STRUCTURAL MASS SAVING POTENTIAL OF A 5MW DIRECT DRIVE GENERATOR DESIGNED FOR ADDITIVE MANUFACTURING

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ABSTRACT

As wind turbine blade diameters and tower height increase to capture more energy in the wind, higher structural loads results in more structural support material increasing the cost of scaling. Weight reductions in the generator transfer to overall cost savings of the system. Additive manufacturing facilitates a design for functionality approach removing traditional manufacturing constraints and labor costs. The most feasible AM technology identified for large direct drive generators in this study is powder-binder jetting of a sand cast mold. A parametric FEA optimization study is performed optimizing for mass and deformation. Also, topology optimization is employed for each parameter optimized design. The optimized U-beam spoked web design results in a 24% reduction in structural mass of the rotor and 60% reduction in radial deflection.

INTRODUCTION

Permanent Magnet Synchronous Generators (PMSG) are advantageous to wind applications as they allow removal of the gearbox and are electrically self-excitatory. Due to their flexibility in accommodating a magnetic path, PMSG are well suited for optimization.

Macdonald, Zavvos and Mueller [1,2] provide a comprehensive structural design and analysis of PMSG machines indicating their attractiveness for offshore applications due to increased reliability and energy yield. Standard structural designs for PMSG's include discs or arms [2]. Through shape optimization, Zavvos reduced structural mass of a spoke arm PMSG, yet his design mass is still heavier than standard arm designs. More recently, NREL [3] developed an optimization tool to reduce structural mass while simultaneously meeting electrical constraints.

Topology Optimization (TO) allows for optimal distribution of material in order to satisfy certain design and loading criteria with the goal of producing a lightweight structure. Resulting designs are oftentimes complex or impossible to manufacture through conventional means. Numerous TO algorithms exist for electric machines including open source models by Zuo and Xie [4] and Gangl et al. [5]. Gangl et al. observed a 27% reduction in the cost function for the final optimized shape.

Additive manufacturing facilitates manufacturing of complicated geometries from TO. By removing subtractive design constraints, the engineer is free to maximize efficiency, weight, and functional variables. Therefore, it is possible to design machines inspired by the design freedom of AM. This study looks to powder-binder jetting, an AM process where alternating layers of sand and binder create a finished sand cast mold. This process allows easy integration into traditional casting.

The design variables and view of the PMDD generator are seen in figure 1 and table 1 [3].

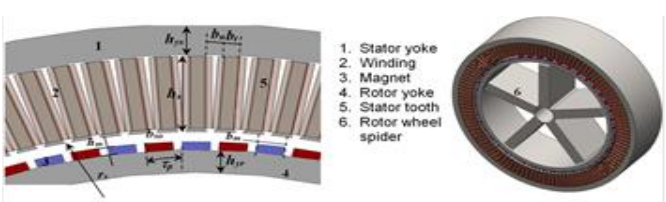

Figure 1: Design Variables of a PMDD Generator

Table 1: Tabulated Design parameters

Symbol	Design Dimension	Symbol	Design Dimension
r_s	Air-gap radius	g	Mechanical air-gap length
h_s	Slot height	b_t	Tooth width
b_s	Slot width	h_{yr}	Rotor yoke height
h_{ys}	Stator yoke height	τ_s	Slot pitch
τ_p	Pole pitch	h_m	Magnet height
b_m	Magnet width		

RESULTS

We examined the optimization potential of a spider web-based support structural as a printable and structurally efficient option for a 5MW RFPMSG. Structural design geometries including solid web, hollow web, and U-beam spoked web geometries were created and parameterized in ANSYS Design Modeler. The designs were evaluated against allowable structural deformation under a Maxwell stress of 0.2 MPa, a shear stress of 40kPa, and gravitational axial loading in case of transportation. The Radial, axial, and torsional deflections were calculated and verified against critical limits [3].

The solid spider web design exhibits 60% less radial deformation with 28% greater structural mass. By making the spokes hollow, the hollow spider web design maintains 60% less radial deformation with 11% greater structural mass than the hollow spoke arm design. However, this design is not manufacturable through AM sand cast printing methods as the core to create a hollow cylinder would have no supports. Therefore, the final design iteration chosen was a U-beam spoked web design capable of being produced via AM. This geometry maintains 60% less radial deformation with a 24% structural mass reduction compared to the conventional hollow spoke arm design. This mass reduction is seen in Fig. 2. Detailed analysis will be available in the final presentation.

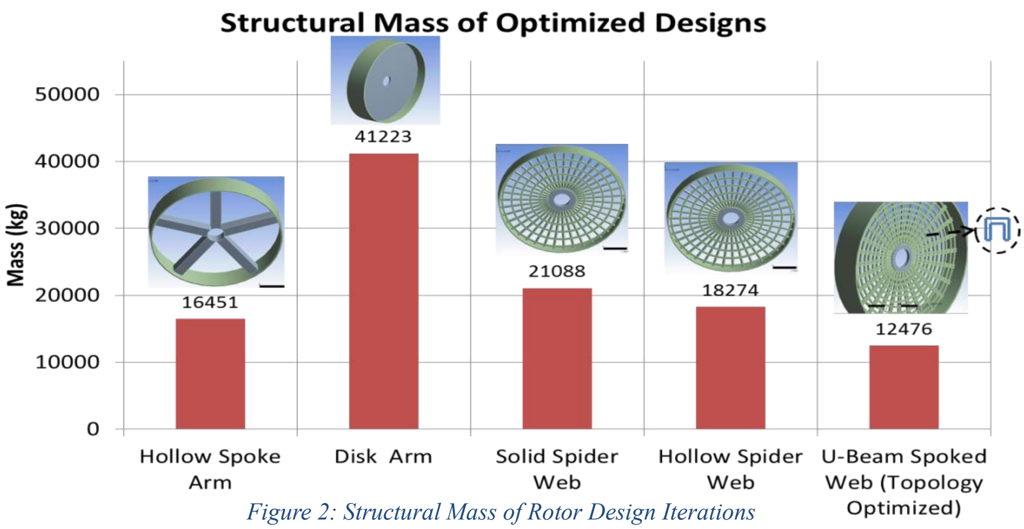

Figure 2: Structural Mass of Rotor Design Iterations

IMPACT

The geometric design flexibility offered by AM helped demonstrate a 24% structural mass reduction on the rotor. It is anticipated that further mass reduction may be possible by optimizing the stator, resulting in substantial weight reduction of the generator. The resulting AM inspired design is structural efficient as the air gap is maintained by structural rigidity. In reducing weight within the nacelle (the generator), the wind turbine system as a whole can be optimized (for example, reduced tower size due to reduced nacelle loading lowers the capital costs associated with wind energy). Therefore, designing for additively manufacturing large direct drive generators has the potential to realize lightweight structures that can help lower the costs of energy.

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