CHARACTERIZING THE RISK OF ELECTRICAL CONTACT TO ARBORISTS

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ABSTRACT

A review of the twenty-year history of electrical injuries and electrocutions of arborists engaged in arboricultural operations was completed, and a summary database was compiled. Sixteen electrical contact incident case study scenarios were identified, and the frequency of occurrence of each was determined. The electrical fault pathway involved in each case study was defined and likely levels of exposure to electrical currents and voltages evaluated. Risk abatement and mitigations practices were identified.

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Acknowledgments

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Executive Summary

Trees commonly grow in proximity to overhead electric utility lines. The presence of energized conductors near trees represents a hazard source for arboricultural operations. Incidents involving tree workers and electrical conductors have been documented for decades. Despite the long association of arborists and energized conductors, there has been little research on the root causes of electrical contact incidents resulting in injuries and electrocutions to arborists. This study reviewed fatal and non-fatal injuries to arborists due to direct and indirect contact with an energized conductor during arboricultural operations over a 20-year period.

This project determined the most common types of electrical contact incidents among arborists and the injuries associated with these incidents.

The overarching question considered by this project is an arborists' risk of exposure to electrical voltages and currents during their work with trees in proximity to overhead electric distribution lines. Risk was defined in terms of the likelihood of exposure, the voltage and current levels that would be encountered, and the consequence of such exposure.

The project focused on five basic questions:

1. What arboriculture activities create electrical expose?
2. What is the relative frequency of arborists' electrical exposures?
3. What levels of exposure to voltage and currents are associated with arboricultural work?
4. What are the consequences of adverse electrical exposure to arborists?
5. How can the likelihood of adverse electrical exposure be mitigated?

Electrical contact scenarios associated with arboricultural operations were identified. A database containing a twenty-year history of arborists' electrical injuries and fatalities was developed. The frequency of occurrence for sixteen different exposure scenarios was determined. The range in expected levels of voltage and current to which an arborist may be exposed while working on trees in proximity to electric distribution lines was identified, as were the physiological consequences of such exposure.

This report is intended as a reference to inform the development and refinement of safe work practices for arboricultural operations. It will also provide practitioners with information on risks associated with work in trees that are in proximity to overhead electric utility lines. The cumulative scientific data summarized in this report supports a definitive link between arborist safety and strict adherence to minimum approach distances.

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Introduction

Trees and overhead electric utility lines commonly occur in proximity to each other. The presence of energized conductors near trees represents a hazard source for arboricultural operations. Incidents involving arborists and electrical conductors have been documented for decades. A 1938 article on safety noted a climber who reached up with his hand saw and contacted a 4.8 kV line (Kiplinger 1938). Electrical contact has been among the most common cause of injury to arborists (Arnoldo *et al*. 2004), representing about 15% of all fatalities and approximately 20 to 40 fatal incidents each year (Wiatrowski 2005, Castillo and Menendez 2009).

Despite the long association of arborists and energized conductors, there has been little research on the root causes of electrical contact incidents resulting in injuries and electrocutions to arborists.

This study reviewed fatal and non-fatal injuries to arborists as a result of direct and indirect contact with an energized conductor during arboricultural operations over a 20-year period from 2001 to 2020. The objective of this project is to determine the most common types of electrical contact incidents among arborists and the injuries associated with these incidents, and to assist in the development and refinement of safe work practices for arboricultural operations.

Methods

This project focuses on characterizing the risk posed by electrical contact during arboricultural operations. Risk is a function of adverse exposure and the consequence of such exposure. An arborist's exposure to electrical injury is a function of likelihood of occurrence and magnitude. The likelihood of exposure was characterized by a review of fatal and non-fatal incidents. The magnitude of exposure was characterized by the level of voltage and current to which an arborist may be exposed. The consequences of exposure were characterized in terms of the severity of injury. Each element considered in assessing risk is described in this report.

A database documenting the 20-year history of electrical contact incidents involving arboricultural operations was developed along with case studies describing the types of exposure. Incident data were allocated to each case study to determine their relative frequency. Estimates of levels of voltage and current for each type of exposure were established and the biomedical literature was reviewed to characterize the potential consequences of exposure. Each case study was evaluated using ANSI Z133 *American National Standard for Arboricultural Operations – Safety Requirements* (2017) to determine if standards are in place that, if complied with, would abate or mitigate exposure to the hazard.

Electrical Contact Incident Database

The data for this study were obtained from two sources. The project focused on incidents that occurred during the performance of activities such as climbing, pruning, and tree removal. For the purposes of this report, the workers performing such tree-related tasks are generally referred to as arborists.

Fatal incidents

The record of fatal incidents was determined using the Occupational Safety and Health Administration (OSHA) Integrated Management Information System (IMIS) through their Census of Fatal Occupational Injury (CFOI). The IMIS dataset included all fatal occupational incidents in the United States. These data also provide information on primary and secondary hazard sources for each fatal incident.

The IMIS database was searched by occupational codes for industries in which workers were conducting arboricultural operations: pruning or removing trees in urban settings. Most incidents were found within the Landscape Services (NAICS 561730) under the following Occupational Codes:

- SOC 37 3013 Tree Trimmers and Pruners
- SOC 37-3011 Landscaping and Groundskeeping Workers

The database was also searched for allied professions under other NAICS codes. These codes contain some incidents that meet the definition of an arboricultural operation such as pruning or removing trees in urban settings:

- 23891 Site Preparation Contractors
- 113000 Logging
- 238210 Electrical Service

Forestry and orchard incidents were excluded from our study.

The IMIS database was searched for incidents of arborists killed by electric shock (electrocution) while pruning or removing shade and ornamental trees within these occupational codes (Table 1). The keywords used for the search were “tree” and “electrocution”. The narrative descriptions for each incident were reviewed to determine which activities the worker was engaged in at the time of the incident (tree pruning or removing). The type of contact was also determined:

- Direct contact - a part of the arborist’s body contacts the energized electrical conductor.
- Indirect contact - a part of the arborist’s body touches a conductive object such as tools, tree branches and trucks, among other objects, that are in conduct with an energized electrical conductor. If the contact was indirect, the contact source was identified from the narrative.

Table 1 Fatal electric contact incidents during arboricultural operations, by industry and occupation

Industry Code (NAICS)	Occupation Code (SOC)	Number of incidents	Percent
Landscape Services		371	94.2%
	Landscaper 37-3011	59	15.0%
	Tree Trimmers & Pruners 37-30333	312	79.2%
Site Preparation Contractors 238910		3	0.7%
Logging 113210		12	3.0%
Electrical Services 238210		8	2.0%

Non-fatal incidents

The record of non-fatal injuries was also obtained through the IMIS using a different database, Survey of Occupational Injury and Illness (SOII). The IMIS database was searched using the same codes as for the fatality data and for workers conducting arboricultural operations. The keywords used for the search were "tree", "electric shock", "burns" and "CPR".

Table 2 Non-fatal electric injury contact incidents during arboricultural operations by occupation

Industry Code (NAICS)	Occupation Code (SOC)	Number of incidents	Percent
Landscape Services 561730		132	86.3%
	Landscaper 37-1011	13	8.5%
	Tree Trimmers & Pruners 37-1033	119	77.8%
Site Preparation Contractors 238910		11	7.2%
Logging 113000		6	3.9%
Electrical Services 238210		4	2.6%

The data from the SOII (*injury*) and CFOI (*fatality*) are not directly comparable as they differ in the methods by which data were collected.

- The CFOI used multiple sources and is designed to capture occupational fatalities within the population of all private and government workers, including the self-employed.
- The SOII data are from a sampling of approximately 230,000 establishments. The data include only private and state/local government employees; it excludes federal workers. It also includes only private workers for establishments of ten or more employees, so workers in small companies and the self-employed are excluded. The data collection methods and limitations in the sampled population mean that non-fatal occupational injuries though the SOII are underreported (Leigh *et al*., 2004).

Since CFOI and SOII data are not directly comparable, the total number of fatal and non-fatal incidents was compared by reviewing all the reported electrical contact incidents involving arborists from a large investor-owned utility company. There were 413 incidents during the sixteen-year period from 2003 to 2018. There was sufficient information on 397 of these incidents to determine the occupation of the person or persons involved in the incident and the details of the cause of the incident. Tree-related electrical contact incidents involving homeowners were excluded from this comparison.

Arborist Activities That Create Exposure

Delphi Analysis

The lack of detailed data on electric contact incidents led us to seek consensus among experts on the electrical safety of arboricultural operations. Delphi Analysis was used to characterize the ways in which arborists are exposed to electrical hazards.
Delphi analysis is a technique designed to obtain the most reliable consensus of a group of experts. It is a means of structuring group communication to enable a group to effectively deal with complex problems. It is a method of conducting research based on consensus. Delphi analysis relies on the use of multiple rounds of review to collect and distill the knowledge of a defined group of Subject Matter Experts (SME) and practitioners. This process recognizes the value of human experience and judgment and provides a means of structuring input into a useful form.

Delphi Analysis begins with an expert or small expert group that conducts an initial analysis. The draft work product is then vetted and validated by a group of SMEs. A refined draft is then reviewed by informed stakeholders. The result is a systematic assessment that draws from a variety of data sources, some formal and others less so. It is intended to draw on the experience and collective wisdom of stakeholders.

Core project team

An initial series of twelve representative electric contact incident scenarios were developed and used to define the likelihood of electrical contact and the outcome of the contact as either fatal or non-fatal. These scenarios were developed based on initial evaluations of incident data from two OHSA databases and the expert knowledge of the project team.

Subject Matter Experts

The twelve scenarios were then reviewed by a larger group of industry SME who are experienced in arborist safety. The SMEs in this project included individuals who have served in safety and/or management roles at commercial tree care or utility line-clearance companies. The majority of SMEs also served on the ANSI Z133 Safety Requirements for Arboricultural Operations as members or observers. There were 15 key informants invited to participate in the process, most with more than twenty years' experience in the industry.

Input from the SME group was used to refine the initial set of twelve case studies. The SMEs were asked open-ended questions about these scenarios, whether there were any that were similar enough to be combined or whether there were others that should be considered. The participants were also asked their opinion on what details needed to be collected from a more detailed investigation of electrical contact incidents among tree workers during the previous 20 years.

The participants made numerous helpful suggestions on details that should be obtained from incidents. One common suggestion was whether a climber was using spurs (gaffs) while climbing or pruning. Since the spurs are pushed into the sapwood, which is more conductive, the use of spurs by climbers may create an additional hazard. Another was whether the injured worker was wearing gloves and if so, the construction of the gloves.

Other suggestions included:

- The voltage at the time of contact
- The duration of contact
- The source (i.e., hands or feet) of the ground and contact points on the injured worker. This information can provide the path of current through the body and the possibility of the current traversing the heart.
- Environmental conditions at the time of the incident, as storm-related tree breakage may have resulted in power line contact with trees, or the lines may be severed and on the ground.
- The crew size at the incident, as incidents may be more frequent on larger crews or situations where multiple crews were working in proximity to each other.

The scenario that the SME group considered to be the most common was a detached branch being guided by the climber and unintentionally contacting the conductor. The least common scenario was identified as a partially cut branch that deflected and made contact with a conductor.

There were two scenarios identified by SMEs that were missing from our initial draft:

- Touch and step potential involving groundworkers that were either touching the aerial device when it made contact with an energized conductor, or they were standing nearby when the device made contact.
- Electrical incidents involving cranes.

A revised and expanded set of sixteen scenarios was then produced and reviewed again by the SME group. This second round of review was conducted by virtual meeting (via Zoom) and assessed the data collection process. Information that could be gathered from incidents through OSHA investigation reports, news articles, and police/fire/EMS reports was limited and inconsistent. For example:

- The use of climbing spurs was rarely mentioned, either because they were not common factors in incidents, or the reports did not mention their use.
- Voltage was frequently missing from reports. An approximate range could be inferred from narratives, but only to the extent that the energized conductor was a primary distribution line or a secondary.
- While the company involved in an incident was always identified, it was not often possible to identify crew sizes.

These data limitations were discussed with the SME panel and the incident scenarios were further refined. The consensus of the SME group was to limit the data collection to frequency of incidents, categorized as either fatal or non-fatal for each of the scenarios.

An on-line survey was then conducted. Thirteen of the original SME group participated in a survey that asked for their first-person knowledge of fatal tree worker electrical conductor incidents in the United States. 'First-person' meant that their opinions were based upon incidents which happened to workers within their current company or one they had worked for in the past. These could also include incidents from other companies where they had detailed knowledge of the factors in the incident. This did not include incidents they may have only vaguely heard or read about in an article or newspaper.

The on-line survey asked SME participants to consider each of the sixteen scenarios and rank the frequency of occurrence from unlikely (an incident of which they had no first-person knowledge) to most likely (one that they had first-person knowledge of multiple occurrences in the industry during the past twenty years). The categories were identified as (1) no incident, (2) one incident, (3) two or three incidents and (4) more than three incidents.

Finally, the sixteen scenarios were divided into three major categories: incidents while the worker was moving to perform a task, incidents that occurred while pruning and incidents that occurred while tree felling or dismantling.

Moving

Less than half the SME's indicated any firsthand knowledge of an incident related to a worker moving to perform a task. More than 70% of the respondents reported firsthand experience of at least one incident relating to an arborist's weight or action deflecting the branch into the conductor.

Pruning

Less than half the SME's indicated any firsthand knowledge of a pruning-related incident. The most frequently reported scenario was a detached branch falling and contacting the arborist and the conductor. About 75% of the respondents had firsthand knowledge of this incident; nearly half had seen this type of incident more than once.

About 46% of the SME's indicated no firsthand knowledge of a scenario in which either a chain or pole saw contacted the conductor. However, almost an equal percentage had seen this occur two or more times.

Removal/dismantling

Most incident scenarios described under pruning/dismantling also had less than half the SME's indicating that they had firsthand knowledge of such an incident. But about 60% of the SME's reported some firsthand knowledge of incidents in which a tree fell on the conductor and remained suspended (R2,) or a tree or tree part knocked a conductor to the ground (R3).

Practitioners

Finally, a survey of 167 working arborists, including climbers and lift operators, was conducted. Survey respondents were employees of the Davey Tree Surgery and worked in both residential and utility line clearance operations. Most of the respondents identified climbing (85%) or operating an aerial device (78%) as part of their job duties. All the climbers had more than five years of experience, with the most (38%) between five and ten years. The aerial device operators had more than five years of experience and 40% had been operating these lifts between five and ten years.

Most climbers also used climbing spurs at least once a month during removals or dismantling operations (76%). Ladders were rarely used by climbers, only 2% noted using them more than once a month. Aerial device operators mostly operated trunk-mounted boom lifts (76%). Another 16% currently operate spider lifts, with scissor lifts used by 8% percent of the operators.

Climbers were asked to rank the likelihood of incidents from most to least likely. Indirect contact through a cut branch was rated as most likely, followed by indirect contact through a conductive tool such as a pole saw. The least likely electrical incident for climbers was direct contact with the conductor.

Aerial device operators identified indirect contact through a cut branch as the most likely, followed by indirect contact through a conductive tool such as a pole saw. The third most likely scenario was the aerial device operator directly contacting the conductor.

Responses from the practicing arborists were in close alignment with incident data, identifying the risk of indirect contact with a conductor through a cut branch or conductive tool. They also were in alignment with the risk of an aerial device operator making direct contact. It appears that arborists who have been working in the field for five years or more are aware of the most common risks.

Electrical Contact Incident Scenario

The sixteen incident scenarios that were developed during the Delphi process can be grouped into three classes reflecting the activity that was occurring at the time of the incident: moving, pruning or removing. Additional information regarding the sixteen case studies is included in the appendix to this report.

Moving

This class of incidents occurred during arboricultural operations while the injured worker was moving into position or repositioning within the crown of a tree.

Table 3 Electrical contact incidents that occurred while arborist was moving into position.

Case	Sub-activity
M1	Climbing, working from rope and saddle. Climber's weight or action deflects branch into contact with conductor (indirect) or climber makes direct contact with conductor.
M2	Free climbing, not roped in. Climber's weight or action deflects branch into contact with conductor (indirect) or climber makes direct contact with conductor.
M3	Arborist is moving ladder into position or climbing ladder. Arborist's weight on ladder deflects branch into contact, or ladder makes contact, or arborist makes direct contact with conductor while climbing the ladder.
M4	Working from aerial device, moving position of basket or boom: a) Boom/basket contacts conductor b) Boom deflects tree branch(es) into contact with conductor. c) Lift operator makes direct contact with conductor.
M5	Aerial lift moves into contact with conductor or energized branch(es), exposure to ground worker.

Examples from the incident reports of electrical contact incidents that occurred while an arborist was climbing or repositioning within the crown of a tree include:

- *"Climber within 6 feet of 16 kV overhead power line reached for a branch. When he touched the branch, he was electrocuted. The wounds showed that electricity entered through his leather gloves, between his index and thumb fingers, and exited through the back of his right and left leg".*

- *"The climber was positioning himself in tree to begin cutting branches and came into contact with the primary power line. He was electrocuted".*

- *The worker climbed up a tree to 30 feet. He slipped and fell backwards onto a 7.2 kV overhead power line. He was electrocuted".*

- *"The climber was about 4 feet from a 13.2 kV overhead power line. He unhooked his positioning device, a flip line, so that he could descend from the tree. When he* *unhooked the flip line, it swung around and contacted the line, and he was electrocuted."*

- *"Two ground workers were repositioning a 40-foot aluminum extension ladder. While moving the ladder, it struck the overhead power line and both workers were electrocuted."*
- *"A tree worker was using a portable lift to trim trees from a customer's property. He raised the lift too close to the overhead power lines. The operator had three burn marks on his back and one burn mark on his left index finger that continued up his arm. He was electrocuted".*
- *"The truck mounted aerial lift touched an overhead power line and energized the truck. A worker standing on the ground was electrocuted when he touched the truck."*
- *"A ground worker was spotting for an aerial lift that was completing some power line tree trimming. The worker was electrocuted when the lower length of the knuckle boom touched the primary phase of the power line and energized the vehicle and surrounding ground".*

Pruning

This class of incident occurs during arboricultural operations while the injured worker is pruning, removing, or reducing branch(es) within the crown of a tree.

Table 4 Electrical contact incidents that occurred while arborist was pruning a tree.

Case	Sub-activity
P1	Partially cut (deflected) branch remains attached and contacts conductor
P2	Detached branch falls away, making unintentional contact with conductor and arborist as it falls away.
P3	Detached branch deliberately guided as it falls, making unintentional contact with conductor as it is being guided by the arborist.
P4	Detached branch gets hung up with other branches as it falls away. Arborist attempts to clear the branch.
P5	Tree or branch is already in contact with conductor. Incident occurs as it is being removed.
P6	Saw contacts conductor during pruning activity.

Examples of reports of electrical contact incidents that occurred while an arborist was in the process of pruning branches within the crown of a tree include:

- *"A climber was trimming tree branches using a metal pole saw. The tree branch contacted a 13.2Kv overhead power line while being cut. This caused an electrical arc from the branch and the pole saw, resulting in a fatal electrocution".*
- *"An aerial lift operator was cutting tree limbs approximately 25 feet above the ground. He was electrocuted as the limb that he was cutting contacted a 14.4 kV phase-to-ground power line. The lift operator was killed".*
- *"The climber was trimming branches away from a 19.9 kV power line that was overhead. The employee had made a snap cut in a tree branch and the branch struck the power line. The climber was still holding the branch when it struck the power line. The climber was electrocuted."*
- *"A climber was trimming a tree at a height of 24 feet with a 7.2 kV overhead power line approximately 3 feet away. The climber's aluminum pole saw touched the line. He was killed instantly."*
- *"A climber was using a chain saw to trim tree limbs near overhead power lines. While cutting a limb above his head, it fell and contacted a 13.2 kV line. The limb then fell across the employee's chest while still in contact with the power line. The climber was electrocuted."*
- *"A tree worker was operating a portable aerial lift. The gasoline-powered pole chain saw contacted a 7.2 kV overhead power line. The chain saw and aerial lift became energized. Electric current entered the employee's body through his hands, which were in contact with the chain saw, the aerial lift, or both. A fire started. The employee sustained an electric shock. He also sustained burns to multiple parts of his body, including his hands, knee, torso, and legs. He was hospitalized, but he later died".*

Removing

This class of Incident occurs during arboricultural operations while the injured worker is removing a tree or tree parts. This is not pruning for structure or form.

Table 5 Electrical contact incidents that occur while an arborist is removing a tree.

Case	Sub-activity
R1	Dismantling - Parts of the tree lowered down by rope and rigging.
R2	Felling whole tree, working from ground. Tree is hung up on the line. Conductor remains intact and energized.
R3	Felling or dismantling – Piece of tree strikes and tears down conductor(s).
R4	Removing vines from tree or structure, typically working from the ground. May include arborist pulling vine into contact with conductor.
R5	Dismantling—using a crane to lower pieces being removed.

Examples from the incident reports of electrical contact incidents that occurred while an arborist was in the process of removing an entire tree include:

- *"A ground worker was part of a crew that was removing dead trees near an overhead power line. A coworker cut a dead branch which fell on a guy. The ground worker was removing the branch from the guy when the guy broke. It whipped up and struck the overhead power line. The energized power line broke and fell to the ground. Current passed through the wet grass and electrocuted him".*
- *"A chipper operator was feeding tree limbs into a chipper. A crane operator was stacking logs perpendicular to the overhead power lines. The crane outrigger was in contact with the chipper when the crane cable contacted a 20 kV overhead power line. The chipper operator was electrocuted as electricity flowed from the cable to the chipper while his hands were on chipper controls. The employee received burns on his hands and feet and killed soon afterwards".*
- *"A climber received a fatal electrical shock while trimming a tree. A crane operator was using the ball of a crane to move the climber from one position in the tree to another. While moving the ball into position the crane cable came in contact or close to a 12.5 kV overhead power line that was above the tree being cut. The climber was electrocuted."*

Frequency of Electric Contacts

The database of fatal and non-fatal incidents was used to assign frequency data to each case study. Note that the case studies assume the electric distribution system is normally configured and working as intended. They do not address abnormal system conditions such as storm restoration work where wire is already down and arborists are working under adverse weather conditions,

Fatal incidents

Fatal incidents involving electricity were the sixth leading cause of occupational fatalities, about 4-5% of all fatal incidents (Cawley and Homce 2003, Janicak 2008). About 40% of these incidents involved contact, either direct or indirect, with an overhead power line (Taylor *et al*., 2002). The fatality rate for serious electrical injury across all industries is about 40% (Luce 1984). Arborists incurred about 1.5% of the electrical injuries in a Texas 20-year study (Arnoldo *et al*., 2004) that reviewed all electrical injuries, so was not limited to those in which overhead power lines were the hazard source.

There were 2,310 fatal incidents reported during arboricultural operations by landscape services companies during the 20-year period study period included in the database. The hazard sources for these incidents included strikes by a falling tree or branch, falls from trees or aerial devices, and individuals caught in chippers, among other incidents. Contact with electric current was noted in 394 (17.1%) of these incidents and occurred at an average rate of 19.7 incidents per year. This is consistent with estimates obtained by others regarding arboricultural operations. Buckley and others (Buckley *et. al* 2008) found 140 incidents involving contacts with electric current during the 10 years from 1992 to 2001, for an incident rate of 14 per year. A factsheet from NIOSH (2008) identified 77 electrocution incidents among this same group during the four-year period from 2003 to 2006, with an average incident rate of 19.3 per year.

Most of the incidents reviewed in this study, 312 out of 394 (79.3%), involved tree workers who identified as arborist as their primary function. These were arborists who were employed to perform tree care for residential or commercial clients or were contracted by utilities to provide line clearance. The occupation was determined by the narrative of the incidents and the name of the company. The terms Tree Expert, Tree Service, and Tree were commonly used in the company name. The 312 electrocution incidents within the 20-year time frame included in the dataset results in a rate of 15.3 fatalities per year. Castillo and Menendez (2009) identified 174 fatal contacts with electric current among arborists during a 15-year period from 1992 to 2007, approximately 11.6 per year. Wiatrowski (2005) reviewed arborists fatalities from 1992 to 2002 and noted 113 fatal contacts with electric current, about 11.3 per year.

The remainder of the electric contact incidents reviewed in this study were to landscapers and grounds maintenance workers who were pruning or removing trees on clients' properties as part of a landscape installation or maintaining grounds. These occupations were determined by the narrative and the company name. Common terms were Landscape, Lawn Care and Property Management. This also included workers employed to clear trees for land development.

Non-fatal incidents

There were 153 non-fatal injuries reviewed within the same 20-year period. Most of the non-fatal injuries (71%) involved individuals described as arborists.

All the non-fatal injuries to residential/commercial arborists, utility arborists and other landscape professions were cross-referenced in the IMIS database. Slightly less than half (42.6%) of these concerned arborists rather than landscapers or other green industry professionals.

Regardless of occupation, 29.2% of tree-related electric incidents were fatal. There was essentially no difference in the rate of fatal incidents between arborists (30.8%) and landscapers/grounds workers (29.3%).

The review of all electrical incidents of all causes at one utility found that a fatal outcome was reported in 102 (24.7%) of the incidents. Electrical incidents are disproportionately fatal across all industries (Cawley and Homce, 2003). Trees were involved in three-quarters (73.5%) of fatal incidents, all causes. The majority (62.7%) of these tree-related fatal incidents involved arborists working on a fee-for-service basis. The remainder (37.3%) of these incidents involved members of the public such as private homeowners who were pruning their own tree or harvesting fruit from it. Most of these incidents occurred from indirect contact through a metal pole in contact with the conductor, either a saw on the tip for pruning or a basket for harvesting fruit. The homeowner was often standing on a metal ladder. Incidents involving homeowners and members of the general public were not included in the dataset used in this project.

Types of electric contact incidents

Electrical contact incidents that occurred over the twenty-year period of interest were grouped by case study. Activities within the crown such as moving, repositioning, and pruning are involved in the majority of electrical contact incidents. In contrast, tree removal, which involves both work aloft near energized conducts as well as work on the ground, logically represents lower exposure and a lower frequency of electrical contacts.

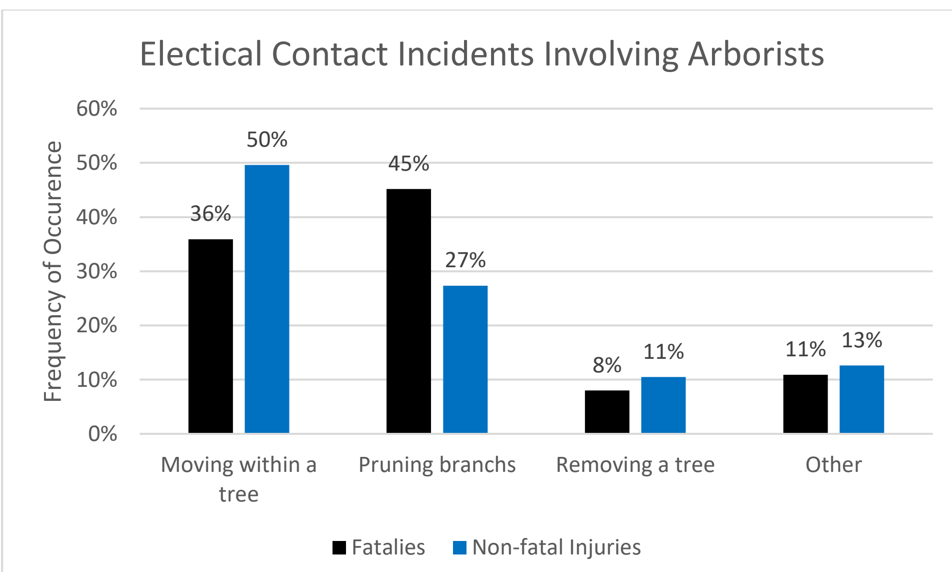

Figure 1 Frequency of electrical contact incidents by activity

It is important to note that the fatality and injury data presented above are from two different datasets. The fatality data reflect the total number of incidents while the injury data is based on a large sample. While the number of incidents in each type of incident in the dataset are not directly comparable, the relative frequency of occurrence within each group is, as reported in Figure 1 above.

Direct and Indirect Electrical Contacts

While the data from two different sources do not support a direct comparison, the relative frequency of direct and indirect contact incidents that resulted in fatal and non-fatal injury, analysis withing each class of consequence is revealing.   Direct contact incidents that resulted in a fatal injury occurred while the arborist was climbing or repositioning within the crown of a tree. It is likely that while moving they inadvertently contacted a high voltage conductor. Fatalities also occurred when the arborist's movement created indirect contact such as through a branch, and the frequency of occurrence between direct and indirect contract were similar. Note that incidents classified as "other" are not included in Figure 1. No fatal direct contact incidents occurred during pruning and removal activities

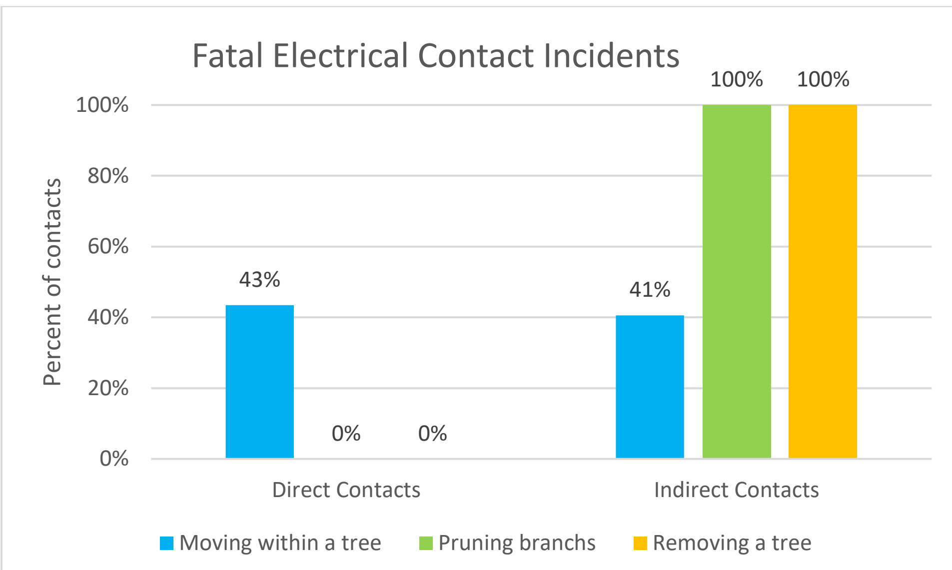

Figure 2 Type of electrical contact resulting in fatal injury by activity at the time of the incident.

Fatalities that occurred during the act of pruning or removing a tree were due to indirect contact rather than direct contact. Indirect contact occurred when either a branch or tool came into contact with a high voltage conductor during the arboricultural operations.

The relative frequency of electrical contact incidents that resulted in non-fatal injuries to arborists is similar to that of fatalities. The only notable difference is that some non-fatal direct contact incidents occurred during tree removal operations.   It is notable that both fatal and non-fatal direct contact incidents are most likely to occur while the arborist is moving as opposed to pruning branches or removing trees.

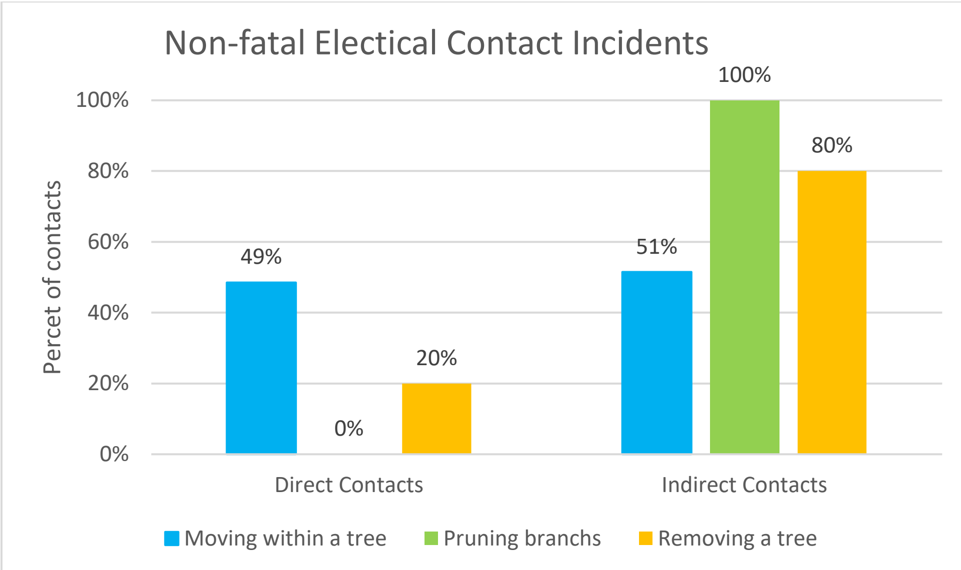

Figure 3 Type of electrical contact resulting in non-fatal injury by activity at the time of the incident.

Moving and repositioning

Five scenarios were identified that define the types of electrical contact incidents experienced by arborists as they climbed, moved into position, or were repositioning to a new work location within the crown of a tree.

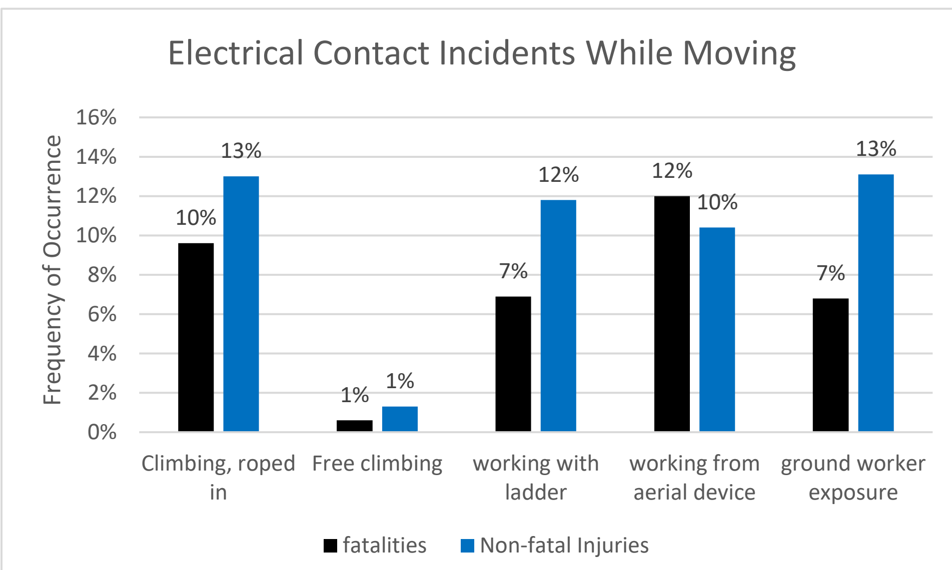

Figure 4 Frequency of electrical contact incidents that occur when an arborist is moving within a tree's crown.

In only four of these scenarios, the injured party was the arborist. In the remaining electrical contact scenarios where the contact occurred as a result of changing locations, the injured party was working on the ground in support of work being performed aloft.

Pruning branches

Pruning is a core service provided during arboricultural operations. Six electrical contact scenarios were considered. Three scenarios involved branches that had been cut clear of any attachment with the remaining portion of the tree. Contact occurred as they fell away, were being guided manually as they fell, or when an attempt was made to clear a "hanger".

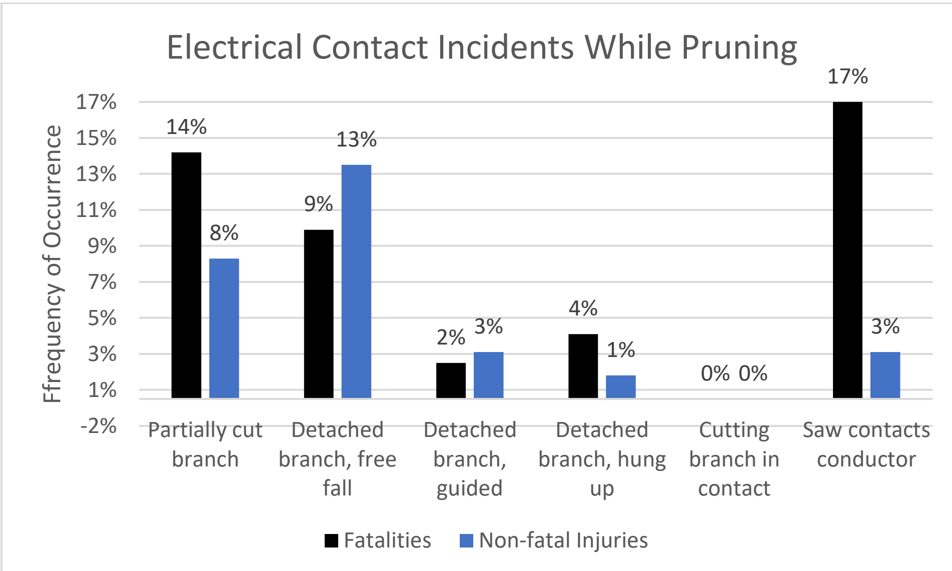

Figure 5 Frequencies of electrical contact incidents that occur when an arborist is pruning branches.

Indirect contact through a fault pathway provided by a cutting tool was a leading cause of fatalities during pruning work. Interestingly, the frequency of electrical contact incidents while pruning a branch that was in contact with an energized conductor was very low, perhaps due to heightened awareness of the potential hazard.

Tree Removal

Arboricultural operations include tree removal work, though less frequently than pruning work. This is reflected in Figure 6 as compared to those pertaining to moving and pruning work above. Five electrical contact scenarios were identified as being associated with tree removal work.

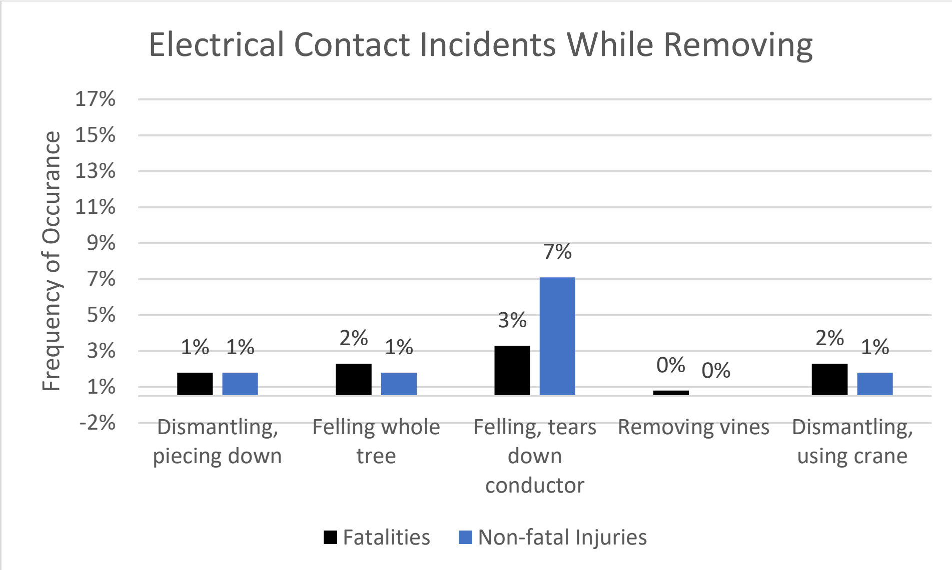

Figure 6 Frequencies of electrical contact incidents that occur when an arborist is removing a tree.

Electrical contact incidents were more commonly associated with felling of whole trees as opposed to disassembling or taking the tree down in a more controlled manner, disassembling it piece by piece.

Fatal incidents

The most common electric contact fatal incident among all arborists, regardless of occupation, was indirect contact through a branch (28.1%). The branch was either being cut or had already been detached but was still held by the worker when it contacted an energized conductor. The contact also occurred from a falling cut and detached branch that simultaneously contacted the worker and an energized electrical conductor. Most of these contacts were to climbers but aerial device operators (including aerial lifts, scissor lifts, and manlifts) and workers on ladders also had some of these contact incidents.

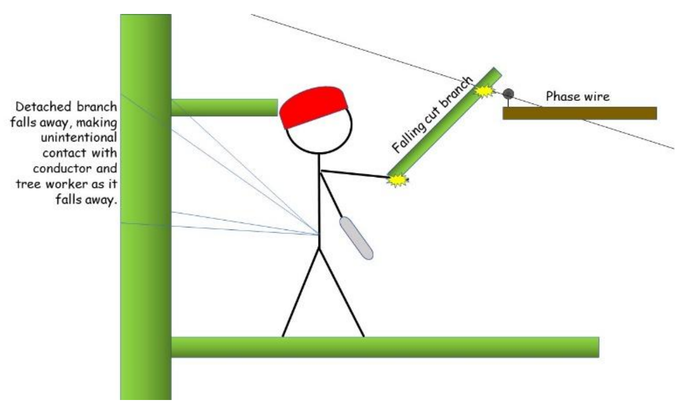

Figure 7 Indirect contact through detached branch.

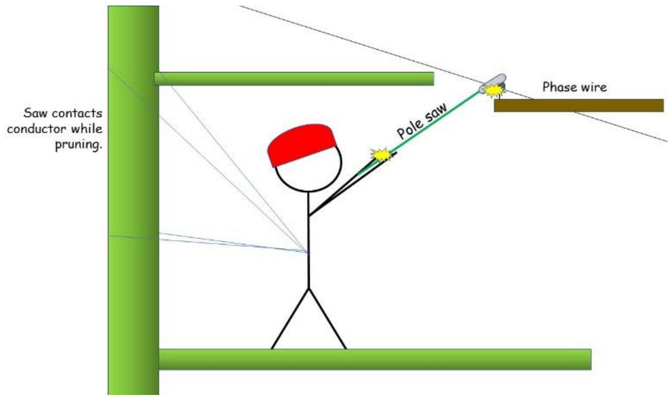

Figure 8 Indirect contract through conductive pole saw

The second most common electric contact fatal incident was indirect contact with an energized conductor through a pole saw/pruner, hand saw, or chain saw (21.8%). Most of these incidents involved a conductive, manual or powered extended-reach pole saw that contacted an energized conductor while being held by the worker. Most of these contacts happened to climbers, but aerial device operators and workers on a ladder also had the same contact incidents. The remainder happened while the worker was operating a pole saw from the ground.

The narratives were sometimes unclear as to whether the contact was through the saw as it was cutting a branch or the partially cut branch deflecting and touching the conductor. Regardless, these two indirect contact events, indirect contact through a saw or cut branch, comprise half (49.9%) of all the electrical contact incidents.

The third most common fatal contact (7.9%) was an aerial lift operator's body making direct contact with energized conductors. These often involved contact through the back shoulder or head to a primary conductor and a hand to the neutral. The underlying cause for this contact was typically a tree or tree part striking the boom and pushing the bucket into the energized conductors. There were also incidents where the aerial device operator was not aware of the conductor or lost sight of it and inadvertently made contact with a phase wire while their hand was touching the neutral.

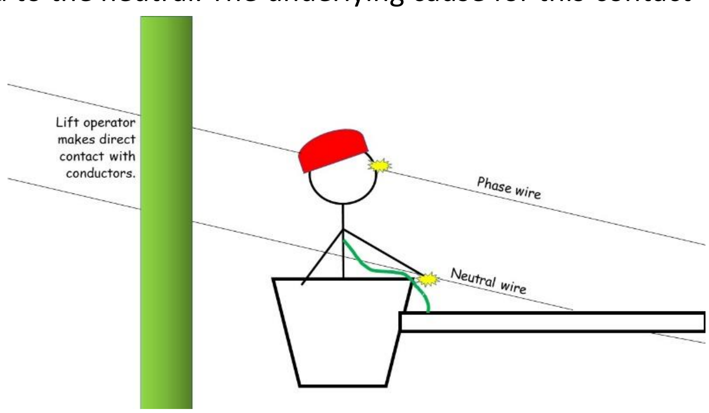

Figure 9 Direct contact with energized conductor.

The fatal electrical contact incidents to arborists reported by a large investor-owned utility were of similar types as found in the CFOI data. The three most common contacts were (1) a saw, typically an extended reach pole saw, contacting the energized conductor, (2) direct contact with an energized conductor by the operator of an aerial device and (3) a detached cut branch contacting the arborists and energized conductor.

Non-fatal incidents

The most common non-fatal electrical contact was through a cut/detached branch contacting the arborist while also striking an energized conductor (13.4%) while it was falling away. This is different than the scenario depicted in Figure 7. These typically occurred to a climbing arborist but could also involve arborists and landscapers who were struck by a detached branch while operating an uninsulated aerial device.

The second most common non-fatal electric contact was a groundworker touching an aerial device while the boom was in contact with the energized conductor (11.8%). Several of these touch potential contacts were to arborists operating a chipper that was hitched to the aerial device truck when the boom contacted the energized conductor. Line-clearance arborists, workers that were clearing space around conductors on behalf of a utility, were the workers who most often experienced touch potential. Touch potential is the difference in voltage between any two points on a person's body, and in this case from hand to feet on the ground.

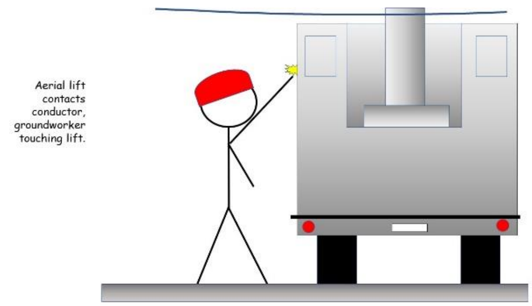

Figure 10 Indirect contact through aerial lift.

The third most common type of non-fatal contact was when the climber deflected a branch that contacted the energized conductor. This was not a very common fatal incident, only about 2.0%, but represented almost 8% of the non-fatal incidents. Many of the non-fatal incidents listed only electric shock as the injury with nearly half also noting burns. The branch deflection contact incidents often mentioned fractures, rather than burns, as the contact startled the climber which resulted in them losing balance and falling or swinging into the tree.

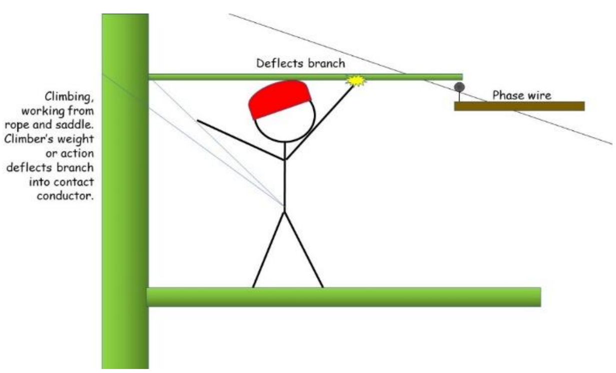

Figure 11 Indirect contract through deflected branch

This contact also was reported in the utility incident reports, about 4.4% of the non-fatal incidents. Climbers noted a "tingle" and either fell or jumped from the tree, resulting in fracture injuries.

The most common non-fatal incident reported among arborists in the utility reports, however, was contact via a detached branch (31.1%). Indirect contact created when a detached branch came into contact with an energized conductor and an arborist was operating an aerial device represented 8.9% of incidents.

Arborist Exposure to Voltages and Currents

A *hazard* is a likely source of harm. In this case, the presence of an energized high voltage conductor in proximity to a tree can be a hazard to arboricultural operations. Direct or indirect contact with an energized conductor may expose an arborist to electrical currents and voltages that can have very serious consequences.

Exposure to Primary Voltages

Overhead electric distribution circuits include two classes of line: primary and secondary. A span of primary line has as many as three high voltage phase conductors and includes a grounded system neutral conductor at 0V which normally carries no or very low current. Distribution primary systems typically operate at 5 - 35kV. Primary conductors typically do not have a coating and are simply bare wire. In some cases, primary conductors are coated with a protective coating of polyethylene; these are commonly referred to as “tree wire”. While this coating does provide some degree of protection from tree-initiated contact fault, it is not rated or intended as insulation.

The other class of line on a distribution circuit is low voltage secondary. Similar to primary lines, there may be as many as three secondary conductors in a span. The secondary system typically shares a common neutral with the primary system. Secondary conductors may be bare wire, could be coated with “weather stripping”, or coated with a protective polyethylene coating that is rated to 600V. This heavy coating allows the bundling of multiple secondary phases into twisted multiplex.

Table 6 Common voltage classes on overhead distribution systems

Class of Distribution Line	Phase to Ground	Phase to Phase
High Voltage Primary	19.9 kV	34.5 kV
High Voltage Primary	14.4 kV	24.9 kV
High Voltage Primary	7.6 kV	13.2 kV
High Voltage Primary	7.2 kV	12.5 kV
High Voltage Primary	2.8 kV	4.8 kV
High Voltage Primary	2.4 kV	4.2 kV
Low Voltage Secondary	120V	240V

Voltage is a measurement of the difference in electrical potential between two points. It can be thought of as the “pressure” pushing current between two points. There are two levels of exposure on overhead primary distribution system lines. Electrical contact incidents involving arborists typically involve a fault pathway from an energized phase conductor to ground (neutral or earth). This would be true for both direct and indirect contact incidents. The level of voltage to which an arborist is exposed varies by an order of magnitude, 2.4 - 19.9kV. The other, much less likely fault pathway, would be between energized phases, and the voltage differential between two energized phases is roughly twice as great. Electrical contact incidents associated with arboricultural operations typically involve a single-phase high voltage conductor and a ground references such as earth (typically 0V). The voltage level drops along the fault pathway as it encounters areas of varying conductivity.

Electrical faults

A fault is the unintended flow of electricity from a source (energized conductor) to ground, which could be a neutral wire, or simply earth. Current flows through the fault pathway that connects these two areas of unequal electric potential (voltage). In an electrical contact incident involving an arborist, a fault pathway is created extending from the conductor, through intermediary objects such as a tree or the worker, and potentially other objects to ground.

The conductivity of the individual elements of the fault pathway determines the level of current that will flow.

Electrical resistance can be thought of as restricting or impeding the flow of electrical current between two points of differing voltage. Conductivity is measured in ohms (Ω) and described as "impedance" on AC power systems ("resistance" is used on DC power systems).

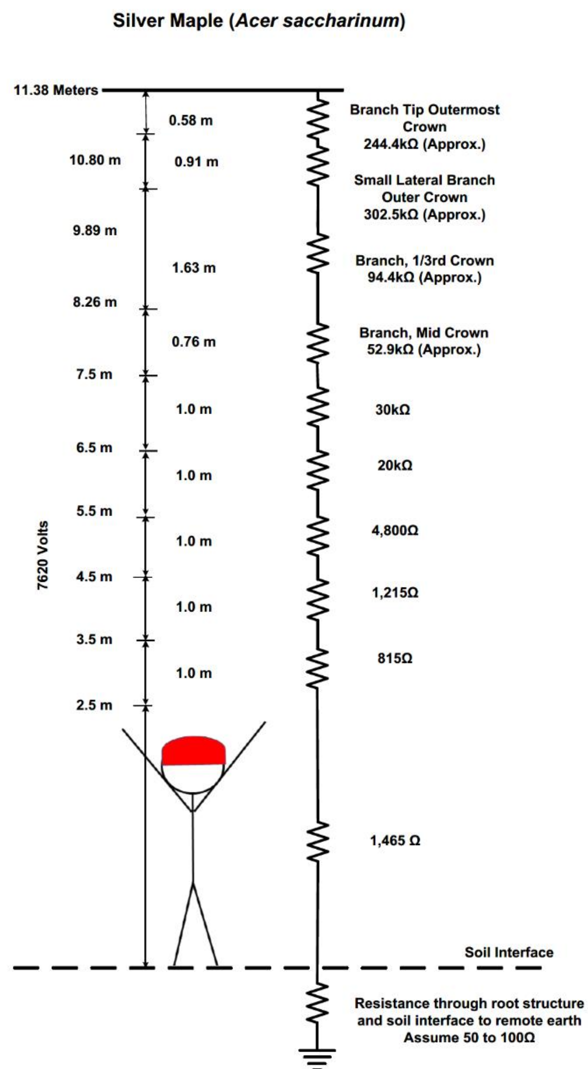

Figure 12 Impedance levels through a mature silver maple (Acer saccharinum) at 7620V RMS.

Goodfellow (2008) measured the conductivity of live trees and developed circuit diagrams that depict changes in conductivity of individual elements of a mature tree from upper crown to earth. The conductivity of a tree from fine twigs in the upper crown to branches, and down the main trunk varies by several orders of magnitude as can be seen in Figure 12. The very high impedance of small twigs and branches typically results in a very significant drop in voltage in the upper crown.

A series of high voltage contacts with progressively larger branch diameters demonstrates the effect of diameter on branch conductivity (Goodfellow 2007).

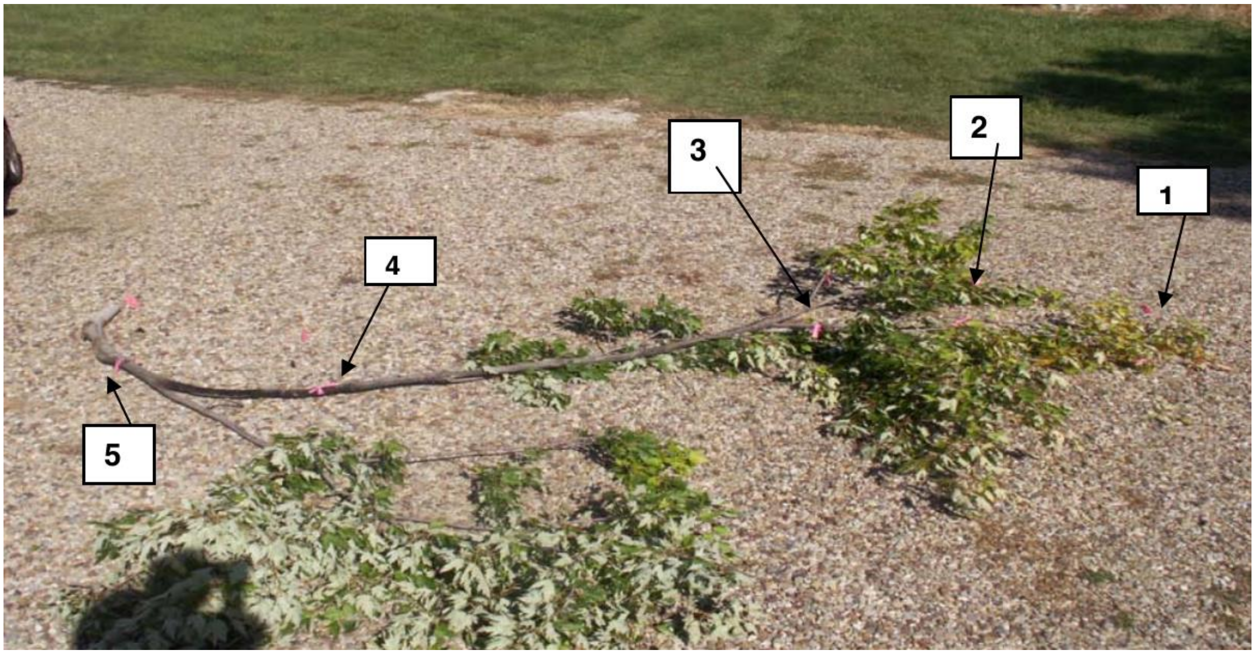

Figure 13 Series of progressively larger high voltage contacts along a silver maple (Acer saccharinum) branch.

Small diameter new growth is much less conductive than larger branches, as can be seen in a series of high voltage contacts with progressively larger branches diameters

Table 7 Observed fault currents and estimated impedance of progressively larger branch segments.

test	Contact points with energized 7.6kV conductor	Diameters at contact (in)	Current (mA)	Impedance (Ω/ft)
1	Fine twig, new growth in outermost crown	<0.2	10	320,000
2	Small diameter lateral branch in outer crown	0.6	15	175,000
3	Secondary branch inside crown	1.2	75	14,000
4	Main branch in inner crown, halfway to main trunk	1.6	750	4000
5	Main branch close to trunk	>2.4	1000	300

The impedance values reported in the table above have been normalized to a common reference of ohms per foot (Ω/ft). The impedance of individual parts of a tree differs by orders of magnitude. The conductivity of a branch increases substantially with diameter. It should also be noted that bark provides relatively high initial contact impedance. The values in Table 7 reflect steady state conditions once initial contact impedance has been overcome and fault current is flowing.

The length of the fault pathway provided by a branch is also an important factor. Branch segments can be thought of as a series of resistive elements. Long branch pathways are much less conductive than short ones. In summary, both the length and diameter of a branch directly influence the conductivity of the fault pathway between areas of unequal electrical potential (voltage). Shorter pathways and larger diameter branches are much more conductive than long slender branches.

The exposure that arborists have to electrical current is created by either direct or indirect contact with an energized conductor. An arc across an air gap from a branch or tool to a conductor energized at typical distribution system voltages (*Table 6*) would not be initiated under normal atmospheric conditions. The dielectric strength of air is 3 kV/mm. The notion that electricity can jumped across an air gap of this distance is scientifically insupportable. Witnesses to an electrical contact incident sometimes report hearing and then seeing an arc in air between a conductor and conductive object such as a tool. What they did not see is that the tool initially touched the line and was pulled away, drawing the arc with it. Once created, the superheated plasma in air provides a very low impedance pathway. An arc in air can also be created when current flowing through the fault pathway provided by a branch creates a highly conductive carbon track along the branch. When this happens, current can flash across the branch resulting in a high-current, low-impedance arc in air.

Exposure to Currents

Current can be thought of as the volume of electricity that flows between two points and is measured in amperes (A). The Safety Standard (ANSI Z133 2017) for arboricultural operations recognizes two types of electrical contacts that have the potential to result in injury or electrocution of an arborist:

1. Direct contact occurs when any part of the body touches or contacts an energized electrical conductor.
2. Indirect contact occurs when any part of the body touches any conductive object including tools, tree branches, a truck, equipment, or other object that is in contact with an energized electrical conductor.

As previously described, most incidents during arboricultural operations occur as a result of indirect contact with the conductor through an intermediary object such as a tree branch or tool. The victim's body then becomes the next step in the fault pathway as current flows to ground through the remaining elements of the pathway. The level of fault current that flows during an electrical contact incident is a function of the conductivity of the entire fault pathway.

Fault currents associated with different contact locations flowing through trees have been evaluated (Goodfellow 2007, 2008). The high voltage contact point was moved from the outer crown to a large scaffolding branch close to its union with the main stem of the tree, as illustrated in Figure 12Figure 13. The test results reported in Table 7 demonstrate that fault current is influenced by the diameter of the branch. Small diameter branches, especially non-suberized tissues characteristic of new growth, are much less conductive than larger branches. This limits the level of fault current associated with incidental contact with energized conductors.

The impedance of small-diameter contact points and fault pathways coupled with long fault pathway lengths limits fault currents. Conversely, shorter, larger diameter pathways result in higher fault currents. Also, relatively high initial contact impedance across a thick layer of bark further limits fault current on the surface of the bark.

High voltage (7820V) faults were created by the Texas A&M Engineering Experiment Station (Goodfellow 2021) in a demonstration intended to simulate indirect contact incidents through tree branches. Live, recently harvested hackberry (*Celtis occidentalis*) branches of various lengths (6', 10', 15') were tested under a variety of exposure scenarios. The branches tested were typical of those that had grown close to an energized conductor, were slender, and included fine twigs. In some tests the branches were electrically detached (isolated) from a tree, and in others the branch was grounded to simulate its remaining attached to the tree. Contact exposure across the bark and from exposed woody tissue were evaluated using a 2015Ω resistor as a human surrogate.

Table 8 Fault current levels through live hackberry (Celtis occidentalus) branches at 7.8kV.

pathway (in)	Large Día (in)	Small Día (in)	Initial fault current	Steady state fault current	Description of fault pathway tested
78	1.00	<0.25	22 mA	83 mA	Detached branch, exposure to current from xylem, multiple (6) small diameter contacts
78	1.00	<0.25	20 mA	130 mA	Attached branch, bark pierced, exposure to current from xylem, multiple (6) small diameter contacts
78	1.00	<0.25	22 mA	32 mA	Attached branch, exposure to current across bark, multiple (5) small diameter contacts
120	1.75	<0.25	23 mA	25 mA	Detached branch, exposure to current across bark, multiple (6) small diameter contacts
120	1.75	<0.25	13 mA	18 mA	Attached branch, exposure to current across bark, multiple (6) small diameter contacts
120	1.75	<0.25	9 mA	29 mA	Detached branch, bark pierced, exposure to current from xylem, multiple (5) small diameter contacts
120 -156	2.75	<0.25	25 mA	29 mA	Attached branch, exposure to current across bark, simulated contact with two hands three feet apart
180	2.75	<0.25	18 mA	25 mA	Detached branch, exposure to current across bark, multiple (6) small diameter contacts
180	2.75	<0.25	<1 mA	<1 mA	Attached branch, exposure to current across bark, multiple (6) small diameter contact

As previously discussed, both the length and diameter of the of the fault pathway provided by the branch are important considerations. Longer pathways have higher impedance, resulting in exposure to lower levels of current. Similarly, small diameter branch and twig contacts with energized conductors create a high impedance fault pathway that limits fault current. The very small diameter branch contact points and long slender branches described in the table above provide relatively high impedance fault pathways (e.g., 250-300kΩ for 120 inch tests). This significantly limits fault current levels. These tests demonstrate that incidental tree-conductor contact with the tips of small branches results in low levels of fault current. Shorter pathways and thicker branches would be more conductive and would expose an arborist to higher levels of fault current. Branches that remain attached (electrically connected) to the tree result in lower currents, as the tree provides a parallel path to ground. In contrast, higher currents result when detached branches are the only path to ground through the surrogate human. The relatively high contact impedance across the bark reduces current levels as compared to exposure to the underlying woody tissues.

Other types of indirect contact incidents involve an intermediate object between the energized conductor and arborist such as a pole saw or chain saw, both of which are much lower impedance (more conductive) than branches. This exposes the arborist to even higher levels of fault current.

The fault current levels reported in Table 8 were measured using a very low impedance connection to ground. The level of fault current that flows during an electrical contact incident is a function of the conductivity of the entire fault pathway. Incidents that take place during arboricultural operations may include conductive objects beyond the arborist in the remaining fault pathway to ground such as aluminum ladders and uninsulated aerial platforms that would do little to limit the magnitude of fault current, and there can be multiple parallel pathways to ground. This is true whether the indirect contact is through a tree branch or a cutting tool.

The available fault current on a typical distribution primary system can be more than 1000 A close to the substation and hundreds of amperes on single phase laterals. Utility overcurrent protection systems are designed to detect and interrupt current levels that exceed the expected load. Experience has shown that the high impedance, low current faults that are typically associated with electrical contact incidents during arboriculture operations are not detected and interrupted by fuses or reclosures, unless there is a short conductive path to ground such as the system neutral or other infrastructure electrically bonded to it.

Consequences of Exposure

The human body will conduct electricity, but the pathway is through the body, not over it. Skin has high dielectric properties (is less conductive), whereas internal tissues, blood vessels and muscles (along the grain) are excellent conductors. If an arborist makes contact with an electrically energized object while simultaneously contacting another object at a different voltage level, current will flow through the body.

Electrical injuries are usually assigned to one of two categories, low voltage (<1000 V) or high voltage (≥1000 V) (Arnoldo and Purdue 2009). The choice of 1000 V as the threshold is arbitrary but is widely accepted. This use of voltage as measure of injury can be misleading. The physiological reaction to the passage of electrical current through the body is the cause of electrical shock, not the voltage. A better means of classifying electrical injuries may be electrical power (Kroll et al. 2012). Power is measured in watts (W) and is calculated as current (A) times voltage (V).

While electrical power may be a better measure, voltage is the common one and will be used in this discussion. The most common cause of a high voltage injury is contact with an overhead power line (Brenner *et al*. 2020). The majority of the electrical contact incidents reviewed in this study were on overhead primary voltage distribution circuits energized at 7.2 kV or higher. The outcome of this contact is high morbidity and mortality. In addition to fatal incidents, complications of contact with overhead power lines include amputations and compartment syndrome.

Low voltage contact resulted in fewer fatalities; less than 8% of the incident reports identified a secondary line (120/240 v) as being the energized conductor. Complications were less severe with fewer amputations (<15 %) recorded incidents in one study (Kym *et al*. 2014). However, among burn injury patients, low voltage injuries produce more long-term physical and psychological sequelae than high voltage (Singerman *et al*. 2008). These may not present until months following the contact.

As previously discussed, it is exposure to current, not voltage, that causes the electric shock, and the extent of injury is proportional to the level of fault current flowing. Other factors include the duration of exposure, the pathway the current travels through the body, and the location of the contact and ground points.

During an electrical contact incident, current flows from high to low voltage across the entire fault pathway created by the initial contact. The sum of the resistance of each step along the pathway limits the amount of current flowing, while the level of fault current is constant throughout the pathway. High voltage electrical contact incidents that involve a relatively conductive pathway from conductor to ground have the highest levels of fault current. For example, when an arborist makes direct contact with a conductor and the pathway to ground includes an aluminum ladder or uninsulated aerial platform, this creates a relatively conductive pathway. Fault pathways involving indirect contact incidents by branch to arborist, and then to earth through a tree, are much higher resistance and involve exposure to lower levels of fault current.

Electrical contact incidents involving arborists can result in three types of injury:

1. Tissue damage due to the flow of fault current through the body. This may include disruption or interruption of the heartbeat and thermal damage to internal tissue.
2. Burns due to exposure to radiant and convective heat energy sources associated with an electrical arc.
3. Physical injuries due to severe muscle contractions or shock-induced falls.

The severity of injury escalates with exposure to increasing levels of fault current. The general progression of electrical injuries is presented in Table 9 at the end of this section. This table is an adaptation of an industry reference (IEEE Std 902), augmented with observations from other general references. The reaction to increasing levels of current are described in the following sections of text.

Sensation

There are no harmful reactions at the very lowest levels of exposure to fault current. The first indications of contact with alternating current have been described as a tingling sensation. This is noted in several non-fatal injury reports where an arborist first noted a tingling sensation as they approached an energized aerial lift. Some took this as a warning and stopped moving towards the truck.

This first indication of contact varies depending on contact impedance across the skin. For example, the initial sensation occurs at a higher level of fault current if contact is across callused hands. Women, who typically have fewer calluses, are aware of current flow at lower levels than are men. As the level of current exposure increases, the sensation becomes painful.

Startle reaction

Contact with an energized source associated with relatively low level of fault current can surprise an arborist causing them to lose contact with the tree and fall. The contact can also cause immediate pain. A painful stimulus to an extremity elicits a NWR (nociceptive withdrawal reflex) (Serrao *et.al.* 2006, Eckert *et.al.* 2013). This is something we all experience when we have touched a surprisingly hot object. The hand and lower arm are immediately pulled back towards the core of the body. The contralateral (opposite) limb tends to move outward to maintain balance. The NWR is quite fast, leading to contact breaking in 150 ms.

Being thrown back

People who have experienced an electrical shock often describe being "thrown" to characterize the immediate and strong involuntary movement they experience (Lee, Wills). A hand-to-hand current can cause a sudden strong contraction in the rhomboid muscles causing the upper body to violently move backwards (Lee 1961, Tkachenko *et.al* 1999). Electric shock recipients often use the term "thrown" to describe this impressive sudden movement of their body (Lee 1961). About 13% of professional electricians recall being "thrown away" by a shock (Tkachenko).

Guest editor Kroll has experienced this three times in his career and has always found it very impressive.

Such an effect typically involves a hand-to-hand shock so that the current is passed through a person's back muscles. (It can also occur with a hand-to-foot shock.) Whether due to a NWR or being thrown back, an arborist may lose their connection to the tree, resulting in a fall or inadvertent swing into contact with the conductor. There were several incidents where an electric shock resulted in the climber swinging by their climbing line into a tree part. The impact led to lacerations and fractures while the electrical shock was the secondary injury.

Grasp reaction

With a fault current > 15 mA entering the palm of a hand, muscle contractions become strong enough that the victim cannot let go of the source of the shock, freezing the victim to the circuit (Dalziel 1956). As a result, the fault created by the initial contact continues until interrupted by some other source. Muscle contractions at increasing levels of exposure to fault currents can be violent enough to result in hemorrhaging, dislocation of joints, and fractures (Leibovici 1995, Karger 2002).

Respiratory reaction

Muscle contractions associated with exposure to current can cause respiratory arrest. Fault current flowing across the chest can cause muscle contractions resulting in tightness and paralysis of the chest muscles. However, this mechanism is rarely associated with high voltage contact incidents. It is more likely that respiratory arrest is secondary to ventricular fibrillation (VF) of the heart (Kroll *et al*. 2012)

Cardiac reaction

As the level of fault current increases, so does the potential for triggering VF, which is responsible for 99.9% of electrocutions. VF is the type of cardiac arrest caused by uncoordinated twitching of the walls of the heart's ventricles, disrupting the circulation of blood throughout the body. Both the level and duration of current exposure are factors in whether an electrical shock results in VF (Kroll 2021). Shorter exposure requires higher fault current levels — and special timing — to induce VF.

The range of currents associated with VF reported in generalized charts typically assume a shock of at least 1 second of duration. This is long enough for moderate currents to affect the heart as it is longer than a heartbeat. (Kroll *et al*. 2012)

The timing of the shock in the context of a heartbeat is also a factor. The T-wave is the part of the ECG signal that represents the initiation of ventricular relaxation; this is the time when the cardiac cells are returning to their "resting" state. The implications of timing of the initial shock have been well described (Kroll *et al*. 2012):

"In the middle of the T-wave, about half of the cardiac cells are back to rest and about half are still active. Because of this, an electrical shock, of appropriate strength, delivered during this time will lead to waves going in unpredictable paths throughout the heart. This leads instantly to VF. That is why the T-wave is referred to as the "vulnerable" portion of the heartbeat".

At much higher levels of fault current (4A) the heart can become electromechanically silent or experience paralysis due to sustained contraction of heart muscles.

Respiratory and cardiac arrest were not identified in any of the narratives summarizing electrical contact incidents involving arborists. There were three fatal events where it was reported that cardiopulmonary resuscitation (CPR) was initiated by fellow workers. CPR training has been an OSHA requirement for working near conductors for decades (NIOSH 1986). OSHA has identified prompt CPR and advanced cardiac life support as critical life-saving interventions. However, burns are the most frequently mentioned injury in the narratives of the incident reports.

Burns

The most common electrical injuries associated with higher levels of fault current are burns. Slightly more than half of the severe non-fatal incidents identified burns as an outcome of the electrical contact. Fault currents associated with contact with an overhead high voltage distribution system primary voltage conductor can be high enough to result in devastating thermal injuries. The cause of these burns may be due to internal resistance heating of tissues and/or external sources of heat.

Current flowing through a fault pathway encounters areas of electrical resistance and generates heat along the way. In an electrical contact incident, the arborist's body becomes part of the fault pathway and experiences resistance heating. Higher levels of fault current have the potential to produce large quantities of heat energy depending on the conductivity of the pathway. The amount of heat produced is a function of voltage ("pressure") exposure across the body, amperes of current flowing ("volume"), the electrical resistance of the body, and duration of exposure. Burns produced by this mechanism can occur deep within tissues.

Dry skin has relatively high resistance to the flow of electricity. High voltage is required to overcome this initial contact resistance. Current flowing through the body results in deep and extensive burns that may extend beyond the contact and ground points. These internal burns result in tissue destruction and necrosis, which may be more extensive than immediately apparent. Partial-thickness burns, those extending into the skin layer, and full-thickness burns, ones that may burn the underlying tissue including muscles and internal organs, may require amputations, debridement, fasciotomies and skin grafts. Low-voltage burns are superficial, residing in the upper layer of the skin, and are localized as the contact and ground points.

Severe burns can also occur from an external source. Limited mechanical connection between areas of differing electrical potential (voltage) may result in the propagation of an arc through air. Once formed, an arc in air provides a low impedance pathway through ionized air with corresponding high levels of fault current. The temperature of the arc may be approximately 4,000^{o} C. The intense heat of an arc can result in severe burns from exposure to either radiant or convective heating. Flash burns from an arc are diffused, causing partial-thickness burns to the skin; they can also result in full-thickness burns extending into underlying tissue. Arc-induced burns were noted in several incident reports involving non-fatal injuries. These burns occurred when the clothing of the injured worker caught fire.

Table 9 Current range and effect on 150-pound human, adapted from IEEE Std 902-2011: Guide for Maintenance, Operation and Safety of Industrial and Commercial Power Systems

Current (60 Hz)	Physiological effect	Consequences
<1 mA	None	Imperceptible
1 mA	Perception threshold	Awareness
1-3 mA	Stimulation	Mild sensation, tingling
3-10 mA	Muscle contraction, painful sensation	"**Startle reaction**"; Noxious withdrawal reflex. Muscular contractions which may result in sudden movement of the body, pulling person away from the shock source. Often referred to as being "thrown".
15 mA	Threshold of paralysis of limbs	"**Grasp reaction**"; Muscular contractions are strong enough that the victim loses ability to voluntarily let go of the circuit.
150 mA	VF very possible.	Cardiac arrest from VF. Universally fatal unless defibrillated. The 150 mA level is for a hand-to-foot pathway. For a hand-to-hand pathway the VF threshold is about 400 mA.
1.5 A	Tissue and organs experience resistance heating	"**Burn reaction**"; Tissues heat and begin to burn. Burns become increasingly severe as fault current increases.
>5 A	Tissue burning	"**Burn reaction**"; severe burning, not fatal unless vital organs are burned

Fault currents that flow during electric contact incidents involving typical primary distribution lines are believed to be less than 10 A (Sances 1979). Indirect contact incidents that include a branch as part of the fault pathway typically result in much lower currents due to the relatively low conductivity of plant material.

Effect of Current Over Time

As previously described, the physiological effects and consequences of exposure to fault currents presented in Table 9 are stated generally. It is also important to consider the duration of such exposure. Current will continue to flow as long as the fault pathway remains intact. Simply put, the severity of the physiological effects and the consequences of electrical contact incidents will increase with fault duration; conversely, short durations result in less-impactful implications.

The authoritative reference regarding the effects of exposure to current over time is found in a safety standard produced by the International Electrotechnical Commission (IEC 2018). The table below is a simplified version of Table 11 contained in that standard. It describes the zones for current over time depicted in Figure 14 of this report and is a direct copy of Figure 20 in the IEC Safety Standard.

Table 10 Physiological effects of exposure to body currents over time, adapted from "Effects of current on human beings and livestock" (IEC 60479-1 2018)

Zone	Physiological Effects
AC-1	Perception possible but usually no startle reaction.
AC-2	Perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects.
AC-3	Strong involuntary muscular contractions. Difficulty in breathing. Reversible disturbances of heart function. Immobilization may occur. Effects increasing with current magnitude. Usually, no organ damage to be expected.
AC-4	Pathophysiological effects may occur such as cardiac arrest, breathing arrest and burns or other cellular damage. Probability of ventricular fibrillation increases with current magnitude and time. AC-4.1 probability of ventricular fibrillation increasing up to about 5% AC-4.2 probability of ventricular fibrillation up to about 50% AC-4.3 probability of ventricular fibrillation above 50%

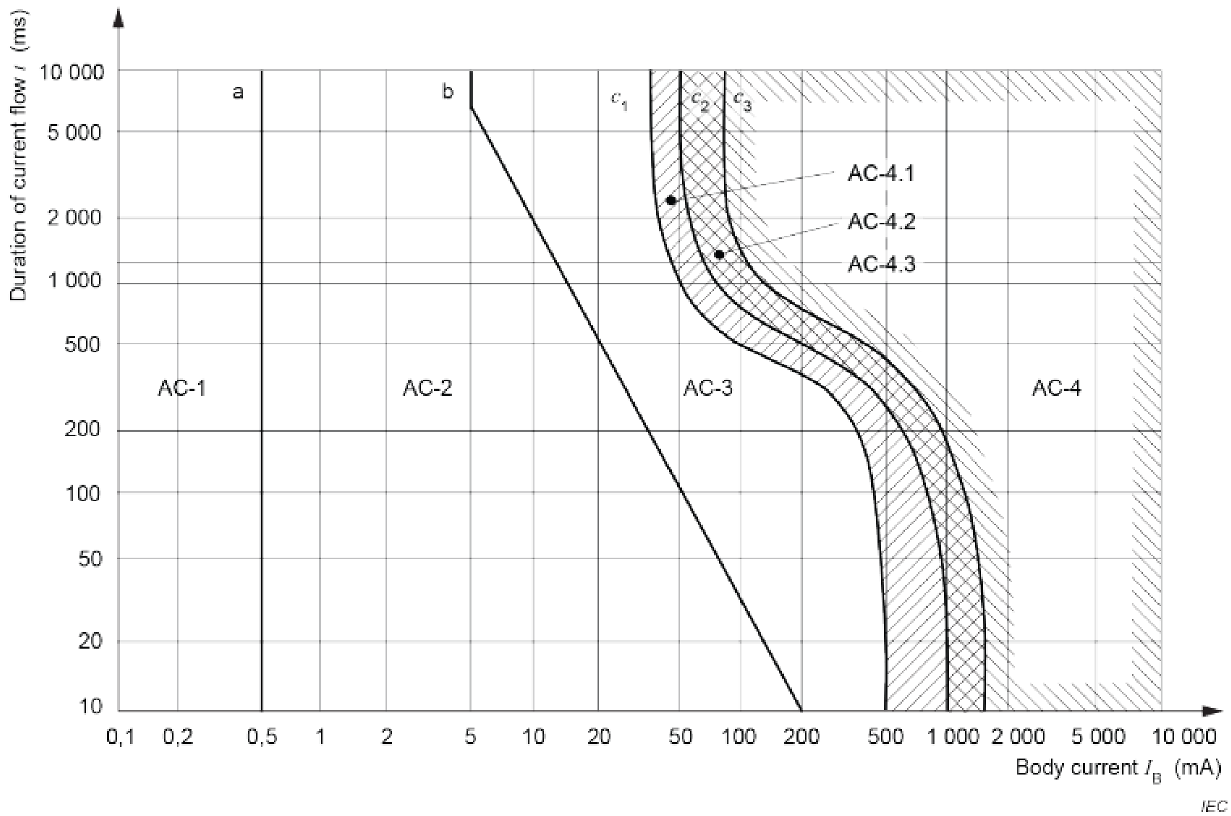

Figure 14 Conventional time current zones of effects of AC currents 15 Hertz to 100 Hertz on persons for a current path corresponding to left hand to feet. Source: "Effects of current on human beings and livestock" (IEC 60479-1 2018)

The effect of duration of exposure to fault current is apparent in the figure above, and reasonably represents exposures that could occur during arboricultural operations. The wide range of possible exposure to current over time adds complexity to the analysis of the likely consequences of unintentional electrical contact incidents by arborists.

Safety Standards

ANSI Z133 -2017 established safety requirements for all aspects of arboricultural operations, including working near electrical conductors.

> *"The standard is intended to serve as a reference for safety requirements that will apply to all employees for persons engaged in the business, trade, or performance of arboriculture for pay, operations of which include, but are not limited to, tree pruning, repairing, or maintaining; removing trees, cutting brush; or performing pest or soil management.*" (ANSI Z133.1.3)

The electrical hazard standards contained in Section 4 of Z133-2017 alert workers to the hazards of direct or indirect contact, as well as touch and step potential, among others. Minimum Approach Distances (MAD), the closest distance a worker may approach or bring a conductive object such as a tool or branch to an energized utility system supply line, are also covered by the standard.

The MADs differ depending on the training, experience, and employment of the worker. People working in or with trees, regardless of whether they are trained in arboriculture, must maintain 10 feet of separation from energized conductors (nominal voltage of 50 kV or less phase-to-phase) from their body, equipment, and conductive tools unless specifically trained and qualified by experience to work near conductors.

The current safety requirements for arboricultural operations include two classes of workers that can work closer than 10 feet to energized conductors:

1. Incidental line clearance arborists are tree workers with training and experience to work near conductors but are not working on behalf of the utility. These arborists may approach closer to a conductor, e.g., 2 feet 10 inches from an energized conductor within a voltage range of 5.1 to 15.0 kV.
2. Qualified line-clearance arborists have the training and experience to work near conductors. They are working on behalf of the utility. The MAD for the qualified line-clearance arborists is less than that for the incidental line clearance arborist, as the former are working near conductors every day so are more aware of the presence of conductors.

Table 11 Current ANSI Z133 (2017) Section 4 recognizing three classes of arborists and associated MAD limitations

Voltage classes (AC)	Non-qualified	Incidental Line Clearance (ft-in)	Qualified Line Clearance (ft-in)
<300 V	10 feet	*Avoid contact*	*Avoid contact*
≤750 V		1-6	1-2
≤ 5 kV		2-9	2-3
≤ 15 kV		2-10	2-3
≤35 kV		3-4	2-8

ANSI Z133 is currently being revised. A sub-committee working on Section 4, Electrical Hazards, has proposed a revision to the current three classifications pertaining to tree work. A Low Voltage Arborist classification would recognize that trees are often in close association with low voltage 120/240 V secondary lines. These would include residential services and sundry other communications lines that may operate at low voltages and carry very low currents. Arborists in this category will be trained in safe work practices around utility lines operating at less than

750 V. The proposal also includes renaming the Incidental Arborist classification to Primary Voltage Arborist.

Table 12 Proposed revisions to ANSI Z133, creating four classes of arborists and MAD limitations.

<table>
<tr><th>Voltage classes (AC)</th><th>Non-qualified</th><th>Low voltage</th><th>Primary Voltage (ft-in)</th><th>Line Clearance (ft-in)</th></tr>
<tr><td><300 V</td><td rowspan="5">10 feet</td><td>Avoid contact</td><td>Avoid contact</td><td>Avoid contact</td></tr>
<tr><td>≤750 V</td><td>1-6</td><td>1-6</td><td>1-2</td></tr>
<tr><td>≤ 5 kV</td><td rowspan="3">10 feet</td><td>2-9</td><td>2-3</td></tr>
<tr><td>≤ 15 kV</td><td>2-10</td><td>2-3</td></tr>
<tr><td>≤35 kV</td><td>3-4</td><td>2-8</td></tr>
</table>

At this writing, the expectation is that the proposed changes to ANSI Z133 will be available for public comment in 2023 and a revised standard issued late that year.

Discussion

The following observations are supported by the data and information presented in this report:

Utility overcurrent protection systems

Most electrical contact incidents involving arborists may not be detected by the utility overcurrent systems. The implication is that substation breakers, line reclosers and fuses typically will not interrupt the fault once initiated. Utility overcurrent protection systems are designed to detect and interrupt current levels that exceed the expected load. Fault currents associated with the sixteen electrical contact scenarios associated with arboricultural operations are believed to be less than that needed to serve customers on a typical distribution circuit. As such, they are too low to determine if they are related to customer demand verses a short circuit fault. This project confirms the industry's experience: the high impedance, relatively low current faults typically associated with electrical contact incidents during arboricultural operations are not detected and interrupted by fuses or reclosures. The exception may be when there is a short conductive path to ground such as the system neutral or other infrastructure electrically bonded to it.

Electrical contact incidents resulting in burns

Burns are the leading cause of arborists' injuries and fatalities due to electrical contact incidents. The extent of burn is a function of the level and duration of the fault current. Higher levels of fault current are associated with relatively conductive pathways between the conductor and earth. Fault pathways that include conductive elements such as uninsulated tools, aluminum ladders and uninsulated aerial platforms expose the arborist to greater levels of current, increasing the severity of burns.   Cardiac arrest from VF does not appear be associated with the high voltage electrical contact incidents involving arborists.

Minimum Approach Distances (MAD)

A MAD of 10 feet provides some level of protection against unintended indirect contact through slender branches that have grown into proximity to conductors and that remain attached to the tree. In contrast, indirect contact incidents involving branches as short three feet, while outside the MAD for qualified workers, can expose arborists to much higher fault currents.

Conductivity of branches

Live branches can conductor electricity. There is no uncertainty about that. The question then becomes how much? Research has demonstrated high variability in the conductivity of branches. The conductivity of very small diameter branches is much lower than larger diameter branches. Similarity, long fault pathways through a branch are less conductive than short branch segments. Initial contact impedance across bark is also a factor, as are branch species and condition. The combination of these factors determine conductivity and directly affect the level of fault current to which an arborist would be exposed. While no indirect electrical contact by an arborist that involves a branch is safe, the consequences can vary from relatively benign to fatal.

Fault Pathway from arborist to earth

This project has focused on electrical contact incidents where the arborist's body has either contacted the conductor (direct) or the arborist has made contact through an intermediary object such as tool or branch (indirect). In either case, the focus is on the pathway from high voltage conductor to arborist. This portion of the fault pathway has been and continues to be the focus of safe work practice. The remaining fault pathway from arborist to ground typically has received less attention. The level of current is constant through the entire fault pathway and its magnitude is a function of the impedance of the *entire* pathway. Low impedance, highly conductive components in the pathway beyond the arborist's position can have as great or greater effect on the level of fault current to which an arborist is exposed than the pathway between the conductor and arborist. Low impedance equipment such as aluminum ladders and uninsulated aerial devices result in a more conductive fault pathway between the arborist and ground, and expose the arborists to higher levels of fault current, as compared to an earth return pathway through the tree.

Indirect contact through branches

The most common electrical contact was indirect contact through a branch that was either being cut or had already been detached but was still in contact with the arborist when it contacted an energized conductor. This was true for both fatalities and serious injuries. The arborist was either holding or guiding the branch when it contacted a conductor, or it contacted the arborist and conductor as it fell. The 20-year history of contact incidents reviewed generally does not provide information on the characteristics of the branch involved. However, it is likely that many of the branches involved were quite large (e.g., long, heavy), and therefore were difficult to control. And the associated larger branch diameters make them more conductive. The "90/3/90" pruning rule of thumb[1] would support this observation, as it emphasizes removal of a few large branches as opposed to many small branches. If a large branch with the potential to contact a power line is being removed, risk can be mitigated by removing it in sections.

The Z133 identifies MADs that apply to any tree work in proximity to energized electric lines. The revised Z133 should include more specific language to clarify that the branch being cut, including its arc as it falls away, remains outside of the MAD.

Uninsulated extended reach tools

There is a need for more specific requirements in the Z133 to reduce the risk of indirect contact incidents involving pruning with extended reach pole saws and cut branches. It can be difficult to judge distances from a branch to the conductor or to predict the fall path of a cut branch. It can also be difficult to judge the distance from a pole saw/pruner tip and the conductor. These tools can be awkward to manipulate when fully extended. The pole and the shaft of powered extended reach pole saws are typically made of conductive materials. All but one of the indirect contact incidents that included a pole saw/pruner involved a metal pole. The other one was fiberglass.

Aerial platforms

While the Z133 does have a requirement for the aerial device operator to watch the direction of travel, a more specific description in the Electrical Hazard section may be needed. Also, some of the incidents were due to falling branches pushing the boom and bucket closer to the conductors. Z133 does have a guideline recommending that climbers be positioned on the side of the tree furthest from the energized conductors, but none for the aerial device operator. It would be helpful to include the hazard of operating the boom between the conductors and the branch being cut.

Summary and Conclusions

Accidents are a result of random chance, bad luck, or acts of God. Incidents, on the other hand, are not random, are the result of specific actions, and are preventable. The 20-year history of electrical contact injuries and fatalities associated with arboricultural operations that were evaluated in this project are due to actions taken (or not taken) by arborists. As such they are incidents. This project establishes a basis for understanding the likelihood of adverse exposure to electrical contact incidents and the potential consequences of such exposure. These two factors define the risk to which arborist can be exposed. The hope is that the information

[1] 90% of the work can be completed by 3 well placed cuts 90% of the time.

provided in this report will inform development of arborist training materials, safe work practices, and relevant safety standards.

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Appendix – Exposure Case Studies

Moving & repositioning

Moving[2]**;** Incident occurs while positioning or repositioning with the crown of a tree.

Fatalities = 36.9%, Injuries = 49.6%

Case	Sub-activity	Fault pathway	Arborist	Utility	Grounds	Total
M1	Climbing, working from rope and saddle. Climber's weight or action deflects branch into contact conductor (indirect) or climber makes direct contact with conductor.	Indirect: conductor-branch-climber through hand(s) or body, earth return through tree.	0.5% 2.6%	1.3% 4.0%	0.3% 1.3%	2.0% **7.8%**
		Direct: Conductor - climber's body, earth return through tree.	4.1% 0.0%	1.3% 1.3%	1.0% 4.0%	**6.3%** 5.2%
		Indirect: conductor-lanyard - climber through hand(s) or body, earth return through tree.	0.8% 0.0%	0.0% 0.0%	0.0% 0.0%	0.8% 0.0%
		Indirect: conductor-line - climber through hand(s) or body, earth return through tree.	0.5% 0.0%	0.0% 0.0%	0.0% 0.0%	0.5% 0.0%
M2	"Free climbing", not roped in. Climber's weight or action deflects branch into contact conductor (indirect) or climber makes direct contact with conductor.	Indirect: conductor-branch-climber through hand(s) or body, earth return through tree.	0.3% 0.0%	0.0% 0.0%	0.0% 0.0%	0.3% 0.0%
		Direct: Conductor - climber's body, earth return through tree.	0.3% 0.0%	0.0% 0.0%	1.0% 1.3%	1.3% 1.3%
M3	Working with ladder. Tree worker is moving ladder into position or climbing ladder. Tree worker's weight on ladder deflects branch into contact, or ladder makes contact, or tree worker makes direct contact with	Indirect: conductor-branch-ladder -tree worker through hand(s) or body, earth return through tree.	0.0% 0.0%	0.0% 0.0%	0.3% 0.0%	0.3% 0.0%
		Indirect: conductor-ladder -tree worker through hand(s) or body, earth return through ladder.	0.3% 2.6%	0.0% 0.0%	2.8% 1.3%	3.0% 4.0%
		Direct: Conductor - tree worker's body, earth return through ladder.	0.5% 1.3%	0.3% 0.0%	0.5% 6.6%	1.3% **7.8%**

[2] Assumes normal weather and working conditions. Also assumes that the power system is normally configured.

	conductor while on ladder.	Indirect: conductor-tool-tree worker through hand(s) or body, earth return through ladder and tree.	1.8% 0.0%	0.3% 0.0%	0.3% 0.0%	2.3% 0.0%
M4	Working from aerial device, moving position of basket or boom: a) Boom/basket contacts conductor b) Boom deflects tree branch(es) into contact with conductor. c) lift operator makes direct contact with conductor.	Indirect: conductor-boom/bucket-lift operator through hand(s) or body, earth return through aerial device	0.3% 0.0%	1.0% 0.0%	0.0% 0.0%	1.3% 0.0%
		Indirect: conductor-branch, bucket-lift operator through hand(s) or body, earth return through aerial device and tree.	2.0% 1.3%	0.3% 0.0%	0.5% 1.3%	2.8% 2.6%
		Direct: Conductor-lift operator's body, earth return through aerial device.	4.8% 4.0%	2.0% 2.6%	1.0% 1.3%	7.9% 7.8%
M5	Aerial lift contacts conductor or energized branch(es).	Conductor-lift-groundworker-earth (touch potential)	1.8% 4.0%	3.6% 6.6%	0.5% 1.3%	5.8% 11.8%
		Conductor-lift-earth - groundworker (step potential)	0.8% 1.3%	0.0% 0.0%	0.3% 0.0%	1.0% 1.3%

Tree Pruning

Pruning[3]: Incident occurs while pruning, removing, or reducing branch(es)

Fatalities = 47.6%, Injuries = 29.9%

Case #	Sub-activity	Fault pathway	Arborist	Utility	Grounds	Total
P1	Partially cut (deflected) branch remains attached, and contacts conductor	Conductor-branch-tree worker through cutting tool or hand, earth return through tree.	11.9% 3.9%	2.5% 2.6%	1.5% 1.3%	13.7% 7.8%
P2	Detached branch falls away, making unintentional contact with conductor and tree worker as it falls away.	Conductor-branch-tree worker's body, earth return through tree.	3.3% 6.6%	2.0% 2.6%	4.1% 4.0%	9.4% 13.0%
P3	Detached branch deliberately guided as it falls, making unintentional contact with conductor as it is being guided by the tree worker.	Conductor-branch-tree worker's hand(s), earth return through tree.	1.0% 0.0%	1.0% 2.6%	0.0% 0.0%	2.0% 2.6%
P4	Detached branch gets hung up with other branches as it falls away. Tree worker attempts to clear the branch.	Conductor-branch - tree worker's hand(s). earth returns through tree.	0.5% 0.0%	2.3% 1.3%	0.3% 0.0%	3.0% 1.3%
P5	Tree or branch is already in contact with conductor. Incident occurs as it is being removed	Conductor-branch-tree worker's hand(s), earth return through tree.	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
P6	Saw contacts conductor during pruning activity.	Conductor-tool-worker, earth return through tree.	8.6% 1.3%	1.5% 0.0%	6.3% 1.3%	**16.5%** 2.6%
		Conductor-tool-operator, earth return through aerial device.	1.0% 1.3%	0.3% 0.0%	1.8% 1.3%	3.0% 2.6%

[3] Assumes normal weather and working conditions. Also assumes that the power system is normally configured.

Tree Removal

Removing[4]: Incident occurs while removing a tree, including tree parts.

(Fatalities = 8.0%, Injuries = 10.5%

Note: Branch removal is not pruning for structure or form.

Case #	Sub-activity	Fault pathway	Arborists	Utility	Grounds	Total
R1	Dismantling - piecing down tree parts, scenarios similar to those listed under pruning P1-P4.	Partial cut piece, remains attached to tree	0.5% 1.3%	0.0% 0.0%	0.0% 0.0%	0.5% 1.3%
		Detached piece, falling away naturally	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
		Detached piece, being guided	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
		Detached piece, hung up	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%
		Conductor, rigging line, ground worker(s)	0.8% 0.0%	0.0% 0.0%	0.0% 0.0%	0.8% 0.0%
R2	Felling whole tree, working from ground. Tree gets "hung up" on the line. Conductor remains intact & energized.	Indirect: conductor, tree, tree worker's body, earth return through tree worker and tree.	0.5% 1.3%	0.3% 0.0%	0.0% 0.0%	0.8% 1.3%
		Indirect, risk of exposure to touch potential and/or step potential.	0.5% 0.0%	0.3% 0.0%	0.3% 0.0%	1.0% 0.0%
R3	Felling or piecing down, tree part strikes and tears down conductor(s).	Indirect: risk of exposure to touch potential and/or step potential.	0.8% 6.6%	0.3% 0.0%	0.3% 0.0%	1.3% 6.6%
		Direct: Conductor, tree worker, earth return.	0.8% 0.0%	0.8% 0.0%	0.0% 0.0%	1.5% 0.0%

[4] Assumes normal weather and working conditions. Also assumes that the power system is normally configured.

R4	Removing vines from tree or structure, typically working from the ground. May include tree worker pulling vine into contact with conductor	Conductor-vine-tree worker's body, earth return through tree worker.	0.3% 0.0%	0.0% 0.0%	0.0% 0.0%	0.3% 0.0%
R5	Dismantling—using a crane to piece down tree parts	indirect: conductor-tree part-cable, crane, worker.	1.0% 1.3%	0.0% 0.0%	0.0% 0.0%	1.0% 1.3%
		Indirect; conductor-tree part-cable, crane, worker	0.5% 0.0%	0.0% 0.0%	0.0% 0.0%	0.5% 0.0%
		Indirect, other	0.3% 0.0%	0.0% 0.0%	0.0% 0.0%	0.3% 0.0%

Other Unknown

Other: "Catch-all" for any incidents that do not fit the case studies.

Fatalities = 7.5%, Injuries = 10.0%

Case #	Sub-activity	Fault pathway	All classifications
O1	Other & Unknown	unknown	7.5% 10.0%