TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

HYDRAULIC DRIVE TRAINS FOR WIND TURBINES

THE TECHNOLOGY

Hydraulic drive trains are being considered to replace the traditional gearbox connecting wind turbines and generators

THE VALUE

Simpler, more compact, more reliable and with lower capital and operating costs, hydraulic drive trains could change design and deployment of wind turbines

EPRI'S FOCUS

Explore the potential for providing independent test results, and assessing reliability, efficiency and operation and maintenance cost of pre-commercial units

TECHNOLOGY OVERVIEW

Wind turbines that swap traditional mechanical drive trains for hydraulic drive trains could potentially be lighter, more reliable and less expensive than those in the field today.

The U.S. wind energy market includes approximately 30,000 aging turbines; 7,000 of which are out of service for repairs at any given time. A significant fraction of those repairs are to address failures in gearboxes, yaw drives, main shaft bearings, generators and power electronics. The cost and duration of repairs can negatively impact wind farm return on investment (ROI), and safety risks are posed by working at heights over 300ft (90m).

Hydraulic drive train technology offers a radical alterative, enabling both variable rotor speed and constant generator speed at all times. It allows the use of standard electrically excited synchronous generators directly connected to the grid without a frequency converter.

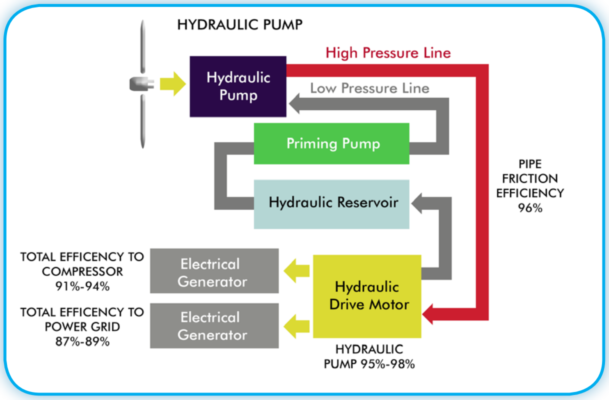

Fig 1 - Hydraulic Drive Concept - Source: Wind Power ENG 10/12

The transformer can be eliminated by incorporating a high voltage generator. Combined, these could lead to increased reliability by removing troublesome components and reducing nacelle weight.

Several different hydraulic drive trains are in development. While fundamental hydraulic principles are common to all designs, two fundamental hydraulic methods are employed:

- Type I-Gearless Hydraulic drive trains, using 100% hydraulic based systems
- Type II Hybrid hydraulic drive trains using a combination of conventional geared technology with the hydraulic solution.

Two different concepts are being considered for wind turbines with hydraulic transmission in onshore, offshore, and offshore floating installations for multi-megawatt machines being developed:

- In the nacelle design, where all components are integrated into the nacelle (Fig 3)
- In the ground sited concept, where a simple nacelle contains only the hydraulic pump, with other components (hydraulic motor and generator) in a power unit at the tower base (Fig 2)

For many reasons, virtually all of today's wind turbine systems are based on electromechanical designs that have been in production for years. The development of new turbines has shifted in recent years towards the use of direct drive technology with large permanent magnet synchronous generators (PMSG) using high flux density neodymium magnets, rather than gearboxes. However this configuration is quite sensitive to the price of rare earths and requires full-scale frequency converters to meet grid compatibility requirements. A hydraulic drive can offer economic benefits compared with electro-mechanic and direct drive-PMSG systems. By delivering power density unmatched by other technologies hydraulic systems could become critical in delivering the greater power density needed in multi-megawatts wind turbine nacelles onshore and offshore.

The partial load efficiency gap may eventually be addressed by new technologies such as more efficient fluids to reduce line losses, and innovative electro-hydraulic control systems to optimize performance.

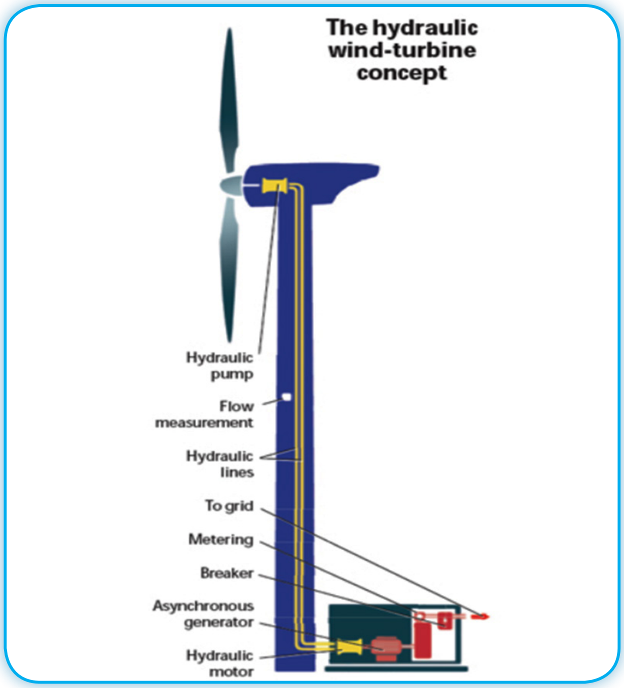

Fig 2 - In-ground Hydraulic turbine concept
Source: Machine Design .com 4/10

BASIC SCIENCE

Hydraulic technology was invented more than 200 years ago to replace steam driven presses in manufacturing. Today its application is widespread taking advantage of its high power-to-size/weight ratio. Traditionally, efficiency of hydraulic units has not been the primary aim, as more powerful motors/engines could simply be added. However, emissions requirements have now drawn more attention to efficiency within the traditional hydraulics industry.

Hydraulic systems apply force or torque multiplication in a simple way, independent of the distance and without the need for mechanical gears or levers. This is achieved either by altering the effective areas in two connected cylinders or the effective displacement between pump and motor. Depending on how the hydraulic system is made and the distance traveled by the hydraulic fluid, different levels of efficiency can be achieved.

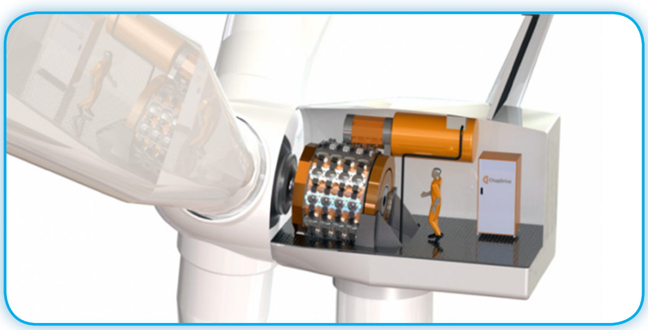

Fig 3 - In nacelle Hydraulic turbine concept
Source: ChapDrive A/S

In hydraulic drives, an infinitely variable transmission ratio is achieved by varying the amount of oil per revolution (displacement) produced by the pump/motor or both. The power that is transferred depends on the oil flow and the system pressure. Maximum pressure in commercial high pressure drives is 200-400 bars (2900-5800psi)

In most applications the lifetime of the hydraulic unit matches the lifetime of the machine with which it is integrated. In these hydraulic systems, there are no "service parts" or spares required, and scheduled maintenance is typically to replace hydraulic fluid and filter. Pumps, motors and shaft seals are the most critical parts in these systems, And most failures are due to contaminated oil, insufficient oil (leading to cavitation damage) or due to relief valves adjusted to higher-than-recommended values.

POTENTIAL IMPACT

As wind turbines increase in size, hydraulic drive systems can potentially compensate for some disadvantages of the conventional gearbox and direct drives. Their higher torque density enables a more compact gear box or transmission, which could lead to more compact nacelles -- particularly significant for large onshore-offshore turbines.

For large machines, there is realistic potential for lower capital cost, especially when completely removing all converters and transformers. For manufacturers to obtain a truly competitive edge, however, operating costs and energy efficiency need to match or exceed, existing solutions.

In many cases practical considerations call for splitting the system and mounting the motor and generator at ground level. Cost savings could be realized through ground level maintenance and by reducing the need for 50-story cranes. A key breakthrough comes from the ability to handle the nacelle's components in larger turbines using an internal crane. Other potential advantages are greater reliability in extreme environments, and torsional vibrations at the rotor hub would no longer affect the generator.

VALUE TO THE INDUSTRY

- Compact nacelles/ high torque weight ratio enable economic development of larger turbines
- No frequency converter and transformer required. Satisfy all current and future grid codes requirements without additional expenses.
- Higher reliability (lower fault rate of the wind turbine up to 19%) (Voith)
- Reduction in the cost of energy up to 20% (ChapDrive)
- Lower O&M cost/unscheduled maintenance cost.

STATE OF THE TECHNOLOGY

Developers are pursuing different types and concepts of hydraulic drives for wind turbines.

The level of maturity for drive train system of the different technologies, based on cumulative installations over time is shown in Table 1.

Table 1 - Drive Train Technology Maturity	TRL (1-9)
Conventional gear-box (Vestas, Gamesa, GE Wind, and others)	9
Direct drive+ PMSG (Siemens and others)	9
Hybrid drive /medium speed gear + generator (AREVA)	8
100% Hydraulic drive in nacelle (Chapdrive Norway)	6-7
100% Hydraulic drive in ground (Chapdrive Norway)	5
100% hydraulic Drive in ground (Artemis-UK MHI Japan)	5
Hybrid gear+ hydraulic drive in nacelle(Orbital2 UK, Wikov Wind Czech)	5-6
Hybrid gear+ hydraulic in nacelle (Voith, WinDrive Germany)	7

Compared with conventional gearbox technology, the hydraulic drive system is relatively immature in the wind business, although hydraulic drives are proven in other heavy industries. Wind turbines will require a high transmission ratio between rotor and high speed generator, which in turn will require that the hydraulic displacement rate for the motor and the pump be very dissimilar.

Major challenges are associated with fatigue life and efficiency, calling for demonstration projects to validate the potential to reduce the capital cost and the cost of electricity of large turbines onshore and offshore.

Benefits of large scale hydraulic drives can only be inferred from other applications until they are successfully demonstrated on large wind turbines. But the benefits seem to be compelling. EPRI estimates hydraulic drives will begin to penetrate the market withing 3-5 years

PUBLIC LITERATURE

These articles address hydraulic drives application to wind turbines. See references below:

http://machinedesign.com/article/hydraulic-wind-turbines-0420

http://wind-energy-the-facts.org/en/part-i-technology/chapter-3-wind-turbine-technology/current-developments/alternative-drive-train-configurations.html

http://www.leonardo-energy.org/design-race-wind-turbine-drive-trains

http://www.windpowerengineering.com/design/goodbye-gearbox-hello-hydraulics/

NEXT MILESTONES

Hydraulic drive technology application for wind turbines is proceeding in Germany, Norway, and the UK, with none presently based in the U.S.

Several suppliers in the hydraulic industry (Bosch, Voith, Eaton) have supplied solutions for smaller turbines (<500kW) using off--the-self technology. However, the introduction of variable hydraulic transmissions and synchronous generators with no frequency converters will require research, development and field testing before a significant market share can be expected. The key to success for hydraulic drives will be their demonstration of high reliability in combination with higher efficiency.

ChapDrive is developing a hydraulic drive nacelle solution for testing in a 3 MWe turbine by 2014. Upon successful completion TRL will move from 6-7 to 7-8. [9]

MHI has announced plans to use the Artemis Digital displacement technology in its 7 MWe SeaAngel turbine, using a standard wound-rotor synchronous generator by 2013. TRL then will move up from 6 to 7.[11]

Voith Turbo has developed a 6.5 MW offshore solution for the Bard group and delivered prototypes in 2010. Now in partnership with some Chinese companies, their VoithWindDrive will be installed in Chinese new 2 and 3 MW turbine models in 2013-14, moving TRL to 8. [10]

INDEPENDENT ASSESSMENTS

There are no known publicly available independent assessments of the hydraulic drive application to large wind turbines.

COLLABORATION

CURRENT COLLABORATORS

Interest in hydraulic drives is growing, but their potential remains to be determined. Recently announced development plans by MHI clearly support this potential development.

Voith-Turbo (Germany) has also partnered with Chinese Guodian Corporation and Lanzhou Electric to develop the hydraulic train technology there in 2-3 MWe new turbines.[10]

ChapDrive (Norway), a spin-off of the Norwegian University of Science and Technology (NTNU), tested its technology for several years at a site in Trondheim (Norway) using converted Vestas 225 kW and 900 kW NEG-Micon machines, and presently is developing a hydraulic transmission based on nacelle solution to be tested in a 3 MW Wind Turbine by 2014.[9]

EPRI ENGAGEMENT

EPRI is not engaged with any of the key developers.

Wind OEM's involved in development of new larger off-shore wind turbines are their primary targets at the level of development of this technology, and this may provide a competitive market advantage to successful early adopters.

Depending on interest from its funders, EPRI may explore a role in providing independent technology/prototype test results reports, but commercial interest of the partners may be a barrier.

OPPORTUNITIES FOR COLLABORATION

EPRI could serve as an observer of the development and testing of the prototypes announced for the different key technologists.

Independent assessment of the first pre-commercial units to monitor the ”as built” long term reliability, efficiency and operation and maintenance cost versus design targets may be relevant to reducing risk and financial cost of subsequent applications.

NEXT STEPS

Key next steps in the development plans to scale-up the TRL levels to 7-8, paving the way to early commercial deployment will require:

- Innovative designs to overcome the current performance barrier of less efficient than electromechanical systems. While operating at the maximum efficiency in the 5,000 psi range, the hydraulic system would be ~10-30% less efficient than a mechanical system, and is not as easily scaled-up to handle the loads of multi-megawatt turbines. Wind turbine rotation normally max out at 150 revolutions per minute (RPM) or less while most hydraulic pumps are designed for input speeds ranging between 500 and a few thousands RPMs. At their design speed, hydraulic pumps are less efficient, and wind turbines' extreme variability with changing wind conditions makes matters worse. New components technology will be required to create pumps optimized for these conditions.
- A key challenge is to scale-up hydraulic pumps and motors from typical industrial applications (<500kW) to multi-megawatt systems without impacting drive. The components are not scalable on a 1:1 basis. Further development would be required
- Large-scale prototype demonstrations at multi-megawatt turbines first in onshore, then in offshore applications, to validate reliability, energy efficiency and operation and maintenance advantages compared with traditional gearbox/direct drives.
- The larger the future wind turbines the greater the benefits of hydraulic drives to reduce nacelles' weight and cost, and to reduce the operation and maintenance (O&M) costs of both onshore and offshore applications where designs up to 20 MWe are being proposed.

EPRI may be able to accelerate development and deployment through funding some of the on-going research and prototypes pilot testing during the next 3-4 years, as well as by performing subsequent independent performance assessment of commercial units.

REFERENCES

1. *http://www.chapdrive.com/technology*
2. *http://www.voithturbo.com/applications/vt-publications/downloads/990_e_cr355_en_voith-windrive-for-wind-turbines.pdf*
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5. *http://www.wikov.com/wind/index_en.php?page=produkty-vychodiska*
6. *http://www.sintef.no/project/Deepwind%202012/Deepwind%20presentations%202012/A2/Thomsen_KE.pdf*
7. *http://www.leonardo-energy.org/design-race-wind-turbine-drivetrains*
8. *http://www.eolos.umn.edu/facilities/test-stand-hydraulic-wind-turbine-drivetrains*
9. *http://www.sintef.no/project/Deepwind%202012/Deepwind%20presentations%202012/A2/Thomsen_KE.pdf*
10. *http://www.gaccom.org/fileadmin/ahk_chicago/Dokumente/EnEff_Presentations/WindEnergy_Nov_2010/8_Voith_Turbo_Wind_Reimesch.pdf*
11. *http://www.offshorewind.biz/2011/11/29/mitsubishi-to-present-wind-turbine-with-hydraulic-drive-train-at-dutch-event/*

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