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Vegetation Clearance Distances to Prevent Wildland Fire Caused Damage to Telecommunication and Power Transmission Infrastructure

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Abstract-- Towers and poles supporting power transmission and telecommunication lines have collapsed due to heating from wildland fires. Such occurrences have led to interruptions in power or communication in large municipal areas with associated social and political implications as well as increased immediate danger to humans. Unfortunately, no studies address the question of what is the appropriate clearance needed to prevent damage to the conductors and support towers by wildland fires. This study presents preliminary findings from two independent studies focused on this question. Findings suggest that steel towers provide the greatest resistance to fire damage; however when failure occurs it is catastrophic, wood poles and towers do not fail catastrophically and thus may provide longer term resistance to failure. Minimum clearance for steel towers in surface and crown fires is 1 to 21 m. The minimum clearances for wood poles exposed to surface fires of low to moderate intensity are on the order of 2 to 6 m. For fires in brush, wood poles and towers require clearances of 5 to 15 m. For crown fires the minimum clearance for wood poles is 13 to 30 m. The susceptibility of wood poles to ignition and sustained burning is dependent on the age and condition of the wood surface: aged poles that present fissures for ember accumulation have the greatest risk. Clearance around telecommunication towers is dependent on the exposure of cables, guy wires, and other materials near the ground.

INTRODUCTION

Flames and smoke from wildland fire can increase the possibility of phase-to-phase, phase-to-tower, or phase-to-ground faults that could lead to subsequent power outages and electrocution risk to humans (Martinez-Canales *et al.* 1997; Andrade 2006; Vosloo *et al.* 2008; Wu *et al.* 2011; Kirkham 2012). Measures taken to reduce fire intensity and thereby minimize risk of faults include expansion of vegetation clearance around towers, reduction of vegetation maintenance intervals in high risk locations, identification of zones warranting more intensive vegetation management based on vegetation and fuel type, slope steepness, or other fire risk factors to reduce the likelihood of crown fire occurrence (i.e. reduction of vegetation load to less than 10 tons/acre [4.5 Mg/ha]), removal of ladder fuels, thinning to a canopy density less than 40% closure, alteration of species composition from high flammability to lower flammability vegetation types, and modification of line patrol frequency (Blackwell *et al.* 2011). Unfortunately, no studies have been found to date that address the question of what is the appropriate clearance needed to prevent damage to the conductors and support towers by wildland fires.

The California Public Resource Code (PRC) section 4292 suggests a “clearance of flammable fuels for a 10-foot (3.3 m) horizontal radius from the outer circumference of power line poles and towers.” Section 4293 requires “clearance of all vegetation for a specific radial distance from conductors, based on the voltage carried by the conductors: four feet for 2.4-72 kV, six feet for 72-110 kV, and ten feet for 110 kV.” In addition it requires the removal or trimming of trees, or portions of trees, that are dead, decadent, rotten, decayed or diseased and which may fall onto the line and trees leaning toward the line (Anon 2008, 2011). One utility company in southern California (SDG&E) specifies a “minimum clearance from ground to any transmission conductor of 500 kV of at least 40 ft (12.3 m) when the conductor is at maximum designed sag.” The California Public Utilities Commission (Commission) recommends a minimum clearance of 18 inches (46 cm) must be maintained between line conductors and vegetation under normal conditions. One study concluded that in "any mountainous land, or in forest-covered land, brush-covered land, or grass-covered land,” electric utilities maintain an 18 inch (46 cm) clearance around the power lines carrying less than 2.4 kV but they must still keep a 10 ft (3.3 m) clearance around poles or towers "which support a switch, fuse, transformer, lightning arrester, line junction, or dead end or corner poles” (Kim). Southern California Edison recommends that any wildland firefighter activity be minimized within 1.5 times the tallest portion of any power transmission or distribution line (personal communication with T. Whitman, Edison Fire Management April 23, 2014). All of these documents specify the clearance distance required to prevent fire ignition or risk to human safety due to arcing from conductors to ground or other conductors. None address the question of how to minimize the risk of fire-induced thermal damage to the transmission or telecom support structure caused by fire burning nearby. This question is the focus of the work described here.

The Fire Sciences Laboratory (USFS) and Xcel Energy Corporation, through its Colorado operating company have each analyzed this question. This report summarizes the findings from the two studies and presents preemptive vegetation management procedures that could minimize fire-induced thermal damage to transmission and telecommunication infrastructure in wildland fires.

PAST WORK

Wood poles ignite but don’t mechanically fail until a substantial portion of the diameter has been burned (Smith 2011). Galvanized steel poles can fail catastrophically at temperatures above 515°C (Sakumoto *et al.* 2003; Smith 2011); however fire resistant steel alloys and temperature resistant coatings can be used to extend time to failure. Generally, aluminum’s tensile strength rapidly drops and elongation accelerates as temperatures exceed 200°C (Rincon *et al.* 2009). Aluminum stranded conductors steel reinforced (ACSR) power lines are primarily used for power transmission and distribution. Of these lines, it was found that “when ACSR conductors are exposed or heated, their mechanical strength is reduced below the rated values of new conductors while their extension rate is increased. Moreover, the zinc layer on the steel strand may be removed and subsequent galvanic corrosion accelerated. This tends to corrode the aluminum strand in the interior layer as well as the bare steel strands. Thus any wildland fire could be an important factor in reducing the life of ACSR conductors in service” (Kim and Morcos 2003). Porcelain insulators start to fail at 300°C and are affected more by heating duration than heating cycle (Lee *et al.* 2008b). Polymer insulators exhibit little-to-no fire-induced effect (Lee *et al.* 2008a). However, deposition of smoke particles or fire retardant on either type of insulator can increase the potential for phase-to-tower faults. These and other related questions are being addressed by some utility companies (Anon 2008; Blackwell *et al.* 2011).

METHOD

Vegetation clearing distances to reduce thermal-induced damge are dependent on three variables, the energy released from the fire, how long the fire burns, and the thermal properties of the pole, wire, conductor, or tower.

Two methods were used to analyze the energy release from fires, 1) the USFS approach used the Fire Dynamics Simulator (FDS) developed at the National Institute of Standards and Technology (McGrattan *et al.* 2010) to simulate the energy release from fire and the thermal response of materials exposed to the heat and 2) the Xcel Energy Corporation approach used the BEHAVE plus 5.0 fire behavior simulator and expert opinion to determine clearance distances.

The USFS study also explored thermal impacts on telecommunication towers and ground located transformer and junction boxes. Using fire intensity data collected from actual wildland and prescribed fires (Frankman *et al.* 2012) simulations were formulated to replicate fires in three broad types of natural fuels (grass, brush, conifer forests) for a range of topographical and weather conditions.

TheXcel Energy Corporation approach estimated energy exposure levels for fires in various fuels. Simulations were based on 90th percentile weather. Reaction intensity and flame length were used to gauge surface fire intensity and crown bulk density and canopy cover to quantify crown fire potential. BehavePlus defines reaction intensity as the rate of energy released per area (square feet or square meters) within the flaming front. 40-50% canopy cover is the generally recognized threshold below which crown fires do not occur.

Fire intensity simulations produced from FDS were controlled by specifying a burning area, surface heat flux, flame front residence time, and rate of fire spread. Increasing the surface flux and decreasing the surface area resulted in taller and narrower flames. Conversely, decreasing the surface flux and increasing the surface area resulted in shorter and thicker flames. All simulations indicated decreasing temperature with height. Flame height was defined as the height at which the gases above the burning surface decreased below the draper point (temperature above which materials emit visible radiation—525°C or 977°F). Simulated flames were: grass 9 ft (3 m), brush ft (6 m), crown 98 ft (30 m). These values exceeded observations by nominally 30 to 50 %, which was considered a “built in” safety factor.

For the FDS simulations all poles were simulated as vertical rectangular prisms. Virtual surface temperature sensors at different heights along the pole were used to determine when thermal failure occurred. For towers, conductors, and transformer enclosures, failure was specified when the exterior temperature exceeded a specified material failure temperature limit. In all cases the temperature limits were determined from published literature. The temperature limits varied for the two studies, the FDS limits were steel 538°C (1000°F), aluminum 162°C (325°F), wood 300°C (572°F) and fiberglass 350°C (662°F). For the simulations conducted by Xcel Energy Corporation the BehavePlus temperature limits for steel and aluminum towers were 260°C (500°F) and 162°C (325°F) respectively. In the case of fiberglass simulations in the FDS study, the temperature limit is based on approximations to published values for mechanical elongation and ignition temperature. Published values for piloted wood ignition temperatures vary from 210 to 497°C (410 - 927°F). A median temperature was selected as the threshold 300°C (572°F). Any of these assumptions could be varied based on the application, surface condition of the material and heating conditions.

RESULTS

Findings were grouped into the dominant vegetation type sustaining the fire (i.e. grass, brush, and conifer forest) (Burgan and Rothermel 1984) and by study type (i.e. FDS versus BehavePlus)

Conductors

Power transmission lines are usually bare aluminum conductor (All Aluminum Conductor, AAC) that may be steel reinforced (Aluminum Conductor Steel Reinforced or ACSR). For telecommunication lines, polymer jackets are placed around the wires to provide protection from ultraviolet (U.V.) rays, weathering, and human interference. These materials consist of high density polyethylene (PE), poly(vinyl) chloride (PVC), and cross-linked polyethylene (XLPE), the preferred material.

It has been observed that when heated the spiral wound wires forming ACSR cable expand resulting in lower cable height, but constrict upon cooling. As stated above there is some evidence in the literature that exposure to heating from fires may compromise the zinc coating on the steel core wire of ACSR lines and may result in lessened conductor service life.

Table 1 presents the clearance distances required to prevent thermal failure based on material thermal properties. The Xcel Energy study did not consider conductors.

Table 1: Recommended Clearance Distances for Overhead Electrical or Power Lines base on USFS study

Fuel Type or Fire type	FDS based minimum distance from vegetation to overhead transmission lines (m/ft)		BehavePlus based minimum distance from vegetation to overhead transmission lines	
	Bare wire	Insulated	Pile height (m/ft)	Minimum height to line (m/ft)
Grass/litter	N/A[1]	N/A[1]	1.25/4	--[1]
Low Brush	N/A[1]	4.5/15	1.5/5	10/32
Tall Brush[2]	-[2]	-[2]	2/9	--[3]
30 m tall Crown Fire	5/16 horizontal 20/65 vertical	25/80 vertical		

[1] Clearance distance much less than nominal height of conductor.
[2] Tall brush was not simulated in USFS study.
[3] Should never be burned under conductors.

Utility Towers/Poles

Wood, steel, aluminum poles and towers were evaluated.

Table 2 presents vegetation clearance distances for steel, aluminum and wood poles based on the USFS FDS simulations. For wood poles clearance distances were 3 m for grass fuels, 5 m for brush fuels and 20 m for crown fires. Simulations indicated that grass and brush clearance was not necessary for steel, aluminum, and fiberglass poles and towers. Crown fires required a 5 m clearance for steel and aluminum and a 15 m clearance for fiberglass poles.

Table 2: Pole and Tower Vegetation Clearance Distances based on USFS Simulations

Material	Temperature (°C/°F)	Reaction	Grass clearance (m/ft)	Brush clearance (m/ft)	30 m tall crown fire clearance (m/ft)
Wood	300/572	Wood chars indefinitely	3/9	5/16	20/65
Steel	538/1000	Steel softens and breaks	0[2]	0	5/15
Aluminum	162/325	Aluminum begins to lose strength	0[2]	0	5/15
Fiberglass	350/662	Fiberglass begins to deform	0[2]	--[3]	15/49

[1] Depends on slope and wind exposure see Table 4 for additional information.
[2] Simulations indicated little to no vegetation clearance needed.
[3] This material not simulated.

Table 3 presents findings from the Xcel Energy Corp BehavePlus based approach. The findings are based on general fuel models by Burgan and Rothermel (1984) but when grouped into common vegetation types suggest clearance distances of 1.5 to 2.8 m for wood poles surrounded by fire burning in grass. If the surrounding vegetation is brush then the clearance distance increases to 5.5 to 15.4 m. For wood poles exposed to crown fires the clearances increase to between 17 and 32 m. Clearance distances for aluminum poles and towers are 4 to 6.5 m for grass fires, 7 to 14 m for brush fires and 13 to 30 m for crown fires. For steel towers and poles the distances decrease to 1.2 to 1.8 m for grass, 2.2 to 4 m for brush and 10 to 21 m for crown fires. Clearance distances for slash fuels are nominally on the order of those for the respective grass, brush and crown fires.

Wood poles are a special case as the failure criteria is ignition rather than degradation of mechanical strength. Data reported elsewhere (Babrauskas 2003: pp. 965) indicates that when there is an impinging flame on wood, ignition occurs in 100 to 800 seconds for a heating magnitude of 20 kW/m^2. As wood poles age they develop large cracks aligned with the long axis of the poles. These cracks provide points where embers can accumulate, ignite, and sustain long term combustion that can cause failure of the pole. Thus greater pole age reduces ignition limits which in turn lead to increased vegetation clearance distances.

One advantage of wood poles is that failure does not occur catastrophically during the fire, but rather occurs after the main fire event has passed and smoldering combustion in wood joints or cracks has reduced the strength of the structure through combustion of the load bearing member.

Thus fire risk is highly dependent on presence of cracks or crevices were embers can cause ignition. These cracks develop over time due to drying of the wood.

Table 3: Pole and Tower Vegetation Clearance Distances Based on Xcel Energy approach

Fuel Model[1]	Type[2]	Reaction Intensity (kW/m^2)	Surface Flame Length (m)	Crown Fire Flame Length (m)	Aluminum Surface Fire	Wood Surf Fire	Steel Surf Fire	Aluminum Crown-Fire	Wood Crown Fire	Steel Crown Fire
					Clearance Distance (m)					
8	g	194	0.6	9.2	4.0	1.5	1.2	13.2	17.2	10.5
TL5	g	322	0.9	9.8	5.2	2.2	1.5	15.1	18.5	11.4
6	g	401	2.5	10.2	5.8	4.9	1.5	16.0	21.2	11.7
11	s	466	1.2	10.8	6.2	2.8	1.8	16.9	22.8	12.6
9	g	508	1.2	9.8	6.5	2.8	1.8	16.3	18.5	11.7
5	b	602	2.8	10.5	7.1	5.5	1.8	17.5	19.4	12.3
2	b	718	2.8	10.2	7.7	5.5	2.2	17.8	21.2	12.3
SB2	s	1038	2.5	11.7	9.5	4.9	2.5	21.2	21.5	14.2
10	s	1224	2.2	12.3	10.2	4.3	2.8	22.5	22.8	15.1
12	s	1338	3.1	14.5	10.8	6.2	3.1	25.2	26.8	17.5
SB3	s	1434	3.7	12.6	11.1	7.1	3.1	23.7	23.4	15.7
SB4	s	1508	5.2	12.9	11.4	9.8	3.1	24.3	24.0	16.0
TU5	s	1677	3.1	15.4	12.0	6.2	3.4	27.4	28.3	18.8
13	s	2012	4.3	17.2	13.2	8.3	3.7	30.5	31.7	20.9
4	b	2474	8.3	15.7	14.5	15.4	4.0	30.2	28.9	19.7

[1] Fuel models based on BehavePlus system.

[2] g—grass, b—brush, c—crown fire, s—slash

Telecommunication Towers

The study considered telecommunication towers (i.e. cellular network towers with guyed or free standing). Towers and guy wires are typically constructed of galvanized or stainless steel, but towers may also be constructed of fiberglass and wood. In the case of free standing towers, the clearance distances should be developed based on the limiting material. For guyed towers additional consideration should include clearance around guy wires. As a result of the fire simulations the USFS study found that a 40 ft (12 m) vertical clearance and 13 ft (4 m) horizontal clearance was adequate for towers and guy wires. When galvanized guy wires are used, the zinc coating can melt at temperatures of 750°F (400°C). Once melted the corrosion protection can be compromised. Inspection of telecommunication tower sites suggests that signal cabling at the base of the tower is likely the most vulnerable point. Typically cabling in this area is encased in PVC or similar insulation, but has no specific protection from fire damage. Thus the focus from a wildland fire point-of-view should be to eliminate combustible materials below or near the signal cables and possibly install steel or aluminum cable enclosures around the cabling in this area.

Junction Boxes

The USFS analysis considered thin wall steel junction and transformer boxes. PVC insulated cable at the center of the box was modeled. The failure criterion was the failure temperature for the insulated cable at the center of the box. In no cases did the cable temperature reach the critical threshold prior to the failure temperature of the steel. Therefore the limiting case was the steel box temperature (Table 4).

Table 4: Junction/transformer Enclosures Vegetation Clearances Based on USFS study.

Material	Temperature (°C/F)	Threshold used to determine failure	Grass clearance (m/ft)	Brush clearance (m/ft)	Conifer fire clearance (m/ft)
Steel	300/572	Steel properties start to change	<1/3	4/13	12/39
	538/1000	Steel softens and breaks	<1/3	<1/3	7/23

DISCUSSION

The USFS approach suggests smaller separation distances than the Xcel Energy approach. Minimum clearance for steel towers in surface and crown fires is 3 to 16 ft (1 to 5 m) for the USFS and Xcel Energy study respectively. The minimum clearance for wood poles exposed to surface fires of low to moderate intensity (i.e brush fires) are on the order of 3 to 16 ft (1 to 5 m) for the USFS and Xcel Energy study respectively. For crown fires in tall brush or conifer tree canopies, wood poles and towers require clearances of 65 to 100 ft (20 to 30 m) for the USFS and Xcel Energy study respectively. Both studies indicate that aluminum towers are most similar to steel in terms of clearance distances for fires in all vegetation/fuel types. Regarding overhead power transmission or distribution lines, proximal fire can result in degradation of material strength and elongation of the line that may result in increased risk of fault (arcing) to nearby structures or ground and associated increased safety concerns. Heating may also impact expected service life. However, the authors have only observed failure of such lines in the highest intensity crown fires in mature conifer forests on steep slopes. Regarding overhead telecommunication lines, the study indicates that 16 ft (5 m) clearance in brush and a 80 ft (25 m) clearance for areas exposed to crown fires. All conditions simulated in the USFS study indicated no risk of failure for ground located steel encased transformer enclosures.

Both approaches summarized in the report suggest that steel towers provide the greatest resistance to fire-caused failure. However when they do fail it is sudden, occurs during the fire event and is difficult to predict (i.e. likely unexpected), while wood towers will survive some exposure and even outlast the fire event but can sustain longer term smoldering combustion that may ultimately result in failure after the fire event has passed. Subsequent delayed failure can be considered good and bad. It is good in that power distribution and communication infrastructure can survive through the fire event, but bad in the fact that the failure can occur after the fire event possibly exposing personnel working in the post fire environment to electrocution hazards.

CONCLUSIONS

This paper summarizes the findings from two studies based on different analysis approaches. The studies address questions from land and utility managers about appropriate clearance distances to minimize damage to power and telecommunication infrastructure from wildland fires.

Anecdotal observations and the simulations suggest that while rare, the potential for failure of power transmission line towers due to heating from wildland fire is real. In fact, while such failures are rare, they have been observed and can have catastrophic impacts. The greatest risk of failure appears to be associated with towers located on or at the top of steep slopes covered with trees that can sustain crown fire. High intensity crown fire can burn hot enough and long enough to cause material failure. Conductors fail even more rarely than towers and their failure seems to be linked to high intensity long term fire durations (i.e. flame front residence times greater than a few minutes). The analysis suggests that telecommunication lines are susceptible to fire-caused damage, primarily due to the lower temperature limits of the insulation on the surface of the line. Telecommunication sites (i.e. cell phone system towers) present unique risks, primarily as a result of the signal and power supply lines at the base of the tower. A reduction in vegetation cover in these areas and possibly the addition of protective coverings would be beneficial.

The clearance distances presented here are based on idealized computer simulations of fire, energy release in relation to support towers and overhead lines. The results have been compared against limited observations in the field, primarily because they are difficult to obtain. Future research should focus on collecting observational date in the field. The findings reported here are based on limited observations, computer simulations, and broad assumptions regarding material properties, ignition thresholds, and fire descriptors; therefore they should be considered preliminary at best. In the absence of any other quantitative work this paper represents the most relevant information available in the open literature to date.

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