164
50	180

Considering that the nozzles used at a pressure of 45 bar have the best efficiency, so the tests were tried to be performed at this pressure.

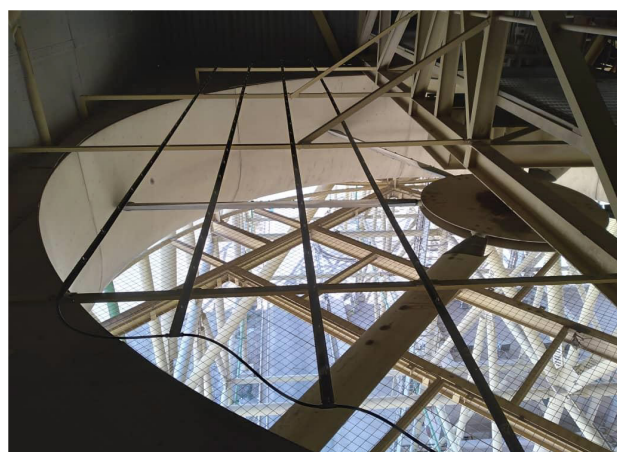


Figure 10. Plan Implemented in Behbahan CCPP

(After repeated tests and data mining in the obtained numbers, this result was obtained:

- Depending on the weather conditions, the temperature inside the fan chamber will decrease between 1.5 and 2.5 degrees Celsius.
- The humidity inside the fan compartment increases between 4 and 20% depending on the humidity of the environment.
- In different conditions, the vacuum pressure of the condenser decreases by 10 mbar (2%) on average.
- According to the formulas presented in the diagram below (Figure 11), in the range between 340 and 400 mbar condenser pressure, with a decrease of 10 mbar, the power of the steam turbine increases by approximately 70 kW.

In addition to the vacuum pressure of the condenser, the speed and direction of the wind also affects the efficiency of the misting system. Therefore, it is suggested to first think about measures to reduce the effect of wind and then focus on the issue of fogging.

In the worst weather conditions, the wind blows from the north and due to the dry nature of this wind, it reduces the humidity to 5% or less. In such a situation, the temperature exceeded 50 degrees, which made the fogging system ineffective (Xiao et al. 2018).

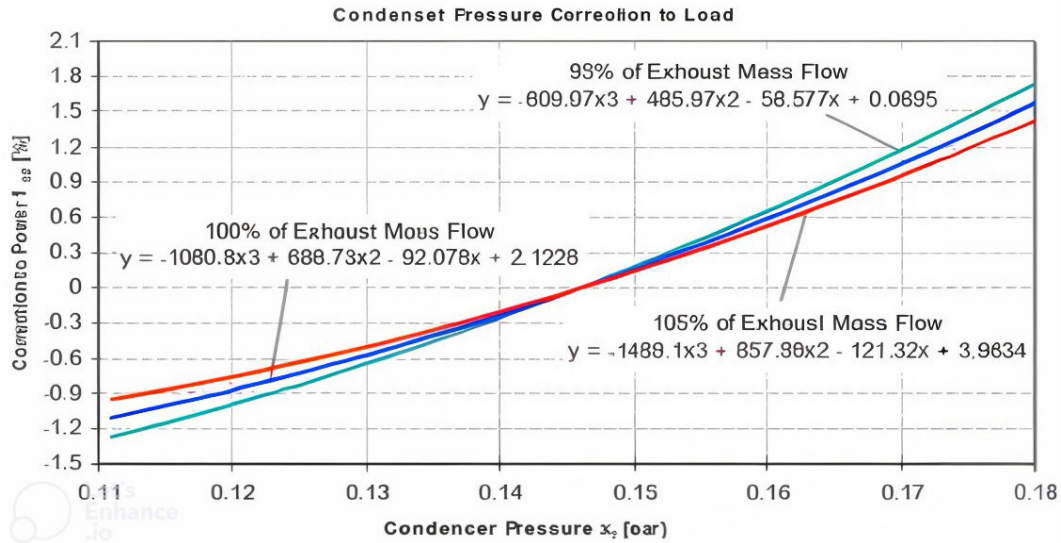


Figure 11. Condenser Pressure Correction to Load

5. Blade Angle Adjustment Testing

A test was conducted on a fan to change the blade angle, adjusting it from 6.4 degrees to 13 degrees based on the manufacturer's recommendation. However, without altering the fan speed, this adjustment was not feasible. It was determined that the limitations of the electric motor, along with the excessive vibration generated, prevented this adjustment from being successfully implemented.

Table 3. Fan Information

After the Change	Before the Change	
13 degrees	6.4 degree	Fan angle
500 m ³ /h	500 m ³ /h	Air flow rate
1270 rpm	1490 rpm	100% RPM
190 A	190 A	Nominal current of electric motors
180-195 A	140-160 A	Current of electric motors in 110% rotations

6. Investigating the Washing of Fin Tubes

The ACC washing system is commonly implemented in power plants worldwide. This system uses a positive displacement pump, operating at pressures between 40 and 80 bar, in combination with valve controls,

to wash fin tubes efficiently and maintain optimal performance. (Figure 12) illustrates the implemented ACC washing system plan in the power plant, demonstrating how this method ensures the desired cleaning quality for the fin tubes.

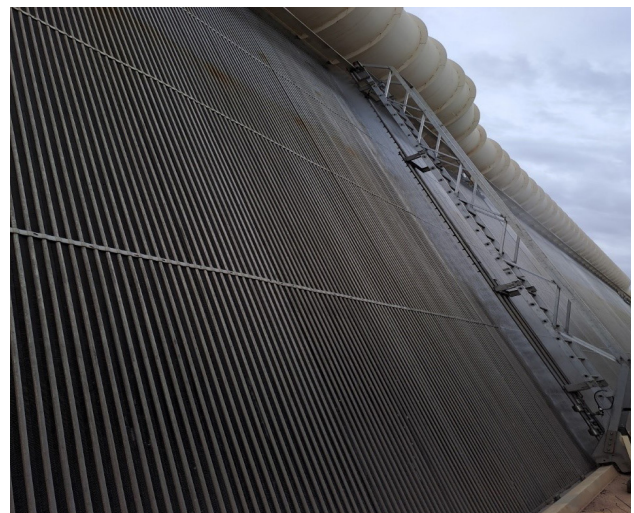


Figure 12. ACC Washing System

To evaluate the impact of ACC washing on condenser pressure, a comparison of the condenser vacuum before and after washing was conducted, using the performance curve as a reference (Table 4). The comparison was made under identical environmental conditions to ensure accuracy and consistency.

Table 4. Comparison Before & After Washing

	Performance Curve	Vacuum conditions at an ambient temperature of 35 degrees	Date	
41 mbar deviation	170 mbar	211 mbar	21/08/2021	Before washing the fin tubes
25 mbar improved	170 mbar	145 mbar	21/10/2021	After washing the fin tubes

7. Conclusion

Based on the investigations and the comparison of condenser pressure at Behbahan power plant with the ACC (Air-Cooled Condenser) system performance chart, it is evident that increased wind speed (both speed and direction) disrupts the system's performance, and under certain conditions, it leads to HRSG (Heat Recovery Steam Generator) runbacks, subsequently reducing the unit's production capacity. If the wind speed remains below 4 m/s, washing the ACC system significantly improves its performance.

Regarding the use of a misting system, tests at the power plant revealed that high water consumption is not a feasible solution given the region's geographical constraints. Additionally, higher wind speeds reduce the misting system's efficiency, leading to its cancellation. Other adverse effects include radiator clogging due to dust accumulation in the area.

Among the problems and challenges caused by changing the blade angle, the following can be mentioned:

- Increased tension in the blades and bolts: Adjusting the blade angle places greater stress on both the blades and the connection bolts, increasing the risk of blade failure under current conditions.
- Increased gearbox stress: The adjustment raises the load on the gearboxes, which presents significant problems due to the high cost of these components and the difficulty of their repair.
- Electric motor current limitations: The system's electric motors become a limiting factor, as increased blade angle

demands higher current. While operation can continue up to the system's rated current, there is concern over whether the motors can sustain operation at this level consistently.

- Doubling of vibration levels: Structural vibrations increased by 100%, making it impossible to continue operating the system under these conditions.

Each fan uses 10 U-bolts, and according to the manufacturer's guidelines, new U-bolts must be installed after every adjustment due to the risk of wear and potential blade breakage. With each U-bolt costing \$250, the total cost for adjusting a single fan amounts to \$2,500. Additional expenses arise from gearbox depreciation, motor bearing replacement, blade failures, and other repairs, which further question the feasibility of this adjustment. While changing the blade angle may seem like a way to enhance performance, it introduces several technical challenges that outweigh the benefits. Combined with the high maintenance and repair costs, adjusting the blade angle is an impractical solution without further modifications to the system's mechanical and electrical components.

In conclusion, the potential benefits of adjusting the blade angle in air-cooled condenser fans are significantly outweighed by the accompanying technical challenges and costs. Increased stress on blades, bolts, and gearboxes, coupled with limitations in motor capacity and heightened vibration levels, pose serious risks to the long-term functionality and reliability of the system. Therefore, this approach is not feasible without major system modifications.

The installation of wind guides and deflectors, which show effectiveness in high wind conditions, lacks economic justification due to the high implementation cost compared to its benefits. Although such solutions to mitigate wind effects are part of modern practices in power plants globally, they have not been implemented in any of the country's plants. Basic studies and relevant calculations by consulting companies are necessary to evaluate the economic feasibility of such plans.

The estimated cost for implementing the project at the power plant is around \$4.5 million. This should be weighed against the production losses caused by runbacks during the summer. In 2021, the energy loss due to HRSG runbacks, caused by adverse weather conditions, amounted to approximately 865MW (megawatts), equating to around \$2,000 in lost production.

In the summer of 2021, wind speed alone was responsible for the runbacks, though in other cases, both temperature and wind speed contributed to the issue. Washing the ACC system reduced the time the boiler remained in runback conditions. Given that ACC washing improved system performance under the same temperature conditions as before (Table 4), and the total power loss due to temperature and wind speed is estimated at around \$2,000, the cost of installing a wind wall (\$4.5 million) lacks economic justification.

By analyzing the provided graphs (Behbahan CCPP Performance Curve), it is clear that, despite fewer fans operating after the ACC washing (Table 4), the vacuum improved significantly. This is notable since fewer fans typically result in higher vacuum levels. However, following the washing, not only did the vacuum improve at the same ambient temperature, but it also showed a substantial reduction compared to the ACC's performance curve. Prior to the washing, the condenser pressure was consistently higher than the pressure specified in the performance curve, while after washing, the vacuum level improved markedly.

In conclusion, the implementation of the ACC washing system has successfully reduced the condenser vacuum and enhanced performance, particularly by minimizing the number of HRSG runbacks during the hot season.

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بررسی بهبود عملکرد کندانسورهای هوا خنک (ACC) در نیروگاه سیکل ترکیبی بهبهان

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چکیده

نیروگاه‌های سیکل ترکیبی یکی از کارآمدترین روش‌های تولید برق هستند که از ترکیب چرخه‌های گاز و بخار برای افزایش بهره‌وری انرژی استفاده می‌کنند. یکی از اجزای مهم در این نیروگاه‌ها کندانسور هوا خنک (ACC) است که نقش مهمی در خنک سازی و تبدیل بخار خروجی از توربین بخار به آب دارد. با این حال، راندمان کندانسورهای هوا خنک به شدت تحت تأثیر شرایط محیطی، به ویژه دمای هوا، رطوبت و سرعت باد است که می‌تواند منجر به کاهش راندمان کلی نیروگاه شود. این مقاله روش‌هایی را برای بهبود عملکرد کندانسورهای هوا خنک در نیروگاه‌های سیکل ترکیبی بررسی می‌کند. ابتدا به چالش‌های مرتبط با طراحی و عملکرد این کندانسورها در شرایط محیطی متفاوت می‌پردازد. در ادامه راه‌حل‌های ابتکاری مانند تغییر زاویه تیغه‌ها، ایجاد مسیرهای پاشش آب در ورودی تیغه‌ها و شستشوی لوله‌های پره و ارزیابی روش‌های کاهش سرعت باد مورد تجزیه و تحلیل قرار می‌گیرد. یافته‌ها حاکی از آن است که با اتخاذ این استراتژی‌ها می‌توان بازده حرارتی نیروگاه را افزایش داد، مصرف آب را کاهش داد و هزینه‌های عملیاتی را به حداقل رساند. توصیه‌هایی برای تحقیقات آینده در بهینه‌سازی و توسعه فناوری‌های خنک کننده نیز ارائه شده است.

واژگان کلیدی: کندانسور هوا خنک، نیروگاه سیکل ترکیبی، بهبود بهره‌وری، سیستم خنک کننده، انتقال حرارت، لوله پره‌دار