Shallow Water Dampers for Mitigation of Wind Turbine Tower Vibrations

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Current tendencies show that multi-megawatt wind turbines are increasing in size [1]. Cost-effectiveness is a prime concern in the industry, and therefore wind turbines of today are being designed with increasing rotor diameters in order to maximise energy-production whilst minimizing costs of construction, installation and maintenance [2]. Along with a larger size of turbines, challenges such as increased flexibility of towers, blades and associated vibration issues arise. These issues are not only the cause of fatigue damage with increased operating and maintenance costs but also compromise the power output of the turbine [3].
Current design approaches are mainly based on strength considerations, while stiffness of structures does not increase proportionally with the height [1]. Therefore, flexible structures are increasingly prone to fatigue failures caused by large defections resulting in fluctuating stresses, which can result in crack growth and may at worst, cause unexpected failure.
A cost-effective way of reducing wind turbine tower vibrations, comes from application of tuned liquid dampers (TLDs). TLDs possess favourable properties such as excellent damping efficiency, ease of installation and low capital- and maintenance costs, thus making TLDs a viable and cost-efficient option to reduce structural vibrations.
An advantageous and convenient method of analyzing TLD characteristics and performance is based on real-time Hardware-In-the-Loop (HIL) simulations [4]. HIL involves, as the name indicates, the incorporation of a physical subcomponent into a numerical model. In this case, a physical TLD is incorporated into a numerical model of a wind turbine. The TLD is exposed to real-time computed physical tower deflections by use of a motion base (figure 1). The employed numerical model is a 10-DOF MATLAB implementation of NRELs 5 MW land-based wind turbine [5]. The 10 DOFs consist of blade edge and flap-wise deformation, tower top lateral and longitudinal deformation as well as rotor and generator rotation. Longitudinal motion is aligned with the direction of the wind. The tower and blades are modelled as Euler-Bernouilli beams. The aerodynamic loads on the blades are modelled using the blade element momentum (BEM) method.

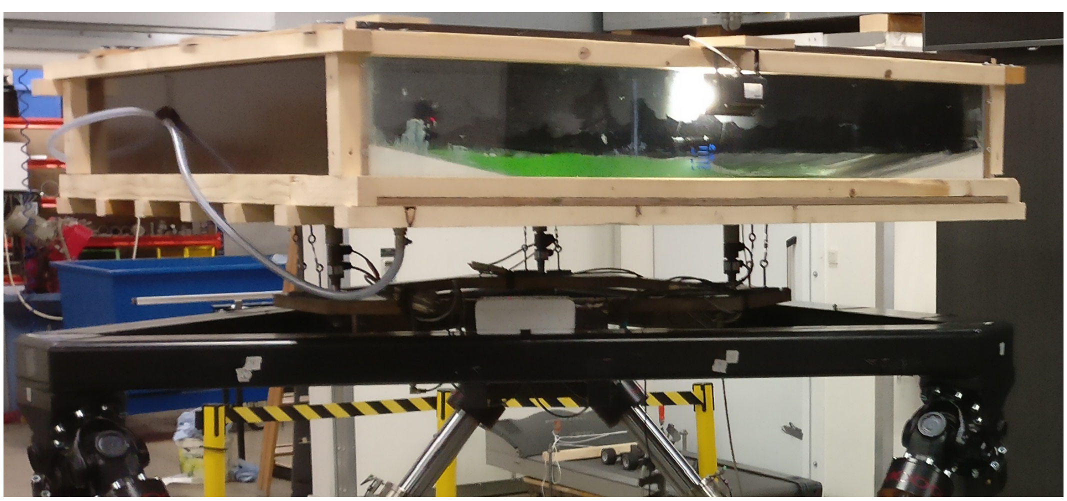

Fig. 1: Experimental TLD mounted on a MOOG MB-E-6DOF/24/1800kg motion base.

Motion generated slosh forces are measured and imposed on the numerical model in real-time generating damped wind turbine tower motion. A delay compensation scheme based on estimated delay and acceleration prediction using spline fitting is implemented. Sloshing forces are scaled with a factor corresponding to a TLD mass ratio of 1 %, i.e. the total mass of TLD fluid related to the combined structural mass. The amplification corresponds to having several identical TLDs (the no. of TLDs being determined by the scaling factor) mounted in a wind turbine. TLD size and wind turbine deflections are true to scale.

The reduction of tower vibration is evaluated based on standard deviation of tower top deflections. Results showed longitudinal damping of the wind turbine tower to be insignificant, mainly due to aerodynamic damping as well as the wind introducing non-periodic deflections, making damping by a single TLD design difficult. In the lateral direction however, vibrations are dominated by a single frequency of 0.34 Hz, making tuned liquid damping applicable.
Figure 2 illustrates damped and undamped lateral tower top deflections for a mean wind speed of 15 m/s.

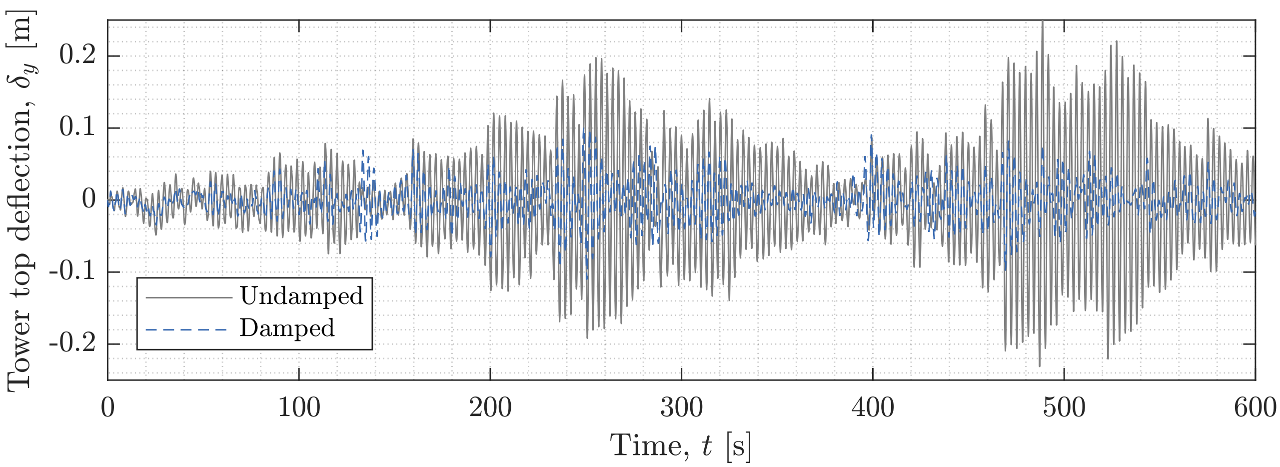

Fig. 2: Damping of lateral tower top deflections at a mean wind speed of 15 m/s at hub height.

For varying wind load cases between 11 and 20 m/s the TLD was found to reduce lateral WT tower deflections by 37 % to 67 %, achieving the largest reduction of deflections at 15 m/s.

Based on the real-time HIL simulations, implementing a TLD reduces wind turbine tower vibrations across a variety of wind loads making TLDs a viable option in terms of reducing material, production and maintenance costs of wind turbines.

References

[1] E. Hau, *Wind Turbines: Fundamentals, Technologies, Application, Economics*. No. ISBN: 3-540-24240-6 in 3rd Edition, Springer, 2013.

[2] P. Veers, "Trends in the design, manufacture and evaluation of wind turbine blades," *Wind Energy*, vol. 6, pp. p. 245–259, 2003.

[3] A. Ahlstrm, "Influence of wind turbine flexibility on loads and power production," *Wind Energy*, vol. 9, pp. p. 237–249, 2006.

[4] Z. Zhang, A. Staino, B. Basu, and S. R. K. Nielsen, "Performance evaluation of full-scale tuned liquid dampers (tlds) for vibration control of large wind turbines using real-time hybrid testing," *Engineering Structures*, vol. 126, pp. p. 417–431, 2016.

[5] J. M. Jonkman and M. L. B. Jr., *FAST User's Guide*, 2005. Technical Report.