



# DON'T CALL THEM WINDMILLS

A QUICK OVERVIEW OF TURBINE TECHNOLOGY  
BY

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**Y**ou are not happy. It's the Fall of 1973. You've been waiting in a gas line for an hour, when a pimply teenaged pump attendant drags out a free standing sign proclaiming, "No More Gas Till Tomorrow!" Ah, the good old days. For the first time, most of us were learning that America was not an energy self sufficient country. OPEC had closed their oil spigot to America. We were mad as hell and needed to do something about it.

In reaction to this frightening reality, government and business scrambled for solutions. One approach was to mainstream the idea of "renewable energy." Wind energy, seemed like a great solution to energy independence. Unfortunately, hastily conceived government construction subsidy programs lead to a flurry of unprofitable windmill installations. The poorly realized scale of turbine technology (too small); its baulky untested designs and most importantly, the normalization of oil prices in 1974, saw the wind energy industry quickly slide out of the spotlight of national energy policy. For decades to come, wind research and development in the US all but ceased.

Like most of the general public, back in those days, the term windmill conjured, in my mind's eye, an image of tulips and quaint Dutch maidens dancing across a background landscape dotted with rustic windmills. We thought, "windmills are cute and oh so quaint". As an apprentice electrician, I saw those stumbling first attempts as pretty marginal and inconsequential to my nascent career.

Today, we are seeing a massive effort to bring wind energy back to the front burner of power production in this country. Unlike the, not-ready-for-prime-time attempts of the 70's, today's wind power is being developed on a scale and with a technology that has a proven track record.



While wind technology languished on the back burner in this country, countries like Denmark, Holland, Spain, Germany, and Japan stuck with it. Their persistent research and development put them in the forefront of today's wind power industry. America has done a pretty good job, the last few years, of playing catch up. In fact, the US has more functioning wind turbines installed than any other country. However, that is to be short-lived, as China is rapidly catching up to us and is expected to pass us by, in a few years. Not surprisingly, they are already the largest manufacturer and exporter of turbines in the world.

Last year a Harvard study<sup>1</sup> made the remarkable claim that there are enough developable wind energy locations in the lower 48 states to provide more than 16 times the total energy requirements of the entire U.S.! This study's results are based on current available technology i.e. 2-3 megawatt turbines.

Yes, that's right, 2-3 MEGAwatt turbine/generators are current technology. And here's where I want to explain the title of this article. The scale of current wind turbine technology is hard for most people to fathom. Today's wind turbines are a far cry from the cute stereotypes of Dutch windmills most of us harbor. Today's wind turbines are massive industrial marvels. For example, if you've ever been on the tarmac of a major airport and found yourself next to a Boeing 747 Jumbo jet, you might have wondered how the heck can this mountain of metal get off the ground? Well it takes wings that are a colossal 211ft. tip to tip. The wing span (diameter of the circle drawn by turning turbine blades) of a typical 2 megawatt wind turbine is 262-295ft! (Figure 2) Fundamental economic viability of wind farms, depend on this enormous scale.



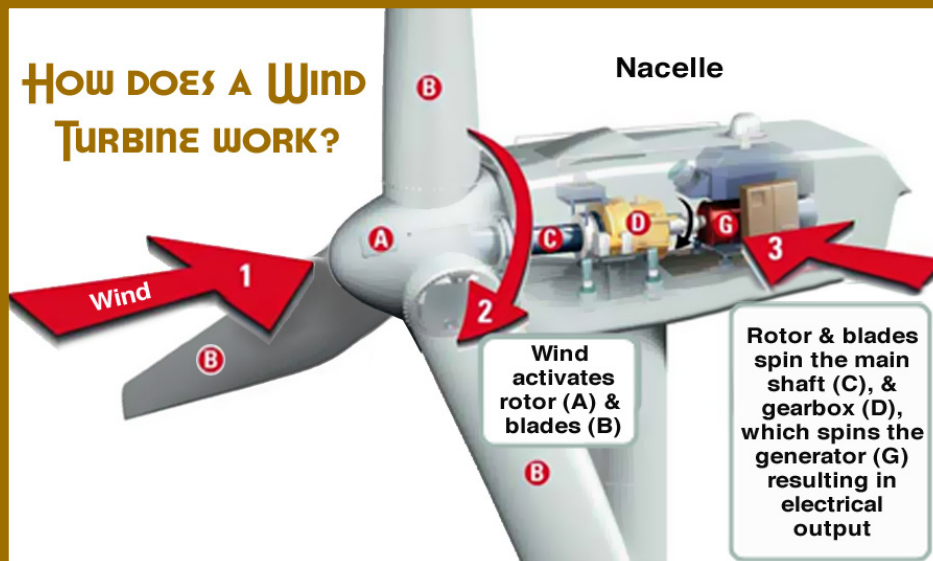
**Figure 1.** Voltages on a typical wind farm range from 5V dc-34.5kV ac. Available fault currents can be above 100kA. Pictured here is a 230kV output from a farm's substation to the grid.



**Figure 2.** These turbines are typical of the scale of current wind turbines. The largest producing turbine in the world, however, is the German Enercon, with a blade diameter of 453ft.!



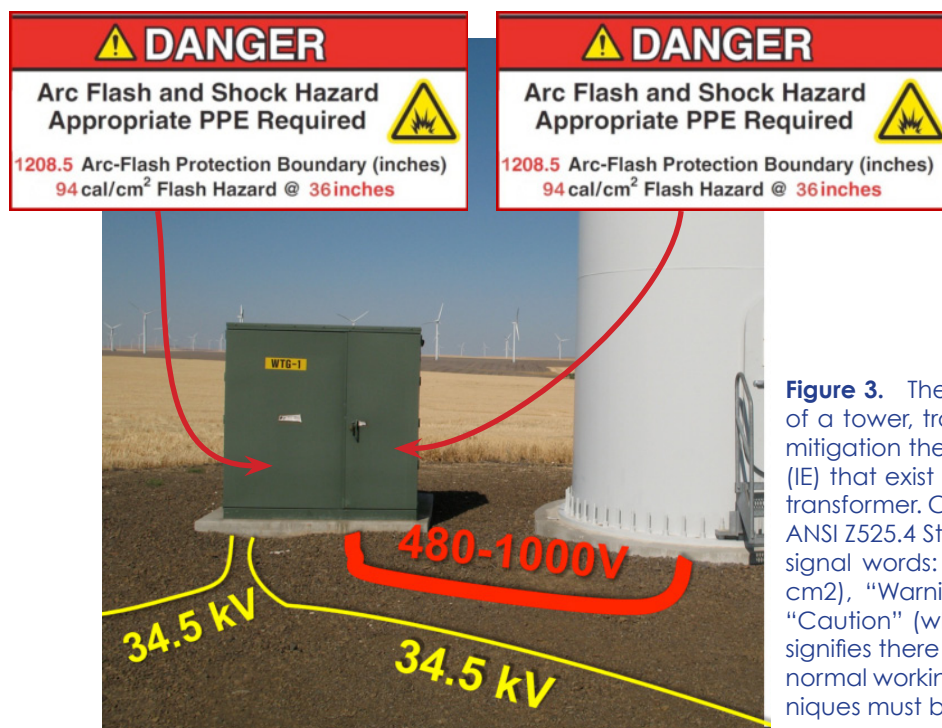
## How Does a Wind Turbine Work?



Man working in generator

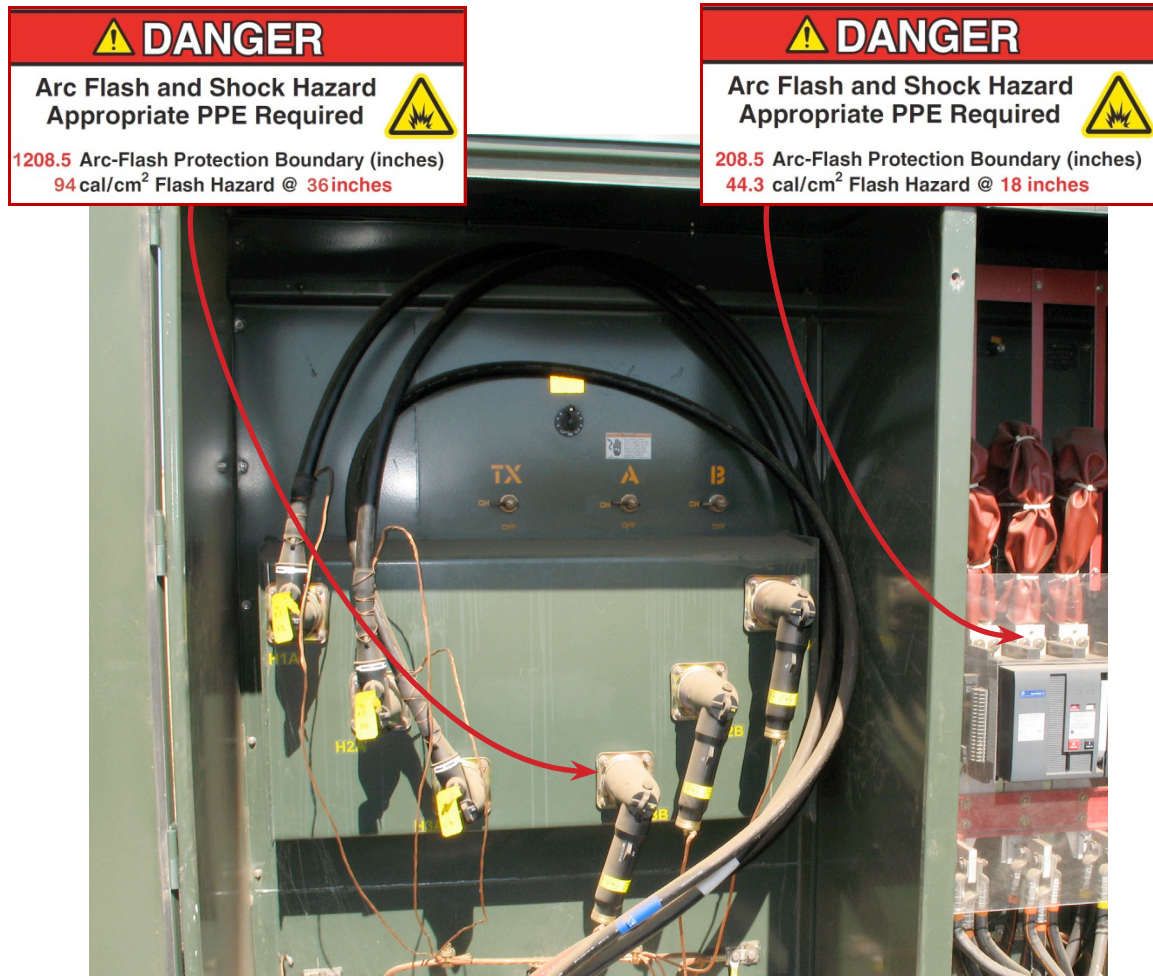
Turbines generate at various voltages depending on manufacturer and model. These generator output voltages can range from 480vac-1000vac. Several manufacturers generate at 690vac. 690Vac turbines are especially difficult to inspect as they defy easy categorization in the NEC® or IEEE standards. The NEC does not list 690V as a “nominal voltage”. Rules for over 600volts are distinguished from rules 600V and under. IEEE (Institute of Electrical and Electronics Engineers) standards for power circuit breakers define low voltage as up to 635V.

Turbine voltages are stepped up at each tower to an industry standard of 34.5kVac (Figure 3). This 34.5kVac is then daisy chained by underground cable runs called a collector circuit. Most wind farms comprise multiple strings of turbines. Strings can be made up of as few as 4 turbines to as many as 16 turbines. Typically, 3-6 strings will terminate at a main bus in the substation powerhouse. Within the substation yard, voltage will be stepped up to the local utility’s transmission voltage i.e. >69kV. 60-80mW substations are common but farm sizes as large as 500MW are in the pipeline.



**Figure 3.** The above illustrates a common configuration of a tower, transformer and collector circuit. Before any mitigation there are “DANGER” levels of incident energy (IE) that exist on both the 34.5kV and .690kV sides of the transformer. Common practice for arc flash labels is to use ANSI Z525.4 Standard For Product Safety Signs and Labels signal words: “Danger” (when IE is greater than 40cal/cm²), “Warning” (when IE is less than 40cal/cm² and “Caution” (when IE is less than 1.2cal/cm²). “DANGER” signifies there is no safe way to work live, safely within the normal working distances i.e. special precautionary techniques must be applied.

One of the principal dangers on wind farms relates to the extremely-high fault currents that are available when short-circuits (faults) occur on the system. One significant source of fault currents is the numerous generators that are networked together on the farm. However, the most significant source of fault current on the wind farm is the transmission system to which the farm normally “backfeeds” power. Any transmission line capable of “receiving” significant amounts of power from the farm are then capable of “delivering” many times as much power should a fault occur in the wind farm. Catastrophic arc fault events have been the unfortunate result of a deadly mix of these astronomical available fault currents and novice electrical workers. Several years ago, one such fatal event helped initiate collaboration between our company, and several wind turbine maintenance companies to develop electrical safe work practices training, geared to the unique hazards associated with this rapidly growing industry.



**Figure 4.** Detail from Figure 3. Because of the extreme danger that these labels indicate, either modifications to the protection scheme must be applied to lower these IE values or special precautionary techniques must be developed i.e. remote switching, recalculation with much greater working distances and long hotsticks etc.. One redeeming factor is the use of an overcurrent device in the transformer enclosure. When this is not present extreme fault currents extend into the main breaker inside the tower.



Another common layout for towers is to locate a dry-type transformer “up-tower” and locate a medium-voltage SF6 gas-filled switch at the base of the tower. Having a large transformer up-tower in the nacelle creates serious working space issues. Additionally, setups like this necessitate long vertical drops of 34.5kV cable running in close proximity to the service ladder (Figure 5). It also means even more critical strain relief techniques for medium-voltage cables than are required for low-voltage cables.

## Worker Safety Issues

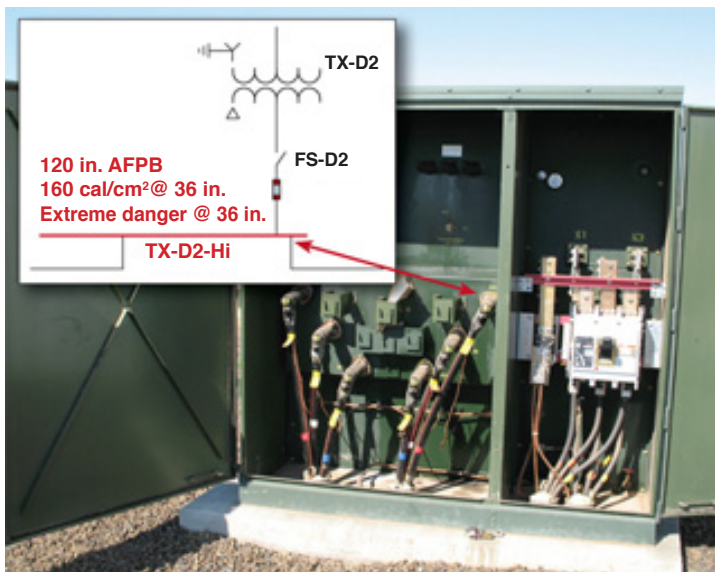
When hiring turbine technicians, most wind turbine companies tend to focus on the prospective employee's previous mechanical skills. Indeed, that is the skill set workers need more often for turbine maintenance. Although electrical troubleshooting and maintenance make up much less of a wind turbine technician's routine work activities than you might think, even the most fundamental electrical troubleshooting is high risk. Despite its low frequency, the high severity of an electrical accident in this work environment produces a high risk.

As a result, lack of electrical background in this industry can be lethal. Here's just one example. One inadequately qualified turbine tech was fatally burned by the plasma blast he created when he mistook a tap changer for a load break switch. He was in the process of de-energizing a 2MVA transformer for a routine maintenance shut-down when this horrific accident occurred.

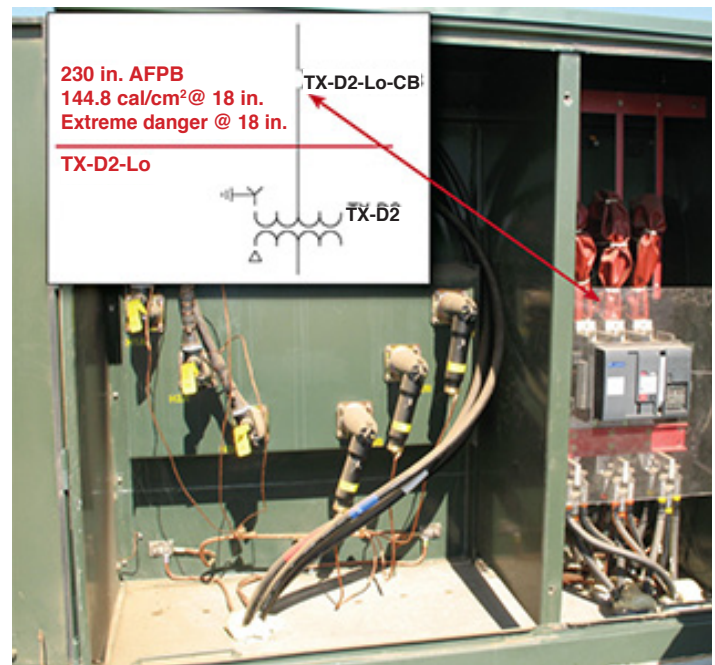
In addition to NFPA 70E training, our company conducts arc flash hazard analyses for wind farms. If we hadn't had the physical evidence from previous multiple wind farm accidents, we would probably have had a hard time believing the off-the-charts magnitude of the incident energy levels our software was spitting out (Figure 6) and (Figure 7). These studies have confirmed the obvious: Potential incident energy on most wind farms is extremely dangerous.



**Figure 5.** Does this strain relief fastener arrangement for this 34.5kV cable meet code requirements?



**Figure 6.**



**Figure 7.**

## Code violations illustrated

The hazards and installation problems are not just confined to explosive levels of incident energy. As a retired electrical inspector, I see numerous NEC violations “down on the farm.” One of the first questions I generally ask my contact person on a wind farm is, “Who is the AHJ responsible for inspecting your turbine and tower installations?” More times than not, I get the same, strikingly consistent, shrug of the shoulders. In other words, they have no idea.

This raises another issue. Does NFPA 70 and 70E apply to wind farms? NFPA purists might contend that because many wind farms “are on property owned or leased by the electric utility for the purpose of ... generation, transformation, transmission, ... of electric energy,” as stated in NFPA 70 and 70E 90.2(B)(5)c, these standards would not apply. Such purists would defer to the more performance-oriented National Electrical Safety Code (NESC) published by the IEEE. However, because the NFPA 70 and NFPA 70E are somewhat more prescriptive than the NESC, most wind farm companies have chosen to use all three standards. Ultimately, wind farms must comply with OSHA. Adopting NFPA's consensus standards and IEEE's NESC provides the best chance for OSHA compliance.

Unfortunately, enforcement of these standards can be lax. As a result of this apparent lack of oversight, I have encountered NEC violations that make me cringe. The most shocking offenses tend to do with egress requirements (Figure 8). On several tower designs, switchboard enclosure doors are hinged such that they open across the only exit path out of the tower. Having personally witnessed the excruciating death (not on a wind farm) of an electrical worker in large part because of inadequate egress, I'm especially vigilant about this violation of NEC requirement 110.26(C).



**Figure 8.** This is a clear violation of the access and egress requirements of the NEC. The Code requires a “continuous and unobstructed way of egress travel.”

Another NEC violation I've seen is the intrusion into the work space [NEC 110.26(A)(1)] by containment walls for the step-up, oil-filled, pad-mounted transformers at the base of most tower configurations as shown in Figure 9. A critical work procedure is performed in the 34.5kV side of the transformer — protective grounding. The darkly tinted arc flash hood worn during this operation makes the containment wall, if placed too close to the enclosure opening, an especially worrisome trip hazard.



**Figure 9.** Does this say adequate working space to you? This containment vessel is both a shock and trip hazard. According to 110.26(A)(3) of the NEC, “... The work space shall be clear and extend from the grade...”.

DLO-type cable is commonly used throughout wind farm power systems. As shown in [Figure 10](#), there was no lug labeling at this location stating this 650-strand 262.6kcmil cable could be terminated on this particular breaker. This appears to be a violation of Secs. 110.3(B) and 110.14 of the NEC. A new sentence has been added to 110.14 in the 2011 edition of the NEC that states, "Connectors and terminals for conductors more finely stranded than Class B and Class C stranding as shown in Chapter 9, Table 10, shall be identified for the specific conductor class or classes." However, the 650-strand conductor shown in the photo at right does not fit into any of these classes.



**Figure 10.** *Do the requirements of the NEC or the NESC apply to this 650-strand DLO-type cable?*

## Induction problems

The conductors in [Figure 11](#) are not grouped as required by 300.20(B) of the NEC. As noted in this section of the Code, "Where a single conductor carrying alternating current passes through metal with magnetic properties, the inductive effect shall be minimized by (1) cutting slots in the metal between the individual holes through which the individual conductors pass or (2) passing all the conductors in the circuit through an insulating wall sufficiently large for all of the conductors of the circuit." By not having all the phases of a circuit grouped through a common opening in a ferrous metal enclosure, circulating currents will be induced in the metal enclosure. This could potentially produce enough heat to damage the conductor insulation where it passes through the hole.



**Figure 11.** *The lack of slotting or larger openings with insulating walls will induce circulating currents on the ferrous metal enclosure wall that could potentially produce insulation damaging heating.*

## What does the future hold?

One of the biggest contributing factors leading to this lack of oversight is the complexity of the business model for this industry. Much of the equipment is manufactured in other countries, which makes it non-compliant with U.S. standards. Also, because of the typically remote locations of wind farms, installation and tower construction are done without the benefit of building permits. Even if local jurisdictions chose to inspect such installations, it is doubtful they would have the technical experience to adequately enforce applicable codes.

Multiple layers of ownership and liability further complicate matters. In some instances, responsibility for worker safety falls to multiple employers. In fact, the responsible party for safety is often split between the tower owner, the contractor responsible for "balance of plant" equipment, and the maintenance contractor who main-

tains the low-voltage equipment up to and including the turbines.

At one of my recent presentations on this subject, I found my audience was largely made up of insurance company representatives. During the Q&A exchange, they expressed a consensus of concern about how to insure this emerging sector, confirming my suspicions about a lack of oversight. They expressed a general sense of agreement that the wind industry's chain of command and layered ownership make their risk/responsibility assessment difficult.



I tell the turbine technicians in my classes that I've got good news and bad news. The bad news is you have elected to work in one of the most potentially dangerous electrical workplaces on the planet. The good news is if you take the proper precautions — and really understand the design of these systems — you can expect a long and worthy career ahead of you.

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*This is a very novel way of re-capturing some of the energy expended by vehicles moving at high speeds on our nations highways which is being proposed by an Arizona State University. Knowingly, air turbulence is generated by vehicles moving at speed particularly trucks and the proposal would involve mounting horizontal wind turbines above the roadway that would be driven by the moving air generated by the passing traffic. The electricity generated by spinning these turbines could be fed back into the grid. Analysis indicate that based on vehicle speeds of 70 mph each turbine could produce 9,600 kWh per year.*

*These wind turbines are of a quiet running type. In many built up areas there is enough constant traffic volume to maintain a steady airflow through much of the day. The big question that needs to be answered is whether the nature of the turbulent airflow could keep the turbines turning.*

*This photo and description courtesy of <http://www.mywindpowersystem.com>*



