Achieving 40% Mass Reduction in PMDD with Floating T-rotor

Presenting Author: Philip Totaro, Totaro & Associates

Co-author / Inventor: Richard Himmelmann, United Technologies Corporation

Conventional direct drive wind turbine systems mount generator components directly to a stationary support structure. The driveshaft (and consequently the generator rotor) is rotatably mounted to the stationary support structure, while the stator is fixedly anchored to the stationary support structure. Driveshafts and stationary tower structures for direct drive generators are ordinarily constructed to be very rigid, so as to minimize driveshaft deflection under transient aerodynamic loads. To achieve this rigidity, stationary support structures are often heavily built and expensive.

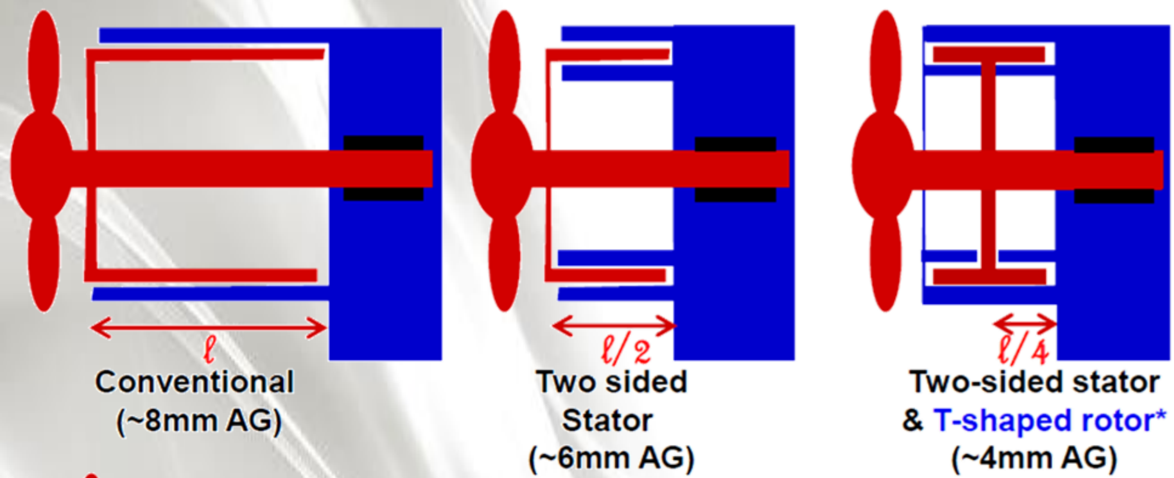
Changes in wind profile (such as sudden gusts and rapid direction changes) exert non-axial forces on the blade rotor during ordinary wind turbine operation, causing the driveshaft to deflect angularly. This deflection has little effect on the position of the generator rotor relative to the generator stator in conventional gearbox-driven wind turbines, since gearboxes are usually configured to absorb driveshaft deflection, and generator rotor diameters in gearbox systems are usually relatively small.

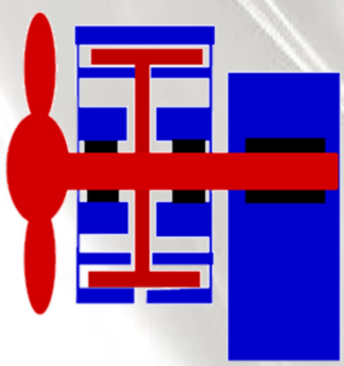
By contrast, generators for direct drive wind turbines typically have very large diameter rotors. These large rotor diameters (which may exceed 10 meters) allow direct-drive turbines to achieve high relative speeds between the generator rotor and stator without a gearbox, but exaggerate the effects of driveshaft deflection caused by aerodynamic loads. In particular, angular deflection of the driveshaft displaces the outer diameter of the rotor by an amount proportional to rotor diameter. Even small driveshaft deflections can therefore have a pronounced effect on the position of the generator rotor relative to the generator stator.

Contact between the rotor and stator can cause generator failure. To avoid contact from driveshaft deflection, direct drive generators typically have large air gaps which provide space for the rotor to deflect without touching the stator. Larger air gaps, however, reduce flux density and therefore generator efficiency, and necessitate increases to the overall size (and cost) of the generator.

Therefore, it is desirable to have a generator that overcomes some of these challenges. Most importantly is to make a compact and lightweight design which can easily integrate with existing technology architectures and utilize conventional bearing and magnet technology.

Paramount to this is to reduce the overall length and minimize the air gap. Conventional designs have a wide air gap due to the amount of deflection between a rotor and stator. If the stator could be mounted to coincide with the rotor, then deflections could be more easily reacted by the kingpin on which the generator is mounted and grounded through the tower.





In this last configuration, the rotor is secured directly to hub, e.g. via bolts, pins, posts, screws, or rivets. Hub rides spindle via blade assembly bearings, which may for instance be cylindrical or tapered roller bearings. Spindle is an elongated, substantially cylindrical portion of support structure, and accordingly does not rotate together with blade assembly and rotor. Rotor is not directly anchored to support structure, but is rather anchored to hub. In alternative embodiments, spindle can be constructed in a conical shape, a box beam shape, an I-beam shape, or any other structurally appropriate beam shapes.

Rotor comprises inner platform and magnet support. Inner platform is a substantially cylindrical bearing surface carrying rotor bearings. In alternative embodiments, inner platform can, for instance, have a conical shape allowing for various diameter bearings. Magnet support is an annular structure extending radially outward from inner platform to support magnets radially between outer and inner stator windings and, respectively. In the depicted embodiment, magnet support has a "T" cross-section, with a radial arm or web supporting an annular ring bearing magnets.

The stator is supported on rotor allowing the air gap of generator to be made very small without risk of rotor and stator contacting as a result of deflection hub and/or rotor. Stator casing of stator is a rigid body that surrounds, supports, and protects stator windings, and provides an attachment point for torque reaction arm.

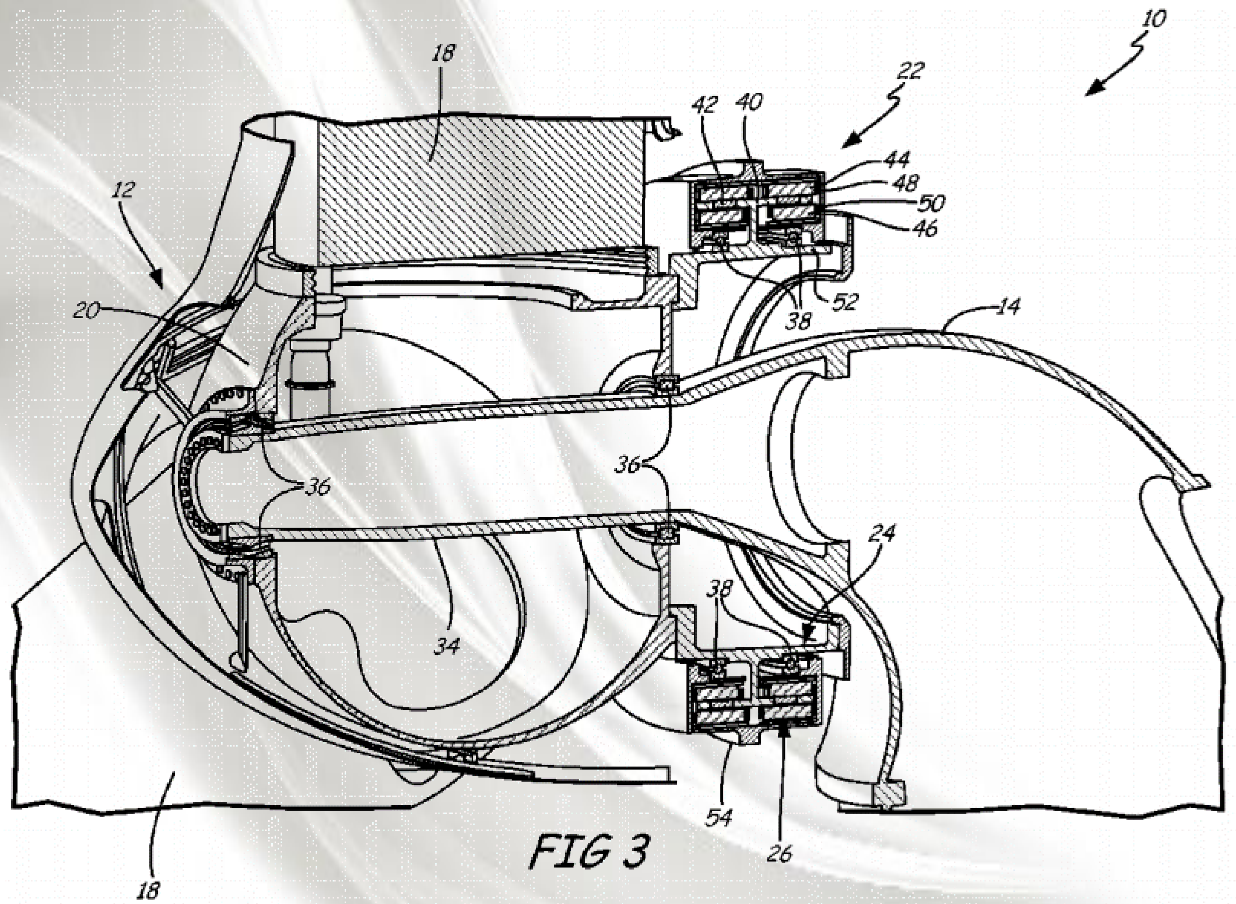


FIG 3

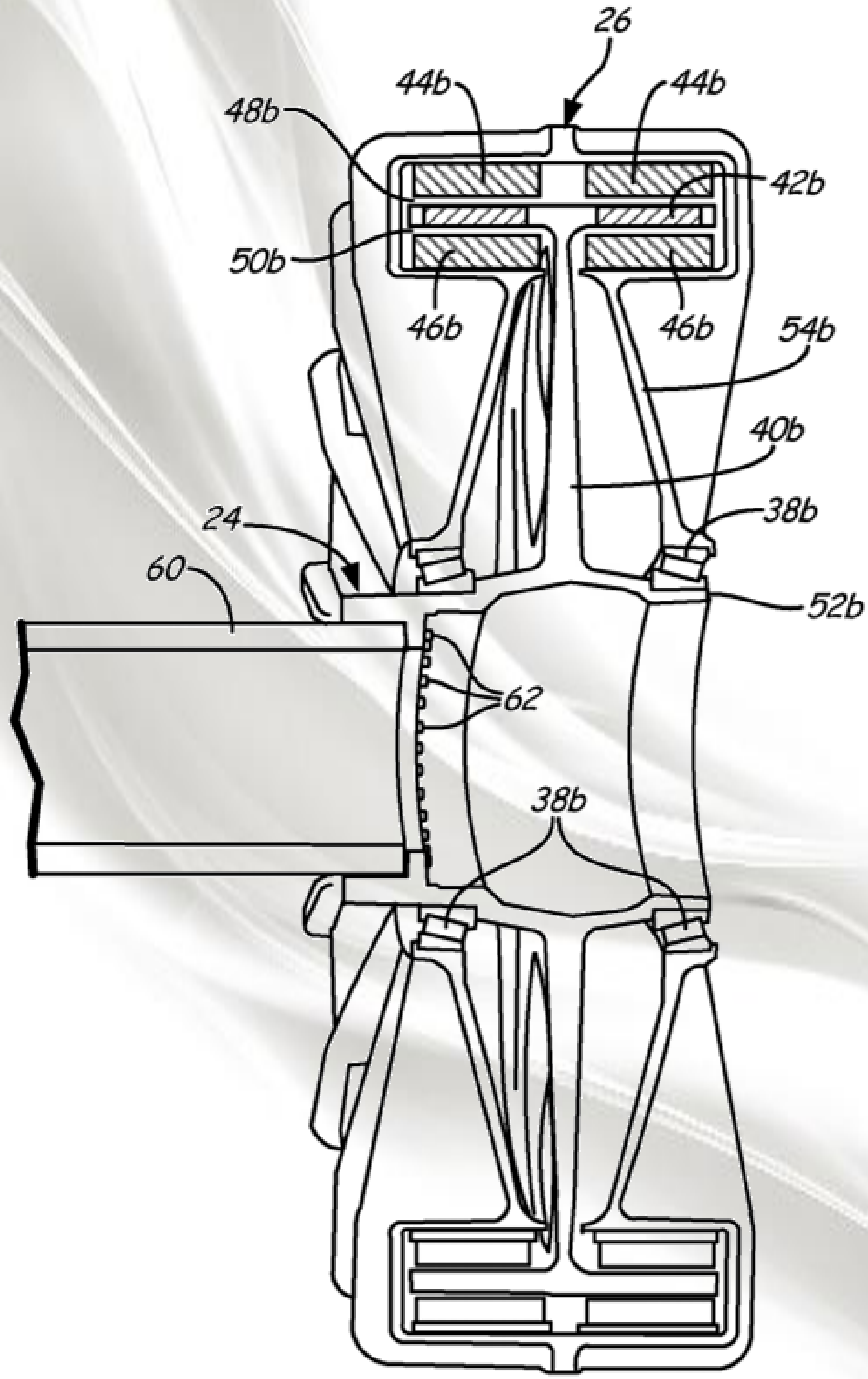
Stator comprises outer stator windings and outer inner windings axially aligned with magnets, and radially separated from magnets by outer air gap and inner air gap, respectively. Stator windings are anchored to stator casing, which in turn rides stator bearings, thereby allowing rotor to support stator without rotating stator. Stator bearings may, for instance, be ball, roller, or plain bearings.

By supporting stator on inner platform of rotor with stator bearings, rather than on a stationary support structure such as support structure as is conventional, generator allows stator to deflect together with (or "follow") rotor and hub under transient aerodynamic loads. Deflecting together allows rotor and stator to avoid making contact even with very narrow air gaps. Accordingly, air gaps can be reduced in width, increasing flux density and improving generator efficiency. The narrower air gaps made feasible by supporting stator directly on rotor also reduce the overall size and mass of generator, further decreasing production costs. Stator is restrained against rotation, but not against deflection, by torque reaction arm or equivalent torque control elements.

Similar architectures with the double sided rotor or stator have already been contemplated in the wind industry by General Electric, Alstom, Guodian United Power, Mitsubishi Heavy Industries, Siemens and some smaller companies, but no commercialization has been undertaken for this type of architecture.

Totaro & Associates

United Technologies



The benefits of this design include:

- Lower overhanging load / moment
- Floating rotor enables off-axis deflection to be absorbed
  - Kingpin design enables grounding of non-torque loading
  - Bearing structure enables balance – no cantilever to rotor/stator arrangement
  - Herringbone or multi-step/skew magnet pole architecture enables induced axial force balance

Neuer Wall 80, Floor 4
20354 Hamburg, Germany
www.totaro-associates.com

Phone: +49 (0)40 822 138 324
eFax: +1 206 202 0593
info@totaro-associates.com

- Estimated 50% reduction in air gap (2 – 3mm)
- ~40 – 50% reduction in magnet mass for a 2.2MW architecture
- ~40% reduction in overall generator mass vs. conventional radial PMDD
- ~40% reduction in generator cost vs. conventional PMDD
- Configuration is scalable to 10MW without conventional scaling drawbacks
- Useful for onshore and offshore

Benchmarking indicates new design indicates there is a marked improvement in key generator attributes vs. conventional technology:

Supplier	UTC/D Cube	A	B	C	D	E	
Cost (k$)	505	930	1,105	1,154	900	1,500	-40%
Rating (MW)	2.2	2.2	3.0	2.3	2.2	2.2	
Speed (RPM)	13.4	18	10.9	13	13.4	13.5	
Magnet mass (Kg)	950		2,208	3,221	1,728	2,500 / Rotor 1,000 / Air gap control	-50%
Copper mass (Kg)	3,582		5,524	6,408	3,087	~ 1,500	
Iron mass (Kg)	10,110		9,017	12,147	6,433	0	
Active mass (Kg)	15,100		16,749	21,776	13,190	4,000	
Total mass (Kg)	40,150	60,000	75,000	47,700		40,000	
Generator Type	Traditional Radial gap with “T” shape rotor	Traditional Radial Gap	Traditional Radial Gap	Radial Gap with the rotor on the outside of the stator	Traditional Radial Gap	Axial Gap rotor	
Diameter (m)	4.2	4.46	5.5	4.2	4.1	17	
Length (m)	1.3	2.8		2.2	2.0		-50%
Mechanical air gap (mm)	2.5	6-8	5	6-8	5.0	5	-50%
Efficiency (%)	94.5	94.4			93.0	95.2	
Cooling	Liquid	Air	Air			Air	

Current status of the development effort is as follows:

- TRL 3 achieved, but need turbine test partner for up-tower proof of concept.
  - Resources available to complete test.

- Patent pending: WO/2013/109611 published on July 25, 2013.

- Commercialization partner sought.
  - Technology and associated IP are available for sale or license.

Neuer Wall 80, Floor 4
20354 Hamburg, Germany
www.totaro-associates.com

Phone: +49 (0)40 822 138 324
eFax: +1 206 202 0593
info@totaro-associates.com