Multiphysics Electromagnetic Analysis of MW Large Capacity Power Generator

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1 Background & Motivation

- Renewable-energy integration requires thermal power units to operate flexibly and perform deep peak shaving.
- Flexible operation shifts generators from stable base-load service to frequent start-stop and wide load variation.
- These operating conditions cause abrupt stress fluctuations, vibration, insulation wear, and fatigue damage in stator and rotor components.
- A physics-based lifetime analysis framework is therefore needed for large-capacity generators.

2 Objective & Contributions

Build an electromagnetic-thermal-mechanical multiphysics coupling model for a 600 MW synchronous generator under actual peak-shaving conditions.

Reveal stress, deformation, and fatigue mechanisms of winding components during flexible operation.

Provide a numerical basis for life prediction, reliability assessment, and operation/maintenance optimization.

3 Methodology / Model Framework

Analysis workflow

Actual operating conditions → Electromagnetic field analysis → Thermal-mechanical coupling → Stress / deformation evaluation → Basquin-Coffin-Manson fatigue life prediction

Finite element model of the generator

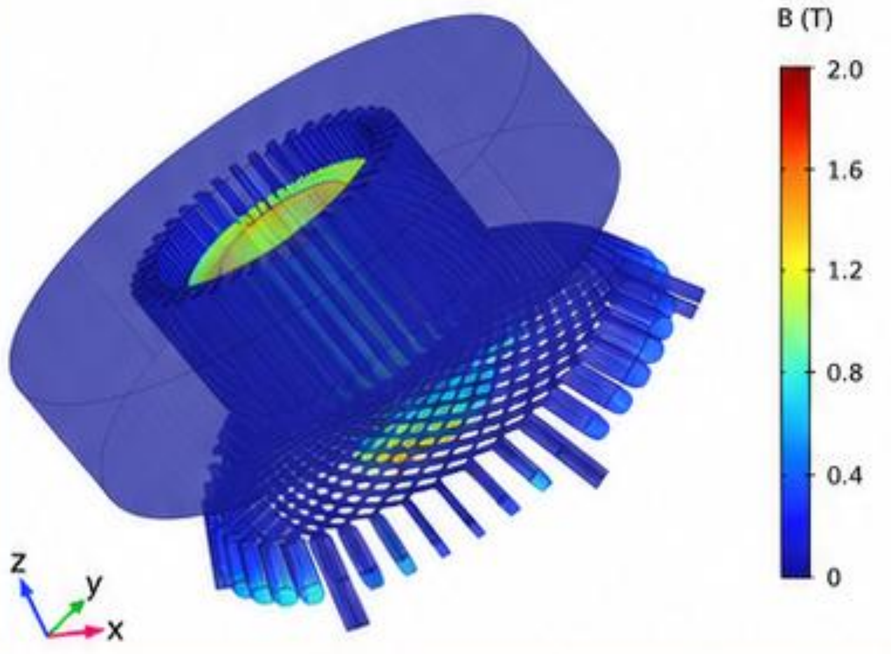


Fig. 1 Finite element model of the large-capacity synchronous generator.

Key generator parameters

Parameter	Value
Rated power	600 MW
Rated current	17495 A
Power factor	0.9
Frequency	50 Hz
Stator slots	42
Rotor slots	32

Fatigue life calculation

Basquin-Coffin-Manson equation:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c$$

Nf : failure cycle E : elastic modulus
σ'f, ε'f : fatigue strength and ductility coefficients
b, c : fatigue exponents

4 Results & Discussion

4.1 Magnetic flux density distribution

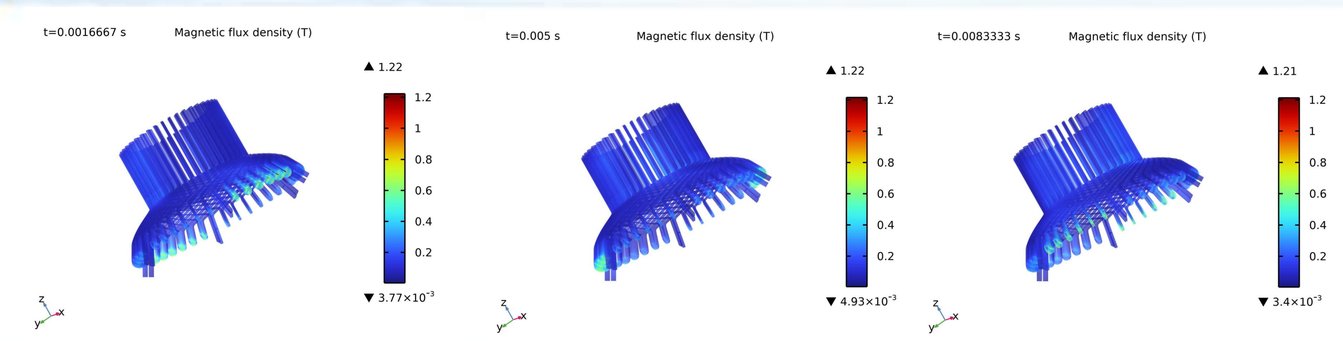


Fig. 2 Magnetic flux density distributions of the stator winding at the peak values of phases A, B and C.

- Flux density shows phase-dependent periodic variation under actual operating conditions.
- Concentration appears in local end-winding regions, creating spatially nonuniform excitation.

4.2 Electromagnetic force on stator winding

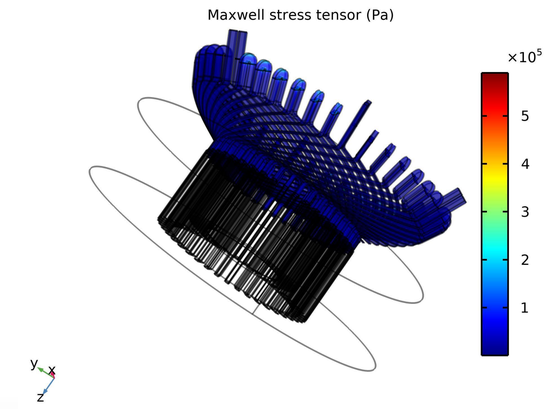


Fig. 3 Maxwell stress (electromagnetic force) distribution on the stator winding.

- Electromagnetic force on the stator winding is highly uneven and concentrated in local regions.
- Alternating force is a primary source of vibration and mechanical fatigue.

4.3 Radial stress along arc length

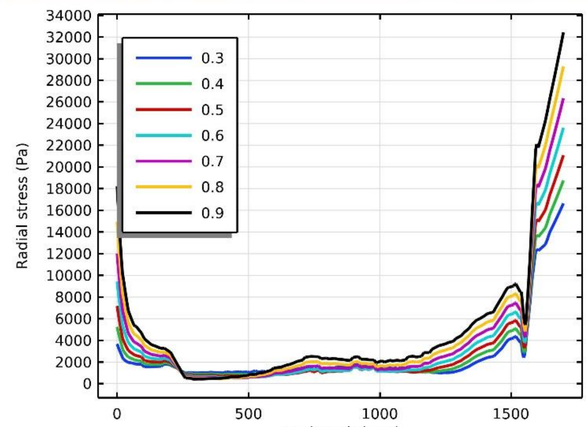


Fig. 4 Radial stress distribution along the arc length under different operating conditions.

- Radial stress varies strongly along the arc length and rises sharply near the end regions.
- Higher operating severity leads to increased stress magnitude.

4.4 Fatigue life analysis

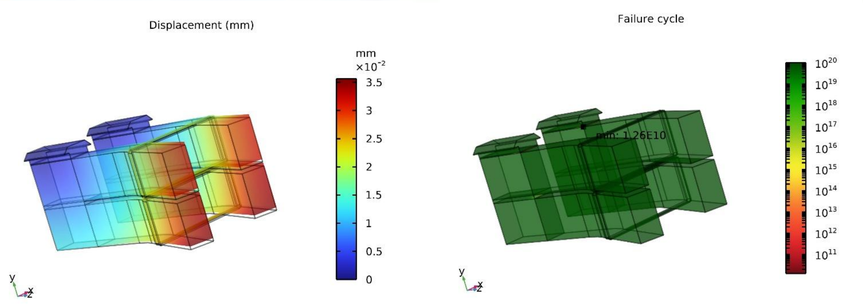


Fig. 5 Predicted fatigue life distribution and the most vulnerable location.

- Fatigue-life analysis identifies the most vulnerable structural locations.
- Minimum predicted failure cycle is approximately 1.26×10^{10}.

Key findings

1. Multiphysics coupling causes localized stress peaks in end-winding regions and stator structures.
2. Frequent peak-shaving operation leads to cyclic displacement and stress fluctuation.
3. Accelerated high-cycle/low-cycle fatigue may occur under actual operating conditions.

5 Conclusions

- Flexible peak-shaving operation significantly affects the mechanical integrity and lifetime of key components.
- Electromagnetic force concentration and thermal stress fluctuation drive localized damage accumulation.
- The proposed multiphysics framework provides an effective path for lifetime prediction and reliability evaluation.
- The results support optimized design, and maintenance planning for large-capacity generators.