UNDERSTANDING ICE ACCUMULATION IMPACT ON UTILITY GRIDS
WHITE PAPER

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BACKGROUND

Ice accumulation on power lines can pose significant issues for utilities and their maintenance crews. When combined with high winds, the threat can become serious. Crews working near these lines risk being struck by falling ice or nearby collapsing vegetation. High winds may cause ice laden lines to gallop, and if the wind is significant, the galloping lines may collide causing faults, downed lines, possible equipment damage and sustained power outages. A single 3-day event, studied by the Federal Emergency Management Agency (FEMA) in 2008, estimated damage and loss of function costs of $1.33 million in 2007 dollars[i]. Understanding the issue of ice accumulation can be extremely helpful for transmission and distribution system operators and help them take advantage of the value a combination of ice and wind forecasts can bring them.

Problems due to ice accumulation on the electrical grid:

- Combined impacts of ice on generation and power lines can force load shedding, impacting hundreds to thousands of households and critical businesses.
- Increased component fatigue from snow, ice and wind loads can cost millions in infrastructure replacement.
- Safety risk to employees and the public due to ice shedding, flashover events, fallen or at-risk vegetation and downed structures.

OBJECTIVE

The intent of this white paper is to help utility industry professionals have a better understanding of the types of ice accumulation to transmission and distribution assets and to clearly understand the weather patterns and conditions that lead to icing. Understanding the different types of ice accumulation will allow for more informed business decisions. While increased awareness of forecast methods and resources will help with preparedness, mitigation of ice accumulation before and after the event, as well as, preparation for future events.

FORECAST METHODS

There are multiple forecasting methods. Publicly available forecasts such as television and the National Weather Services can bring awareness to precipitation based icing and freezing fog. However, they are targeted to predict ice accumulation on surfaces and roadways. Forecasts from private, commercial sources, continue to improve and new ensemble model forecasts are more accurate and can target ice accumulation forecasts at electrical conductor heights. Additionally, alerts can be issued to provide advance notice of impactful events. Larger utilities may have meteorologists on staff who can perform a deeper analysis of weather patterns and conditions to deliver a more asset specific impact forecast. This can be especially valuable for in-cloud icing events in elevated terrain areas, or localized extreme wind events. However, not all utilities have this luxury.

TYPES OF ICE ACCUMULATION, RELATED WEATHER CONDITIONS, PROPERTIES

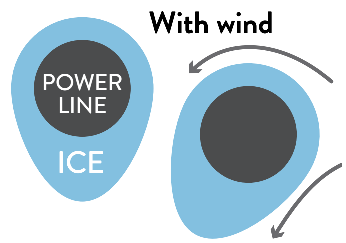
PRECIPITATION BASED ICING

- Freezing drizzle
- Freezing rain
- Wet snow

Freezing drizzle and freezing rain occur when supercooled water droplets fall onto the surface of an object (electric conductor, structure, or tree limb) with a temperature below freezing. In the case of freezing rain, light precipitation events over a long duration, greater than six hours, are much more concerning than heavier precipitation events, with moderate to heavy freezing rain. One reason being the heavier event usually lasts a short period of time and the rate of precipitation is such that adequate time for ice formation and accretion is inhibited.

Wind speed during an event of 10 mph or higher is an important factor in the ice accretion process. Higher wind speeds will generate larger accumulations of ice. The wind speed is essential to ice formation because it dissipates the surface heat and heat from UV radiation. Ice can still occur at low wind speeds, but the accumulation will be less.

The wind speed plays a second role. In the absence of significant wind, ice forms on power lines in a teardrop shape. During events with significant wind, power lines oriented perpendicular to the mean wind direction will accumulate more ice in an airfoil, or aircraft wing shape and when the load is great enough and winds strong enough, the ice accumulation shape can promote lift and the lines can begin to gallop. Galloping can cause wires to eventually touch, resulting in a fault, or even prolonged power outage if faults keep occurring. The increased movement can also cause cross-arms to break bringing powerlines to the ground.[ii]



The time of day is also important, there is a marked drop in ice accumulation from noon to 6 pm due to solar radiation effects. Events before or after these hours are more likely to be significant.

Wet snow can cause ice accumulation on equipment because it is made up of partially melted snow crystals which can stick to the surface and freeze upon contact. A wet snow icing event followed by a cold snap with very low temperatures can cause strong accretion of ice that can persist for an extended period of time (days).

Precipitation based icing is the best understood type of icing by the lay person and it is also the most frequently forecast type of icing by local TV and National Weather Service sources. Precipitation based icing results in a glaze type of icing. The ice accumulation that occurs from precipitation events is generally clear in color and has the highest density of the icing types. The rate of accumulation is dependent on the following:

- Wet bulb temperature
- Wind speed / stronger winds = more ice
- Rate of precipitation

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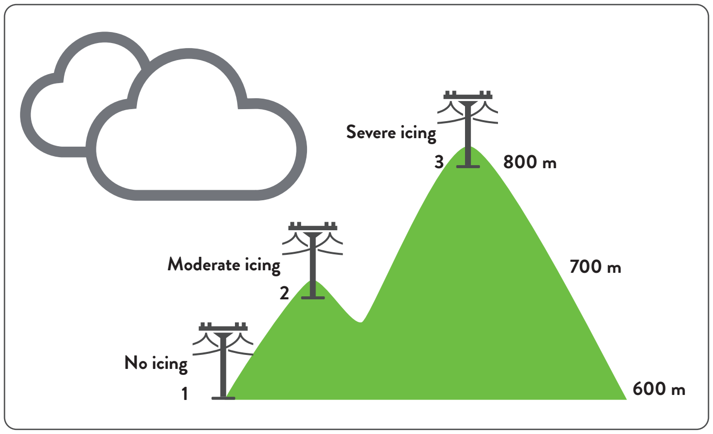

IN-CLOUD ICING

- Impacts transmission lines in mountainous terrain
- Most likely to cause long term, dense, ice load events
- Transmission structures susceptible to channeled high force winds
- Investigation and repair complicated by remoteness and weather hazards

In-cloud icing occurs when super-cooled water droplets in the cloud come in contact with a surface (transmission conductor or structure) and freeze on impact. Not only is in-cloud icing the most common type of icing on transmission lines in higher elevations, it also has the most significant impact with pro-longed events lasting over 24 hours, and significant ice accumulation is possible. In-cloud icing is dependent on the height of the cloud base.

In-cloud icing is the most complex type of icing because it can result in two types of ice accumulation.

- Glaze
- Hard rime

In the first category, in-cloud and precipitation-based icing can occur at the same time resulting in a heavy glaze ice accumulation. In the case of rime icing, accumulation is dependent on the water droplet size, wind speed and atmospheric moisture content. Forecasts for in-cloud icing are challenging and typically come from private sources

FREEZING FOG/MIST

- Usually results in light ice accumulation
- Often not well forecasted
- Prolonged events can occur causing bigger issues

As with in-cloud icing, accumulation of ice occurs in freezing fog or mist when super-cooled, tiny water droplets come in contact with a surface that has a surface temperature below freezing. This form of icing can occur with air temperatures well below freezing. It can also occur when air temperatures are above freezing but the surface is below freezing.

Icing from freezing fog and mist results in a soft rime accumulation which has the lowest density of the ice types and often has a frosty appearance. This type of icing is more common in the central and northeast United States in the mid to late winter. One common scenario when freezing fog occurs is when an arctic cold front with shallow, dense air undercuts a warmer, moist airmass in place causing lift, clouds and in some cases, even freezing mist/ fog. Another example would be when a warmer, moist airmass is transported into a region with snow cover. Cooling occurs, the airmass becomes saturated and fog develops. At that point the tiny water droplets of fog can freeze onto the cold, surrounding surfaces.

Long duration events, greater than six hours, are critical. Events lasting 1-2 days should be of greater concern. Wind is again important primarily because it causes a greater mass horizontal flux of water droplets to the equipment or wire increasing accumulation. If the freezing fog event lasts a day or more the ice accumulation could become great enough to trigger galloping in the right wind conditions. Even on overcast days the ground absorbs solar radiation which can raise temperatures a few degrees which could warm conductors. Therefore, these events are more impactful if there is snow cover and if the temp is below 30 degrees during the event.

UTILITY EXPERIENCES

Indji Systems investigated a customer galloping line event from January 12-15 2019 in North Dakota where a long duration freezing fog event lead to sustained outages. There were several icing incidents, but this one in particular was quite impactful. The transmission operators described icing that was constant, but it wasn't an issue until the sustained winds picked up to between 15 and 20 mph on the 15th of January. The System Operations Manager indicated that ice was about ¼ inch thick while rime icing was 4-6 inches. These lines are remote and not along the highway and usually need UTVs, ATVs or Snow CATs to get to them. Knowing of an ice event well in advance, especially one combined with high winds, would allow operators to make an informed decision about de-energizing the line sooner and eliminate some of the faults before crews could safely patrol the line.

Another long duration event in the Midwest actually lead to federal emergency declarations. The reports by (Jones, 2007) and (FEMA, 2008) described an area of significant winter weather which affected large sections of southcentral Nebraska and northcentral Kansas on Friday, December 29, 2006, through Sunday, December 31, 2006. This impact area also included an area of the northeastern portion of Nebraska to the northwestern portion of the Texas panhandle. The storm brought freezing rain, sleet, wind, and snow. Most of the snow subsided Friday night while the sleet and freezing rain continued pressing further east to US Highway 183 in Kansas and US Highway 281 in Nebraska. By the end of the night on Saturday, the 30th, both States had experienced a significant amount of ice accumulation. Most affected locations received at least 0.5 inch of ice, and as much as 0.75 to 1 inch of radial ice accumulated on trees and power lines in southwest Kansas. Up to 2 to 3 inches of total ice accumulated in some parts of southwest Kansas causing significant damage (Jones, 2007). Approximately 10,500 utility poles toppled and 21 steel towers were damaged from the weight of the ice and strong north winds. These winds ranged from 25 to 40 mph[iii]. The combination of ice accumulation on the power lines accompanied by high winds near the end of the storm resulted in significant damage to power transmission and distribution lines and poles. This resulted in widespread power outages. The storm's impact led to presidential disaster declarations in Nebraska (FEMA-1674-DR-NE) and Kansas (FEMA-1675-DR-KS).

While each event brought a different type of ice accumulation and associated weather, they both caused significant issues to Utility operations.

CONCLUSIONS

Icing to power lines can grow to become more serious during a longer duration event and can become a critical problem when these heavy ice loads are combined with extreme wind events. Advanced notification and awareness of these events will increase preparedness and aid in mitigation efforts to reduce the impact the event has on operations. Consider the following actions that could take place:

- Awareness of expected significant events could lead to faster and more informed decisions by transmission and distribution operators to help mitigate faults, avoid damage to equipment and prevent sustained outages.
- Smarter response planning including material and labor scheduling through awareness of the event duration and total impact.
- Improved safety awareness through review of the post event forecast to determine the ice shedding threat.
- Fine-tuning of power forecast and scheduling of supplemental generation to account for increased consumer demand (system load) at a time when availability issues may arise from ice damage and related outages.
- Forensic analysis of these events can help system engineers better understand at-risk infrastructure and plan for methods to reduce the impact of ice related damage in the future.

Forecasts from commercial providers continue to improve in this area. Industry stakeholders can expect and should require continued improvements in the area of ice forecasting accuracy and advanced alerting of events to help mitigate the impact to operations.

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References

[i]Electrical Transmission and Distribution Mitigation: Loss Avoidance Study, Nebraska and Kansas FEMA-1674-DR-KS and FEMA-1675-DR-NE April 2008

[ii]Ice has weighty effect on power lines. The WIRE, Energy News from Omaha Public Power District, January 2020

[iii]Evaluation of the Severity of the December 29-31, 2006, Ice Storm-Final Report for POWER Engineers, Inc. (Jones, 2007)