Boost Wind Turbine Availability and Reduce O&M Costs with Ultracapacitors for Emergency Pitch Control Backup Systems

BY MAXWELL TECHNOLOGIES

If a wind turbine is not spinning, it is not generating revenue. Wind farm operators make every effort to maximize uptime, but a variety of factors contribute to turbines being offline. One challenging area can be the turbine's battery-based emergency pitch control backup system.

Site managers often spend additional budget dollars and perform unscheduled maintenance to address the many performance issues associated with battery-based systems, including degraded performance in cold and hot weather conditions, battery voltage faults, and additional weekly or monthly turbine climbs to replace failed battery systems.

How can site managers eliminate costly and time-consuming maintenance of the pitch system's backup power system? Fortunately, alternative robust energy storage technologies are available to help overcome the common pain points with battery-based systems.

Ultracapacitor energy storage is a well-established technology used as backup power for emergency pitch systems in turbines worldwide, both onshore and offshore. Ultracapacitors, also called supercapacitors or electric double layer capacitors (EDLCs), are high-power energy storage devices that store charge electrostatically with minimal chemical reactions which commonly occur in lead-acid batteries. As a result, ultracapacitor technology provides site managers with a significantly more reliable emergency pitch control energy storage solution that requires minimal maintenance and contributes to greater turbine uptime.

This white paper will examine the technical and business advantages of ultracapacitor-based energy storage for emergency wind pitch control systems.

The Challenges of Battery-based Emergency Pitch Backup Systems

The energy storage for emergency pitch control provides the energy necessary to pitch the wind turbine's blades to a safe position during an emergency situation, such

as loss of utility power or critical pitch system faults. The emergency pitch function is integral for preventing severe damage to or total loss of the wind turbine in the event of a dangerous condition. In GE 1.5 MW turbines, the emergency pitch systems are tested at least once per month to ensure the systems are prepared to react in the event of such emergencies.

Wind farms dealing with battery-based backup systems face three primary challenges: (1) battery faults; (2) premature battery system failures; (3) inventory, storage and waste management.

1. Battery voltage faults frequently appear within SCADA and require troubleshooting.

Site managers are all-too-familiar with pitch faults reported by the SCADA system. Pitch faults account for more than one-third of all faults, and over the course of a year it is not uncommon for over 2,000 SCADA pitch fault alarms to occur.[1]

Battery voltage faults are one type of pitch fault and are specific to the turbine's emergency pitch backup system. Battery voltage faults often appear when:

- a turbine reboots after a utility grid power failure
- a failure occurs during the battery load test
- there is a battery charger failure
- cold weather affects battery system performance and the battery fails to charge

In addition, if the control system detects a failure within any of the battery functions, the turbine will shut down and send a message via SCADA for follow-up by a wind technician.[2] Faults that cannot be managed remotely require two and sometimes three wind technicians to climb the turbine and perform diagnostic inspections. Turbine climbs are costly in terms of maintenance hours, complexity of the process, and lost energy revenue from turbine downtime.

These issues and resulting losses are driving the need for an energy storage technology that does not trigger time-consuming pitch faults but instead contributes to streamlined performance of the emergency pitch system.

2. Battery systems often fail before their lifetime expectancy.

Lead-acid batteries operate under varying ambient environmental conditions which make it difficult to predict their operational lifetime. On average, batteries used for the turbine's emergency pitch system last four to five years.[3] However, site managers and wind technicians often deal with battery outliers that fail within one to two years.

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[1]Godwin, Jamie L. and Peter Matthews. "Classification and Detection of Wind Turbine Pitch Faults Through SCADA Data Analysis." School of Engineering and Computing Sciences, Durham University. 2013. <http://ftp.phmsociety.org/sites/phmsociety.org/files/phm_submission/2013/ijphm_13_016.pdf>
[2]Kilcollins, Wayne. Maintenance Fundamentals for Wind Technicians. Cengage Learning, 2012.
[3]Opie, Ray. "Pitch Control Critical for Wind Power." Machine Design. March 2, 2018. <http://www.machinedesign.com/mechanical/pitch-control-critical-wind-power>

Early failures are typically the result of extreme weather conditions. Frigid temperatures slow the rate of batteries' chemical reactions which results in high internal resistance and inefficient charge acceptance. Generally speaking, a battery that provides 100 percent capacity at 80°F (27°C) will typically deliver only 50 percent capacity at 0°F (–18°C).[4] Moreover, each charge/discharge cycle lowers battery capacity due to poor charge acceptance. As a result, continual operation at frigid temperatures can render the battery ineffective in executing an emergency pitch. Typically, pitch systems are fitted with heaters to warm the batteries to their optimum operating temperature.

Batteries operate much better in warm conditions, but extreme heat is detrimental to battery chemistry and increases the rate at which the battery deteriorates, often resulting in battery failures. Wind farms in hot and humid parts of the United States face multiple battery replacements due to the damaging effects of heat.

Other reasons for premature battery failures can include a high resistance pitch motor that puts excessive load on the battery, a malfunctioning charger or a short circuit in the battery. Many times a battery short will cause the battery's charger board to fail, a component that costs upwards of $800 dollars to replace.

The business repercussions for premature battery system failures include higher component costs due to battery and/or charger board replacements, additional turbine climbs and labor hours, downtime and lost revenue, as well as the added safety risks that are inherent with climbing turbines and transporting heavy lead-acid batteries while ascending and descending towers.

Ideally, an emergency pitch system's energy storage must not be compromised by extreme temperatures and other conditions. Alternative energy storage technology currently available on the market offers wind farm operators significantly improved performance, minimal maintenance and improved reliability despite demanding conditions.

3. Backup batteries require warehousing efforts while end-of-life and failed batteries produce excess waste.

Battery replacement is not a precise science. Due to the many unpredictable factors that can cause battery system failures, wind farms keep a plentiful supply of batteries warehoused. Wind farms with GE 1.5 MW turbines, which contain a total of 12 batteries (plus their respective chargers), typically warehouse four to five sets of batteries per farm site. Pallets of batteries take up significant space and, per manufacturer's recommendations, should be trickle charged to prevent self-discharge and capacity loss. In addition, personnel must adopt a FIFO (first-in, first-out) process, making sure to install the batteries that arrived on site first.

[4]Buchmann, Isidor. "Discharging at High and Low Temperatures." Battery University. July 2017. <http://batteryuniversity.com/learn/article/discharging_at_high_and_low_temperatures>

Lead-acid batteries that fail prematurely or that reach end-of-life must be prepared for hazardous waste disposal. The wind farm operator typically hires a third party to dispose of batteries in accordance with federal regulation. Factors contributing to the total cost include battery type and weight, quantity, labor required (including de-energizing batteries and stacking batteries on pallets) and distance from the wind farm's site to an EPA-certified recycling facility.

Ideally, once installed up tower, the energy storage within the emergency pitch systems should operate reliably for a minimum of 10 years, significantly reducing the cost of backup components and warehousing efforts, regular replacements and regular disposal efforts.

The Solution: Ultracapacitor-based Energy Storage Retrofit Designed for Use in GE 1.5 MW Turbine Emergency Pitch Backup Systems

To overcome the challenges discussed in the previous section, wind farm operators have the option to retrofit wind turbines with ultracapacitor energy storage modules. Maxwell Technologies designed an ultracapacitor-based retrofit solution for use in GE 1.5 MW wind turbines to address chronic maintenance issues associated with battery-based systems and to help wind energy farms streamline operations and reduce O&M costs (see Figure 1).

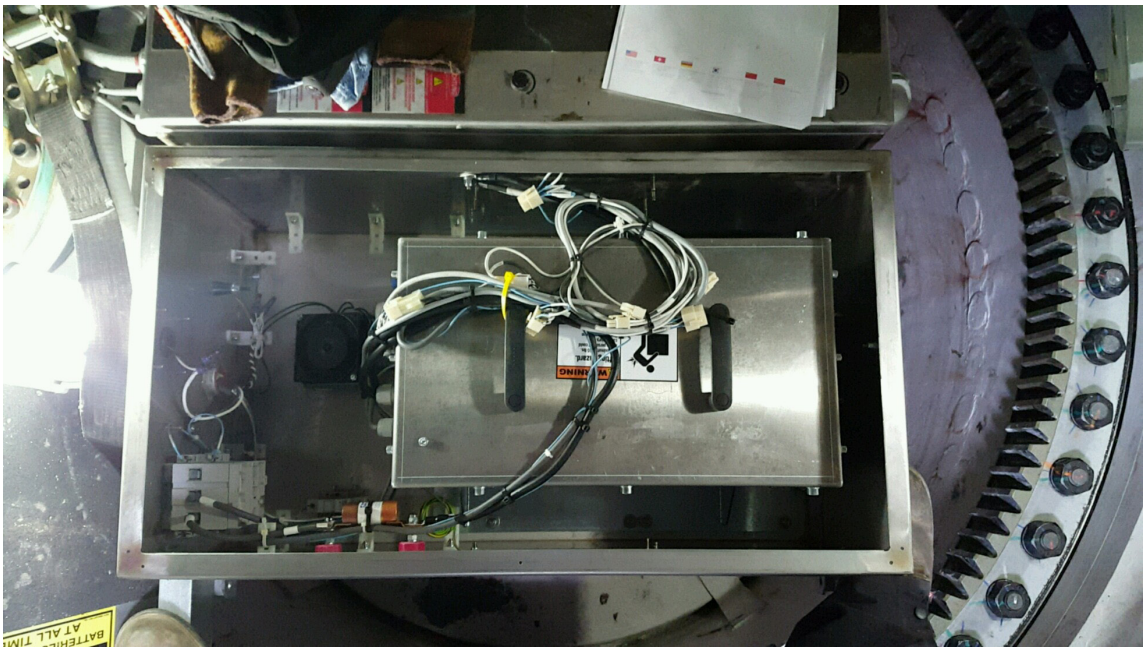


Figure 1: Maxwell Technologies' ultracapacitor-based retrofit solution installed in the pitch system of a GE 1.5 MW wind turbine. The solution replaces the turbine's original battery/charger system for each blade for optimal performance and reliability.

How it works

The retrofit solution consists of three ultracapacitor-based energy storage modules per turbine, one module per blade. The existing batteries and chargers are replaced with the retrofit modules, considerably simplifying the backup system. Wind farm operators typically replace failed or end-of-life batteries with the retrofit solution, potentially eliminating further maintenance and replacements for an estimated 15 years.[5]

During adverse conditions, the ultracapacitors provide the power for feathering the blades to a safe position. The retrofit solution performs the same function as the original battery system with the following advantages:

- *Ultracapacitors withstand the pitch system's load with minor voltage drop as compared to battery systems.* Ultracapacitors are able to pitch the blades on average three consecutive times before a recharge is necessary. Recharge time for ultracapacitors is significantly shorter than that of batteries, and ultracapacitors are ready for deployment within a few minutes. Often, site personnel must wait for batteries to recharge before the pitch process can be completed. The fast-responding power and charging capability of the ultracapacitors recovers valuable time and streamlines operations.

- *Ultracapacitors perform reliably after long periods of idle time.* This is a performance advantage considering the length of idle time between uses and monthly pitch tests. Ultracapacitors have the unique ability to provide quick, high power even after long stretches of non-use.

- *Ultracapacitor aging is highly predictable.* It is not uncommon for ultracapacitors to operate with an efficiency of >95% over a wide range of temperature. Figure 2 shows the estimated lifetime of Maxwell's ultracapacitors as a function of voltage and temperature. This information is useful for estimating the lifetime of ultracapacitors based on operational ambient temperature. As a reference, ultracapacitor operating voltage is set at 2.45V per cell within the module. If operated at 40°C, the lifetime of the ultracapacitor module is estimated to be approximately 11 years.

[5]Results may vary. Additional terms and conditions, including the limited warranty, apply at the time of purchase. See the warranty details for applicable operating and use requirements.

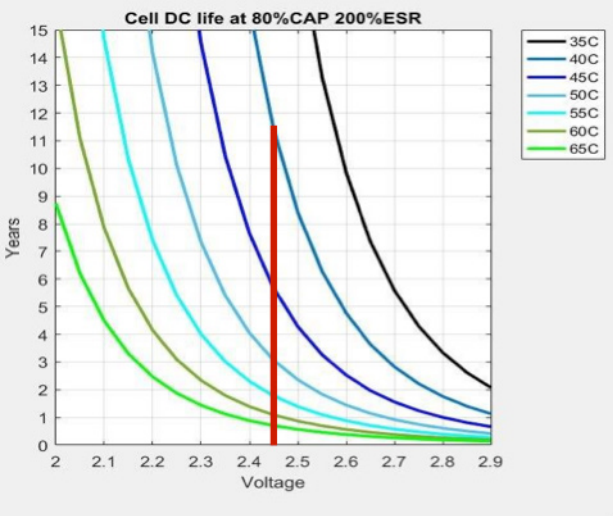
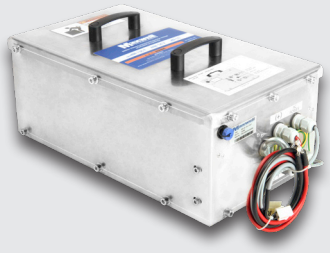


*Figure 2: Maxwell Technologies Ultracapacitor Lifetime Estimation**

The ultracapacitor-based retrofit system is designed with an integrated charger and communication interface. Initiation of ultracapacitor system check, voltage and temperature are reported to the turbine SCADA system. The retrofit solution is a form-fit-functional replacement for battery pitch systems and does not require any modifications to the turbine hardware nor the lockout/tagout (LOTO) safety procedures.

Features of the Technology

Maxwell Technologies' ultracapacitor-based energy storage retrofit solution for use in GE 1.5 MW Wind Turbines



Feature	Wind Farm Operator Benefit
Estimated lifetime of 15+ years* (dependent on use)	Few, if any, turbine climbs are needed for monitoring or maintaining the retrofit solution
Reliable operation from –40°C to 65°C*	Important for wind farms in geographic areas that experience storms, ice, snow and intense heat
No lead or acid	Low risk of collateral damage to other turbine components due to acid leakage
Minimal to no modifications to the existing emergency power unit (EPU)	Installation of the retrofit solution is similar to that of batteries; minimal technician training required

*Results may vary. Additional terms and conditions, including the limited warranty, apply at the time of purchase. See the warranty details and datasheet for applicable operating and use requirements.

Integrated communication	No change to the communication method ensures streamlined data delivery via SCADA
Four-year warranty	Committed customer support

Important benefits for the wind farm operator

When wind farm operators install ultracapacitor-based energy storage for emergency pitch systems, the following benefits occur:

Reduces O&M costs. Ultracapacitor-based energy storage eliminates the high number of hours spent maintaining and troubleshooting battery-based systems, and as a result, reduces the cost of additional turbine climbs that are performed routinely to address battery system issues. The ultracapacitor-based system significantly reduces system failure rates, repair time and unscheduled O&M costs. Technician hours are saved, turbine availability and operational efficiency are increased, helping to improve levelized cost of energy.

Boosts turbine availability. An increase in wind turbine generation represents a tangible financial benefit. To remain competitive with other power generation sources, wind farms must ensure that the turbines are operating at their maximum capacity. The ultracapacitor retrofit solution contributes to turbine availability by acting as reliable energy storage for the emergency pitch system. Seamless operation of the system boosts valuable hours of turbine availability and redirects personnel's efforts from performing unscheduled maintenance to optimizing energy production for the end customer.

Increases wind farm operational efficiency and safety. Wind farms that have installed Maxwell's ultracapacitor-based retrofit solution have reported that several hours per week, previously spent on managing battery system failures, have been redirected to the wind farm's main operational priorities, saving time and improving overall efficiency of wind farm operations. In addition, fewer turbine climbs present fewer risks for technician climbing injuries.

Partner with Maxwell Technologies

Maxwell Technologies was founded in 1965 and has been the pioneer in ultracapacitor energy storage technology since the mid-1990s after identifying the limitations of legacy battery technology in applications across diverse industries. Our engineering, R&D and manufacturing teams form the core of Maxwell's technical expertise in the unique space of ultracapacitor cell technology.

Maxwell provides its partners with the following advantages:

- **Twenty years of proven success in the field:** For the past 20 years, Maxwell has partnered with OEMs as a trusted supplier of reliable energy storage for onshore and offshore wind farms. In the early 2000s, Maxwell was awarded its first design win with a major OEM after initial deployments confirmed significant advantages of Maxwell's ultracapacitor energy storage over battery storage. Today, Maxwell's solutions are installed in over 61,000 wind turbines worldwide. In the past five years, Maxwell has worked directly with wind farm operators in North America and Europe to provide aftermarket energy storage retrofit solutions for improved pitch system performance.

- **System integration expertise:** Maxwell has the most in-depth experience with integration of ultracapacitor-based retrofit solutions for pitch system backup power and incorporated customer feedback into its retrofit solutions to address specific problems faced at the wind farm level.

- **Unmatched R&D engine and portfolio of technologies:** A key factor in Maxwell's successful technology integration worldwide is its superior research and development capability, which continuously generates innovative products. The result is unsurpassed quality and solid performance, giving customers the confidence that Maxwell has the ability to meet their most challenging requirements.

For customer references or more information, please consult with your sales representative or contact Maxwell Technologies at **retrofit@maxwell.com**.

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