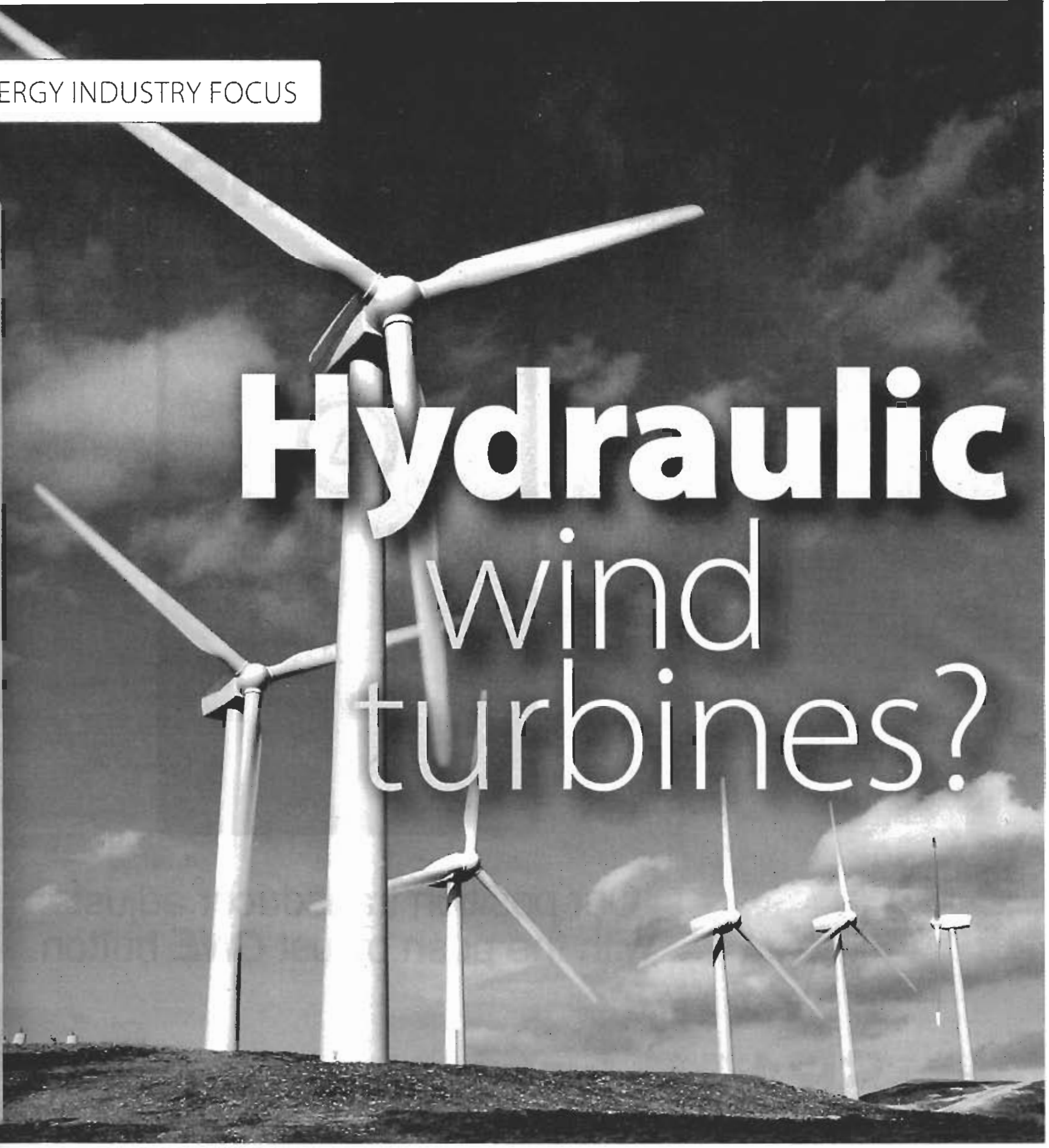

Hydraulic wind turbines?

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Key points:

- A nacelle-mounted hydraulic drivetrain could be thousands of pounds lighter than the mechanical gearboxes used today.
- Today's off-the-shelf hydraulic components are practical for wind turbines with outputs up to about 500 kW.
- Hydraulic drivetrains would decouple torsional vibrations generated in the rotor hub from the generator and boost reliability in the bargain.

Resources:

Eaton Corp., *wind turbine hydraulics info, tinyurl.com/yjt2422*

Consider the make-up of a common megawatt-scale wind turbine erected today. Inside the nacelle, behind the turbine blades, is a multiton planetary gearbox hooking the turbine rotor to a synchronous generator. A cabinet full of electronics converts the generator output to grid-compatible power. One generally also finds a sizable dehumidifier stationed in the nacelle to keep the electronics in an environment where they can function reliably.

The nacelle itself can be elevated some 50 stories off the ground, so major maintenance issues can involve hauling in huge cranes to swap out components. At the least, technicians must make the 50-story climb periodically to handle ordinary upkeep.

It is fair to say that there are a number of complicated mechanical and electronic systems in the nacelle of the typical utility-scale wind turbine. With this in mind, consider a thought-provoking question: Why not instead use a hydraulic drive? Why put the generator head up in the nacelle? Why not just put a hydraulic pump there and let the hydraulic pressure spin a generator on the ground?"

These are very good questions.

One approach would be to mount a radial piston-type pump in the nacelle and an in-line or bent-axis motor on the ground to drive the generator. A radial piston-type pump provides the best performance at the low input speeds typical of wind turbines, and an in-line or bent-axis generator motor provides the greatest efficiency. This arrangement simplifies the task of regulating generator speed under varying wind conditions. It also reduces the nacelle's overall weight and isolates the generator from the low-frequency torsional vibrations that characterize wind turbines.

As a practical matter in most, but not all, cases it makes sense to split the system so the motor and generator can mount at ground level. But no matter which approach is used, a hydraulic drive of this nature could result in smaller, lighter nacelles. Nacelle-mounted hydraulics for a 100-kW system would typically weigh 700 to 1,000 lb. In the same vein, the towers and bases to support the smaller, lighter na-

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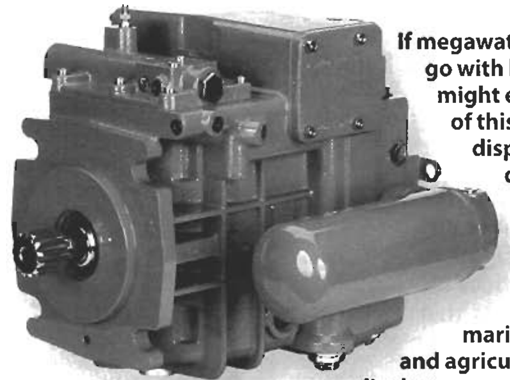
Wind turbines that swap traditional mechanical drivetrains for hydraulics could potentially be lighter, more reliable, and less expensive than those fielded today.



If megawatt-scale wind turbines ever go with hydraulic drivetrains, they might employ scaled-up versions of this Eaton 760 Series variable displacement pump and fixed displacement motor which is optimized for use in wind turbines as well as for such closed-circuit applications as mining and drilling equipment, marine thrusters, tub grinders, and agricultural sprayers. It provides displacements of 130 cc/rev (7.93 in^3/rev) at 3,200 rpm, and 160 cc/rev (9.76 in^3/rev) at 2,950 rpm.

celles would themselves be less expensive. Moreover, most maintenance activities could take place at ground level.

Such hydraulic systems would eliminate the need for mechanical gearboxes. Consequently, the overall wind-turbine mechanics would be less complex and the uptime of the apparatus would likely improve. And a setup of this nature would decouple torsional vibrations generated in the rotor hub from the generator. Finally, a hydraulic pump would have less inertia than existing wind-turbine mechanics and thus would let the turbine begin generating power in lighter winds. The turbine's operational envelope would expand as a result. All in all, such systems would have lower operating costs over their lives than those we see today.

But though there are benefits to a hydraulic approach, there is no free lunch. The hydraulic solution is currently less efficient than an electromechanical system, and it is not as easily scaled up to handle the loads of multimegawatt turbines.

The simple fact is that even operating at maximum efficiency in the 5,000-psi range, the hydraulic system would be from 10 to 30% less efficient than a mechanical system in moving energy from the turbine blades to the generator input shaft. Add in the line losses encountered in moving the hydraulic fluid up and down the length of the tower for a split system and the deficit would be even greater.

One factor often ignored is the relatively low rotational speed of a wind turbine. Most hydraulic pumps are designed for input speeds ranging between 500 and a few thousand revs/min, while wind turbines normally max out at 150 rpm or less.

The issue is that pump losses are not strongly related to input speeds. Operating a piston-type pump at 150 rpm when it is designed for 600 rpm, for example, reduces the volumetric output linearly by a factor of four. But it does not reduce losses by a factor of four. Pumps are less efficient below their designed speed, and the extreme variability of the input speed with changing wind conditions makes matters worse.

Today's technology will eventually create pumps optimized for these conditions. Early adopters of hydraulic drives will have to depend on off-the-shelf components, which leads directly to a second set of challenges. In general terms, today's off-the-shelf hydraulic components are practical for wind turbines with outputs up to about 500 kW. Our company has designed and built several successful wind systems in this size range. For megawatt-scale systems, however, designers must resort to suboptimal solutions like multiple pumps and motors to get enough capacity. When they do, efficiency suffers further.

These drawbacks are a reflection of the industrial and mobile applications that historically have been the primary focus of hydraulic manufacturers. Outside of a few highly specialized applications, there's little demand for pumps and motors rated for thousands of horsepower. But a multimegawatt wind turbine generates thousands of horsepower, and multimegawatt turbines are where the action is today.

Eaton, and probably other manufacturers as well, has the technology to devise components able to output this horsepower range. But the creation of such equipment will require significant investment. One can't simply make a pump or a motor twice as big to double the capacity. They aren't scalable on a 1:1 basis.

Pressure drops, for example, typically are a square function of port size. We certainly have the design tools to overcome these nonlinear effects, but the market dynamics present challenges to any company developing the necessary technology.

More research

Today the world's major wind-turbine manufacturers all operate at full capacity, as do suppliers of their critical components like gearboxes. Under those circumstances it's difficult to justify putting resources toward new technologies that would require fundamentally different product designs, manufacturing systems, and suppliers.

For a multitude of historical reasons, today's wind-turbine systems are virtually all based on electromechanical designs that have been in production for years or even decades. Both producers and users understand their benefits and shortcomings quite well. And support systems have evolved to take advantage of their strong points and minimize their weaknesses. There is no doubt that a hydraulic solution can offer solid economic benefits compared with today's electromechanical systems. Hydraulics offer power density unmatched by any other technology, and power density is precisely what is needed in a wind-turbine nacelle. The efficiency gap may eventually succumb to new technologies like more-efficient fluids to reduce line losses and electrohydraulic-control systems to optimize performance. But even without such developments, hydraulics look attractive on a life-cycle cost basis. Hydraulic wind turbines could potentially make it feasible to field less-expensive nacelles, towers, and tower bases.

For example, consider the difference in cost between ground-level maintenance by normally skilled operators versus in-nacelle maintenance by teams of highly skilled technicians in climbing gear. The differences over the projected 20-year life of a wind turbine would be substantial. And there would be much less need for 50-story-high cranes.

It's also likely that ground-level maintenance would be more frequent because it would take less planning. (It is worth noting that rumors now circulate in the wind industry about many wind farms being behind on their maintenance. Such rumors are hard to verify, though, because wind-farm operators generally treat their maintenance data as proprietary.) Yes, the pump in the nacelle would still need maintenance, along with the hub and other equipment. But the overall cost would still be much lower.

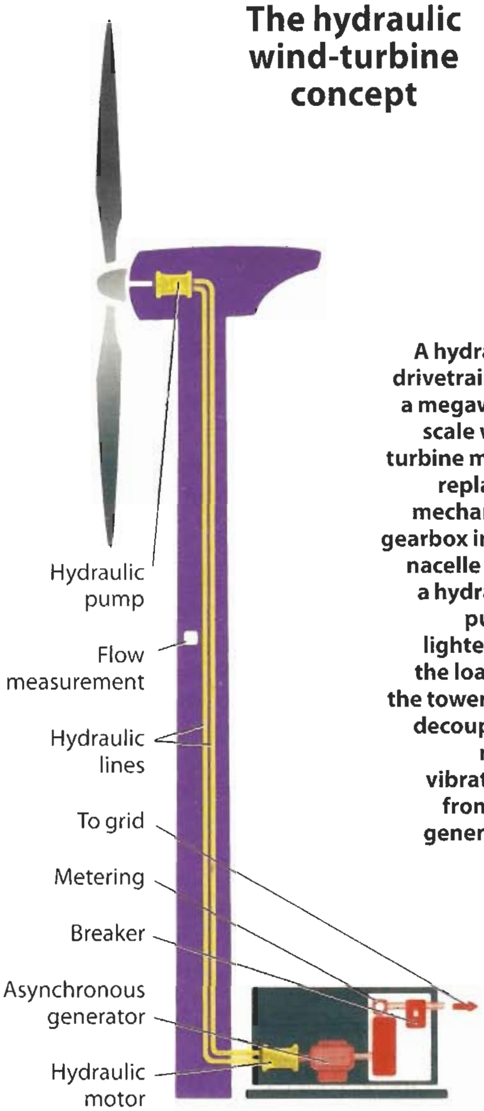
It should also be said that the specialized gearboxes used in today's wind turbines are proving to have a much shorter service life than what their manufacturers have predicted. This reality perhaps more than any other may provide the opportunity to launch hydraulic drivetrain alternatives.

One must also consider the fact that hydraulics are much more reliable than mechanical systems in extreme environments. Eaton's experience with hydraulics, which is consistent across the industry, spans environments ranging from the high arctic to the ocean floor. Users continue to report consistently reliable, and more important, predictable performance from hydraulic components and systems under the most adverse conditions imaginable.

Much of the experience gained in these applications is transferable. For example, the petroleum industry has fostered the development of virtually all the technology needed to overcome issues related to moving fluid up and down wind-turbine towers. Sea-floor-mounted hydraulic controls operate reliably fed by literally miles of pressure hose. By comparison, there is no great challenge in handling a few hundred feet of extra head at the motor, or preventing pump cavitation in the nacelle of a wind-turbine tower.

All in all, the benefits of large-scale hydraulic drives can only be inferred from other hydraulic applications because nobody has successfully demonstrated them on a large wind turbine — yet. But the benefits would seem to be compelling. It's just a matter of time until hydraulic drives are put to work harnessing the wind to produce clean, renewable energy. **MD**

The hydraulic wind-turbine concept



A hydraulic drivetrain for a megawatt-scale wind turbine might replace a mechanical gearbox in the nacelle with a hydraulic pump, lightening the load on the tower and decoupling rotor vibrations from the generator.