Wind Turbine Availability Excellence

Using Advanced Control and Communications to Decrease Downtime

"The world faces a once-off transition to sustainability," says Dr Eddie O'Connor, CEO at Mainstream Renewable Power. "By reducing our dependence on imported fossil fuels and shifting to low carbon sources of power generation, we can grow the economy and lower the price the consumer pays for energy. Innovation in and around clean energy generation will drive economic growth and create long-term manufacturing and service sector jobs."

Across the globe, with energy supply demands continuing to outpace energy supply[1], efforts are under way to move to clean, eco-friendly, renewable energy resources such as wind, solar, geothermal and biomass. Of these, wind shows the greatest promise, particularly when wind farms are deployed offshore. Confirming the potential of offshore wind power, the European Environment Agency (EEA) estimates 80 percent of the projected EU electricity demand could be economically harnessed by 2030.[2] Sharing this view, U.K. former Prime U.K. Prime Minister Gordon Brown noted the North Sea may become the Saudi Arabia of wind.[3]

The move away from fossil fuels to renewable energy also requires significant energy grid improvements that increase reliability, bridge long distances, simplify energy trading and create a vast, sustainable energy resource. In Europe, this vision is captured by the concept of an integrated energy infrastructure, called the supergrid, which improves sustainability by allowing utility operators to move energy from places where the wind is blowing to where it is not. Sustainable energy is predicated on designing reliability and availability into all aspects of the infrastructure, comprising systems generating energy, controlling distribution and finally, consuming energy. It is crucial to keep the entire energy network, from wind farms to homes and businesses, up and running in order to maintain proper service levels.

This paper examines innovative ways to help ensure uninterrupted operation of remote offshore wind turbines through the use of advanced remote management, virtualization and wireless technologies. These approaches can increase turbine availability and reduce the number of required onsite repair visits, which are expensive and hazardous.

A Short History

Well before the discovery of electricity, wind power was a vital source of energy, powering grain mills and pumping water. For example, about six million small windmills were used in the American Midwest to operate irrigation pumps on farms between 1850 and 1900.[4]

The first windmill for electricity production was built in Scotland in 1887 by professor James Blyth of Anderson's College, Glasgow.[4] Wind farms have been around for over a hundred years; by 1900, Denmark had about 2500 windmills driving pumps and mills and producing an estimated combined peak power of about 30 MW.[3]

Fast forward to 2004, when the European Union (EU) defined ambitious goals at the European Conference for Renewable Energy in Berlin – to meet 20 percent of its total energy consumption requirements with renewable energy sources.[5] The end of 2008 marked significant progress, as Europe's wind power capacity met over four percent of the European Union electricity demand, with the North Sea offering a tremendous opportunity for growth.

Commenting at the Ernst and Young Global Renewable awards ceremony, Dr. O'Connor said:

> "The European offshore supergrid has the potential to achieve energy independence for Europe as well as reducing its greenhouse gas emissions by 80 percent by 2050."[6]

Helping improve the economics of wind power, wind turbines are becoming cheaper and more powerful. Rotor blade lengths are increasing, as shown in Figure 1, enabling them to harness more wind and therefore produce more electricity, which brings down the cost of renewable power generation.[7] Wind farms are also increasing in size, requiring them to incorporate leading-edge control, communications and computing technologies to successfully manage the growing energy infrastructure.

Offshore Wind Farm Basics

Offshore wind farms offer significant energy production advantages over onshore farms with respect to wind quality and available area of deployment. Wind traveling over large bodies

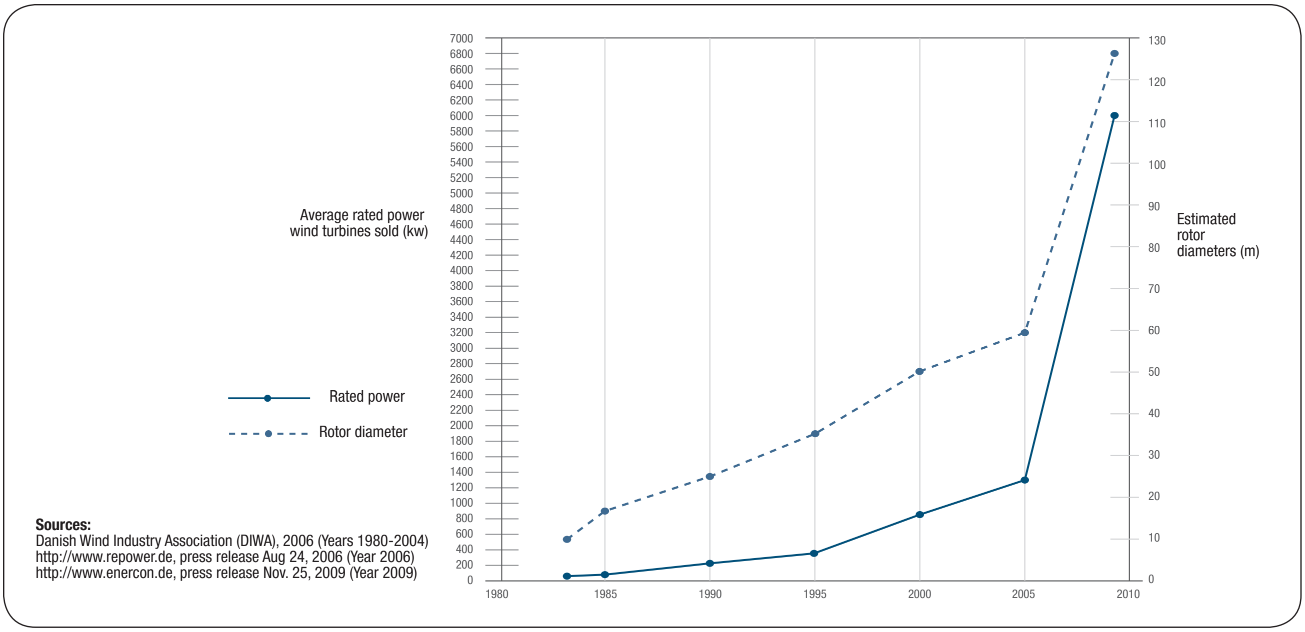

Figure 1. Historical Turbine Size and Capacity

of water tends to be more uniform with higher velocity than onshore wind, which encounters obstructions such as forests that create eddy currents. The consistency and quality of offshore wind makes it relatively easy for utility operators to predict and manage. There is also an abundance of offshore area on hand to build huge wind farms capable of serving energy needs well into the future. In a scenario where 50 percent of Europe's electricity comes from wind by 2050, the bulk of this power will be generated offshore reflecting the lack of available land for development. However, putting wind turbines out to sea presents some big challenges, such as how to connect them across large expanses.

Traditionally, optical fibre is the preferred communications technology for offshore wind turbines, as illustrated in the upper portion of Figure 2. Typically, the communications link is a relatively delicate optical fibre running down the center of thick copper power cabling. This represents a potential single point of failure. Breakages to optical fibre under such conditions are difficult to repair in the hazardous offshore waters. Furthermore, an optical fibre network failure could disrupt communications with downstream turbines.

In the future, wireless networks, such as WiMAX, will likely connect wind turbines in a mesh fashion. A mesh, where each turbine has multiple communication paths to the control station (lower portion of Figure 2), is not susceptible to single point failures. In addition, wireless equipment is above water, making it easier to fix. The investment associated with increasing equipment availability is paid back several different ways. By reducing equipment failures, utility operators minimize repair costs and avoid financial loss due to missing output targets, while maximizing revenue opportunities because the electricity production is sustained.

About Mainstream

Mainstream Renewable Power, based in Dublin, Ireland, was founded in February 2008 by Dr. Eddie O'Connor and Mr. Fintan Whelan, former chief executive and corporate finance manager of Airtricity. Its core business is to develop, build and operate wind energy, solar thermal and ocean current plants by partnering with governments, utility companies, developers and investors across North America, South America, Europe and South Africa.

The Supergrid

If the wind is not blowing, how do utility operators maintain service to energy consumers? "What's needed is Eddie's vision of an energy supergrid that allows us to redistribute power from any wind farm to any consumer in Europe. In the North Sea, the wind is always blowing somewhere!" says Joe Corbett, Head of Technical Services at Mainstream Renewable Power. The supergrid concept, depicted in Figure 3, is becoming a reality in Europe, where hundreds of offshore wind turbines, solar panels and hydropower will ultimately be connected together, acting like a giant integrated energy source. "The real potential for wind power specifically, and marine energy generally, is to generate up to half of Europe's electricity by the middle of the 21st century", says Adam Bruce, Renewables UK chairman. Since energy sources are geographically dispersed, the supergrid must be

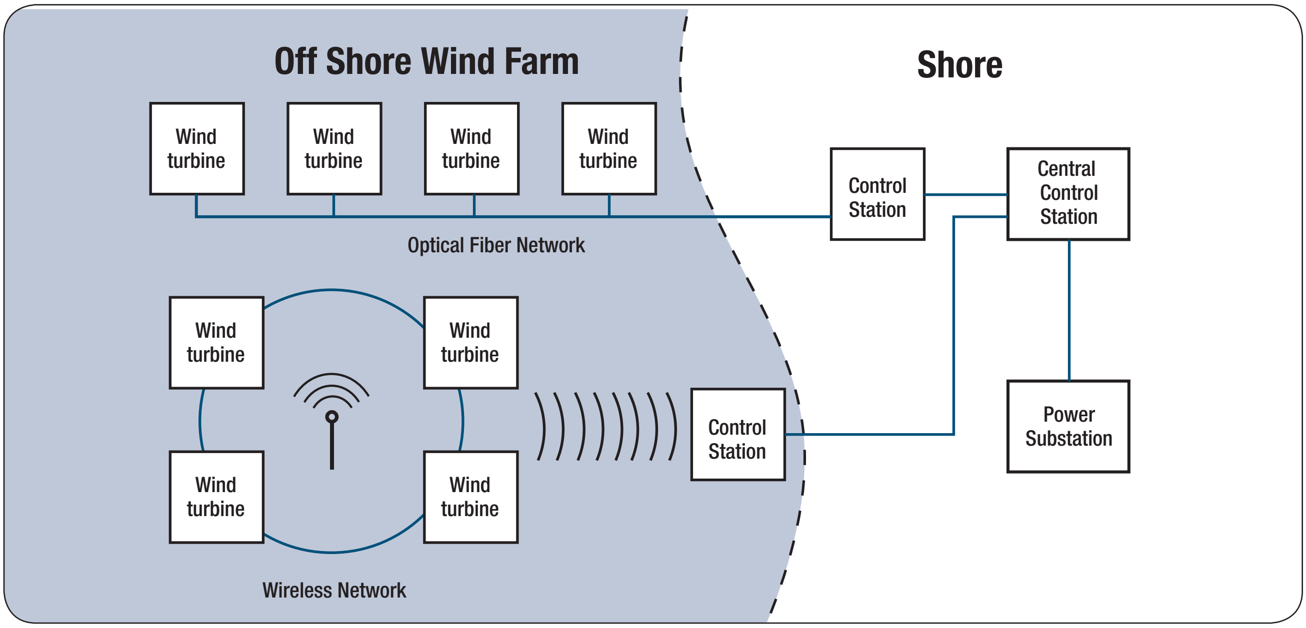

Figure 2. Wind Farm Illustration

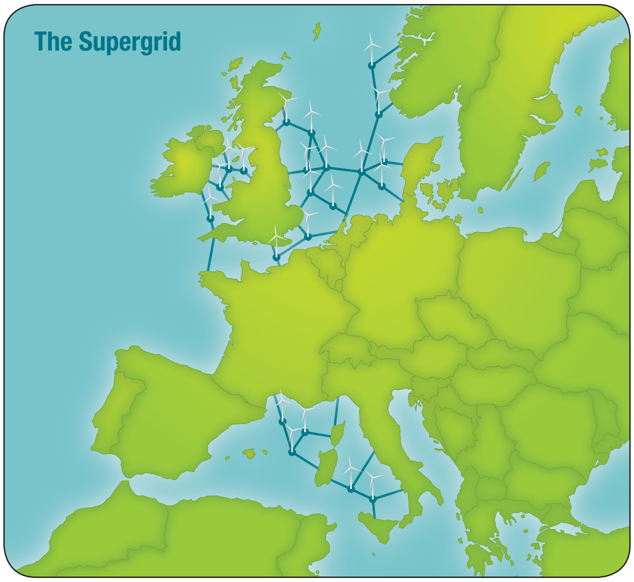

Figure 3. The Supergrid Concept in Europe

designed to minimize energy loss and to transmit energy at an economically viable cost. This can be achieved using high voltage direct current (HVDC) transmission.

An important issue for offshore wind farms is wind forecasting, a type of weather prediction. If utility operators forecast more wind power than they actually produce, energy shortfalls may ensue, forcing them to purchase expensive power on the open market. Wind forecasting is compute-intensive, projecting how the atmosphere will evolve according to fluid mechanics and thermodynamic principles. Running these scientific models requires some of the world's most powerful supercomputers to perform complex calculations on vast datasets.

Major Turbine Elements and Control Functions

Simplistically, a wind turbine is like a giant fan spinning in reverse and generating energy. Fundamentally, the wind strikes two or three blades connected to a rotor, causing it to rotate, which in turn drives a shaft connected to a generator, as shown in Figure 4. The generator produces electricity, which is then sent on to a control station and later to a power substation.

A wind turbine usually has a turbine control system comprising three independent controllers that perform specific tasks. Taking into account wind speed and direction, the turbine control system adjusts the rotor pitch, direction and speed to optimize energy production. When wind speeds are in excess of 90 kilometers per hour (56 mph), most turbines shut down automatically to avoid damage. Orchestrating the operation of wind turbines, controllers must manage over 100 different parameters, like gear oil temperature and vibration level.

However, there are a number of limitations to the conventional turbine control system, according to John Shaw, Head of Information Services at Mainstream. Generally, the design has lagged behind the advanced control systems seen in other industries. There is typically no resilience built into the design, with reliable components being the focus instead.

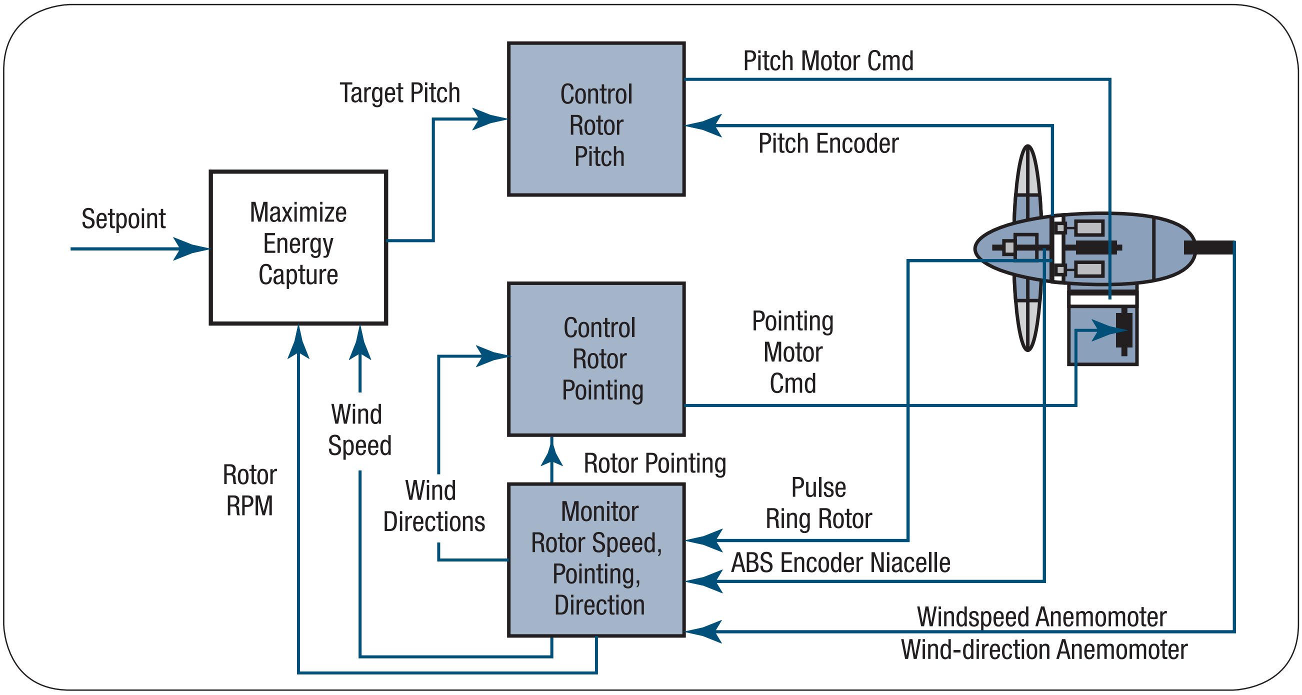

Figure 4. Simple Wind Turbine Anatomy

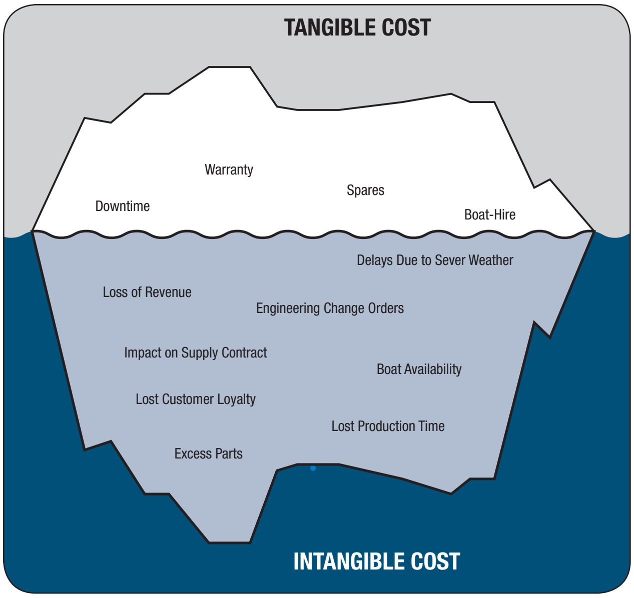

Figure 5. Cost of Availability "Iceberg"

Wind Turbine Control System: Current State of the Technology

Typically, turbine manufacturers guarantee 95 percent turbine availability over a 20 year operating window. One percent of the downtime can be attributed to the turbine control system, also referred to as the Turbine Programmable Logic Controller (PLC) and its associated instrumentation. The meantime between failure for a turbine control system is conservatively estimated to be 1 failure per 2.2 years. (source: ISET). This equates to an expected rate of forty five failures per annum for a 100 turbine farm. Some failure events would require an engineering team, spare parts, boat and boat crew to inspect and correct the failure. Each failure event has a tangible cost and a corresponding 'iceberg effect' intangible cost, as outlined in Figure 5. Over the 20 year operating life of a wind farm, these costs can mount up to a significant level, and any technology that can keep turbines online is valued.

The turbine control system is responsible for many other tasks, including loading software updates, running diagnostic tests and reading sensors (e.g., bearing oil pressure). In addition, it plays a major role in predictive maintenance and prognostics, such as alerting when a turbine component is performing marginally and should be serviced, thereby helping to circumvent an imminent turbine failure. According to industry estimates, maintenance expenses for offshore wind farms can reach 20 to 30 percent of total costs[8], a big hit to a utility operator's bottom line. However, it is possible to cost-effectively increase availability using state-of-the-art Intel® technologies that target remote management, virtualization and enhanced wireless communications.

Keeping Turbines Online with Remote Management

Wind farm operators are using remote management solutions to get turbines online faster and at lower cost by diagnosing and repairing problems over a communications link. When a wind turbine goes down, energy production is interrupted until technicians find and fix the problem, which may require an on-site visit. Such repairs can be expensive, especially when it means sending a repair crew out in a helicopter.

Typically each wind turbine's control system is connected to the control station's Supervisory Control and Data Acquisition System (SCADA) via a communications link. Using the communications link, the operations team can perform many support tasks remotely, such as restarting controllers, updating software and reading system error logs. However, the drawback to this 'in band' approach is it relies on the continued operation of many wind turbine controller components: CPU, machine code and system memory. In other words, if the controller is not functioning, the only option may be to dispatch a technician.

Providing a significant remote management breakthrough, Intel® vPro™ technology with Intel® Active Management Technology (Intel® AMT)[9] enables the operations team to access and control a wind turbine controller even when the software is corrupted. It implements a special circuit in the Intel® chipset that can access and service the turbine controller, whether or not key hardware and software components are functional. This circuit establishes an 'out-of-band' link that allows the system to communicate with a management console without relying on the system's standard networking functionality (e.g., Ethernet NICs, CPU, operating system, protocol stacks). Intel vPro technology is a cross-platform solution, meaning it can support the wind farm infrastructure, including wind turbines, control stations and power substations, as shown in Figure 6.

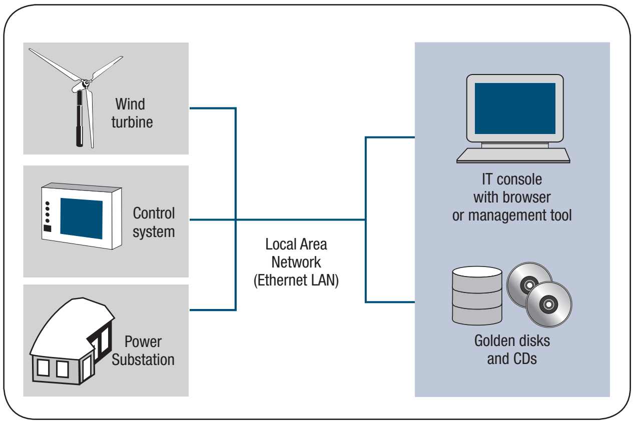

Figure 6. Remote Management Solution for the Energy Network

"The latest version of Intel® Active Management Technology serves as a key component for increasing wind turbine availability, providing out-of-band manageability to reduce downtime for utilities; even if the unit is powered off, diagnostics and many repairs can be accomplished remotely."

Joe Jensen, General Manager, Intel Embedded Computing Division

By employing Intel vPro technology-based remote management solutions, the operations team can use a true keyboard-video-mouse (KVM) switch to perform maintenance and fix a wide assortment of system defects. In addition, it is possible to track inventory – including warranty and software license information – and monitor intermittent failures, as described in Table 1 and in the following. This capability reduces cost and saves time by supporting devices without requiring hands on intervention.

Table 1. Benefits of Intel® Active Management Technology

Capabilities	Results
Fix Hung Systems	Restore systems by cycling power, reloading software or booting from a gold hard drive over the network.
Track Turbine Components	Identify installed hardware and software components, even if the turbine is not running, easing debug and repair.
Monitor Intermittent Failure Modes	Access system error logs and event records from FLASH, accessible at all times to the remote console.

Reduce Onsite Repair Costs

When a control system won't boot due to corrupted software (e.g., ladder logic), the usual remedy is to send a technician on-site to reload the software image. Using Intel vPro technology, it's possible to remotely boot a device from a networked drive (golden disk in Figure 6) with known good software, which greatly aids troubleshooting. The operations team can also remotely change configuration settings or load new ladder logic, whether or not the system is running.

Monitor Intermittent Failure Modes

When logging events and hardware/software errors, control systems leave valuable clues about their health, including intermittent fail conditions that could eventually turn into hard failures. With Intel vPro technology, systems can continually store this information in non-volatile memory, accessible at all times to the remote management system, regardless of the system state. If an on-site visit is required, this capability can help identify failed components in advance, which enables technicians to arrive with the appropriate spares and fix the system faster.

Ensure Mission Critical Software is Running

Intel vPro technology supports a feature, called agent presence, that alerts the operations team's remote management console if a critical turbine software function unexpectedly stops running. For example, if a software driver communicating with sensors (e.g., temperature, pressure) fails, the operations team can take corrective action like restarting the software.

Check the Operating System Log

The operations team can use Integrated Drive Electronics (IDE) redirect to boot a diagnostic image and read the OS log to identify potential problems. This is done by reading the partition on which the OS was running, checking the OS log for errors, fixing the problem (e.g., reloading a bad driver) and then rebooting the main OS.

Improving Software Stability and Determinism

Running thousands of lines of code, wind turbine control systems provide real-time response to constantly changing weather conditions. Helping to keep the software running, virtualization technology offers several mechanisms that can improve system stability and increase real-time determinism. This is achieved by running multiple OSs and their associated applications called virtual machines in secure partitions, which facilitate software failover, protect against unintended software interactions and preclude software from competing for CPU resources.

Virtualization has been around for many years, most notably used in data centers where many applications are consolidated onto a single physical server. Intel has enhanced the capabilities of virtualization technology with a complementary hardware-assist technology called Intel® Virtualization Technology (Intel® VT)[10]. Intel VT performs various virtualization tasks in hardware, like memory address translation, which reduces the footprint of virtualization software and improves its performance. This capability increases

Table 2. Intel® Virtualization Technology Capabilities and Benefits

Capabilities	Benefits
Isolates applications in secure partitions	• Prevents software applications from interfering with one another • Provides a software failover mechanism
Runs RTOS on a dedicated processor core	• Improves real-time determinism • Eases software consolidation
Restarts applications without booting the hardware	• Gets the system working faster • Resolves potentially catastrophic failure conditions

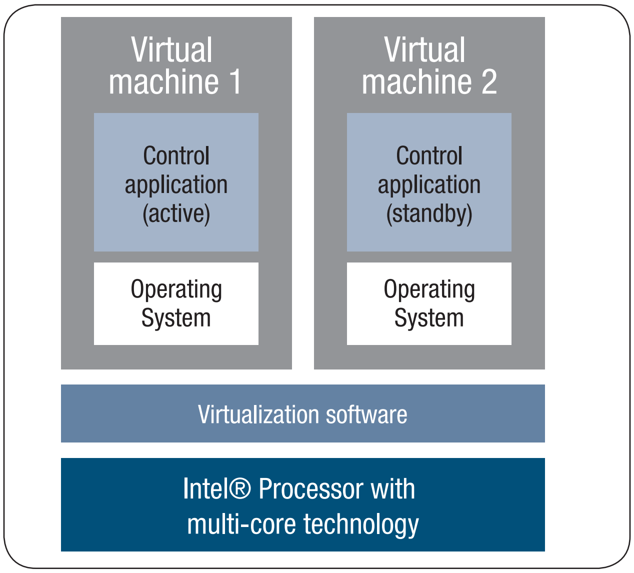

Figure 7. Wind Turbine Controller Virtualization Example

the performance and robustness of virtualized environments and provides many benefits, as shown in Table 2 and described in the next three sections.

Software Failover

A software failure in a turbine controller can cause a wide variety of problems, ranging from constant resets to catastrophic damage to the rotor. In the event of software failure, it is possible to quickly failover to a clean software copy using virtualization. This is done by creating active and standby partitions, each with a copy of the control application, as illustrated in Figure 7. If the active software fails – perhaps detected by a 'heartbeat' monitor – the standby copy takes over, often without a hardware reboot. Similarly, developers can use virtualization to restart failing software running in one partition without impacting the software executing in other partitions.

Software Isolation

For turbine controllers, stability is built into the way the code is written. Software conflicts are very unlikely, such as two applications contending for the same memory locations, resulting in unforeseen consequences. To safeguard code and improve system reliability, developers can run code in safe, virtualized environments that isolate different workloads and prevent them from interfering with one another.

Real-Time Determinism

The determinism of real-time functions, like controlling the position of the rotor, can be negatively impacted when they must vie for CPU resources with non-real-time applications such as statistical programs. It is possible to eliminate this contention with virtualization and multi-core processors, a combination that enables systems to run time-critical unctions on a real-time OS and on a dedicated processor core. As a result, real-time functions do not have to share interrupts or CPU resources, which can increase their determinism and performance.

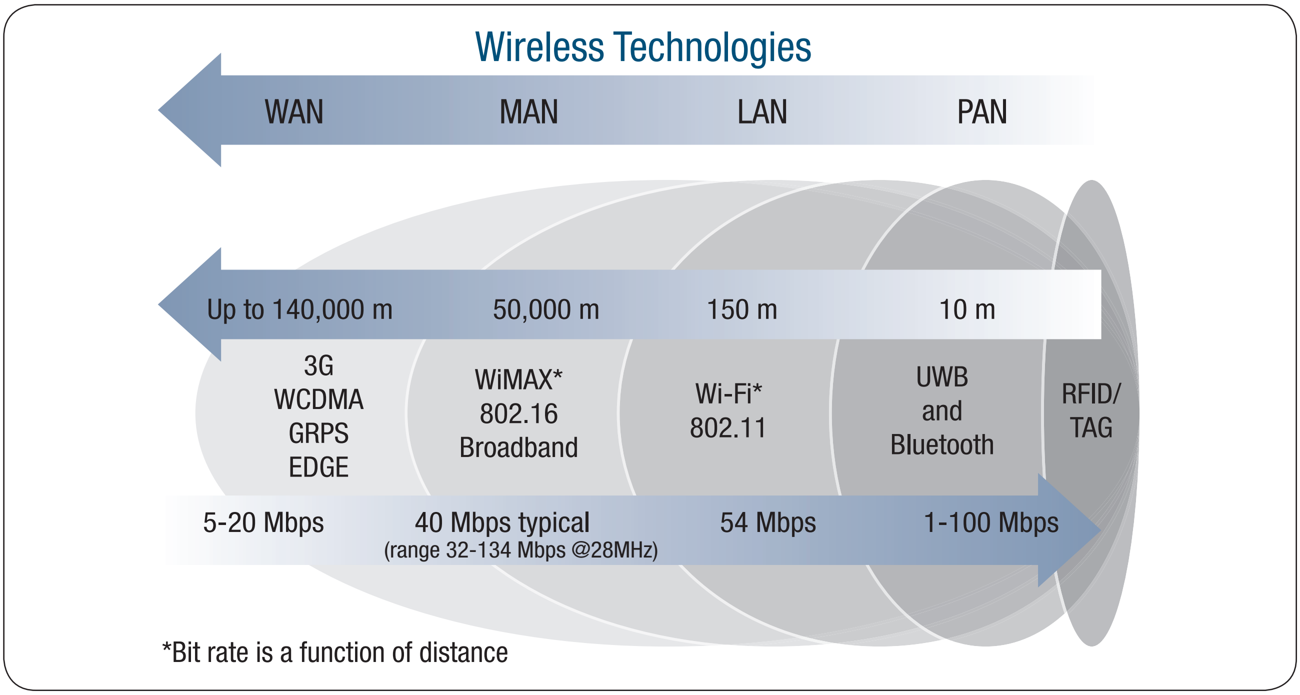

Figure 8. Typical Bit Rates and Distances of Wireless Technologies

Communicating Over Long Distances

Supporting long distance networks for wind farms of any type, WiMAX[11] is a wireless standard offering a reliable, cost-effective alternative to optical fibre communications links. WiMAX, or IEEE* 802.16e, is designed to deliver superior data rates and scalability, lower costs and reduce network complexity while covering distances up to 50 kilometers (31 miles). With this wireless technology, wind farm operators can easily construct a mesh network, allowing a wind turbine to communicate with other turbines in range and eliminating single points of failure in the communications link.

WiMAX provides two to three times the performance of 3G (i.e., cell phones) solutions today, with the ability to scale to ten times the performance in the future.[12] Compared to other wireless technologies, shown in Figure 8, WIMAX is designed for relatively long distance and high bit rate. As a driving force, in collaboration with industry leaders, Intel is working towards further expansion and support of WiMAX through technology advancements such as Intel® WiMAX/WiFi Link 5050 Series, an integrated module solution with advanced multiple-input multiple-output communications (MIMO) antenna technology.

Using mesh architecture and redundant radios, wind farm operators can deploy networks with 99.999 percent reliability.[13] This is the same level of availability required of carrier-grade equipment, which represents the pinnacle of the communications industry. In addition to enabling reliable networks, WiMAX provides other key benefits listed in Table 3.

Table 3. WiMAX Features and Benefits

Features	Benefits
Based on open standards	Lowers cost through economies of scale
High throughput and range	Supports many wind turbines over large expanses
Flexible implementations: mesh networks and redundant radios	Enables high reliability (99.999%) networks[13]

Energy Blowing in the Wind

Governments worldwide are advocating renewable energy as the direction for reducing dependency on fossil fuels. Wind turbines represent a reliable technology, and plans are underway to build many more offshore wind farms in the North Sea, Baltic Sea and the Atlantic Ocean. In order to deliver the type of return required to justify offshore wind farms, it is extremely important that both turbine and wind farm infrastructure are highly available. Intel technologies, including advanced remote management, virtualization and wireless technologies, can help wind equipment manufacturers make significant advances in availability. Intel and Mainstream Renewable Power are working closely with the wind industry to achieve availability excellence through the deployment of leading-edge computing and networking technologies.

Learn more about Mainstreamrp at **http://www.mainstreamrp.com**

Learn more about Intel solutions for the Energy industry at **http://www.intel.com/go/energy.**

[1] The Joint Operating Environment (JOE) 2010, page 26, http://www.jfcom.mil/newslink/storyarchive/2010/JOE_2010_o.pdf.

[2] "Europe's onshore and offshore wind energy potential", p. 49, June 8, 2009, found at http://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential.

[3] David Perry, the Press and Journal, 27/06/2008 http://www.pressandjournal.co.uk/Article.aspx/711503?UserKey=0

[4] http://en.wikipedia.org/wiki/History_of_wind_power

[5] http://www.erec.org/fileadmin/erec_docs/Events_Documents/Berlin_Policy_Conference/Berlin_closing_EREC_PR.pdf

[6] http://www.renewableenergyfocus.com/view/4123/eddie-oconnor-wins-leadership-award-at-ernst-young-global-renewable-energy-awards-for-offshore-energy-commitment/

[7] http://www.bwea.com/ref/econ.html

[8] http://www.spiegel.de/international/germany/0,1518,567622,00.html

[9] Intel® vPro™ technology includes powerful Intel® Active Management Technology (Intel® AMT). Intel AMT requires the computer system to have an Intel AMT-enabled chipset, network hardware and software, as well as connection with a power source and a corporate network connection. Setup requires configuration by the purchaser and may require scripting with the management console or further integration into existing security frameworks to enable certain functionality. It may also require modifications or implementation of new business processes. With regard to notebooks, Intel AMT may not be available or certain capabilities may be limited over a host OS-based VPN or when connecting wirelessly, on battery power, sleeping, hibernating or powered off. For more information, see www.intel.com/technology/platform-technology/intel-amt/.

[10] Intel® Virtualization Technology requires a computer system with an enabled Intel® processor, BIOS, virtual machine monitor (VMM) and, for some uses, certain platform software enabled for it. Functionality, performance or other benefits will vary depending on hardware and software configurations and may require a BIOS update. Software applications may not be compatible with all operating systems. Please check with your application vendor.

[11] WiMAX connectivity requires a WiMAX-enabled device and subscription to a WiMAX broadband service. WiMAX connectivity may require you to purchase additional software or hardware at extra cost. Availability of WiMAX is limited; check with your service provider for details on availability and network limitations. Broadband performance and results may vary due to environmental factors and other variables. See www.intel.com/go/getwimax/ for more information.

[12] Up to 5x better performance (compared to 802.11a/g) with Intel® Centrino® 2 processor technology enabled notebooks. Faster Wireless N performance requires Intel Centrino 2 processor technology-based notebooks with optional Intel® WiFi Link 5300, and a 450 MBPS wireless router. Actual results may vary based on your specific hardware, connection rate, site conditions, and software configurations. See www.intel.com/performance/mobile/wireless/index.htm for more information. Wireless N standard is not available in all countries. Check with local PC and access point manufacturers for details and availability.

[13] http://www.wimax.com/education/wimax/reliability

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