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

B.W. Butler and **T. Wallace** U.S. Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula MT and **J. Hogge** Brigham Young University, Provo Utah

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. Vegetation clearance standards for overhead conductors in the US have been specified to prevent ignition due to arcing from the power line to ground or to minimize potential fire ignition by hot sparks from a line fault that fall into vegetation on the ground. The California Public Resources Code (PRC) section 4292 suggests "clearance of flammable fuels for a 10-foot horizontal radius from the outer circumference of power line poles and towers." Unfortunately, no studies were found addressing the question of what is the appropriate clearance needed to prevent damage to the conductors and support towers by wildland fires. Recognizing the lack of quantitative information, The Fire Sciences Laboratory (USFS) analyzed this question. The results 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 5 m. The minimum clearances for wood poles exposed to surface fires of low to moderate intensity are on the order of 1 to 5 m. For crown fires in tall brush and tree canopies, wood poles and towers require clearances of 20 to 30 m. The study indicates that aluminum towers are most similar to steel in terms of clearance distances for fires in all vegetation types. 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. There is evidence from the USFS study simulations that the possibility exists for overhead conductors to fail although this occurrence has not be observed. Transformer and junction enclosures were not susceptible to damage primarily due to the steel exterior material. Clearance around telecommunication towers is dependent on the exposure of cables, guy wires, and other materials near the ground. Analysis and conclusions from this study should be characterized as preliminary.*

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 and others 1997; Andrade 2006; Vosloo and others 2008; Wu and others 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 type, slope, or other fire risk factors to reduce the risk of crown fire (i.e., reduction of vegetation load to less than 10 tons/acre), 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 and others 2011).

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The California Public Resource Code (PRC) section 4292 suggests a "clearance of flammable fuels for a 10-foot 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 ft for 72-110 kV, and 10 ft 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 into or 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 be at least 40 ft when the conductor is at maximum designed sag." The California Public Utilities Commission (Commission) recommends a minimum clearance of 18 inches 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 clearance around the power lines carrying less than 2.4 kV but they must still keep a 10 ft 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.

There have been documented observations of steel towers failing in wildland fires. In a recent presentation Southern California Edison representatives stated that they have not observed failure of conductors or steel towers in their transmission and distribution systems in southern California caused by wildland fire; but they do regularly observe failure of wood poles

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 and others; Smith 2011); however, fire resistant steels or 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 and others 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 forest 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 and others 2008b). Polymer insulators exhibit little-to-no fire-induced effect (Lee and others 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 in Canada and southern California (Anon 2008; Blackwell and others 2011).

Recognizing the need for information about vegetation clearances that would minimize the potential for fire caused failure of power and telecommunications infrastructure, the Joint Fire Science Program funded a study by the Fire Sciences Laboratory (USFS) in 2010 to explore this question. This report summarizes the findings.

Method

Vegetation clearing distances are dependent on two variables, the energy released from the fire and the thermal properties of the item of interest. Both are discussed here.

The Fire Dynamics Simulator (FDS) developed at the National Institute of Standards and Technology (McGrattan and others 2010) was used to simulate the energy release from fire and the thermal response of materials exposed to the heat. This model was designed to simulate structural fires and has complex chemistry and physics intended to accurately approximate the combustion processes and energy release from the flames. For this study FDS was formulated to simulate fires in various vegetation types and compute the thermal impact on power transmission lines, telecommunication lines, and support poles/towers composed of wood, steel, aluminum, and fiberglass. This 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 and others 2012) simulations were formulated to replicate fires in three types of natural fuels (grass, brush, conifers) for a range of topographical and weather conditions.

FDS fire intensity was controlled by specifying a burning area, surface heat flux, residence time, and rate of 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 longer than the observed flames for grass and brush (grass simulation flame length 3 m, brush flame length 6 m, crown flame length 30 m). This is considered a "built in" safety factor.

Model outputs included air temperature, radiative, and convective heating rates and a cable failure index. 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 the case of insulated cables the thermally induced electrical failure (THIEF) cable model (included in FDS) was used to determine cable failure (determined from a specified temperature limit). In all cases the temperature limits were determined from published literature. The temperature limit for steel was 538 °C (1000 °F), aluminum 162 °C (325 °F), wood 300 °C (572 °F) and fiberglass 350 °C (662 °F). The temperature limits for steel and aluminum were based on the approximate temperature at which elongation was greater than 10-30% for loaded members. In the case of fiberglass, 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, shrub, and crown) (Burgan and Rothermel 1984).

Conductors

Power transmission lines are usually bare aluminum conductor (All Aluminum Conductor, AAC) that may be steel reinforced (Aluminum Conductor Steel Reinforced, ACSR). For telecommunication lines, polymer jackets are placed around the wires to provide protection from 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 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.

The study used the FDS cable model to simulate heating and failure of cables. Table 1 presents the clearance distances required to prevent thermal failure based on material thermal properties. The results were developed from the USFS study and are based on a simulation without consideration of wind or slope.

Table 1—Recommended clearance distances for overhead lines.

	Minimum distance from vegetation to overhead transmission lines (m/ft)	
	Bare wire	**Insulated**
Grass/litter	N/A[5]	N/A[5]
Low Brush	N/A[5]	4.5/1[5]
Tall Brush2	-2	-2
30 m tall Crown Fire	5/16 horizontal 20/65 vertical	25/80 vertical

[2] Tall brush was not simulated in USFS study.
[5] clearance distance much less than nominal height of conductor.

Utility Towers/Poles

Wood, steel, aluminum poles and towers were evaluated in both studies. The study also evaluated pultruded fiberglass poles. Table 2 presents vegetation clearance distances.

Wood poles are a special case as the failure criteria is ignition rather than degradation of mechanical strength. Data reported elsewhere (pp. 965 Babrauskas 2003) indicate 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 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 the age of the wood and to a lesser extent on the preservative treatment type.

Slope and Wind

Subsequent USFS analysis explored the impact of slope and wind on clearance distances for towers located in forests burning with fires of different flame heights. The results suggest steel and aluminum towers provide the greatest resistance to fire induced damage. Non-aged wood towers and poles are more dependent on distance (Table 3).

Surprisingly the results indicate little impact of wind or slope on clearance distances for steel and aluminum poles and towers. There is however a direct correlation between clearance distances and wind and slope for wood. The data also suggest a correlation between flame height and clearance distance for wood, steel and aluminum. The few data developed so far suggest that high wind, high slope or tall flames can mandate increases in vegetation clearance of up to 50%; however additional analysis is needed to further define this effect.

Telecommunication Towers

The study considered telecommunication towers (i.e., cellular network towers [guyed or free standing]). Towers and guy wires are typically constructed of galvanized or stainless steel, but towers may also be constructed of fiberglass

Table 2—Pole and Tower Vegetation Clearance Distances.

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	02	0	5/15
Aluminum	162/325	Aluminum begins to lose strength	02	0	5/15
Fiberglass	350/662	Fiberglass begins to deform	02	--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—Tower clearance as function of slope, wind, and flame height.

Slope %	Upslope Wind (mph)	Flame ht[1] (m/ft)	Clearance for wood poles (m/ft)	Clearance for steel poles (m/ft)	Clearance for aluminum poles (m/ft)
0	0	50/160	5/15	5/15	5/15
0	7	50/160	10/32	5/15	5/15
0	15	50/160	15/50	10/32	10/32
20	0	50/160	10/32	5/15	5/15
20	7	50/160	15/50	10/32	10/32
20	15	50/160	20/65	15/50	25/80

[1] There is some evidence that flame height can be scaled as two times vegetation height or vice versa; vegetation height is one half flame height.
[2] Not yet simulated.

Table 4—Junction/transformer Enclosures Vegetation Clearances.

Material	Temperature (°C/F)	Threshold used to determine failure	Grass Clearance (m/ft)	Brush Clearance (m/ft)	Crown 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

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. USFS simulations found that a 12 m (40 ft) vertical clearance and 4 m (13 ft) horizontal clearance was adequate for towers and guy wires. When galvanized guy wires are used, the zinc coating can melt at temperatures of (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 fire management point-of-view should be to eliminate combustible materials below or near the signal cables and possibly install steel or aluminum cable enclosure around the cabling in this area.

Junction Boxes

The 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).

Discussion

The study indicates that steel towers provide the greatest resistance to fire-caused failure. However when they do fail it is immediate, while wood towers likely 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. Minimum clearance for steel towers in surface and crown fires is 1 to 5 m. The minimum clearance for wood poles exposed to surface fires of low to moderate intensity are on the order of 1 to 5 m. For crown fires in tall brush to tree canopies, wood poles and towers require clearances of 20 to 30 m. The study indicates that aluminum towers are most similar to steel in terms of clearance distances for fires in all vegetation 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, no observations of failure due to heating and separation of such lines have been reported. Regarding overhead telecommunication lines, the study indicates that 5 m clearance in brush and 25 m clearance for areas at risk of crown fire. All conditions simulated in the study indicated no risk of failure for ground located steel encased transformer enclosures.

In the absence of any other quantitative work this report represents the most relevant information available in the open literature to date. The findings from both studies 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.

Conclusions

This report summarizes the findings from a computational analysis initiated to address questions from land and utility managers about appropriate clearance distances to minimize damage to power and telecommunication infrastructure from wildland fires. The approach follows a quantitative heat transfer and combustion physics method.

Anecdotal observations and the simulations presented in this report suggest that while rare, the potential for failure of power transmission line towers due to heating from wildland fire is real. 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 where the magnitude and duration of heating can be high 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 (i.e., greater than a few minutes resident time). 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 associated with signal and power supply lines at the base of the tower. In a fire event, reduction of vegetation in these areas and possibly the addition of protective coverings would be beneficial.

The clearance distances presented in this summary are based on idealized computer simulations of fire, energy release and support towers and overhead lines. The results have been compared against very few observations, primarily because they do not exist. Future focus should attempt to collect observations from field engineers. Due to the lack of data with which to verify the findings, they must at this point be considered preliminary.

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