Load reduction of offshore wind turbines using tuned liquid column dampers
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Offshore wind turbines are exposed to rough conditions from wind and waves, making them vulnerable to damage, which interrupts energy production and necessitates repairs. Also, their location relative to shore makes operations and maintenance a difficult and expensive process, accounting for upwards of 15-20% of the turbine’s lifetime cost. By using a structural control device, such as the tuned liquid column damper (TLCD), we can reduce the probability of failures, decreasing maintenance costs and making offshore wind a more viable energy source.

**Objectives**

- Develop an equation of motion in six degrees of freedom (DOF) to describe the motion and forces exerted by the TLCD, located in the turbine nacelle
- Incorporate this equation of motion into the existing tuned mass damper (TMD) module in FAST, an open-source software developed by NREL for the simulation of wind turbines (Figure 2)
- Run a parameter sweep over a range of TLCD design variables to determine optimal TLCD parameters that minimize the turbine structural response to an initial perturbation
- Assess the impact of the optimal TLCD design on the structural loads of an offshore wind turbine

**Proposed equation of motion:**

\[
\rho ALw = 2\rho Aw^2 (\dot{G} + \dot{P} + \rho AB\dot{\theta} (L - B/2) - \rho AB\theta \psi (L - B/2) + 2\rho A \ddot{\theta} (L - B))
\]

The liquid column acceleration is a function of inertial, Coriolis, centrifugal, gravitational, and damping forces.

We then extracted reactionary forces from these calculations, following the format of the existing code, expanded the TMD module to incorporate the capability for modeling a TLCD.

**References**


**Results & Future Work**

| Conditions for Ultimate Limit State Simulations |
|------------------|------------------|------------------|------------------|------------------|------------------|
| DLR | Wind speed [m/s] | Turbulence Int. | Wind Shear | Waves Height [m] | Peak Period [s] | Peak Shape |
| 6.1s | 41.50 | 10.00% | 0.14 | 1.70 | 0.30 | 2.386 |

By running ultimate limit state simulations on the NREL 5MW Monopile turbine, we can examine the efficacy of the TLCD compared to a TMD with the same mass (20,000 kg). The results show that the two mechanisms have similar impacts, and that both reduce the response of the structure significantly. This data is promising, and in the future we plan to:

- Add a capability for non-uniform cross-sectional area
- Add a capability for multiple, orthogonally aligned TLCDs, allowing damping in two dimensions
- Perform a complete loads analysis to assess efficacy of a TLCD

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**Figure 1** When subject to external excitation, the inertia of the liquid inside the TLCD resists movement, causing reactionary forces which are transmitted to the structure, as well as a potential energy difference between the two vertical columns. The result is the reduction of structural vibrations as kinetic energy is dissipated by the liquid through the orifice.

**Figure 2** Structure of the FAST v8 framework, including the AeroDyn, ElastoDyn, HydroDyn, and ServoDyn modules, which are all called by the glue code to simulate the movements of the turbine body. The TMD module, shown in red below, is located within the ServoDyn module, which controls the power generation via pitch and torque control. The TLCD model was implemented in the TMD source code.

**TLCD Mathematical Modeling**

Most existing literature uses the energy method to determine equations of motion of the TLCD in a reference frame with limited DOFs. To integrate the TLCD into FAST, we elected to use Newton’s Second Law, in order to incorporate all 6 DOFs of the nacelle motion into the equations. After arriving at a proposed equation of motion, we compared it to those proposed by other papers by limiting our additional DOFs, validating our model with these other works.

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