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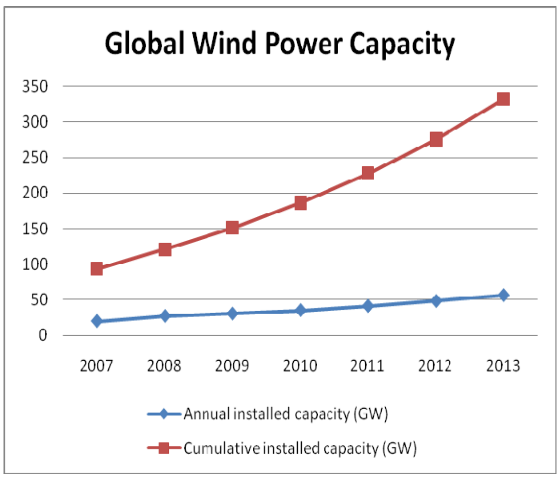
The Reliance on Wind Energy Depends on Advancements in Blade Pitch Control

By Sal Spada

Overview

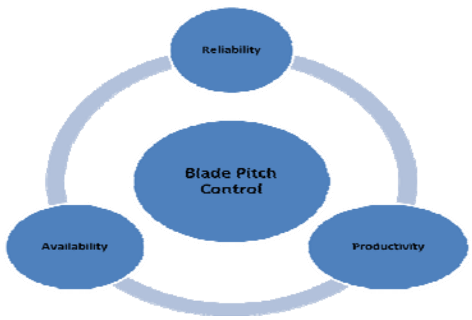
Many nations are in the process of making wind power an integral part of their overall energy portfolio. The increasing dependency on wind power places greater emphasis on reliability and availability. To achieve these goals, the energy generating capacity of individual wind farms needs to increase significantly requiring larger turbines located in remote locations with harsher environmental conditions both onshore and offshore. However, wind farms assets are long-term capital assets that are evaluated based on their overall return on investment (ROI) by the operators and utilities alike. As such, the lifecycle of a wind farm from site evaluation, turbine specification, projected operational & maintenance (O&M) costs, and expected availability involve a multitude of critical decisions. Specifically, the associated cost of O&M and the requirement for higher availability has come to the forefront in determining the ROI of remotely located wind farms. This is raising the importance of technology selection inside the turbine that increases reliability while maximizing the energy generating capacity.



Source: GWEC

Technological Innovations Improve Reliability and Availability

The objectives of high reliability and availability fundamentally begin with the wind turbine. From the very initial stages, project leaders managing a wind farm deployment need to ensure that the asset lifecycle value chain from the selection of an individual wind turbine to the grid connection understands the impact of their decisions. One of the most important technology innovations applied today that allows wind turbine manufacturers to improve operational effectiveness is Electromechanical Blade Pitch Control Systems. Electromechanical Blade Pitch Control Systems are repre-



Pitch Control Improves Reliability, Availability and Power Production

senting a cornerstone in wind turbine design. As the wind power industry moves to increase the ratio of the power generation capacity and initial capital investment, Electromechanical Blade Pitch Control Systems will become dominant. Advancements in Pitch Control Systems contributed to reduce wind power generation costs per unit to a level that is competitive with electrical power generated by fossil fuel plants.

Pitch Control is a Centerpiece of Technology Improvements in Variable Speed Wind Turbine Control

The first generation of wind turbines was stall-regulated, fixed speed designs, with geared transmissions. The primary advantage of fixed-speed turbines is their relative simplicity resulting in a lower capital investment. Fixed speed designs are now being displaced by variable speed turbine systems. **Variable speed designs** are reliant upon **blade pitch control** to regulate the turbine speed.

Blade pitch control is implemented with either hydraulic actuation or electromechanical actuators today. The installed base of wind turbines is currently divided evenly between the two technologies; however, the adoption of electromechanical solutions is growing at a much higher rate. In practice, either actuation technology has the dynamic performance required for this application. Typically the blades pitch only changes between 3-4 degrees per revolution. The selection of hydraulic or electric actuation technology is generally a subject of debate; however, the industry has not reached consensus (and most likely will not) from strictly a performance perspective. Turbine manufacturers generally standardize on a specific technology and use this throughout all product lines.

	Hydraulic	Electric Motor
Force Density	↑	↓
Energy Consumption	↓	↑
Maintenance Costs	↓	↑
Initial Cost	↑	↓
Dynamic Performance	↑	↑
(↑) Advantage (↓) Disadvantage		

Hydraulic and Electromechanical Pitch Control System Relative Comparison

A recent survey of Wind Turbine Manufacturers, conducted by the ARC Advisory Group, suggests that the tide has turned in favor of electromechanically solutions. Shipments of pitch systems based on electromechanical solutions are expected to grow at an annual rate between 27 to 30 percent through the year 2014. The expected high growth of electromechanical solutions is divided almost evenly between solutions based on AC asynchronous motors and synchronous motor servo systems. Survey respondents indicated that motor-based technology (synchronous and asynchronous) will achieve higher adoption rates compared to electro-hydraulics technology for blade pitch control due to lower maintenance requirements.

	Technology Options	CAGR 2009-2014
Electric	AC Permanent Magnet synchronous servo motor	30%
	AC inverters & asynchronous motors	27%
	DC drives and motors system	6%
Hydraulic	Electro-Hydraulic System	11%

Blade Pitch Control Technology Adoption Forecast

Source: ARC Advisory Group "2008 Wind Turbine Control Systems Market Outlook Report"

Applications for hydraulic solutions will coexist with electric motor solutions as the power density in hydraulic actuators surpasses any available electric motor. It is expected that wind turbines below 10MW will adopt electric motor technology as this enables wind turbine designers to implement a more compact design with the benefits of higher reliability, environmentally safe (no fluid leakage), and lower maintenance costs. Turbines above 10MW face greater issues as electric motor solutions cannot generate the required torque for these applications. Electric motor technology is comparable to hydraulics in terms of operational range (i.e. wind speeds and temperature ranges). However, as more wind turbines are placed in offshore locations with more difficult access by maintenance personnel the trend toward electromechanical blade pitch control solutions will increase, but wind farm operators will need to weigh the potentially higher cost of O&M if considering turbines larger than 10MW.

Variable Speed Turbines Leverage Blade Pitch Control

Wind Turbine Control suppliers continue to improve systems with better technology, but the underlying control architecture has been divided into five primary systems: Main Turbine Control, Condition Monitoring, Power Conversion, Blade Pitch Control and Yaw Control. Blade Pitch control systems have evolved from primarily safeguarding the wind turbine from over loads induced by high winds to an actuation system capable of improving the productivity of the turbine.

A variable speed wind turbine fundamentally requires a Blade Pitch Control System; however the dominating strategy is to apply the same pitch angle on each blade. This provides the ability to capture energy in a wider range of the wind conditions. When wind speeds are low, the pitch control system adjusts the rotor blades to maximize the angle of attack and increases the blade rotation speed. When a strong air flow creates too much load, the pitch control system adjusts the angle of attack to prevent turbine damage.

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Variable speed turbines generate power over a wider range of wind speeds and the power output is maximized in the dominant segment of the wind spectrum of the specific location. Blade Pitch Control Systems manage the mechanical stresses within design limits to ensure that the equipment is not subjected to forces which would cause premature fatigue. Algorithms in these systems continuously evaluate wind speed and power density to determine the optimal blade pitch. The goal is to minimize the mechanical stresses to increase reliability and lower maintenance costs while also maximizing energy production.

Variable speed turbines seek to maximize the energy generation from wind gusts. With a combination of yaw control and blade pitch control a turbine can turn directly into the wind to maximize the speed and store the excess energy as rotational energy similar to a flywheel. This requires a highly dynamic control strategy that is capable differentiating between gusts and higher sustained wind speeds.

Justifying the Value of Individual Pitch Control

Some of the latest turbine designs incorporate **Individual Pitch Control** where each blade pitch follows an individual motion profile. This requires the control of each blade with rotary actuators and electronics that are independent (uncoupled) . Individual Pitch Control is considered an optimal solution compared to conventional Blade control. Researchers at Garrard Hassan (www.gl-garradhassan.com), a consultancy firm in wind energy, believe that the investment in individual pitch control on a turbine can be cost justified.

The primary justification is that power production can be held near constant for all types of wind conditions at a location rather than an improvement in efficiency. Wind turbine controller algorithms are relatively complex in this case as they seek to reduce the peak torque and balance the load on the three blades in order to minimize the wear on the gearbox as well as minimize the fatigue loads on the tower and rotor blades. Individual Pitch Control raises the cost of an implementation since this requires the addition of strain gauge sensors on each of the blades to measure the bending moments on the blade during rotation. Advanced algorithms are required when individual pitch control is employed. The first generation of variable speed turbines displaced by the more robust pitch control designs have demonstrated a superior energy performance and reduced loading profiles. Other technology improvements in inverters and the use of direct drive turbines are supporting increased power conversion efficiency and improved condition monitoring, however individual pitch control along with advances in dynamic pitch control algorithms hold the greatest promise for improvements in reliability and power productivity.

Offshore Installations: "Beneficiaries of Electromechanical Individual Blade Control Systems"

Offshore wind farms are gaining momentum as the benefits of a more abundant wind supply and lack of visibility make these locations attractive. The average offshore wind speeds can be 20 percent higher than on land, providing the potential for as much as 70 percent higher energy yield, which significantly offsets the cost differential in the initial capital outlay. The capital investments required for offshore wind farms are relatively high compared to onshore installations. Furthermore, operational costs can be higher since offshore turbines are exposed to stronger winds more months of the year, harsher environmental conditions and access is more difficult.

Wind Turbine Power Capability	CAGR 2009-2014
250 - 499 kW	9%
500 - 999 kW	10%
1.0 - 2.5 MW	18%
2.5 - 5 MW	26%
>5 MW	26%

Source: ARC Advisory Group "2008 Wind Turbine Control Systems Market Outlook Report"

Increases in Blade Size Makes Pitch Control System Essential

Utility companies tend to prefer larger wind turbines because the power generation capability is a factor of the square of the rotor blade diameter. The power generation capacity of the larger blade diameters offsets the cost of the foundation for each offshore site, making it more cost-effective per megawatt to install a single large turbine, rather than multiple turbines. Although, in some instances the landscape in mountainous regions for example limits the maximum size as logistics prohibits the erecting of large turbines. The offshore market has added an additional impetus to drive installations to much larger sizes as the installation costs are much higher than land based systems. The higher power wind turbines use significantly larger blade sizes, resulting in uneven loads on the blades, drive shaft, and turbine structure. These uneven loads increase component wear, reduce, efficiency and increase maintenance downtime. Pitch control systems with individual blade control overcome this situation and optimize power.

Optimize Performance of Electromechanical Blade Pitch Control System

The wind power industry has been transformed as wind farms grow from a few dozen megawatts capacity, to several hundred megawatts requiring locations in more remote areas. Wind turbines are also being designed to best match the wind and temperature profile of the location they are placed. This has lead to an increasingly more custom design in the electromechanical systems and the underlying control algorithms. To this point, integration of an Electromechanical Pitch Control Systems requires an engineered solution in order to optimize the overall mechatronic system. Off the shelf standard products are generally suboptimal for a wide range of turbine designs. Furthermore, consideration for slip ring, gear box, feedback sensors, integrated braking, and motor sizing all are considered simultaneously when using a systems engineering approach.

Recommendations for Turbine Designers

The design tradeoffs for pitch systems are innumerable; however the selection of the optimal solution remains critical to improving ROI. Turbine design engineers should seek an expert with the experience to provide an objective perspective on the technology to achieve these goals. The primary consideration for a wind turbine manufacturer is to work with an automation supplier that has the capability to perform the analysis that results in an overall solution that maximizes reliability and minimizes mechanical complexity.

About the Author: Sal Spada is Research Director with the ARC Advisory Group focuses on Motion Control, Machine Safeguarding, CNC, Robotics, Packaging Machinery, Mechatronic System Design, and Uninterruptible Power Supplies. Sal has over 15 years experience in motion control systems as a software developer, project manager, and marketing manager with EG&G Torque Systems, Boston Digital, and Schneider Automation. Sal also has a B.S., M.S. in Electrical Engineering, University of Massachusetts. M.B.A., Babson College.