OPTIMAL CONTROL ALGORITHM FOR PREVENTING TOTAL FAILURE OF WIND-TURBINE INSTALLATIONS WITH FLEXIBLE BLADES

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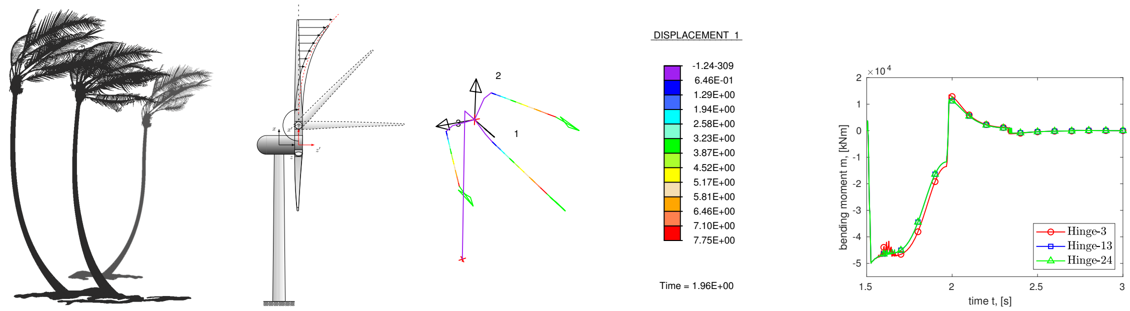
Rising energy demand necessitates an increased energy supply, but without improvements in energy efficiency, global consumption will continue to increase, requiring the construction of new power plants. Climate change has led many countries, including the EU, to prioritize research projects (e.g. Horizon 2020) in order to accelerate the transition from fossil fuels to renewable energy sources.

As a result, we are interested in delivering a wind turbine installation with a capacity of 10 MW/year. To achieve this, we aim to optimize wind turbine systems in both offshore and in-land locations by replacing stiff blades with flexible ones (see Figs.1a,1b) to enhance performance under varying wind conditions. Such a change should increase efficiency, extend the operational wind speed range, and reduce the risk of fatigue failure. To protect the wind-turbine installation, we have already proposed a passive control (submitted papers 2023 S.LJ, A.I.), which is based on energy dissipating hinges with non-linear material behavior.

The study is initiated by reviewing the famous works on Reissner's beam model within both 2D and 3D settings, a class of problems characterized by finite rotations (for further details, see [1, 2, 3, 4, 6]). We proposed the elastoplastic model of a 3D Reissner's beam model (geometrically exact beam), which can capture localized bending deformation leading to a plastic hinge. We replaced the multiplicative split with the corresponding additive decomposition of the rotation vector derivatives. The discrete approximation is built in terms of the embedded-discontinuity finite element method (ED-FEM), [5, 6], which introduces a jump in rotation vector that can be handled at the level of a particular beam element. The computations are carried out by the operator split method, which separates the computations of global state variables (displacements and moments) from local (plastic curvature) variables.



(a) (b) (c) (d)

Figure 1: A wind turbine with flexible blades: (a) Palm leaves withstand strong winds; (b) Out-of-plane deflection and hinge activation; (c) Transition to revolute joint (resistance free), (d) Softening response (material profile).

We report that once the hinges have broken down Fig.1d (or when potential energy is dissipated), we recover the revolute joints and the system undergoes uncontrolled vibrations, representing a significant challenge in preventing the total failure of the wind turbine installation.

In the present work, we explore the modern control algorithms designed to make the system behave "as well as possible" with minimal control effort during extreme events. We seek to couple the advanced controller algorithm, a Linear-Quadratic Regulator (LQR) [7, 8, 9], with the 2D/3D Reissner's beam model, aiming to minimize the cost-to-go functional with respect to control and state variables. Furthermore, various objectives for minimization can be considered, including minimal time, terminal error, control effort, and etc.

With the following research we advance development of wind turbine technology by providing powerful tool that can optimize and save the wind turbine system from total failure during extreme events.

References

[1] Ibrahimbegovic, A., Frey, F. and Kozar, I. (1995), *Computational aspects of vector-like parametrization of three-dimensional finite rotations.* Int. J. Numer. Meth. Engng., 38: 3653-3673. https://doi.org/10.1002/nme.1620382107

[2] Ibrahimbegovic, A. (1997), *On the choice of finite rotation parameters.* Comput. Methods Appl. Mech. Engrg., 149: 49-71. https://doi.org/10.1016/S0045-7825(97)00059-5

[3] Cardona, A. and Geradin, M. (1988), *A beam finite element non-linear theory with finite rotations.* Int. J. Numer. Meth. Engng., 26: 2403-2438. https://doi.org/10.1002/nme.1620261105

[4] Argyris J., Poterasu, V.F. (1993), *Large rotations revisited application of Lie algebra*, Comput. Methods Appl. Mech. Engrg., 103: 11-42. https://doi.org/10.1016/0045-7825(93)90040-5

[5] Ibrahimbegovic A., *Nonlinear solid mechanics: theoretical formulations and finite element solution methods*, Springer, Berlin, (ISBN 978-90-481-2330-8, E-book 978-1-4020-9793-5), pp. 1-571, (2009)

[6] Ibrahimbegovic A., Nava-Mejia R.A., *Structural Engineering: Models and Methods for Statics, Instability and Inelasticity*, Springer, Cham, (ISBN 978-3-031-23594-8, E-book 978-3-031-23592-4), pp. 1-532, (2023)

[7] Lewis F. L., Vrabie D. L., Syrmos V. L., *Optimal Control*, John Wiley & Sons, New Jersey, (ISBN 978-0-470-63349-6, E-book 978-1-118-12263-1), pp. 1-540, (2012)

[8] Glad T., Ljung L., *Control Theory*, CRC Press, London, (ISBN 0-203-48475-4, E-book 0-203-79299-8), pp. 1-482, (2000)

[9] Kirk D. E., *Optimal Control Theory: An Introduction*, Dover Publications, New York, (ISBN 0-486-4348-2), pp. 1-452, (2004)