Innovative Medium-Speed Drivetrain Design Program and Dynamometer Testing

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
The NGD is a medium-speed, medium-voltage drivetrain, featuring advances in the gearbox and power converter that increase efficiency, reliability, and annual energy production (AEP) while also reducing operation and maintenance (O&M) and cost of energy (COE).

NREL's research on the NGD has two phases:

- **Phase I** investigated NGD benefits; findings included a 5% increase in AEP and 13% decrease in COE at 5 megawatts (MW).
- **Phase II** has designed, built, and will test key drivetrain technologies.

Comparisons of drivetrain cost and efficiency at 5 MW.
NGD Technology Impacts

Benefits to turbines from NGD technology include:

• **Gearbox**
  - Increased reliability from single-stage gearbox and journal bearings
  - Increased capacity from multiple planets and flex pins

• **Generator**
  - Decreased manufacturing cost from concentrated winding
  - Decreased O&M costs from segmented stator

• **Power Converter**
  - Increased reliability of drivetrain with utility fault control algorithms
  - Reduced curtailment time with utility fault control algorithms
  - Increased efficiency from hybrid silicon carbide modules
  - Increased efficiency from medium-voltage design
  - Decreased capital costs from medium-voltage design
    - Reduced pendant cable size
    - Reduced/eliminated tower cooling requirement.
NGD Project Structure for Phase II

**Funding**
U.S. Department of Energy
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**Prime contractor**
National Wind Technology Center (NWTC) at NREL

**Subcontractors**
- DNV GL
- Cinch LLC
- CREE
- Powerex

NGD mechanical design team
- Romax Technology
- Miba
- Vattenfall
NGD Mechanical Innovations

Drivetrain architecture features:

• Single-stage gearbox
  o Four-point mounting configuration
  o Four planets mounted on flex pins
  o Journal bearings support planets
  o Ferrium C61 premium gear steel

• Medium-speed generator
  o Medium voltage
  o Surface mount, permanent magnet
  o Concentrated windings
    – Edge-wound coils and salient poles
    – Low cogging torque
  o Uptower maintenance
    – Segmented stator
    – Rotor and stator extraction tools.

Blue: To be tested in phase II
Gray: Part of phase I paper study only

The 650-kilowatt technology test bed. Illustration by Josh Bauer, NREL
Single-Stage Gearbox Design

Critical design conditions

- Nominal torque (353 kilonewton meters [kNm])
- Extreme torque (1,059 kNm).

Gearbox design:

- Two tapered roller main bearings
- Cantilevered flex pins support planets
- Oil passes through carrier and pins
- Sun gear drives generator rotor.
Flex Pin Design Benefits

Planet Mesh Misalignment

“Neck” in flex pin reduces mesh misalignment
Tooth microgeometry centers tooth loads

Gearbox models demonstrating reduced misalignment.
Illustrations by Romax Technology

Pin and Spindle Stress

von Mises stresses within acceptable limits at pin-spindle and pin-carrier interfaces.
Illustration by Romax Technology
Medium-Speed Generator Design

Generator rotor. *Photo by Jon Keller, NREL 33343*

Generator stator. *Photo by Jon Keller, NREL 33345*

Salient pole design and the prepotted edge-wound concentrated winding. *Illustrations by Global Energy Concepts*

http://www.nrel.gov/docs/fy12osti/51175.pdf
Medium-Speed Generator Design

Uptower stator extraction. Illustration by Global Energy Concepts

Uptower rotor extraction. Illustrations by Global Energy Concepts

Stator segment replacement in the NWTC’s dynamometer facility. Photo by Lee Jay Fingersh, NREL 33350

Key Instrumentation

The NGD is instrumented to take extensive measurements of the gearbox and generator:

- **Within the gearbox:**
  - Ring gear tooth load
  - Flex pin bending strain
  - Journal temperature
  - Oil supply pressure and temperature
  - Main bearing temp, oil sump temperature, oil cleanliness, and particles
  - Gearbox vibration

- **Within the generator:**
  - Torque tube torque
  - Winding temperature, inside and outside end turns
  - In each quadrant, three-phase current and voltage.

*Red and green marks indicate where the NGD is instrumented. Illustration by Romax Technology*
Single-Stage Gearbox Assembly

Planet carrier and pins. Photo by Jesse Graeter, Romax Technology

Planet spindles. Photo by Jesse Graeter, Romax Technology
Planet Pin Calibration

Using a crane to apply load. Photo by Jon Keller, NREL 33342

Pin bending characterization, showing the schematic and the results of planet pin calibration. Illustrations by Romax Technology
Drivetrain Assembly

Installing the ring gear. Photo by Jon Keller, NREL 33346

Installing the torque tube. Photo by Jon Keller, NREL 33347
NGD Testing Programs

Journal bearings will be tested on the NWTC's dynamometer for:
- Temperatures and wear
- Normal power, start-stop, rotor idle, and rotor locked states
- Torsional modes.

Torque and response will be tested during grid events produced with NREL's controllable grid interface for:
- Torsional mode active damping
- Symmetrical and asymmetrical fault responses
- Frequency deviation response.
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Dynamometer test setup. Photo by Jon Keller, NREL 33349