

Mitigation of Wind Effect on Air Cooled Condenser Performance

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ABSTRACT

Rankine cycle condenser thermal performance determines the turbine back pressure, thus has direct impact on power plant generation, especially in low enthalpy (geothermal heat resource) Organic Rankine Cycle application. Wind has a major effect on Air Cooled/Heated Heat Exchangers in general and Air Cooled Condensers (ACCs) thermal performance in particular. Ambient wind interferes with air flow regime causing reduced airflow, reduced effective heat transfer area and hot air recirculation for induced and forced draft air-cooled heat exchangers.

Wind effect analysis was performed in Don A Campbell (DAC), an Ormat geothermal power plant in Nevada, US. Degradation of 4%-23% in net power plant generation was recorded and attributed directly to wind effects, wind velocities ranging at 3-15 m/s. In order to mitigate the deteriorating wind effect on the ACC, Wind Guiding Vanes (WGV) system was developed using computational fluid dynamics (CFD) analysis and optimization process, currently patent pending. Negligible effect on the ACC performance in no wind conditions, low manufacturing cost and zero maintenance, were key considerations in the WGV system design. A two-phase implementation process was performed: First phase: an experimental WGV system was installed on 6.5% of the total ACC having a plot area of approx. 375x20 m². Field tests were executed including fan flowrate measurements and smoke tests, for aerodynamic performance validation. A dedicated fan flowrate device was designed for continuous airflow measurement and data acquisition at windy and still ambient air conditions. Results showed a significant performance improvement with the WGV system equipped bays in windy conditions. A good validation of CFD analysis was obtained via field tests. Second phase: following the proof of concept, full-scale WGV system implementation on all of DAC ACC was executed. Up to 15% of net power generation increase was achieved at windy conditions by equipping the ACC with a WGV system.

This paper reviews existing wind effect mitigation methods for air cooled condensers, fundamental analysis of the problem and Ormat designed solution. The conceptual design, considering cost-effectiveness and thermal performance recovery is explained. Experimental system field tests results and full-scale implementation results are presented, as well as yearly power plant generation gain.



Figure 1: Don A Campbell Air Cooled Condenser

1. INTRODUCTION

Geothermal power plants largely operate in rural areas, where winds can easily peak and blow towards the plant with no interferences. When the wind velocity increases the ACC performance is deteriorated, leading to an increase in the turbine back pressure, thus to degradation in plant power generation

In order to thoroughly investigate the wind effects on plant performance, data collection and statistical analysis were performed over 18 months of DAC power plant operation. Data was filtered to similar ambient temperature and unit heat load, over wide range of wind velocities in order to experimentally obtain the direct wind effect on power plant performance. Net power vs. cross (perpendicular) wind velocity in ambient temperature of 20°C is presented in Figure 2.

A further investigation of wind effects on Ormat's ACC was performed using a 3-dimensional CFD analysis. Results show two major factors defining the performance deterioration on induced draft ACCs:

- Air flowrate reduction through the bundle at cross wind velocity - The ACC air inlet becomes unidirectional in the upstream direction, as shown in Figure 4, dynamic pressure below the ACC increases and the static pressure decreases. The differential static pressure on the upstream fan goes up, thus the airflow goes down according the fan curve and up to stall. Air flowrate reduction is increasing the LMTD (Log Mean Temperature Difference), causing a decrease in heat transfer coefficient according to (1) $Q = UA(LMTD)$. Where Q is the heat dissipated, U is the heat transfer coefficient, A is the effective heat transfer area and LMTD is the Log Mean Temperature Difference.
- Non-uniform distribution of the condenser air inlet at cross wind velocity- Significantly reducing the effective heat transfer area, causing a severe deterioration of the ACC performance according to (1).

Air inlet streamlines in no wind compared to cross wind velocity of 7 m/s are presented in Figure 4. Projected view of CFD analysis results is demonstrated in Figure 3

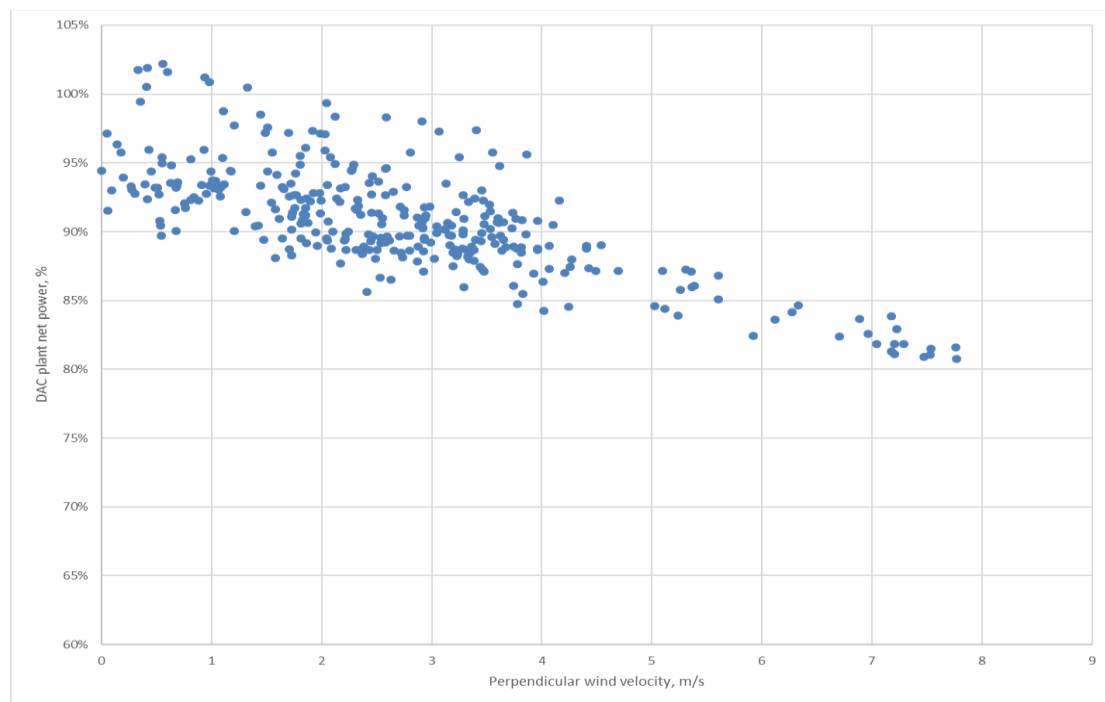


Figure 2: Net plant power vs cross wind velocity @ 20°C ambient temp.

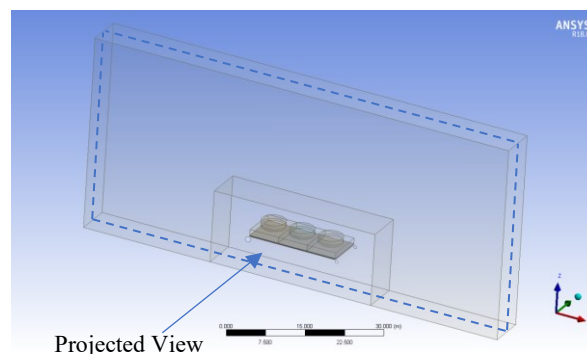


Figure 3: The displayed section and view of CFD analysis results

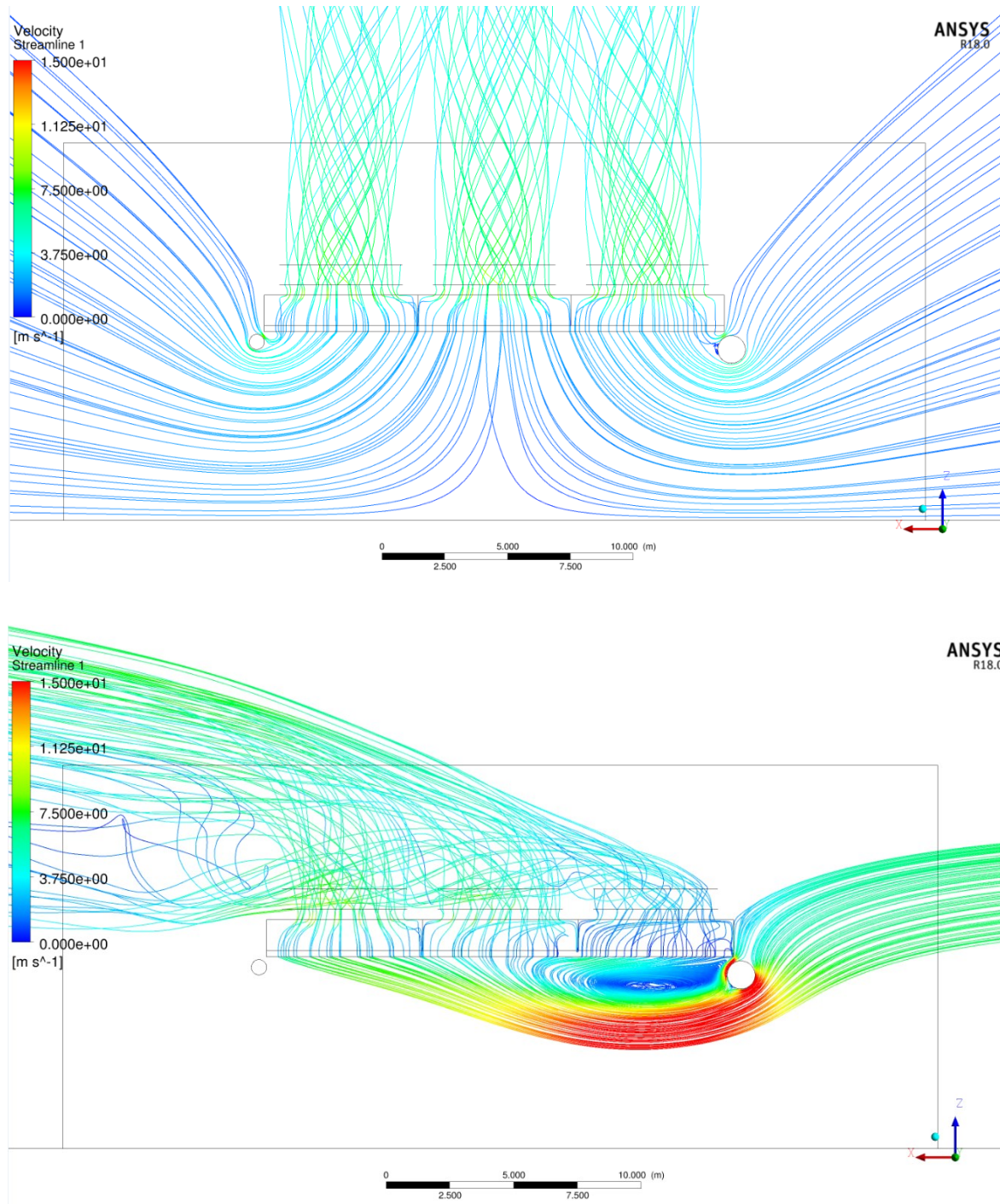


Figure 4: ACC air inlet streamlines in no wind conditions compared to high cross wind velocity (single bay)

Several methods for ACC wind effect mitigation are existing in the energy industry:

- Wind screens - Porous screens in different configurations around the ACC, extending from a defined distance above the ground to a defined distance below the fan deck. The intent is to impede the high velocity wind blowing through the space under the ACC. The mitigation effect depends on the screen densities and configurations. An effect on fan's differential pressure in no wind conditions is possible, which can lead to decrease in fan flowrate in no wind conditions (1)
- Wind barrier (wind lip) - Horizontal barriers which extending outward from the periphery of the ACC at the bottom of the windwall. The concept is to turn the flow of air coming down the side of the ACC outward and to move the start of the separation zone upwind and away from the inlet area of the first row of fans. The solution is less effective in high wind velocities and recovers mostly the upstream fan.(2) (1)
- Cooling tower louvers and drift eliminators - To minimize losses due to drift and help direct airflow into the tower, louvers and drift eliminators are commonly used. Louvers are most often seen along the sides of the tower structure,

while drift eliminators reside in the top section of the tower to capture entrained water droplets that may otherwise leave through the stack. (3)

Using ANSYS Fluent CFD software, Ormat has developed a wind effect mitigation method based on guiding vanes. The concept is to break the velocity head beneath the ACC and redirect the airflow towards the bundle in windy conditions, yet, keep nominal flowrate (pressure drop) in no wind conditions. Optimization process was performed, the optimized solution was derived.

An experimental setup of WGV was installed on 3 out of 46 bays on DAC ACC. An improvement of 14% on bay air flowrate in high cross wind velocities was recorded using WGV, with a negligible effect on bay performance in no wind conditions. After very promising test results, a full-scale coverage was executed in DAC. A net power recovery of 2,000 MWh/year was obtained with a fully WGV equipped ACC. WGV as installed are presented in Figure 5.



Figure 5: WGV as install in DAC power plant ACC

2. CONCEPTUAL DESIGN

Cross wind velocity, m/s	Fans air flowrate without WGV, % of nominal flow				Fans air flowrate with WGV, % of nominal flow			
	Upstream	Middle row	Downstream	Complete bay	Upstream	Middle row	Downstream	Complete bay
0	100%	100%	100%	100%	100%	100%	100%	100%
3	79%	95%	100%	91%	90%	97%	100%	96%
5	67%	91%	100%	86%	86%	96%	100%	94%
7	48%	84%	100%	77%	84%	96%	100%	93%

Table 1 : CFD results in cross wind velocities

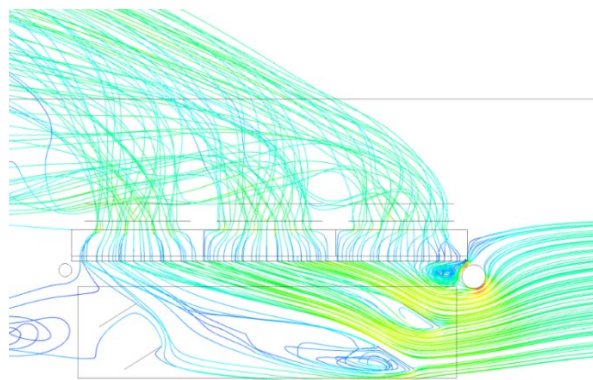


Figure 6: ACC air inlet streamlines in 7 m/s cross wind velocity with WGV

Various vanes designs have been examined. The positioning of the guiding vanes was determined according to air inlet streamlines in no wind conditions. The variable parameters that were investigated by CFD were: number of vanes, length, curvature, height and depth. The chosen design had the best combination of high air flowrate in windy conditions, negligible impact on design point and simplicity of the solution. Economic design for best cost-effective model was considered in the analysis.

The vanes location should guide the air flow towards the bundle in windy conditions and cause negligible disturbance on normal non-wind weather operation. Flat vanes were chosen after thermo dynamic vs cost effectiveness optimization process. Chosen WGV

configuration analysis results are presented in Table 1. Air inlet streamlines with WGV in cross wind velocity of 7 m/s are presented in Figure 6.

3. RESULTS AND DISCUSSION

3.1 Experimental test facility

Prior to major capital investment of full-scale WGV system, an experimental setup of 3 bays equipped with WGV was installed on DAC ACC. Proof of concept and aerodynamic performance validation are the goal of this setup. Field tests were performed including fan flowrate measurements and smoke tests.

3.1.1 Test results in no wind conditions

Each bay is equipped with 3 fans, a total of 9 fans were tested. In order to test the effect of WGV in no wind conditions, Fan motor power and air flowrate were measured in no wind conditions, prior and after the WGV experimental setup installation. Results are summarized in Table 2

Fan #	Fans Flowrate, ACFM		Fan motor power, kW	
	Before WGV	After WGV	Before WGV	After WGV
1	164,317	175,975	9.5	9.7
2	175,573	176,076	10.0	10.2
3	182,005	182,407	9.6	10.2
4	169,342	175,071	9.6	9.8
5	179,995	183,741	9.9	9.9
6	179,091	171,855	9.8	9.7
7	182,508	172,910	10.1	10.2
8	181,906	173,262	9.9	9.9
9	187,231	174,670	10.0	10.0

Table 2: Test result in no wind conditions

A comparison of bay air inlet streamlines in no wind conditions via smoke tests is presented in Figure 7.



Figure 7: Air inlet streamlines in no wind conditions, WGV bays vs standard bays

- Fan air flowrates and motor power measurements in no wind conditions, resulted in similar values (within the error range) before and after WGV installation. Air inlet streamlines in no wind conditions, with and without WGV, were visually verified by smoke tests, Figure 7. Negligible effect in no wind conditions assures nominal operation conditions without impact on plant performance.
- A good agreement of CFD analysis was obtained via smoke tests in no wind conditions.

3.1.2 Test results in windy conditions

Two major factors are defining the performance deterioration:

- Decrease in effective heat transfer area
- Reduction of air flowrate

It was decided to perform measurements of air flowrate, as reduction of air flowrate and effective heat transfer area are correlative one to another and due to dimensional challenges, it is not feasible to obtain a reliable measurement of effective heat transfer area.

Due to high transient characteristics of wind effects, a continuous measurement is required over a period of time, to collect enough data for statistical analysis and a clear picture. For that purpose, a dedicated device was designed, manufactured and installed on DAC ACC. The device consists of 20 rotating vane anemometers, fixed on 2 aluminum beams, Figure 8. The locations of the anemometers along the beams were determined according to ASME instructions for fan measurements (4). The device is portable and can be moved from fan to fan on the condenser deck. Air flowrate data and wind velocities were recorded continuously in DAC plant, over a period of 2 months. In addition, smoke tests were executed in DAC for WGV vs standard bays comparison in windy conditions. Results are summarized below.



Figure 8: Continuous air flowrate measurement device

Upstream fan flowrate measurements with and without WGV in cross wind, are presented in Figure 9. Downstream row fans showed a negligible air flowrate reduction in cross winds and were considered to deliver 100% air flowrate for the analysis, with and without WGV. Complete fans air flowrate results in cross wind velocities of 3,5,7 m/s are presented in Table 3.

	Fans air flowrate without WGV, % of nominal flow				Fans air flowrate with WGV, % of nominal flow			
Cross wind velocity, m/s	Upstream	Middle row	Downstream	Complete bay	Upstream	Middle row	Downstream	Complete bay
0	100%	100%	100%	100%	100%	100%	100%	100%
3	72%	94%	100%	89%	86%	96%	100%	94%
5	62%	91%	100%	84%	82%	93%	100%	92%
7	46%	86%	100%	77%	77%	92%	100%	91%

Table 3: Air flowrate measurements results in cross wind velocities

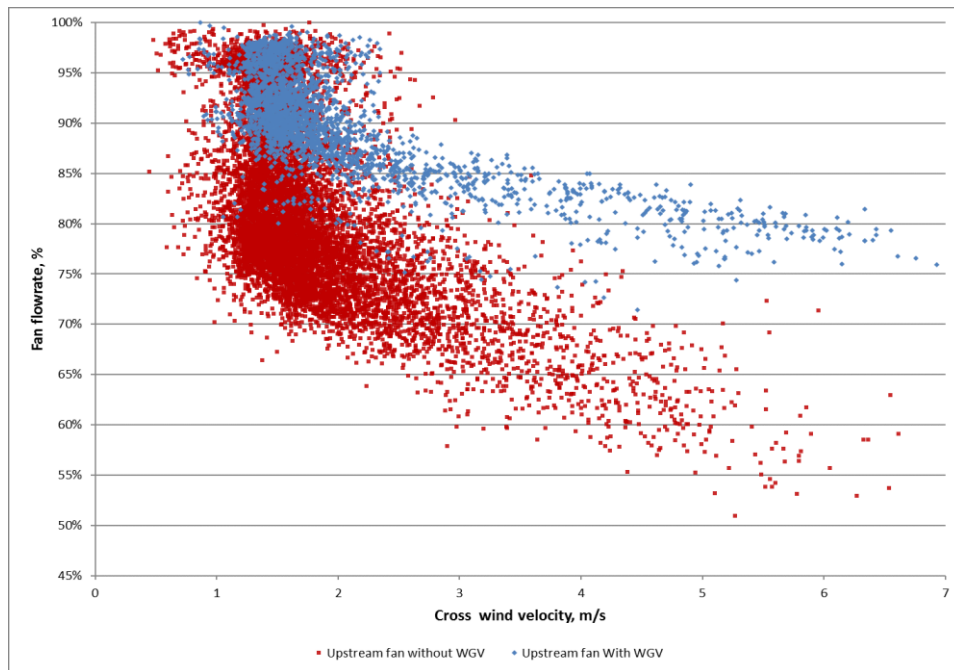


Figure 9: Upstream fan air flowrate vs. cross wind velocity

A comparison of bay air inlet streamlines in cross wind was performed via smoke tests. Results are presented in Figure 10 and Figure 11.



Figure 10: Air inlet streamlines in cross wind WGVS



Figure 11: Air inlet streamlines in cross wind without WGVS

- Complete bay air flowrate recovery of 14% was recorded with WGV at 7 m/s cross wind velocity, higher improvement is expected in stronger winds. Due to the correlation between air flowrate reduction and effective heat area, actual recovery of plant net power generation is expected to be significant. It can be directly measured only after full WGV implementation.
- Plant operation under windy conditions is unstable due to extreme and fast changes in turbine backpressure - causing vaporizer level instability. WGV installation is expected to improve the operation by smoothing the high and fast transients caused by the wind gusts.
- As expected, upstream fan has experienced the sharpest air flowrate reduction in cross wind velocities. Its recovery while equipped with WGV was the most significant among the 3 fans, 31% improvement in air flowrate at cross wind of 7 m/s.
- A good match of ~5% deviation to CFD analysis in flowrate recovery was obtained.
- A good agreement of CFD analysis was obtained via smoke tests in cross wind conditions.

Following the experimental setup test results, a full scale WGV implementation was executed in DAC ACC. Results are summarized in chapter 0.

3.2 Full scale WGV implementation

Two identical plants are operating in DAC complex, DAC-1 and DAC-2, with identical ACCs at the same orientation. The WGV were implemented only in DAC-2 ACC during March 2018. Data was gathered during two months after the installation was completed. A comparison between DAC-1 without WGV and DAC-2 equipped with WGV was performed, as well as DAC-2 equipped with WGV compared to DAC-2 before the installation, results are presented below.

3.2.1 Plant net power recovery in cross wind velocities

As in the initial wind effect analysis, Figure 2, the trended data was filtered to constant ambient temperature and unit heat load, over wide range of wind velocities to experimentally obtain the direct wind effect on power plant performance. DAC-2 equipped with WGV vs DAC-1 without WGV Net power vs. cross wind is presented in Figure 12. DAC-2 plant net power generation before vs. after the WGV installation is presented in Figure 13.

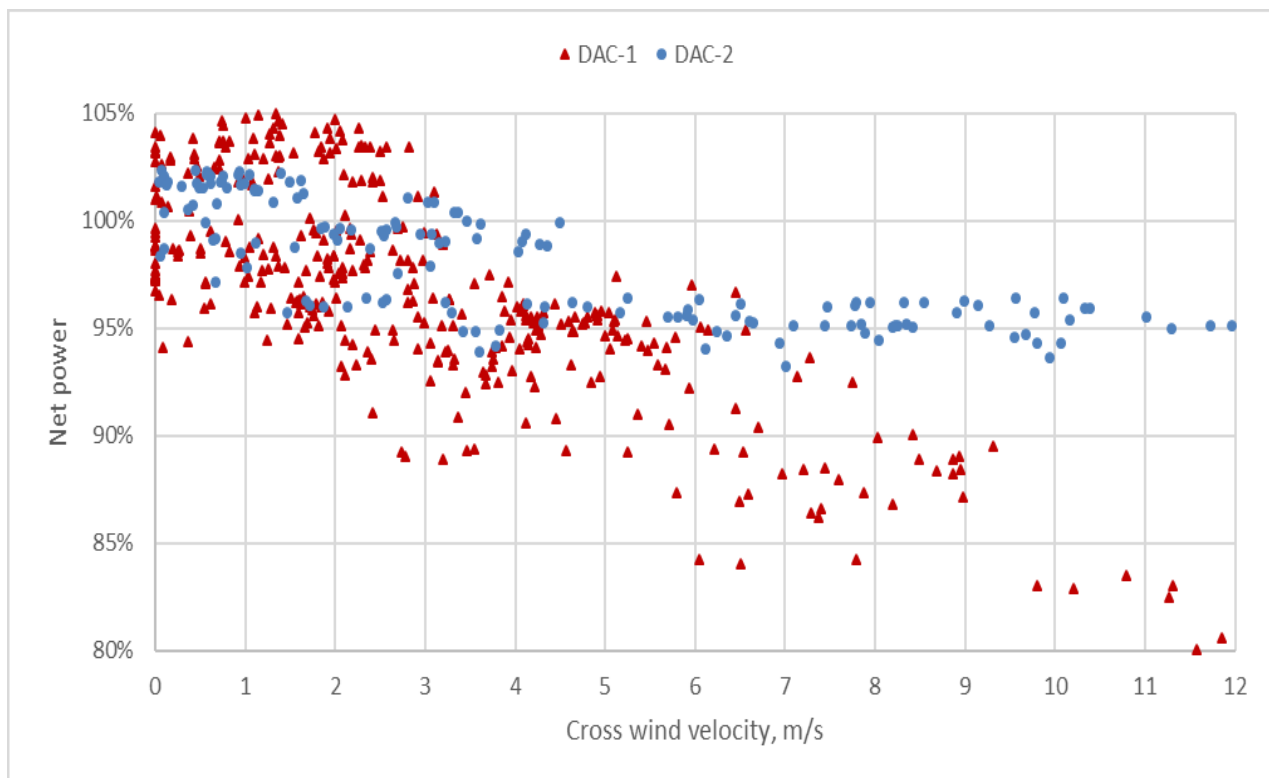


Figure 12: DAC-2 with WGV vs. DAC-1 net power vs. cross wind velocity @ 15°C ambient temperature

A comparison of plants power decrease between DAC-1 without WGV and DAC-2 before and after the WGV installation is presented below, Table 4.

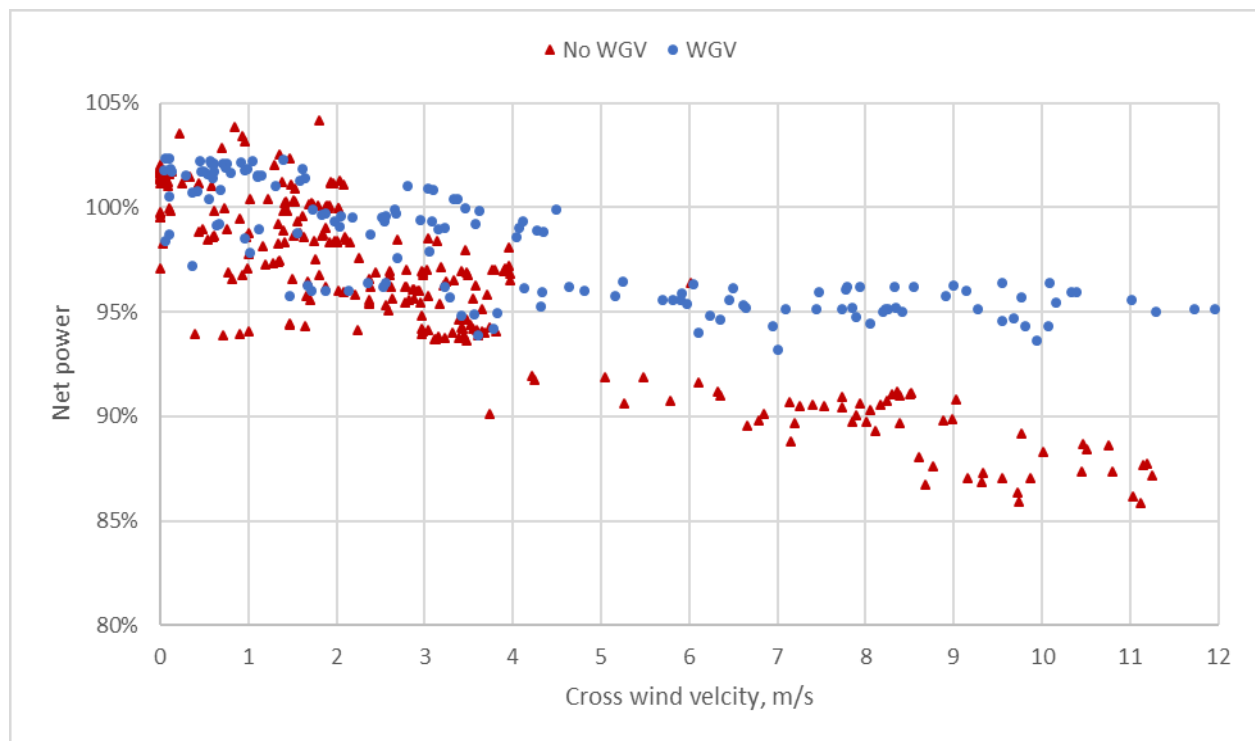


Figure 13: DAC-2 before WGV implementation vs. DAC-2 after WGV implementation net power vs. cross wind velocity, @ 15°C ambient temperature

	Unit	DAC-1	DAC-2 before WGV	DAC-2 with WGV
Vaporizers pressure L-1	bar	17.58-17.65	18.95-19.03	17.44-17.58
Vaporizers pressure L-2		12.05-12.20	12.61-12.69	11.79-11.93
Power decrease, 3-7 m/s	%	6-10	5-10	3-5
Power decrease, 7-12 m/s	%	12-20	10-13	5-6
Maximum power decrease	MW	3.9	2.9	1.2

Table 4: Net power decrease during cross winds of DAC-1 without WGV, DAC-2 with WGV, DAC-2 before WGV

- The WGV equipped ACC shows stable performance over all sampled wind velocities range with approx. 6% power reduction at highest wind velocity. ACC with no WGV system installed shows approx. linear degradation in performance proportional to wind velocity. Thus, the WGV power recovery increases with wind velocity.
- The WGV equipped ACC clearly shows better performance at windy conditions:
 - 3-9% power generation recovery in wind velocities of 3-7 m/s
 - 5-15% power generation recovery in wind velocities of 7-12 m/s

According to the full-scale test results above, correlations for power recovery factors in cross wind velocity were derived. Incremental net power recovery calculation for DAC-2 power plant was performed. The calculations are based on a yearly wind regime logged during March 2016 – Feb 2017. A net power recovery of 2,000 MWh/year in DAC-2 was obtained. Wind regimes, hence power recovery, can vary from year to year.

At low wind velocities, WGV equipped bays show effective mitigation of air flowrate instability and transient flow regime. This contribution cannot be quantitatively evaluated but expected to be significant in terms of power recovery.

3.2.2 Plant operation stability

Plant operation under windy conditions is unstable due to extreme and fast changes in turbine backpressure - causing unbalanced axial loading on the turbine, as well as vaporizer level instability that may reduce the level valves lifetime. In order to compare the plant operation stability with and without the WGV, turbine backpressures of both plants were recorded and presented on the same timeline together with cross wind velocity, Figure 14.

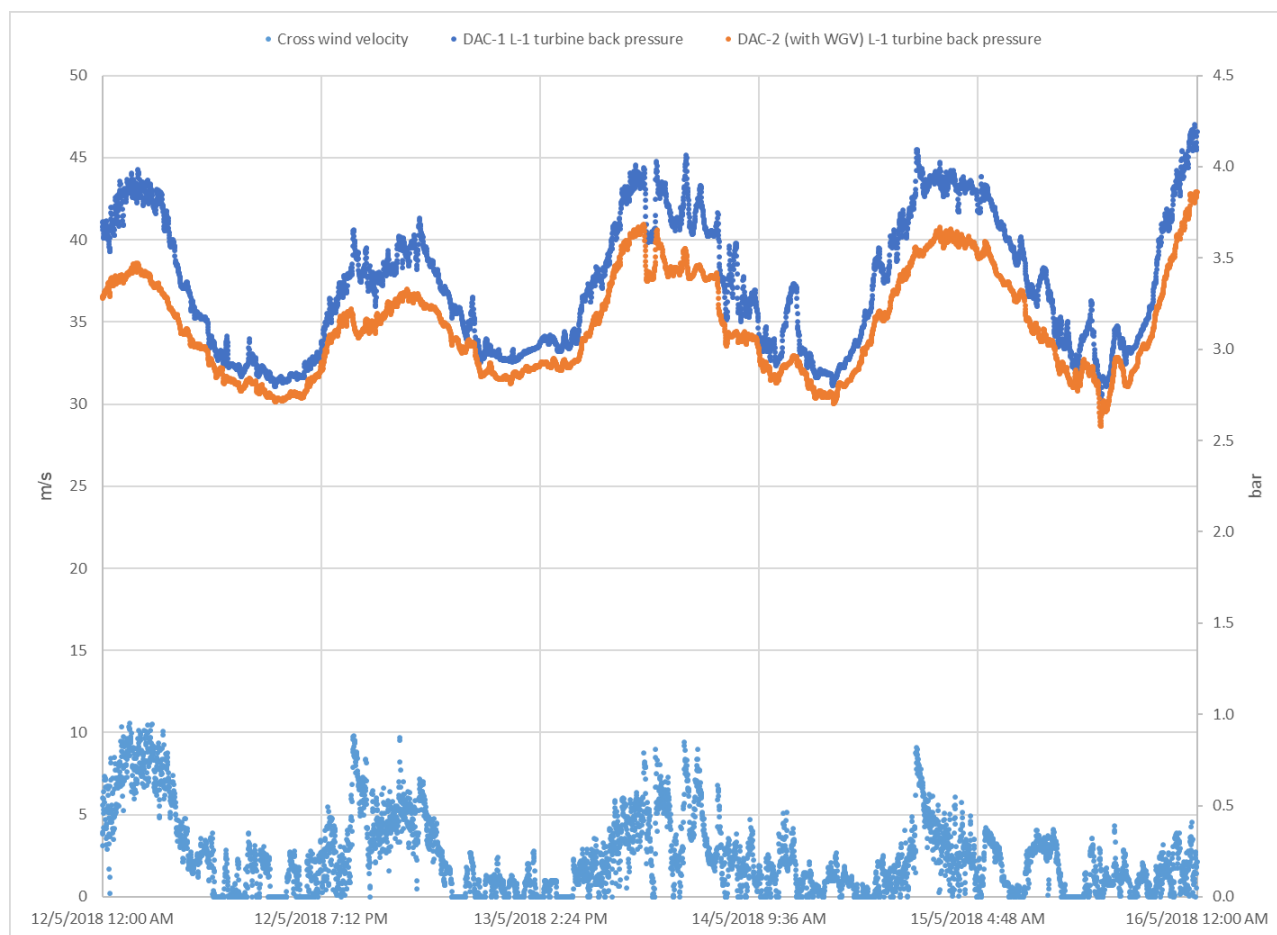


Figure 14: Plant operation stability comparison, DAC-2 equipped with WGV vs DAC-1 without WGV

According to the turbine backpressure comparison, Figure 14, ACC without WGVs shows low operational stability (high turbine backpressure peaks during cross winds). ACC equipped with WGV significantly more stable in strong wind gusts.

CONCLUSIONS

According to yearly power generation analysis in Don A Campbell power plant, a significant power generation loss is evident due to wind. To mitigate that phenomenon, Wind Guiding Vanes method was developed by CFD tools. The unique solution was designed to be located on the air flow streamlines in the entrance to the ACC. This configuration prevents losses in no wind conditions, yet, when wind is blowing, WGV break the velocity head beneath the ACC and redirect the airflow towards the ACC inlet. Test system in small scale was installed and tested. As expected, a major improvement of ACC bays' airflow, 5%-14% was witnessed, thus, an improvement in heat transfer area and plant performance was obtained. WGV method was managed to keep the same performance in no wind conditions while significantly improve the performance in windy conditions.

CFD results were validated via airflow measurements and smoke tests as shown in section 0. It is an important phase in the R&D process, because it allows one to develop further configurations and improve existing systems by CFD analysis, with no major additional costs.

Full implementation of WGV in DAC-2 ACC allowed to trend directly the plant power recovery and yearly power gain, likewise, to compare plant performance with an identical non WGV equipped power plant. The WGV equipped ACC clearly shows better performance in windy conditions, as can be seen in Figure 12 and Figure 13. Up to 15% improvement in net power generation with WGV was recorded, according to the net power decrease comparison in Table 4. This improvement sums up to 2000 MWh/year of net power generation addition, according to yearly power recovery analysis, section 0. Analysis results and the economic WGV design are making the WGV solution a very cost effective one for DAC facility.

Plant operation instability caused by wind gusts was significantly improved with WGV equipped ACC, as can be seen in Figure 14. Operation stability prevents unnecessary plant trips and equipment wear, for example vaporizer level valves and turbine bearings lifetime is expected to increase with WGV equipped ACC.

Power recovery by WGV depends on yearly wind regimes, thus can be slightly changed from year to year. Each plant and location should be separately analyzed for wind effects and cost-effectiveness of the project. For example, according to Figure 12 and Figure 13, power recovery is increased with wind velocity, one may want to take it into consideration in strong wind gusts areas.

DAC-1 will be covered with the current WGV configuration. For different ACC configurations, further development is in progress.

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