Motivation

- Design reliable and cost-effective composite wind turbine blades considering wind load uncertainty and manufacturing variability for 20-year operation at various locations.

Objective

- Develop reliability-based design optimization (RBDO) of composite wind turbine blades for fatigue life considering wind load uncertainty and manufacturing variability.
- Obtain RBDO optimum design which minimizes cost and satisfies reliability requirement for 20-year operation.

Methodology

- Dynamic Wind Load Uncertainty Model
  - Measured Wind Speed Data
  - Joint PDF of $V_{10}$ & $I_{10}$ Determined by $(C, k, a, b, \tau)$ (Annual Wind Load Variation)
  - Distribution of Probability of Wind Condition (i.e., $V_{10}$ & $I_{10}$)
  - Dynamic Wind Load Uncertainty Model

- Manufacturing Variability Model

- Accurate Surrogate Models for 10-Minute Fatigue Damage

- RBDO Flowchart
  - RBDO Initial Design
  - Check Hotspot
  - After Four Iterations?
  - Create Local Surrogate Models of 10-minute Fatigue Damages at Selected Hotspots
  - MCS of 10-minute Fatigue Damages Evaluated Using Local Surrogate Models
  - MCS of 20-year Fatigue Damages for Probabilistic Constraints
  - Reliability Analysis Using MSC & Sensitivity Analysis Using Score Functions
  - Matlab Optimizer
  - RBDO Optimizer
  - Optimization Converged?
  - Check Hotspot
  - RBDO Optimum Design
  - New Hotspot Found?
  - Yes

Application

- Parametric FE Model of a 5 MW Composite Blade
  - Variables:
    - Material Distribution
    - Layer Thickness
    - No. of Layers

- Wind Pressure Calculation for FEA
  - Given $V_{10}$ & $I_{10}$

- Fatigue Damage Evaluation under Complex Stress State
  - Experimental Fatigue Data

- RBDO of The Composite Wind Turbine Blade
  - Random design variables: 7 normalized laminate thicknesses
  - Objective: total composite material cost
  - Constraints: $P(\text{Fatigue Life < 20 Years}) \leq P^\text{ref} = 2.275\%$
  - (9 hotspots → 10 hotspots)

- RBDO Results
  - $d_1$, $d_2$, $d_3$, $d_4$, $d_5$, $d_6$, $d_7$ Normalized Cost Probability of Failure Mass (ton)
  - RBDO Initial
    - 1.133 1.571 1.818 1.299 1.115 1.091 0.867 1.03 2.28% 24.192
  - RBDO Optimum
    - 1

Conclusions

- Developed RBDO of composite wind turbine blades for reliability considering wind load uncertainty and manufacturing variability for 20-year operation.
- Optimized for cost-effective and reliable wind turbine blade using RBDO.

Future Work

- RBDO of other wind turbine components, e.g., gear and bearing, considering wind load uncertainty and manufacturing variability.