

Abstract

The promise of advanced Wind Farm Control (WFC) of **increased power and reduced loads** through coordinated control of all turbines in a wind farm has been around for more than a decade. Many groups have worked on different aspects and with different methods to solidify the knowledge about the potentials and control approaches. However, it still is not commercially available. The **International Energy Agency (IEA)** and the EU funded **FarmConnors** Coordination Action sponsored a recent Topical Expert Meeting on state of the art and research gaps in WFC.

The first activity of the FarmConnors project was a workshop and subsequent paper on the currently available knowledge, both as abstract knowledge and as existing data sets. The workshop (held in Amsterdam on 25 September 2019) was attended by more than 50 experts around the world, of which many are collaborating in FarmConnors. Alongside keynote speeches, the results of two online questionnaires and regular talks presenting and summarising the current knowledge and existing datasets for verification, some sessions also discussed a way forward.

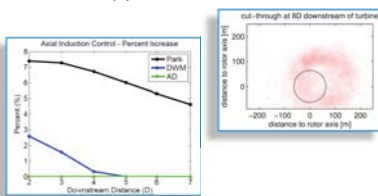
Wind Farm Control State of the Art

Induction control



Status:

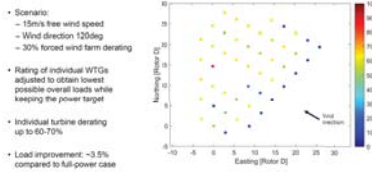
On life support for AEP increase:



[2]

Potential for load reduction / rebalancing

Optimization of loads in cases of externally forced derating



[5]

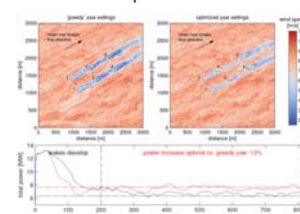
Can it be made to work anyway? Can we combine wake steering and induction control, depending on wind direction?

Wake steering



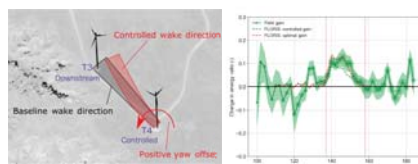
Status:

Current best option for AEP increase



Potential for load reduction / rebalancing

Tested in several places, usually with good results, but often with single turbine only



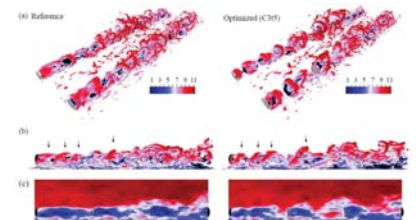
[6]

Are load impacts believable?

Other

Dynamic Induction Control:

Shows potential for AEP increase [11, 12]



Unclear for load reduction / rebalancing

Increase tip speed in wake:

Novel concept, untested [13]

Potential for AEP improvement

Wake steering through individual pitch:

Debunked [9, 14]

Control of electrical system to reduce losses:

Worked on e.g. in TotalControl



Wind farms designed for WFC:

Allows densification of wind power [7]

Anything we overlooked?

Except provision of Ancillary Services, which for most AS is established already.

Research Gaps

Validation Campaigns	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Understanding Load Impact?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Understanding Derating Mechanisms?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Understanding Number of Loads?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Real-time Control Strategies?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Understanding Dependence of Atmospheric Conditions?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Developing Highly Accepted Validation?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Reliable Experimental Data?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Understanding how WFC research is valued?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Grid Support?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Farm Farm Cluster Control?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Integration with Storage and Grid?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Understanding Sound Impact?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Result of expert solicitation [10] (questionnaire) in advance of the workshop. The scale shows how many people of about 50 participants prioritised which topic. **Validation campaigns** are missing most. Understanding **load impacts** comes second.

Benchmarks:

'Synthetic' Dataset high-fidelity simulations

Wind Tunnel experiments including dynamic yawing

Wind Farm Field data 'normal' and controlled operation

Position papers:

Certification, Standardization and other Regulatory issues

Value proposition:

Showcase of WFC in various electricity market scenarios; compliance and revenue including Economic benefits of WFC in design phase

References

- Fleming, P., Annoni, J., Shah, J., Wang, L., Alcarman, S., Zhang, Z., Hutchings, K., Wang, P., Chen, W., and Chen, L.: Field test of wake steering at an offshore wind farm. *Wind Energy*, 20, 229-239, <https://doi.org/10.1080/15114347.2017.1317171>.
- Annoni, P.M., Giebel, A., Scholbrock, P., Fleming, P., and van Wingerden, J.: Analysis of axial induction based wind plant control using an engineering and a high-order wind plant model. *Wind Energy*, 19(6), p. 1135-1150, 2016.
- P.A. Fleming, P.M.G. Giebel, S. Lee, W. van Wingerden, K. Johnson, M. Churchfield, J. Michalakes, P. Sparler, P. Moriarty: Evaluating techniques for reducing turbine wake losses using SOWFA. *Renewable Energy*, 79, 2014.
- Giebel, P.M.G., Teunissen, P.W., van Wingerden, J.W., Fleming, P.A., Ruben, S.D., Marsden, R., & Pas, L.: Wind plant power optimization through yaw control using a parametric model for wake effects - a CFD simulation study.
- Dimitrov, N., Galinos, C., Urban, A.: Wind farm power and load optimization with surrogate models. *Wind Energy Science Conference 2019*, Cork, Ireland.
- P. Fleming, J. King, S. Dykes, E. Simons, J. Redmond, A. Scholbrock, P. Moriarty, R. Lumbard, P. Moriarty, K. Fleming, J. van Dam, E. Bay, R. Mulder, H. Lopez, J. Shapiro, M. Soti, B. Ryan, C. Gentry, D. Brakes: Initial results from a field campaign of wake steering applied at a commercial wind farm - Part 1. *WESG*, 4, 273-285, 2019.
- Stanley, Andrew P. and Andrew Wing: Massive Simplification of the Wind Farm Layout Optimization Problem. *WESG*, July 2019.
- Giebel, P., J. Thomas, A. Neg, P. Fleming, K. Dykes: Maximization of the Annual Energy Production of wind power farms by optimization of layout and yaw-based Wake Control. *Wind Energy*, 2016. <https://doi.org/10.1002/we.1606>.
- Fleming, Paul A., Pater M.G. Giebel, Sang Lee, Jan Willem van Wingerden, Kathryn E Johnson, Matt Churchfield, John Michalakes, Philippe Sparler, and Patrick J. Moriarty: Evaluating Techniques for Reducing Turbine Wake Losses Using SOWFA. *Renewable Energy*, March 2014.
- Michael Lawson, presentation at IEA Wind TEM 97, Amsterdam, 2019.
- Wim Munters and Johan Meyers: Towards practical dynamic induction control of wind farms: analysis of optimally controlled wind farm boundary layers and sinusoidal induction control of free-flow turbines. *WESG*, 3, 409-425, 2018.
- Joeri Frederix, Robin Weber, Stefano Cascella, Filippo Campagnolo, Alessandro Croce, Carlo Bottasso, and Jan Willem van Wingerden: Periodic dynamic induction control of wind farms: proving the potential in simulation and wind tunnel experiments. *WESG* discussions, Aug 2019.
- U. Chi, M. Rotta, C. Santoni, S. Leonardi: Large-eddy simulations with extremum seeking control for individual wind turbine power optimization. *Wind Energy*, 20, 1617-1634, 2017.
- J. Wang, C. Bottasso, F. Campagnolo: Wake redirection: comparison of analytical, numerical and experimental models. *Torque*, IPhyConfSer 753(2016) 032064.

MEET US AT C1-B51 (DTU Wind Energy)

