NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

March 22, 2016

VIA ELECTRONIC FILING

Ms. Erica Hamilton, Commission Secretary
British Columbia Utilities Commission
Box 250, 900 Howe Street
Sixth Floor
Vancouver, B.C.
V6Z 2N3

RE: Correction to Notice of Filing of the North American Electric Reliability Corporation of Proposed Reliability Standard FAC-003-4 (Transmission Vegetation Management)

Dear Ms. Hamilton:

On March 17, 2016, the North American Electric Reliability Corporation ("NERC") filed a Notice of filing of Proposed Reliability Standard FAC-003-4 –*Transmission Vegetation Management*. Please find attached an updated copy of Exhibit D, which contained a Draft watermark that is now removed. No other changes were made.

Respectfully submitted,

/s/ Candice Castaneda

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Exhibit D

Drafting Team Summary of EPRI Conductor-Tree Air Gap Flashover Testing

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Introduction

Testing completed by the Electric Power Research Institute (EPRI) of the strength of the air gap between transmission conductors and trees established an empirical basis for selection of an appropriate Gap Factor used in determining the revised Alternating Current (AC) Minimum Vegetation Clearance Distances (MVCD) values found in FAC-003-4. The testing also provided new insight as to how the shape of trees growing in proximity to energized conductors influences the likelihood of a flashover. The testing demonstrated that trees with large flat tops growing directly below energized high voltage conductors resulted in the weakest air gap. The intent of this document is to provide practitioners with additional context regarding the implications of the testing as it applies to vegetation management activities on the North American high voltage transmission grid.

Background

Following the 14 August 2003 Northeast Blackout, the Federal Energy Regulatory Commission (FERC), and subsequently the North American Electric Reliability Corporation (NERC), have been focused on reducing vegetation-related incidents by enforcing a Transmission Vegetation Management Standard. That standard, FAC-003-1, was adopted in 2006 and enforced in 2007 as a NERC Facilities Design, Connections, and Maintenance Reliability Standard for the electric utility industry.

A review of the record [1]of reportable Category 1 grow-in[2] outages since 2005 demonstrates that the industry has been successful in reducing the instances of flashovers due to vegetation, as seen in Figure 1.

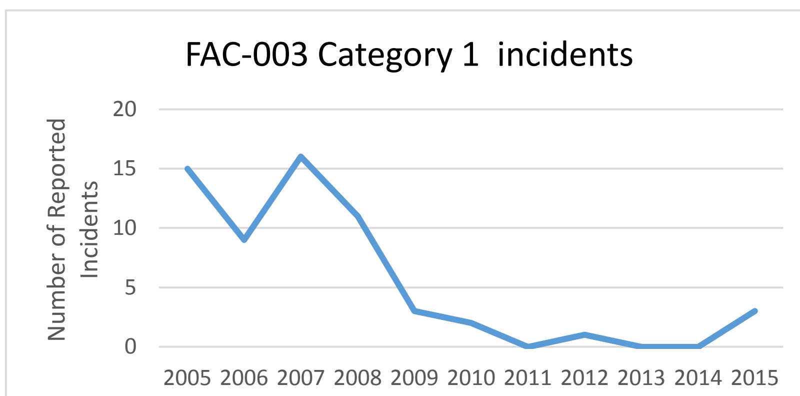

Figure 1 Reportable Category 1 outages since 2005

Integrated Vegetation Management

There are 160,000 miles of transmission line operating at 230 - 765 kV in the US. EPRI has estimated that the total land area being managed as transmission corridors encompasses 8.6 million acres. This land area is typically managed using the principles of Integrated Vegetation Management (IVM), which are intended to create, promote, and conserve stable plant communities that are compatible with overhead transmission lines, and to discourage incompatible plants that may pose a

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[1] See: http://www.nerc.com/pa/comp/ce/pages/vegetation-management-reports.aspx

[2] Category 1 is an outage caused by vegetation growing into lines from vegetation inside and/or outside of the right-of-way.

risk to the reliable operation of the transmission system. American National Industry Standards[3] (ANSI) and industry Best Management Practices[4] (BMPs) define IVM on transmission rights-of-way. IVM[5] uses combinations of methods to promote sustainable plant communities that are compatible with the intended use of the site, and to control, discourage, or prevent the establishment of incompatible plants that may pose safety, security, access, fire hazard, utility service reliability, emergency restoration, visibility, line-of-sight requirements, regulatory compliance, environmental, or other specific concerns. Both references define a *"wire zone"* below the electric supply lines, which is typically managed to promote low-growing, primarily herbaceous, vegetation. Incompatible tree species growing in the wire zone present the greatest likelihood of encroachment within MVCDs, leading to a reportable Category 1 event.

Air Gap Factors and MVCD

MVCDs in the initial version of FAC-003-1 were based on IEEE Standards that established minimum air insulation distances[6] (MAID) for live line work. The MAID and MVCD distances were determined for the case when a transient overvoltage (TOV) occurs due to switching operation. The MAID clearance distances, which pertain to line work, were believed to be very conservative when applied to tree-conductor clearances.

The calculation method for determining MVCDs in later versions of FAC-003 utilizes the Gallet equation multiplied by a gap factor (k_g) to describe the strength of the air gap MVCDs in the subsequent version FAC-003-2 and FAC-003-3 are based on this method, and also used a level of expected TOVs by voltage class. MVCDs in both versions 2 and 3 are based on a Gap Factor (k_g) of 1.3.

As a result, new MVCDs were approved[7] with an additional caveat directing NERC "*to conduct or contract testing to develop empirical data regarding the flashover distances between conductors and vegetation," and to use an approach based on "statistical analysis [that] would then evaluate the test results and provide empirical evidence to support an appropriate gap factor to be applied in calculating minimum clearance distances using the Gallet equation."* [8]

Twelve of 20 high voltage tests performed by EPRI yielded gap factors lower than 1.3, which was used in the calculations to determine the MVCDs in FAC-003-3. These test results indicated that a Gap Factor of 1.3 may not be suitable for all situations. As a result, the NERC Advisory Team recommend use of a Gap Factor of 1.0 as a more conservative approach. FAC-003-4 reflects the revised MVCD values using the Gallet equation and a Gap Factor of 1.0. MVCDs in FAC-003-4 were increased compared to FAC-003-3 based on the lower Gap Factor, yet still are less than those found in FAC-003-1.

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[3] ANSI A300 (Part 7) -2012 *"Tree, Shrub, and Other Woody Plant Management – Standard Practices (Integrated Vegetation Management, a. Utility Rights-of-way."*

[4] BMP *"Integrated Vegetation Management" 2nd Edition* (20142), International Society of Arboriculture.

[5] Ibid, IVM BMP 2014, page 5.

[6] IEEE Std. 516-2003, *"IEEE Guide for Maintenance Methods on Energized Power Lines".*

[7] FERC Order 777

[8] FERC Final Rule *"Revisions to Reliability Standards for Transmission Management*", 21 March 2013

Air Gap Flashover Testing

The testing focused on AC MVCDs which by definition apply to distances between trees and conductors, and are relevant to two categories of reportable outages as defined in FAC-003-3.

> Category 1 – Grow-ins: Sustained Outages caused by vegetation growing into applicable lines by vegetation inside and/or outside of the ROW. *This relates to a vertical gap.*
>
> Category 4 – Blowing together: Sustained Outages caused by vegetation and applicable lines blowing together from within the ROW. *This relates to a horizontal gap.*

Outages due to tees failing structurally and striking transmission conductors (Categories 2, 3) were not included in the investigation.

The history of reportable incidents since 2005 was reviewed to determine the species and crown characteristics of the trees that had been involved in reported outages. This information was used to determine the tree types tested.

Switching surge impulse tests were performed for each system voltage level to determine the average strength (critical flashover voltage) of the conductor to tree gaps. The results were then used to determine whether the Gap Factor used with the Gallet equation to calculate the MVCDs was appropriate. These tests revealed that a Gap Factor of 1.0 was more appropriate to use than a Gap Factor of 1.3.

Revised MVCD values in FAC-003-4 were calculated based on a Gap Factor of 1.0 and tests performed again at the TOV levels specified in the standard to show that the conductor tree gaps *were* able to withstand the voltages. The 230 kV test results are shown in the table below. The switching impulse flashover and withstand voltages[9] are significantly greater than the nominal line AC voltages because MVCDs are determined by applying switching over voltages and not every day 60Hz operating voltages.

Table 1 Example of operating voltages and voltages applied during Gap Factor tests.

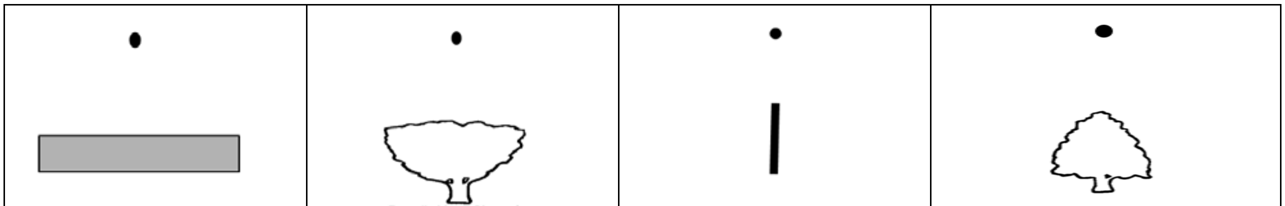
Nominal Ø-Ø AC Voltage	Ø-ground(tree) AC Voltage	Critical Flashover Switching Impulse Test Voltage	Withstand Switching Impulse Test Voltage
230kV	133kV	496-590kV	395kV

One of the key findings from the test was the impact of the tree size and shape on the flashover strength of the air gap between the tree and conductor. This impact can be explained theoretically:

- Theoretically, the weakest conductor gap is a “conductor-plane gap” shown in figure 2 with a Gap Factor of k_g=1.1. This is similar to a “conductor vase shaped tree gap” which was measured with a Gap Factor of k_g*=1.03 – 1.15.*
- The strongest conductor gap is considered to be a “conductor-rod gap” with a Gap Factor of k_g=1.4-1.6. This is similar to a “conductor pyramidal shaped tree gap” which was measured with a Gap Factor of k_g*=1.44.*

[9] “Withstand voltage” is defined as the voltage at which flashover will only occur 0.13% of the time.

As a result, the testing provides the new insight that trees with large flat tops growing directly below energized high voltage conductors resulted in the weakest air gap as compared to pyramidal shaped trees.



Conductor - Plane	Conductor Vase Tree	Conductor - Rod	Conductor - Pyramidal
k_g=1.1	k_g=1.03 – 1.15	k_g=1.4-1.6	k_g=1.44

Figure 2 Examples of Gap Factors (kg) between a conductor and rods, planes and trees

Situations That Increase the Likelihood of a Conductor-Tree Flashover

Season

The majority of the reported Category 1 outages since 2005 have occurred during the growing season. Factors that contribute to this are:

- Tree growth varies within a growing season. Stem elongation begins shortly after full leaf development[10], and is typically completed by August. As a result, clearance is lost during the first half of the growing season.
- Ambient air temperatures and system loads are high in the summer, resulting in greater conductor sag and loss of clearance.
- The crown of a deciduous tree more closely simulates a conductive plane during the growing season due to the presence of more leaves and increased mositure in the branches.

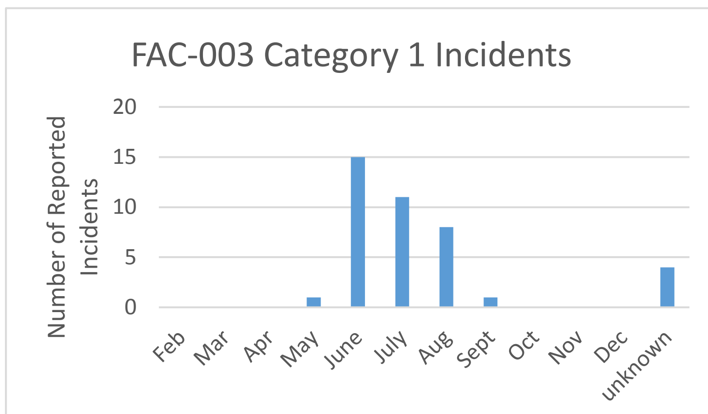


Figure 3 Seasonal trend in reportable Category 1 outages.

Voltage

The 230kV MVCDs (based on a Gap Factor of 1.3) found in FAC-003-3, when tested from conductor to a broad, flat-topped tree, failed the voltage withstand test and are a primary reason that the MVCDs in FAC-003-4 are being revised to utilize a more conservative Gap Factor of 1.0. Therefore, through the

[10] This is generally true for most of North America. In arid regions tree growth may be initiated with rainfall, and in subtropical regions stem elongation may occur over longer periods.

testing, the revised MVCDs were evaluated for various tree shapes, below or adjacent to lines of any voltage class.

Line Clearance Pruning

While some species of trees may naturally develop broad flat-topped crowns, this condition is more likely to be created by trees maintained by crown reduction pruning[11] using directional pruning[12] techniques which involves selective removal of limbs to reduce the overall height of a tree. The result of pruning can lead to the development of a broadly spreading, flat-topped crown directly under transmission conductors. As identified in the EPRI testing, this is the type of tree-conductor configuration that results in the weakest air gap. Directional side pruning of trees along the edge of narrow corridors also has the potential to create a horizontal plane with a similarly weakened air gap.

There are typically three reasons why trees are pruned rather than removed in the wire zone directly under transmission conductors:

1. Preservation of riparian vegetation associated with streams and wetlands in the right-of way.
2. Maintaining a visual screen or barrier between areas frequented by the public and the right-of-way.
3. Retention of landscape trees in parks and on private property.

Each of these scenarios may increase the likelihood of encroachment to within MVCDs, and must be addressed to ensure reliability of the transmission system.

Confidence in the new MVCDs

The "*Transmission Vegetation Management NERC Standard FAC-003-2 Technical Reference*" states that the probability of an air gap flashover between a conductor and a tree at MVCDs is 10^{-6}; however, we have been unsuccessful in confirming the assumptions associated with the statement. Based on our best understanding of the approach developed by the original authors, we have used accepted methodology[13] to provide an estimate. The resulting calculated risk of a flashover is 2.49×10^{-4}, based on a probability of flashover of 0.135% at MVCD and a transient overvoltage that has a 2% probability of exceeding the defined levels. This equates to less than one flashover across MVCDs per 4000 switching surges.

Additionally, the worst case tree shape (large flat-topped vase shape) was shown to have Gap Factor (k_g) of 1.03. Since this is higher than the Gap Factor used in the calculation, the resulting tree-conductor clearances are somewhat greater based on a Gap Factor of 1.0 and provides additional confidence.

[11] ANSI A300 (Part 1) -2008 *"Tree, Shrub, and Other Woody Plant Management – Standard Practices (Pruning)*

[12] BMP *"Utility Pruning of Trees",* (2004) International Society of Arboriculture

[13] "Transmission Vegetation Management NERC Standard FAC-003-2 Technical Reference" FAC-003, and IEEE Std. 516-2009, "IEEE Guide for Maintenance Methods on Energized Power Lines".

Placing the Likelihood of Air Gap Flashovers in Perspective

The revisions to the AC MVCDs in FAC-003-4 provide a substantial degree of certainty that with compliance, the likelihood of a flashover between an energized conductor and a tree is extremely low:

- The MVCDs are based on potential transient overvoltage (switching surge) conditions associated with switching operations in the system. The vast majority of the time the system operates at steady state nominal voltages.
- The industry recognizes that MVCDs are not the targeted clearances for a vegetation management program, and has a goal to maintain tree-conductor clearances well in excess of MVCD.
- The weakest air gap tree-conductor configuration identified in the study, was that of a broadly spreading flat-topped tree directly below a conductor, yielded a Gap Factor between 1.03 and 1.15. Since these Gap Factors are higher than that (k_g 1.0) utilized for the MVCD calculations, the actual likelihood of a flashover reduced, since the actual MVCDs require greater clearance.
- The testing provided new insight regarding the influence of tree shape on the likelihood of an air gap flashover. This new information will provide practitioners with an informed basis to enhance vegetation maintenance strategies and/or methods that address scenarios where trees are being maintained on transmission rights-of-way.

Summary

EPRI's testing on the strength of the air gap between energized high voltage conductors and trees established a quantitative basis for the MVCD values in FAC-003-4. Maintaining the new AC MVCDs reduces the likelihood of an air gap flashover to a tree on the transmission system.

The tests also demonstrated that trees with broad flat tops growing directly below high voltage conductors create the weakest air gap for a potential flashover incident. This condition is most often associated with trees that are being maintained by repeated crown reduction pruning[14]. As a result, line clearance pruning of trees directly under transmission conductors may unintentionally increase potential exposure to a flashover between a transmission line and the tree, and emphasizes the need to maintain MVCD within FAC-003-4. A similar condition may develop in the case of trees adjacent to conductors.

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[14] ANSI A300 (Part 1) -2008 *"Tree, Shrub, and Other Woody Plant Management – Standard Practices (Pruning), section 9.3.*