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High-Fidelity Modeling of a Type-5 Wind Turbine Gearbox (Intern Technical Presentation)

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Changing the World's Energy Future

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High-Fidelity Modeling of a Gearbox for Type 5 Wind Turbine

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Introduction

Type-5 wind turbines are characterized by their use of a hydraulic torque converter and permanent synchronous generator. This combination promotes steady and grid-ready energy without the use of a power converter. Thus, researchers were prompted to study the potential impact on grid reliability, stability, and resilience using a Real Time Digital Simulator (RTDS) model of the type-5 turbine, including a high-fidelity model of its gear box.

Task

RSCAD, the software run on RTDS, lacks a high-fidelity gearbox model. RSCAD is pre-loaded with components and example cases for users to utilize. Within this repertoire, there is a pointed lack of a dynamic gearbox model, as the gearbox is often represented simply by a gear ratio value. This presented the task of developing a high-fidelity, comprehensive gearbox model in RSCAD for use in the broader RTDS Wind Turbine Models.

Methods

As there was no existing RSCAD component representing a gearbox, C-Builder was utilized to initialize the concept. C-Builder is RSCAD's software to implement user-developed components using the coding language C. To promote computational efficiency, a lumped parameter model was adopted, where the gears are evaluated in tandem by generalizing the gear-mesh forces as linear springs. The gears' stiffnesses, inertias, and coordinates are represented in matrices according to the gearbox configuration. However, due to C's inability to conveniently implement matrix math, MathWorks' conversion program was used to convert Simulink code to C. The gear-math used in this model are primarily Linear Ordinary Differential Equations represented in state-space form. State-space represents step-based updates of the gearbox system in relation to the rest of the turbine, thus the ODEs are implemented using Euler's Method.

Fig. 1: Block diagram depicting the code conversion process.

$$T_{in} = \sum_{i=1}^{n} t_{in} \frac{r_i}{r_{i-1} \dots r_1}$$

$$\begin{bmatrix}\dot{\Theta} \\ \ddot{\Theta}\end{bmatrix} = \begin{bmatrix} 0 & diag(1) \\ \frac{\mathbf{K}_r}{\mathbf{J}} & 0\end{bmatrix}\begin{bmatrix}\Delta\Theta \\ \dot{\Theta}\end{bmatrix} + \begin{bmatrix}0 \\ \frac{1}{\mathbf{J}}\end{bmatrix} T_{in}$$

$$T_{out} = \begin{bmatrix}\mathbf{K}_{(end,:)}\mathbf{r} & 0\end{bmatrix}\begin{bmatrix}\Delta\Theta \\ \dot{\Theta}\end{bmatrix}$$

$$Update : \Delta\Theta = \dot{\Theta} * \Delta T \qquad \dot{\Theta} = \dot{\Theta} + \ddot{\Theta} * \Delta T$$

Fig. 2: State-space equations used to update the simulation. **K** is the stiffness matrix, **J** is the inertia matrix, and theta, theta', and theta'' are vectors representing gear displacement, velocity, and acceleration, respectively.

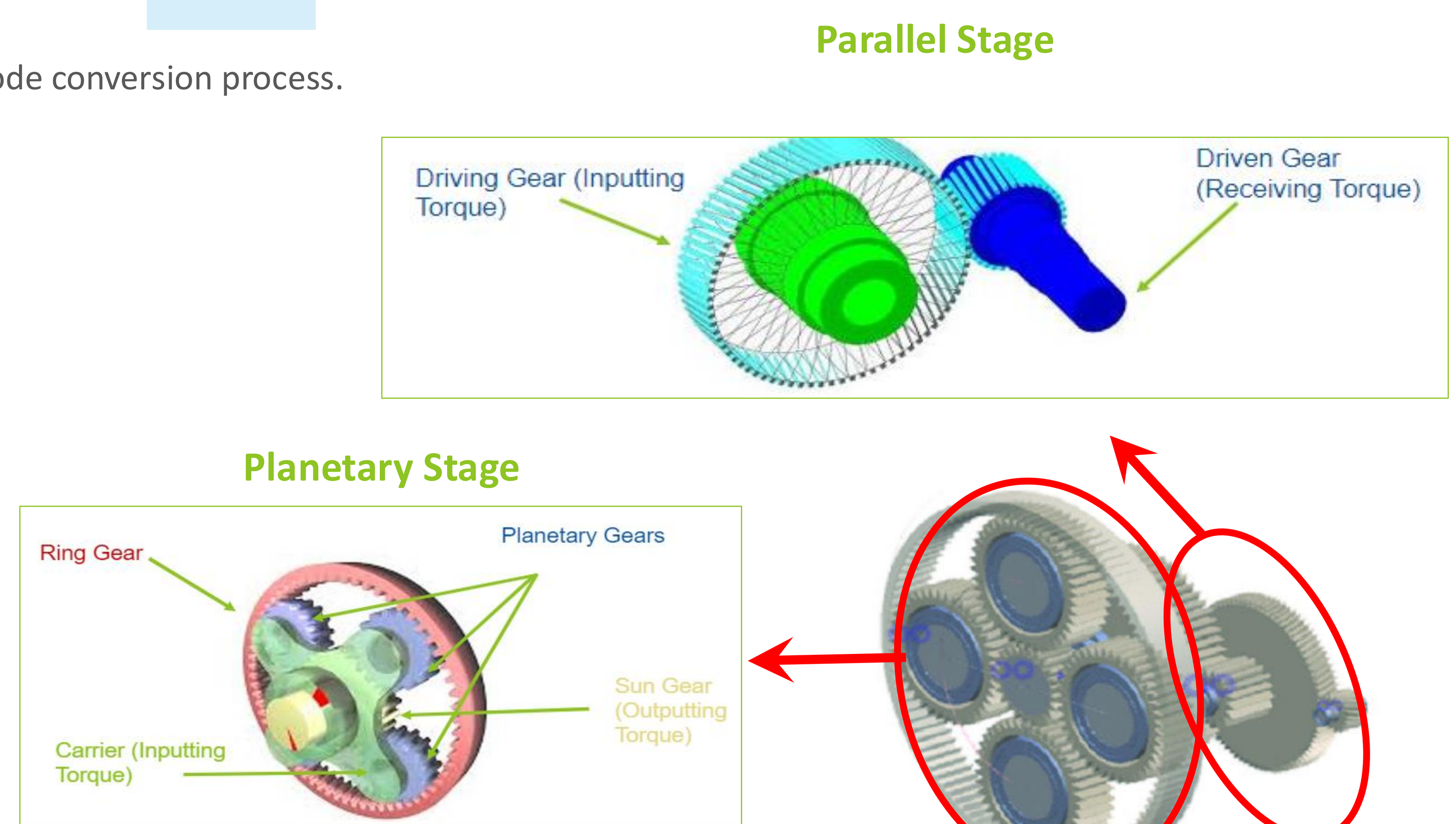

Fig. 3: Labeled diagram of a planetary-parallel-parallel gearbox, the configuration being modeled. Each 'stage' of the gearbox has a dedicated section of the stiffness and inertia matrices.
(Image sources: https://www.researchgate.net/figure/One-stage-planetary-and-two-stage-helical-parallel-gear-arrangement-6_fig2_317805319, https://gearmotions.com/fundamentals-planetary-gear-systems/, https://www.researchgate.net/figure/Rigid-multibody-model-of-the-high-speed-parallel-gear-stage_fig4_229010747)

Results

Currently, I have a one-dimensional (1D) parallel gear Simulink simulation that needs to be validated. The model's output (see Fig. 3) include the torque and displacement of the final gear in the system to be connected to the next component in the gearbox, presumably the generator shaft.

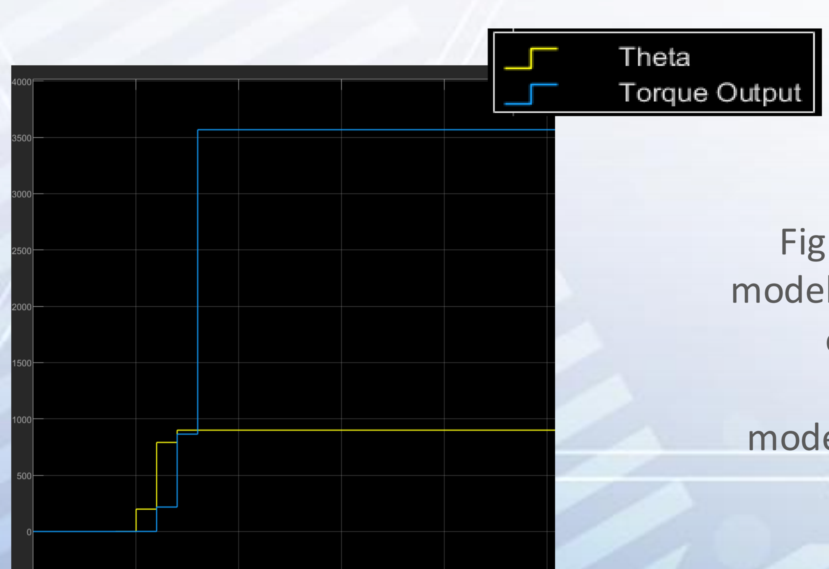

Fig. 4: Graph of the one-dimensional parallel gear model output values. The model parameters are based off NREL's "Gearbox Reliability Collaborative Phase 3 Gearbox 2 Test Plan," and the model's validation will draw from this case study, too.

Further Work

I plan to convert the validated gear model into C code before implementing it into C-Builder. Then, I will complete a full planetary-parallel-parallel gearbox for use in the Type-5 Wind Turbine Model. This model will be validated and then implemented in the same method as the existing gear model. The 1D planetary-parallel-parallel model is computationally identical to the 1D parallel model, except with concatenated matrices to represent the connected components.

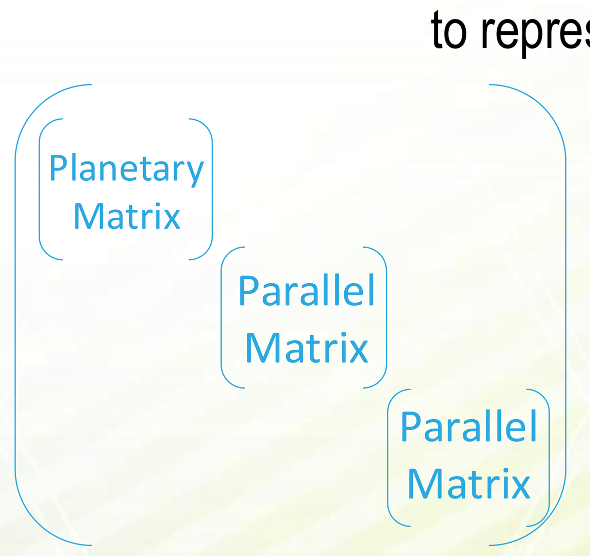

Fig. 5: Depiction of a lump-parameter matrix configured to represent a planetary-parallel-parallel gearbox. The matrix is 10x10, and the matrices are overlaid with their diagonals along the main diagonal. All elements that are not representing a gear stage component are zeros. The stiffness and inertia matrices are configured in this way, while the state vectors are simply vertically concatenated.

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