Optimization of Intracycle Velocity Control for Cross Flow Turbines

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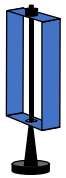
Introduction

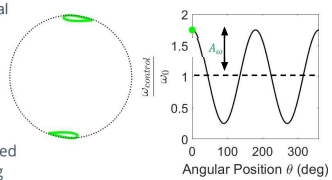
Cross flow vs Axial Flow Turbines

- Lower individual efficiency, higher per unit area
- Constructive interference
- Insensitive to flow direction
- Lower optimal rotation rate



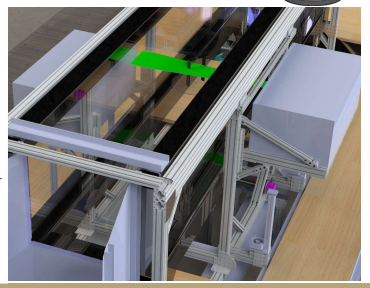
Why Intracycle Speed Control?

- Controlling angle of attack and hydrodynamics with fixed geometry
- Improves understanding of beneficial flow phenomenon
- Simple control scheme
- $\omega_{control} = \omega_0 + A_\omega sin(2\theta + \phi)$
- Downside: models predict improved performance cause higher loading



Methods

- Alice Flume Test Facility at Harris Hydraulics Lab
- Temperature and Inflow velocity Fixed to maintain nondimensional parameters
- Forces and moments measured with 6 axis load cells mounted at top and bottom of turbine
- Dual Motor/Generator allows control of, and power extraction from turbine.
- Sweep of control parameters fixing $\omega_0 = 21$ [r/s], the optimal value for our turbine
- $A_\omega = [0 \quad 0.64\omega_0]$
- $\phi = [0 \quad 2\pi]$
- High speed camera and Laser used in Particle Image Velocimetry (PIV) for key cases to explore near blade hydrodynamics.



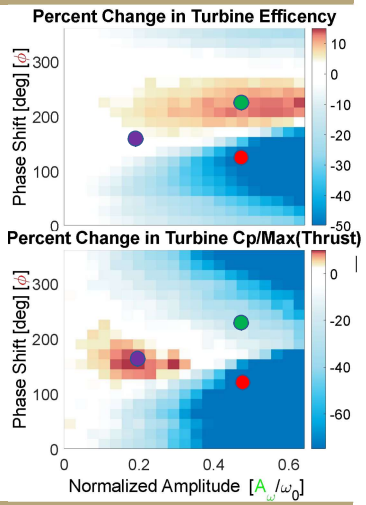
Optimization

- Higher sensitivity to changes in phase
- Small region of beneficial kinematics, more combinations produce poor performance
- It is possible to decrease loading while still improving performance

Optimal Control

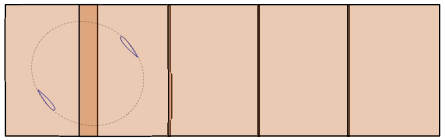
Suboptimal Control

Optimal Cp/Max(Thrust)



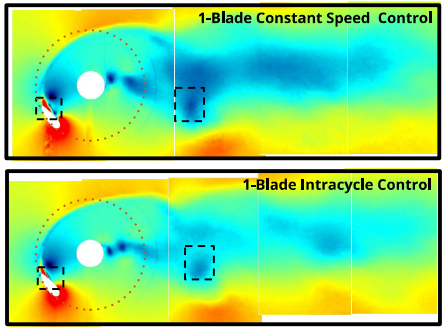
Particle Image Velocimetry (PIV)

PIV Capture Flow Domain



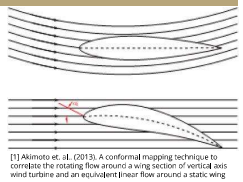
Preliminary Mean Flow Field Results

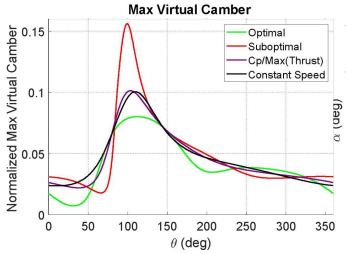
- Vortex suppressed near blade in optimal power Intracycle
- Vortex detachment occurs earlier and progresses further down stream as well.
- Mean wake flow speed is higher in Intracycle control



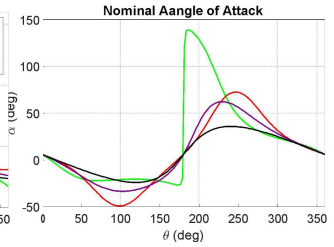
Virtual Camber and Angle of Attack

- Rotational motion of blades causes our symmetrical foils to behave as cambered foil would in a linear flow "Virtual Camber"
- Interpreting results from the perspective of virtual camber shows beneficial directions of future research





- Improved performance under conditions of reduced VC
- Decreased loading when higher camber is experienced earlier



- Better performing cases have smaller AOA earlier in the rotation and larger later
- Causation of performance is not immediately clear

Conclusions

- Intracycle is relatively insensitive to amplitude but more to phase shift
- Optimal power kinematics reduce virtual camber through the cycle
- Forces do not scale directly with performance as models predict
- Large dataset of in-rotor hydrodynamics will allow connection between optimized kinematics and flow field phenomenon to identify beneficial and detrimental features

Future Work, References, and Acknowledgments

- Further Processing and analysis of hydrodynamics observed in PIV data
- Connect blade level forces with PIV flow field
- Validation of CFD collaboration results.
- Repeating work with a cambered profile blades to assess impacts on hydrodynamics and performance.
- Interpretation of results through the lens of Coriolis and virtual camber effects

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References:

[1] Akimoto, H., Hara, Y., Kawamura, T., Nakamura, T., & Lee, Y. S. (2013). A conformal mapping technique to correlate the rotating flow around a wing section of vertical axis wind turbine and an equivalent linear flow around a static wing. Environmental Research Letters, 8(4), 044040.

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