White paper

Five key characteristics make wind farms more financially viable

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Successful wind farms are not simply the result of good fortune. Several characteristics of success, such as the prompt delivery of equipment, efficiency, and risk management, must be factored into their design well before the first shovel turns.

Wind power comes with a few significant challenges. For instance, wind-farm construction deals with long supply chains that hamper on-time deliveries and predictable completions. The facilities also are spread out in remote locations with generators far off the ground, so it's no small task getting the right technicians and tools to the nacelle that needs attention.

Also, wind is variable, making reliable power transmission troublesome. The entire grid works best when voltage is high and steady. And then working near high voltage and at height brings a certain amount of risk with every task, making safety paramount.

Construction companies and their support organizations have devised ways to meet these challenges. As a result, they are providing a more reliable grid across the entire country. For a closer examination of the characteristics of a successful, safe and financially sustainable wind farm, we spoke with developers and manufacturers for their insight. The issues they focus on include on-time equipment delivery, efficiency, reliability, maintenance, safety, and risk management.

Prompt delivery of equipment

The date on which the first financially feasible power flows from a new wind farm has a special place on construction schedules. It marks the end of a long sequence in which hundreds of shipments of complex mechanical and electrical equipment should be mounted, wired, and ready to run. How does an organization track such an enormous effort?

A detailed critical path-method schedule is essential, says Mortensen VP of Project Development Jerry Grundtner. His company schedules several hundred wind-farm activities on such a chart along with a clearly plotted critical path.

"It tracks things that must happen before tackling other tasks. Wind turbine deliveries are on the chart along with the main-power transformer and substation equipment."

Critical-path equipment often has an arrival window of less than a week.

"Should a major piece of equipment, such as a main power transformer for the substation, arrive late, it has a significant negative impact on the project's completion. If five of 100 turbines are late it's not a big problem. But there is only one main power transformer, and its late arrival negatively impacts the overall schedule," says Grundtner.

To keep equipment on schedule, the company assigns engineers to mentor and coordinate delivery of all major materials.

"An individual may have responsibility for coordinating delivery of the wind turbine, another for electrical components, and so

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forth. Those individuals use the master schedule to know when we need the equipment, so they stay in communication with its manufacturer confirming the delivery dates. Occasionally, we'll send a representative to the factory to verify construction progress on critical equipment."

For another perspective on prompt delivery, look at the substation. Prompt delivery is critical because just about everything there is customized.

"Once you determine the size of the wind farm and the utility-transmission voltage, you can select its equipment," says Melvin Brown, ABB manager of business development for renewables. "Developers often start a project only after they have the Power Purchase Agreement (PPA) and environmental permits in place."

The PPA or Interconnect Service Agreement is critical because it sets the date on which the wind farm is to first deliver power to the grid," says Brown. "That date is set in stone." If it changes, the entire development suffers because the wind-farm owner does not know when he will be given the next date. "Worse still, if the developer misses the PPA dates, the owner says 'goodbye' to treasury grants and production tax credits."

After the substation is completed, it must be commissioned, a process that tests the equipment. "So until testing and commissioning finish, the wind plant cannot deliver power to the grid. And consider this: whatever the date set in the PPA to begin transmission, the substation must finish about eight weeks before that to leave time for commissioning," adds Brown.

And here's more plan-ahead planning. Transformers are the substation's long-lead items. Depending on size, transformers could have lead times of 40 to 52 weeks. Other substation items with long lead times include medium-voltage switchgear and circuit breakers, from 26 to 36 weeks. High-voltage breakers take 20 to 26 weeks.

Schedulers must look to when the environmental permits expire and pre-purchase the transformers accordingly. "If they wait for the contractor to purchase the units, for example, the transformer delivery dates could fall beyond the PPA service date," says Brown.

While equipment delivery is critical, most new wind farms are likely to encounter difficulty getting the energy to its load center. Don E. Martin, executive consultant with ABB, conducts feasibility studies for wind developers to spot transmission problems and solutions.

"Before a developer goes too far in a project, he should examine what it will take to get its power to a load area," he says.

Where only low-voltage lines exist, there may be no way to get another 70 to 150 MW out without stringing more line. "It's a frequently encountered dilemma because we're getting to a point where there is a lot of wind power, but it cannot get onto the grid because transmission is near capacity."

Efficiency

A recent study shows room for efficiency improvements in wind farms' electrical equipment. For instance, up to 6-7 percent of generated power is lost to heat in transmission alone. Increasing line voltage is one way to cut losses, while improved transformer design is another. Most conventional transformers work at a respectable 98 percent efficiency, but higher ratings are possible and desirable.

Larger conductors are one way to make transformers more efficient. "Better yet, an improved magnetic structure allows more efficient transfer of electric fields," says ABB transformer design specialist Doug Getson. Transformers can be classified as grain oriented which use traditional steel; and amorphous, which use a special thin metal. Grain-oriented steel is about 10-times thicker than amorphous steel. In a nutshell, thinner material reduces losses. Amorphous transformers cost more, but they reduce no-load losses, a measure of efficiency, by 70 percent at times.

"Transformer losses are measured at load and no-load," says Getson. "Even when they aren't working hard, transformers are consuming power often priced from $2 to $8 per watt over a 20-year equipment life. A 0.5 to 1 percent boost does not sound like much, but consider the many transformers on a wind farm, and you suddenly see the operator could be losing a significant sum."

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Look at the side-by-side losses columns in the accompanying table.

Transformers on turbines working at 100 percent rating have comparable losses. But at the lower end of the table [12.5 percent output] where turbines spend more time, losses are 3.22 percent versus 2.11 percent. The distribution in MWh is based on an actual wind farm outputs. In this case there would have been a loss of nearly 2,000 MWh. At $0.15/kWh in the PPA, this is a $300,000 annual loss and $6 million over the 20 year life of the farm.

Comparing transformer losses

Turbine Output	Grain Oriented		Amorphous	
	Energy Sales (MWh)	Losses	Losses	Energy Sales (MWh)
100.0%	5,880	3.25%	3.17%	5,885
87.5%	68,386	2.91%	2.81%	68,462
62.5%	88,837	2.87%	2.68%	89,008
37.5%	234,890	2.52%	2.17%	235,736
12.5%	50,113	3.22%	2.11%	50,690
0.0%	-208	0.00%	0.00%	-39
	447,899	2.78%	2.38%	449,741

Reliability

For this paper, let's examine two areas of wind farm reliability. One is the reliability of transformers and the other is maintaining a steady line voltage.

One way to shorten a transformer's life is to ignore frequency harmonics, or stray line frequencies.

"Line frequency is normally 60 Hz, but some equipment generates harmonics at five times [300 Hz] or seven times [420 Hz] the 60 Hz," says ABB's Martin. "Different equipment create different harmonics, and you have to consider the losses of the higher ones. Instead of being just 1 or 2 percent of voltage, it can be 20 or 30 percent, and such high over-voltage damages equipment."

If a wind farm puts both frequencies on top of the 60 Hz, they generate heat in transformers, which shortens their expected 20-year life. Filters remove some of the higher harmonics.

"Not long ago, we were seeing many different transformer specs from wind-farm owners, all intended for the same sized wind turbine," says Martin. "Why? We asked our engineers who design them if they were ever given specs that would identify the harmful harmonics to filter out. They were not. Harmonics were being ignored, yet it is important to know what they are because transformers were failing on wind farms and most likely because of harmonics."

If wind farm owners share details of line irregularities with transformer manufacturers, transformer life may be extended.

The second reliability issue deals with maintaining a steady line voltage. Keep it steady, and the grid becomes stable and productive.

"It's easier said than done, but there are several ways to do it," says Eric John, an ABB electrical engineer and director of marketing and sales. One way uses reactive power compensation.

Power on a transmission line is made of two components: active power end users consume, and reactive power that is needed to stabilize line voltage. Reactive power is not sold, so too much is wasteful.

"The cheap way to control reactive power is by switching reactors and capacitors on and offline with a mechanical switch. The drawback is that it is not smooth control, and the line ends up having step changes to the voltage," says John.

Wind farms try to control voltage within 5 to 10 percent on 69 and 138 kV lines. To complicate matters, events transpire in less than a second, so a response to a power system fault must be in less than a second. It needs an automated response, not one at a human interval.

A better way to control reactive power is through the use of power electronics as a switch rather than a slow-acting mechanical device. "First, this electronic switch works fast," says John. "It responds in milliseconds and it's controllable throughout its rating. These devices are rated for -40 to 50 MVAr, (a measure of reactive power). It can produce -30 MVAr and change output in less than a second to +50 MVAr, and with a smooth ramp instead of a step. It is thyristor based — a power semiconductor device with 30 years of use in power control."

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Maintenance

The complexities of maintaining a wind farm are daunting. A single nacelle, for instance, can have 10,000 mechanical and electrical components. Tracking repaired and replaced items with spreadsheets or homegrown software creates opportunities for error and is not a best practice. Maintenance on a wind farm is better served with something more automated. One challenge with large wind farms is that certain assets, such as motors and transformers, move around.

"Say a transformer is removed from a tower and brought into a repair facility," says Terry Roberts, a product management at Ventyx, an ABB company. "Technicians fix it and move it to another location. Asset management software can track the asset's location and keep tabs on what's been done to it. For the repair task, it lets workers detail the time and materials spent, the transformer's working condition, and where it's stored."

The software keeps logs on repairs and preventive maintenance work. Algorithms that users can adjust let O&M teams define how and when they want preventive maintenance done. The software then generates maintenance work orders when needed. Repair reports are available to managers so they can make decisions on, for example, further repairs or a new purchase.

"Software can also consider the work load on the wind farm and apply algorithms to generate a most efficient schedule for a technician or crew," says Ventyx VP Steve Radice. "Today's state-of-the-art solutions can monitor the needed technical skill level, provide ground-level routing to an ailing turbine, and track other factors to make crews more productive." In the past, someone in a call center would make a commitment but have no idea if the available technician or maintenance crews had the right skills for the job.

"Today's solutions give instant access to the resources for the day's scheduled work and the near future," says Radice.

Even more notable is an ability to forecast workloads. "A neural network in the asset management software works on historical data amassed over months and years of use. That gives it an ability to forecast what workloads could be," adds Radice.

An operations chief might use it this way: Suppose a large program is slated for next year on the oldest turbines. The chief would run the model adding detail, such as available parts or time of year until it gives a reasonable work schedule. That information would be released to the rest of the system, which would schedule and route crews based on the computer model. It's important because wind farms have to decide how many workers they need, where they need them, and even a mix between employees and contractors. The goal is to provide a real-life projection at what workloads might be.

Safety

Safety begins well before the project does. "It has to be built-in to company thinking because there is no way to manage it if it does not start at the beginning," according to IES Safety Director John Ellis. The company develops wind farms, and in the process has won several safety awards. "Most are the results of safety records we've earned from a scarcity of incidents, and staying off incident reports," he adds.

So how do you stay off incident reports? "One way is to treat OSHA rules as a place to start a safety program and then go above and beyond them," suggests Ellis. The greatest hazard on a wind farm is, not surprisingly, falling because so much work is done at height. For that reason, Ellis says the company has an orientation class for new hires, and then adds hands-on training. For up-tower work, IES adds an eight-hour class that goes over OSHA rules and company policy with respect to different aspects of what they will be doing.

Part of company policy is proper use of personal protective equipment, the safety harnesses, carabineers, ropes, and so on. "We go over how to properly wear them and use them — mostly hands on," says Ellis. "Working around electrical equipment calls for additional training. If we hire someone without electrical experience, they will not be doing electrical work. They have to qualify first in training and then with experience. More importantly, they should have a journeyman's electrical license. Getting one varies from state to state. In Nebraska, for example, you must have four years experience and then pass a test administered by the state."

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Arc-flash accidents may be one of the largest single safety risks in any electrical installation. Online reports say such accidents occur five to 10 times each day. A few modern electrical devices, however, can mitigate the safety concern from new installations.

“Many wind turbines have step-up transformers in their nacelles,” says ABB consultant David Georg. “Switchgear located in the tower connects and disconnects that high voltage to the collector, and that protects the transformers. That switchgear must be arc resistant – safe for the people operating in such a closed environment,” says Georg.

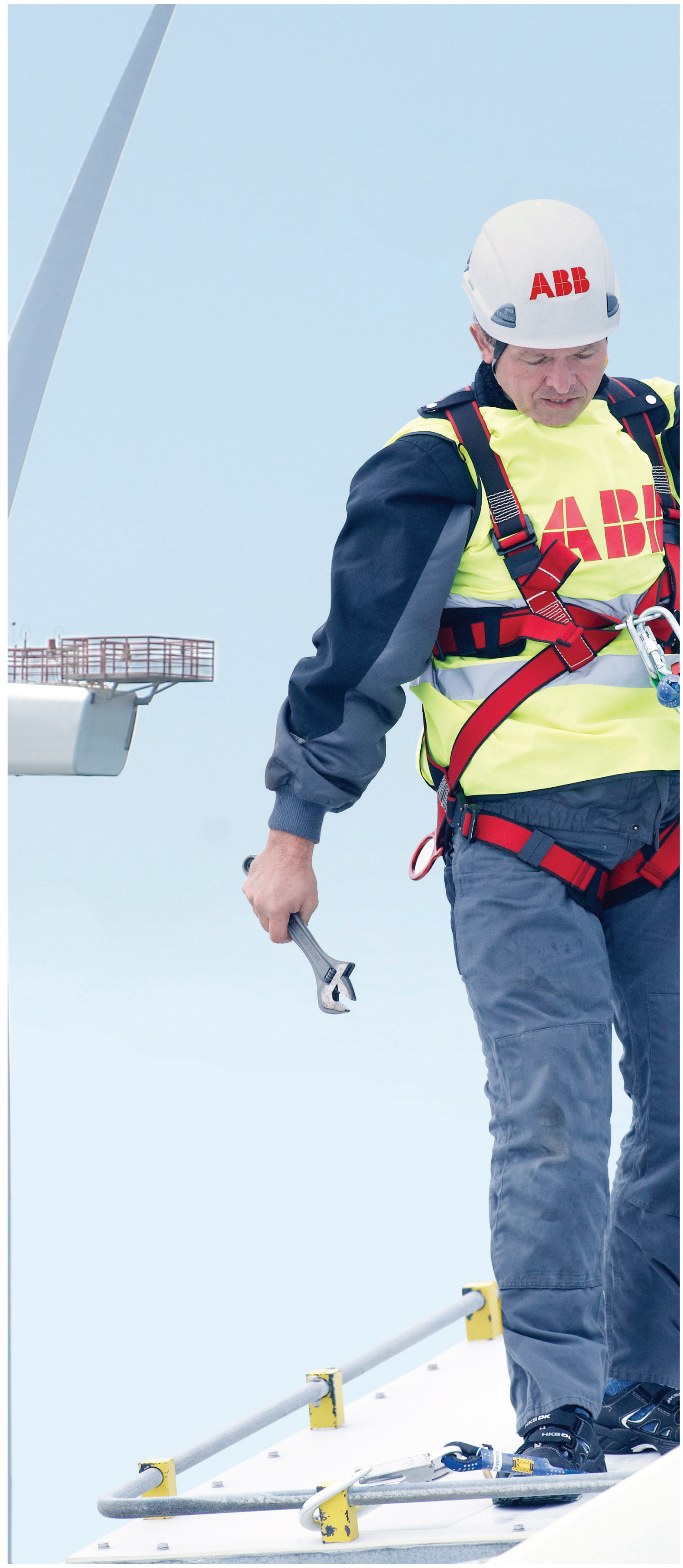
Arcs are usually caused by a problem inside the switchgear. It could be a misadjusted bus or a connector. “Most accidents occur when racking out a breaker or putting one in service. For most arc-resistant gear, a technician positions the breaker, closes the door, and ‘racks it’ in a closed-door environment. That’s significant. If an arc occurs while racking equipment, high-speed relays should take it offline before it does physical damage, most importantly to the service technician. The fastest equipment available uses a light sensor energized by the arc light to trigger the breaker. Light sensors are quicker than a current transformer. Arc mitigating relays can also be used under certain low-fault current conditions.”

Conventional switchgear has other drawbacks. Some turbines must place switchgear on foundations because the cabinets are so large. Turbine towers are then lowered over the equipment. When a repair issue calls for removing the switchgear, it has to be disassembled to fit through the 600-mm wide tower door.

To slim down switchgear cabinets, the latest designs are filled with a high-dielectric gas that allows mounting high-voltage circuit breakers closer together than a conventional cabinet would. This allows cabinets thin enough to fit through tower doors.

There is still room for improvement. “For instance, conventional mechanical switchgear must be in perfect order to work,” Georg says. “But because of wide temperature ranges and dust, mechanical devices are a constant problem.”

Georg encourages all purchasers to do some homework before purchasing switchgear, because there are several ways to get arc-resistant gear. “Buying cheap gear to save a few bucks opens the owner to risk from a safety standpoint,” he says.



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Risk management

The best way to reduce risk is to select manufacturers and service companies with a proven track record of helping wind-farm developers meet their construction dates, and installing reliable and safe equipment. Insurance is another way to manage risk or "exposure" in insurance parlance. It's the potential for loss, which would adversely affect the financials of a project, such as physical-damage loss.

"A lot of managing risk has to do with proper project management and vendor selection," says GCube wind farm specialist Curt Maloy. The Achilles heel of a wind project, from an electrical perspective, is the substation, which collects electricity from many turbines and puts it onto the grid. If there is a problem with the substation, the project's turbines may be perfectly able to deliver power, but they cannot make the grid connection, so there's an investment without delivery of power.

Wind farms are usually insured with an all-risk policy, according to Maloy. "That means if something is not specifically excluded, it's covered."

As part of the underwriting process, wind farm owners are asked to provide what insurers call a statement of value. It lists the value on individual components and a total basis for the project. Major components would include the turbine, pad-mount transformers, electrical switchgear, the substation transformers, SCADA system, inverters, and controllers. All that is part of the operating all-risk coverage for mechanical and electrical breakdowns.

What tangible results can the insurance industry bring to the risk-mitigation table? Consider this, says Maloy: Several years ago, one of the three legs on a high-voltage substation transformer failed. The transformer was a one-off design, not standard, so a quick replacement was unavailable.

Maloy says GCube had to find a transformer repair company. "We found one and made a deal with the company to fix the transformer by a certain a date. If they delivered early, we would pay them about $10,000 per day because it was costing significantly more than that in losses. More than 400 turbines were idle. The repair firm rallied their employees to a 24/7 effort, and got the transformer back and started in eight weeks, about half of the projected repair time. Our loss was a few million but it could have been worse."

To avoid losses, companies like Maloy's insist that electrical equipment is built to national and international code, IEEE and IEC. "We assume that when the engineer puts his stamp on the drawings, that verifies the design meets all IEC regulations and requirements," he says. The same goes for a wind turbine. The company requires that its wind turbines be certified by an organization such as Germanischer Lloyd or Det Norske Veritas.

A few lessons

Each section here provides useful lessons. For instance, having the shortest possible supply chain leads to more reliable delivery dates, and that suggests factories in North America have a significant advantage over those farther away.

The latest electrical equipment can improve a wind farm's financial sustainability by providing stable power that keeps all its equipment working for longer periods between repairs, and by being safer to work with. When maintenance is needed, it can be provided in the most efficient and timely manner possible.

Efficiency studies show that even small percentage improvements can reduce losses. And safety must never sleep.

Managers at utilities with conventional generation face the same challenges. The wind industry, however, has simply highlighted the problems because of their high risks during installation and maintenance, and the urgency of meeting PPA agreement dates. The utility industry will look different in five years but be sure its wind component will be stronger and more reliable because of the steps taken today.

Contact us

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