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Effect of Shaft Damping on the Dynamic Performance of a Wind Turbine Drivetrain: A Two-Mass System Approach

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INTRODUCTION

Wind energy is a rapidly growing renewable source in which drivetrain dynamics play a crucial role in overall performance and reliability. The flexible shaft connecting the rotor and generator in wind turbine drivetrains often induces torsional oscillations, leading to mechanical stress, component fatigue, and system instability. Shaft damping is a key factor in controlling these oscillations, as it determines the balance between vibration suppression and energy efficiency. This presentation investigates how shaft damping influences the dynamic behavior of a two mass wind turbine drivetrain, providing insights into improving stability and optimizing drivetrain performance.

OBJECTIVES

- Assess the influence of shaft damping on drivetrain dynamics.
- Analyze its effect on resonance, torque transmission, and stability.
- Identify the trade-off between vibration reduction and energy dissipation.

SYSTEM MODELING

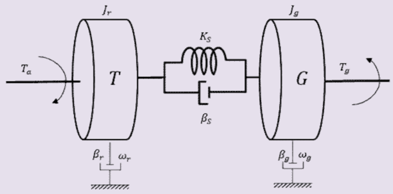

Figure 1: mechanical schematic of wind turbine drivetrain two mass model

J_r: rotor inertia
K_s: shaft stiffness
J_g: generator inertia
ω_r: rotor angular velocity
β_r: rotor damping coefficient
ω_g: generator angular velocity
β_g: generator damping coefficient
T_a: aerodynamic torque
β_S: shaft damping coefficient
T_g: generator torque

The equations of the two mass system are as follow:

$$J_r\dot{\omega}_r = T_a - T_s - \beta_r\omega_r \quad (1)$$

$$J_g\dot{\omega}_g = T_g - T_s - \beta_g\omega_g \quad (2)$$

$$T_s = K_s(\theta_r - \theta_g) + \beta_s(\omega_r - \omega_g) \quad (3)$$

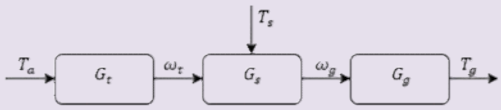

Figure 2: Wind turbine block diagram of two mass model

The transfer function of the motor, the load and the shaft are respectively

$$G_r(s) = \frac{1}{J_r s + \beta_r} \quad (4)$$

$$G_g(s) = \frac{1}{J_g s + \beta_g} \quad (5)$$

$$G_s(s) = \beta_s + \frac{K_s}{s} \quad (6)$$

The key transfer function analyzed in this study are

$$H_{ra} = \frac{n_g^2 J_g s^2 + (n_g^2\beta_g + \beta_s)s + K_s}{\Delta(s)} \quad (7)$$

$$H_{sa} = \frac{n_g^2(\beta_s s + K_s) + (J_g s + \beta_g)}{\Delta(s)} \quad (8)$$

Where:

$$\Delta(s) = n_g^2 J_g J_r s^3 + [\beta_s(J_r + n_g^2 J_g) + n_g^2 J_r\beta_g + n_g^2 J_g\beta_r]s^2 + [\beta_s(\beta_r + n_g^2\beta_g) + K_s(J_r + n_g^2 J_g) + n_g^2\beta_g\beta_r]s + K_s(\beta_r + n_g^2\beta_g) \quad (9)$$

The parameters we used in our simulation

Symbol	Value	Unit
J_r	27.36	Kg.m²
J_g	34.4	Kg.m²
β_r	27.36	Nm/rad/s
β_g	0.2	Nm/rad/s
K_s	325000	Nm/rad

Table 1: wind turbine drivetrain two mass model parameters

β_S (Nm/rad/s)
0
5000
9500
20000
30000

Table 2: Shaft damping values

RESULTS & DISCUSSION

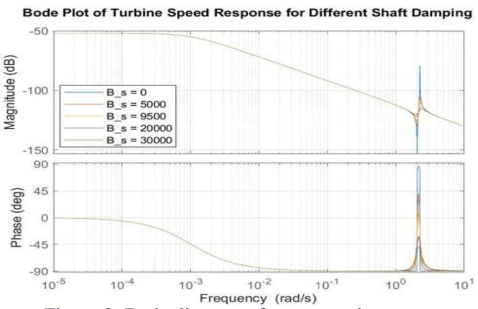

Figure 3: Bode diagram of rotor speed response

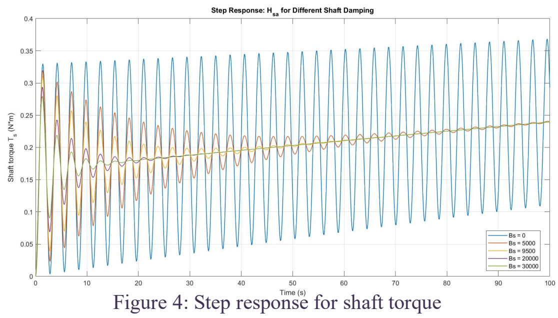

Figure 4: Step response for shaft torque

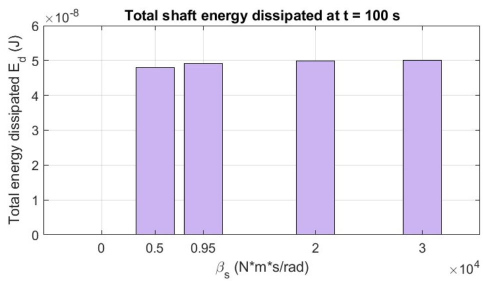

Figure 5: Energy dissipation in the shaft

- Zero damping causes strong resonance and high torsional oscillations.
- Increasing damping reduces vibrations and resonance peak.
- Higher damping improves system stability and stabilizes the drivetrain.

- Zero damping results in large, long-lasting torque oscillations due to torsional resonance.
- Increasing damping reduces the amplitude and duration of oscillations.
- Highest damping produces a smooth, stable response, improving drivetrain stability.

- Zero damping results in no energy dissipation in the shaft.
- Introducing damping increases the dissipated energy.

CONCLUSION

This study investigated the effect of shaft damping on a two-mass wind turbine drivetrain. Increasing damping reduces torsional oscillations and resonance, improving torque transmission and stability, but also increases energy dissipation. An optimal damping level is therefore needed to balance drivetrain stability and efficiency.

ENGINEERING INSIGHT

- Higher damping reduces drivetrain vibrations and torsional stress
- Too high damping increases energy loss

→ Optimal damping is required

FUTURE WORK

- Experimental validation on a real drivetrain.
- Extension to multi-mass wind turbine models.
- Integration with torque/speed control strategies.