The 5 to 7MW range turbine is the upper end of what you can achieve by enlarging megawatt-scale architecture, but it is an awkward size range. The weights are high, the installation equipment is not commonly available and the cost of energy is not on a par with 1 to 3MW onshore installations. The question is how can we upscale beyond this awkward limit, and bring costs back down? The Nextwind Gaia architecture overcomes the barriers to upsizing existing wind turbine technologies, and aims to make possible large-scale offshore wind plants which will beat the initial cost, and cost of energy, of land-based wind farms.

By Rain Byars and William Miller, Nextwind, USA

The Gaia Ultra-Large Wind Turbine

How to Build Tomorrow's 12MW Turbine with Components Available Today

The Nextwind Gaia wind turbine architecture is a design concept which can be applied to wind turbines with rated output 12 to 20MW and higher. This article presents a brief overview of the design goals and concepts with a focus on the drive-train, the modular rotor system and the offshore structure. The work presented here is the result of internal research and development performed by William Miller and Nextwind team members.

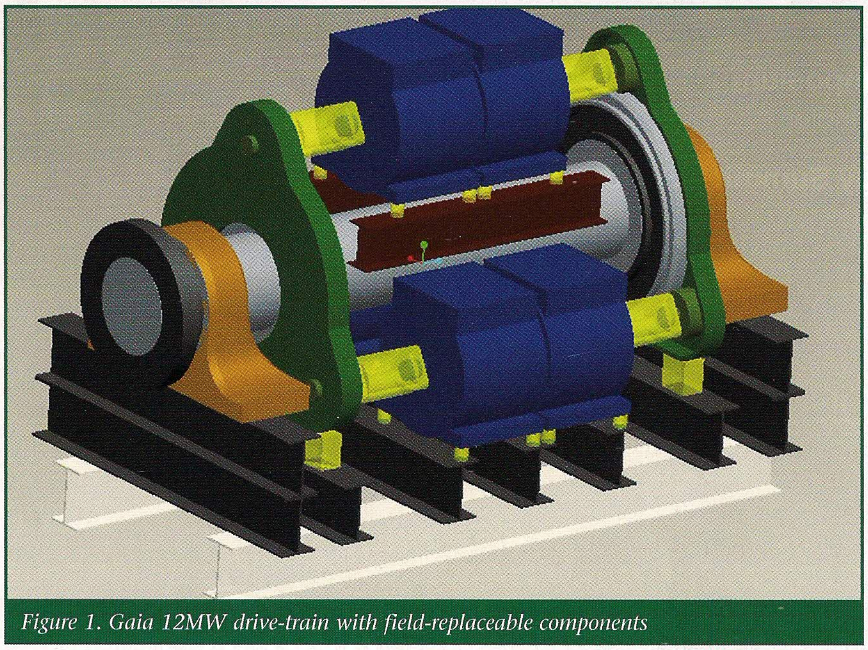


Figure 1. Gaia 12MW drive-train with field-replaceable components

Design Goals

In every turbine development, the designers must consider the driving design requirements that influence the return on investment. Some of the main considerations are:

- structural integrity and operational safety
- up-front costs including materials, transportation and installation
- reliability
- maintenance and service costs
- annual energy production

For offshore installations and ultra-large wind turbines, Nextwind has defined the following additional goals, which we consider to be critical to commercial viability:

- reduced single crane lift weight
- reduced single truck transport weight and dimensions
- make every component field replaceable
- reduced tooling investments and supplier Non-Recurring Engineering (NRE)
- extended lifetime of the entire structure

Architecture

The Gaia is an upwind, horizontal-axis, offshore wind-driven power plant with active control of yaw position, blade pitch, rotor rpm, structural loads and power output. The Gaia is built like a bridge. The tower top structure is comprised of bolted standard shapes, and is intended to be assembled on site with a standard crane size. Each drive-train component can be repaired or replaced on site without dropping the rotor. The individual components then become replacement parts, instead of structural parts, and the structure itself can be maintained for an extended life.

Drive-train

The Gaia drive-train comprises a long main shaft supported by two main bearings, two main gear assemblies and six generators. The main shaft is attached at the upwind side to the modular rotor system. The main bearings (upwind and downwind) can be removed from each end of the main shaft and can be serviced or replaced up tower.

Gear Assemblies

The main gear assemblies are supported on the main shaft between the two main bearings. The gear assemblies are segmented, and each segment can also be serviced or completely replaced up tower. The gear assemblies have a single-stage planetary configuration with multiple output shafts. This layout eliminates bearing wear associated with high-speed stages, and helps distribute and reduce tooth contact loads. The housings of the gear assemblies are supported on hydraulic dampers.

Generators

Each output shaft of the gear assemblies drives a permanent magnet generator. Dampers and torque-limiting couplers are used to mitigate loads transferred between the mechanical and electrical systems. The generators are manufactured to a common frame size with minimal tooling investment required. The size, weight and loads on a direct-drive generator with 12MW power output would present challenges to manufacturing and transportation as well as reliable operation and field service. The medium-speed generators have a higher power to weight ratio and use less rare earths and copper compared to a direct drive generator. The compact size and low weight allows low cost transportation and easy replacement in the field.

Structure

The entire drive-train is mounted on a support frame made of standard forms bolted together. This eliminates costly tooling as well as manufacturing limitations and transportation restrictions which are associated with massive cast structures.

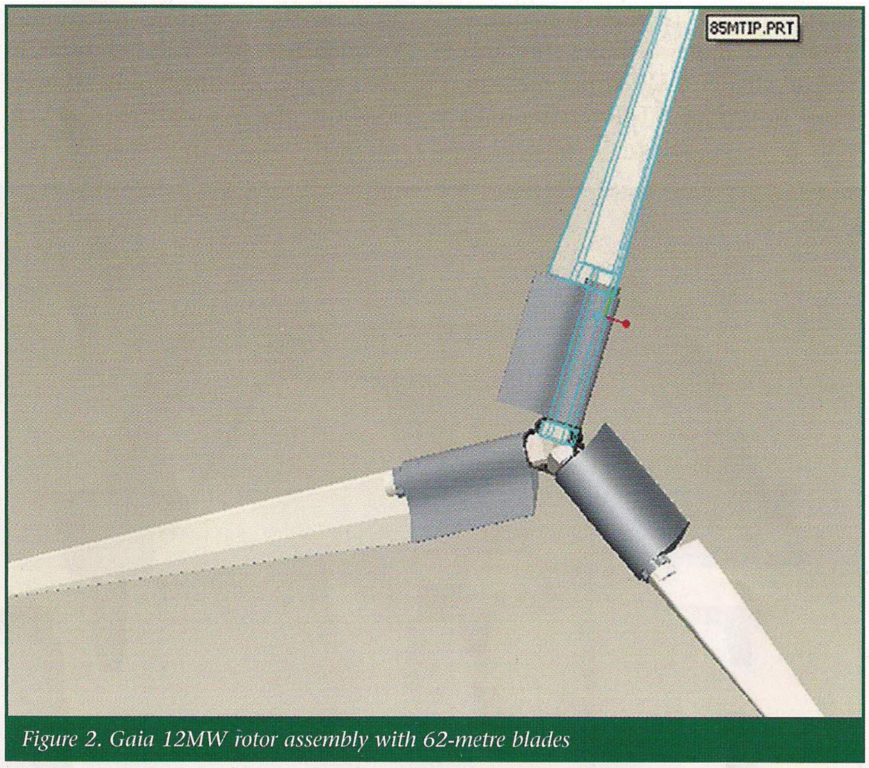


Figure 2. Gaia 12MW rotor assembly with 62-metre blades

The support frame and drive-train assembly are positioned into the current wind direction using an active yaw system. The load and position are controlled precisely with electric yaw drives and friction bearings.

Modular Rotor System

The modular rotor system comprises a central hub made of bolted, shaped, plate steel structural blade support members, passive aerodynamic covers, an active electric pitch system and fibreglass blades.

The bolted hub concept eliminates costly tooling as well as manufacturing limitations and transportation restrictions which are associated with massive cast structures. The hub assembly is made of standard materials which can be readily sourced globally and transported by standard means.

Tomorrow's Rotor with Today's Blade

The structural blade support members and passive aerodynamic covers allow a significant extension of the rotor area beyond what is currently possible with existing cast ductile iron hub and fibreglass blade manufacturing technology. Therefore a 12MW rotor can be achieved with blades which are currently in manufacture for 5 to 6MW wind turbines. Each of the three structural blade support members are attached at their inboard end to one face of the central hub. The pitch interface is located at the outboard end of the structural blade support member. The blade is mounted to the structural blade support with a bearing. An electric pitch drive is used to change the pitch position of the blade around the pitch axis.

The electric pitch system is specially adapted to the modular rotor system in order to withstand loads and environmental conditions at the extended pitch interface locations.

Offshore Structure

The optimum design of the offshore structure to cope with both strength and frequency requirements of large turbines presents special challenges. Neither onshore wind towers or offshore structures for other purposes present a technology solution at this scale.

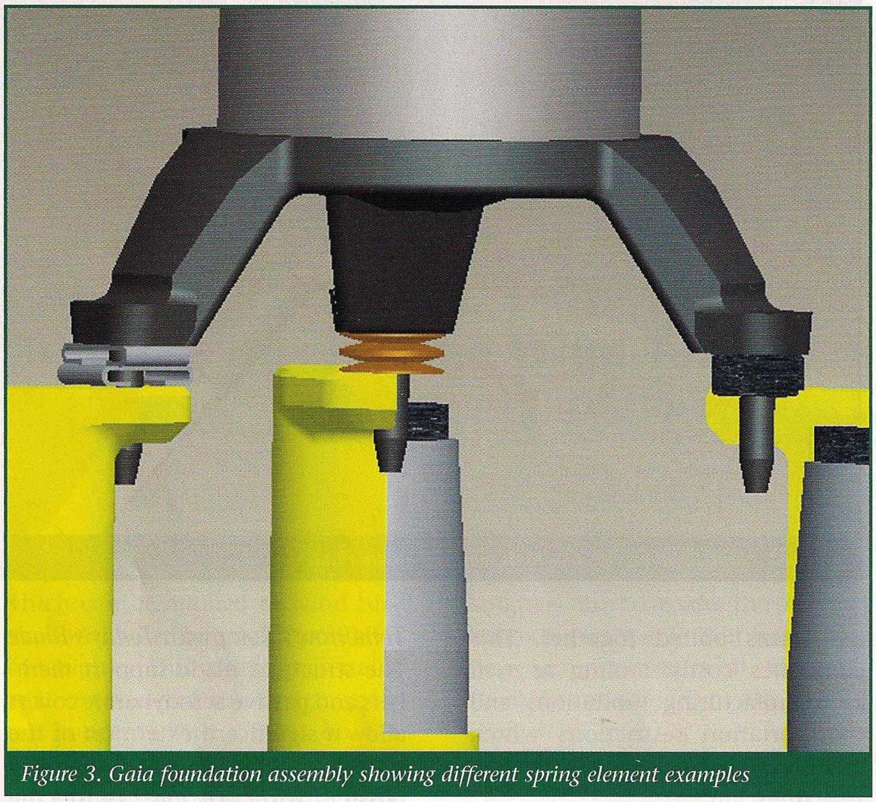


Figure 3. Gaia foundation assembly showing different spring element examples

The foundation system is assembled from smaller components for ease of transport as well as on-site alignment and tuning. Therefore the foundation assembly requires smaller cranes and support vessels compared to current 5MW offshore foundations. The tower and foundation systems are designed to withstand higher loads, increasing the estimated lifetime.

The transition piece between the underwater structure and the above-water structure is designed to be self-aligning and forgiving of tolerance stack-up, installation accuracy and settling.

Frequency Tuning at Installation

The stiffness and natural frequency of the offshore structure is limited by the operating (rotational) frequency of the wind turbine, as well as the periodic wind and wave loading. The natural frequency of the Gaia offshore structure is able to be adjusted and tuned at the time of installation by using inserts and variable masses. This allows the theoretical natural frequencies to be achieved precisely, and also allows adjustment away from the theoretical values in case of factors not fully modelled during simulation, or a change of operational strategy.

With the addition of a cement base section and variable ballast the overall weight, and weight distribution, can be adjusted. Water, sand or gravel could be used for the variable ballast to maintain future adjustability.

The yaw interface and the tower bottom mounting interface incorporate optional spring elements to further fine-tune the stiffness of the structure as well as allow some compliance.

Compliance

The tower should be able to withstand the higher load by complying to extreme load events such as high winds and/or waves. Compliance is achieved with local spring and damper elements which are designed to maintain stiffness during normal fatigue loads but deform under extreme loads.

Crush

For machine survival in extreme weather conditions such as 100-year hurricane occurrence, the compliant elements could be designed as replaceable 'crush zones'. Under extreme loads, which might deform a structure designed with standard methods, the crush elements would yield, while the remaining structure remains intact. This crushed component could then be replaced and the turbine could be returned to operation.

Active Frequency Tuning

In soft–stiff wind towers, it is typical for the first mode tower natural frequency to fall within the operational rotational frequency of the wind turbine. Turbine control software monitors the operational frequency, and increases or decreases the turbine rotational speed in order to avoid the tower natural frequency.

With active frequency tuning it becomes possible to change the stiffness of the offshore structure in real time during turbine operation to avoid high fatigue loads associated with the structure being excited by the turbine's operation.

The actuators are spring and damper elements located at the tower mounting interfaces which are capable of real-time adjustment.

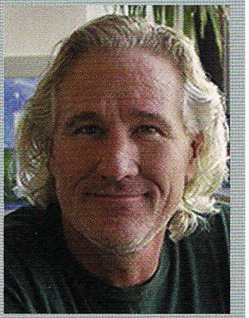
Conclusion

The Gaia represents a shift in design philosophy, which is necessary to overcome existing barriers. Various subsets of the Gaia architecture can be applied separately to different wind turbine designs. When all parts of the Gaia architecture are implemented together, the Gaia becomes a true wind-driven power plant. Early studies indicate that the initial cost per megawatt of the Gaia is competitive with onshore turbines, but, beyond that, the real advantage is seen in the reduced transportation, installation and service costs, which will push the cost of offshore energy below current onshore levels. Additional information will be released as development of these concepts continues. ■

Biography of the Authors

Rain Byars has worked in wind technology for the last 14 years. With an engineering degree from Carnegie Mellon University, Rain has directed wind technology development from blank sheet to prototype to production. Rain is currently employed in the role of CEO at Nextwind, leading consulting activities.

William Miller has a background in design and technology spanning over 25 years, with 15 years in wind. He has been responsible for product upgrades with Zond and GE Energy, and design of turbines up to 5MW as a technology consultant. William is the co-founder and CTO of Nextwind, Inc., leading new technology development.



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