SECONDARY DAMAGE AFTER ARC FLASH IN WIND TURBINES

Following an arcing or fire incident involving a wind turbine, it is imperative that all affected equipment and systems are properly assessed and decontaminated. Failure to do so may result in operational problems for the remaining life of the WTG (Wind Turbine Generator). Across the energy industry, loss prevention and mitigation best practices exist so that incidents involving business-critical equipment are not catastrophic. The wind energy industry is rapidly growing in North America, and for WTG stakeholders, the consequences of not knowing, neglecting or underestimating the effects of secondary damage on internal equipment can be disastrous in terms of loss of production, unforeseen downtime, increased component replacement and even new, more serious incidents.

BACKGROUND

U.S. wind power has more than tripled over the past decade, and wind is the largest source of renewable generating capacity in the country[1]. The demand for renewable energy is expected to increase in the coming years. Failures and outages within WTGs are costly. Between lost PPA (Power Purchase Agreement) revenue and Federal Wind Production Tax Credits, a WTG that is out of service may cost a producer upwards of $25,000 USD per week. Continuous improvement programs have reduced failure rates year over year, but with the increasing volume of turbines being installed across North America, the number and severity of incidents will inevitably increase.

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Historically associated with traditional power generation failures, arc flashes pose significant risks in the wind energy industry as well. Implications for safety, accessibility, equipment reliability and equipment costs inherent to WTG are often underestimated after damages occur. Consider the engineering: arc flash hazards in a WTG are often magnified because of the compact design of critical electrical components, such as bus bar systems. These systems perform most optimally when installed in arc-free assemblies; however, small WTG nacelles do not afford the space required for this type of set-up. In addition, WTG are often located in harsh environments, constantly being impacted by extreme heat and cold, humidity and lightning, as well as dust, sea mist and other contaminants. These elements contribute to severe secondary damages after electrical incidents. This whitepaper provides an overview of the common types of contamination that can impact WTG after arc flashing incidents, and technical best practices for maximizing safety, reliability and capital investment following secondary damages.

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[1] "Wind Energy in the United States." American Wind Energy Association, 2018, https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance. Accessed 4 October 2018.

Arc flashes are defined as the light and heat produced as part of an arc fault, a type of electrical discharge resulting from a low-impedance connection through air to ground or another voltage phase in an electrical system. Arc flash temperatures can exceed 35,000 °F; one can only imagine the impact of this level of energy release on a WTG.

Much effort is spent ensuring the electrical safety for WTG operators working in nacelles, because when an arc flash occurs, there is a very high risk that individuals in the vicinity will be severely injured or killed. However in a WTG, the risks and impacts of equipment damage are also heightened. Fires resulting from arc flashes cause direct damage and secondary damage to the WTG. Direct damage, burned out equipment and melted material, is easy to identify as scrap, and will be replaced in a later repair process.

Secondary damage, or contamination, is widespread damage in the WTG caused by residual chemicals after arc flashes incite fire, explosion or combustion events. Contamination is usually spread by the warm smoke to structures, installations and equipment. The combination of the tower chimney effect and higher pressure in heated air pushes the contamination into closed equipment like control boxes and electrical cabinets. The warm and humid air condenses on the cold surfaces and then dries as a layer of residuals. Except for the visible effects of contamination, impacted equipment is typically intact and functional immediately following an arc flash event.

COMMON CONTAMINANTS AFTER ARC FLASHES IN WTG

After a typical fire, more than a thousand unique, residual chemicals and byproducts are generated depending on which materials have burned and at what temperature. It is not possible to describe all of them within this paper, but the most common and important ones are mentioned below.

HYDROCHLORIC ACID (HCl)

When PVC (Poly Vinyl Chloride) burns, chloride ions are released. PVC is commonly used for cable insulation, electrical cabinets and building materials. When combined with hydrogen in the air, hydrochloric acid (HCl) is formed. HCl is a very strong corrosive agent on almost any type of metal, and is the most common cause of corrosion after fires.

For every kilo of PVC burned, one liter (.26 gal) of HCl is released, which equates to almost 100 L (26.4 gal) of HCI gas.

The corrosion process on metal surfaces starts immediately after condensing on the cooler metal surface. The first sign is a thin, light brown layer of rust on iron. Chemically, the brown rust is iron chloride (FeCl), and has a similar hydroscopic effect as traditional table salt (NaCl). This means, it attracts humidity to the surface. Humidity is a corrosion accelerator and this process will go on as long there are metal and humidity present.

Soot in high voltage installations can cause arc flashes as the soot is conductive.

Following a fire, even small concentrations of HCI can lead to corrosion.

The visible sign of contamination on copper is a blackish or even green-blue color change. For aluminum and tin (including tin alloys like solder) the surface usually turns toward gray.

Following a fire, it is wise to be aware of the long-term effects of chemical contamination, as even small concentrations of HCl can lead to corrosion over time.

Fortunately, this type of contamination can easily be measured and mitigated by trained professionals. Situations where high levels of contamination are measured require fast intervention as the corrosion process is rapid and ongoing.

SULFURIC ACID

When materials such as rubber, lubricant and batteries burn, sulfur is emitted. As the sulfur interacts with humid air and settles on cooler surfaces, it turns into sulfuric acid.

Sulfuric acid also leads to corrosion on metals in the WTG equipment, with the impacts being similar to those of HCI.

Those inspecting sulfuric acid contamination should be aware of a slower corrosion process than for HCl. Often a couple of days can go by before the signs of contamination are visible. Corrosion on iron presents itself more like a color change than rust.

The presence of sulfuric acid can be determined by analyzing samples in the lab. The removal process is similar to that of HCl contamination.

The melted PVC, at the top of the photo above, is a clear warning. PVC releases large amounts of hydrochloric acid in the combustion process and corrodes metal surfaces.

CARBON CONTAMINATION

Carbon is a byproduct of all combustion events. Soot and ash, both containing high levels of carbon, can be easily identified as dark grey dust and sticky, black soot.

Nylon is a commonly used material in WTG, being present in components such as cable ties and fasteners. The combustion of nylon will form CO_2 and H_2O along with relatively weak, organic, acidic products. Nylon is known to develop large amounts of conductive carbon soot and corrosive nitrates.

Soot and ash can cause major problems in affected electrical equipment, in that it is highly conductive. If not removed properly, the risk of short circuits and arc flashes increases significantly, so carbon contamination should be seen as both a safety problem and a technical problem.

Soot and ash are both highly conductive, and if not properly removed, can increase your risk of short circuits and arc flashes.

COPPER

Arc flashes that exhibit long arc times can pose another serious problem for WTG. Due to the high temperatures encountered, metals will start to melt and evaporate.

An arc flash is a powerful energy release. Even metals can melt and evaporate in the high temperatures.

Often, there is a large amount of copper in switchgear, transformers and cabling near the arc. When copper evaporates, it will metallize or adhere on the tower walls and internal equipment. Metallized copper poses significant risks in that it is highly conductive and may cause new, often serious, faults. It is not possible to clean contaminated copper components, but they can be insulated with paint.

It is important to note that an arc flash near the tower or nacelle wall can affect the strength of the metal surface. All impacted areas should be inspected for heating spots and if any are identified, a metallurgical analysis should be performed.

TREATMENT OF CONTAMINATION IN TURBINES: RECONDITIONING VS. CLEANING

Why is secondary damage such a risk, and what can you do? As you can see, chemical contamination to WTG can have serious implications if damages are not handled promptly and thoroughly.

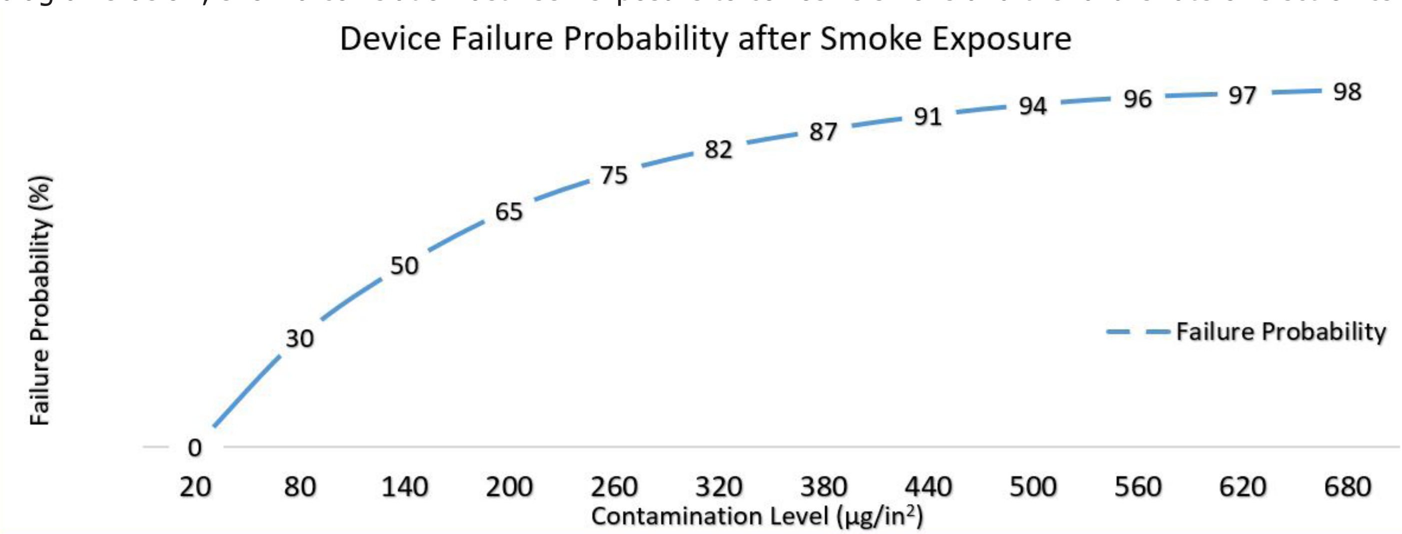
After these types of incidents, the focus is on cleaning tower walls and outside surfaces within the nacelle. Cleaning is good maintenance, but this process will not remove the real threat: contamination to internal technical equipment. To access the critical surfaces, skilled technicians need to dismantle the equipment and use appropriate chemicals to remove contaminants.

Arc flashes near the tower or nacelle wall can affect the surface strength. Impacted areas with heating spots, need a metallurgical analysis.

Proper decontamination begins with determining the levels of all corrosive contaminants. As you've just read, there are many contamination scenarios that can impact WTG equipment. Measures should be taken to reduce the ongoing development of corrosion and to plan the right decontamination solution.

Often, secondary damages caused by arc flashes or other electrical incidents will necessitate both equipment decontamination and component replacement. Time is of the essence to ensure that all efforts are maximized. It is important to realize the exact mechanism of the corrosion process, and the environmental conditions, such as temperature and humidity, that may accelerate that corrosion. For both onshore and offshore WTG's, these conditions fluctuate wildly. Eventually, failures will occur from corroded equipment within weeks, months or years if the equipment is not properly decontaminated.

On the other hand, if equipment decontamination is implemented quickly and properly, it can greatly reduce the downtime and costs associated with sourcing replacement components. Many studies, such as Hughes diagrams below, show a correlation between exposure to corrosive smoke and the failure rate of electronics.



It is not uncommon for stakeholders to encourage equipment replacement following secondary damages. Safety, reliability and business continuity are among the top priorities after an incident, and for that reason, retaining experienced equipment restoration consultants with familiarity of WTG should be considered. These specialists are experts in handling the various forms of secondary damage or contamination that impact business critical equipment and systems. They can provide recommendations for proper cleaning and reinstatement and are trained to provide on-site WTG reinstatement.

In the coming years, North American wind energy capacity will continue to increase. As this occurs and the market becomes more mature, the volume and severity of equipment failures will also increase. Given this, it is critical that all WTG stakeholders be vigilant in understanding their unique equipment risks, and develop business continuity and mitigation plans so that critical operations continue as intended.

Source: Hughes Associates, "DOE Fire Protection Handbook Volume II, Fire Effects and Electrical and Electronic Equipment," US Department of Commerce, 1996, pp. 41, 43.