)LJ 6SHFLPHQ DW WHVWLQJ

The voltage gradient impressed on each specimen was controlled and varied for different sample lots by varying the voltage input. A variable output AC high potential test transformer provided a means of voltage control. A 60:1 power transformer with a maximum rated output of 15 kilovolts was used as a high voltage source. An instantaneous current-sensing trip coil of a protective relay protected the test circuit. The relay was set to interrupt at fault current level of 275 mA. Test set instrumentation provided for a continuous record of time and current, as well as real-time observations of current, time and voltage. When the voltage stress gradient was applied to each test specimen, a timer was automatically actuated. Each test was concluded when the current level flowing through the test specimen exceeded the test set output, tripping the protective circuit breaker. In each case, the time to fault (defined as current flow sufficient to cause the instantaneous current sensing trip coil of a protective relay to operate) was recorded. Tests were also declared complete for those specimens that failed to flash over when the fault current levels being measured dropped to a steady level well below that observed on initial energization. A third variant occurred when the specimen failed by either burning through or falling clear.

FINDINGS

- Electrical conductivity Varies by Species. Figure 2 summarizes the variability in measured conductivity observed in 18 of the species tested. Rho is a standard measure of the resistivity of a material.

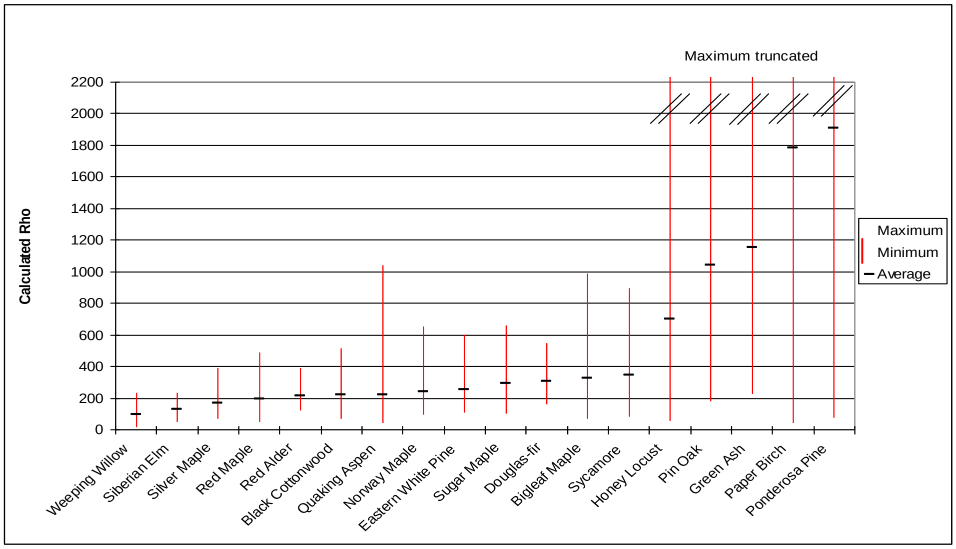

Figure 2. Chart of calculated Rho by species tested.

- Electrical Conductivity Varies by Branch Diameter. Time-to-fault decreases as diameter increases at a given voltage stress gradient as illustrated in Figure 3.

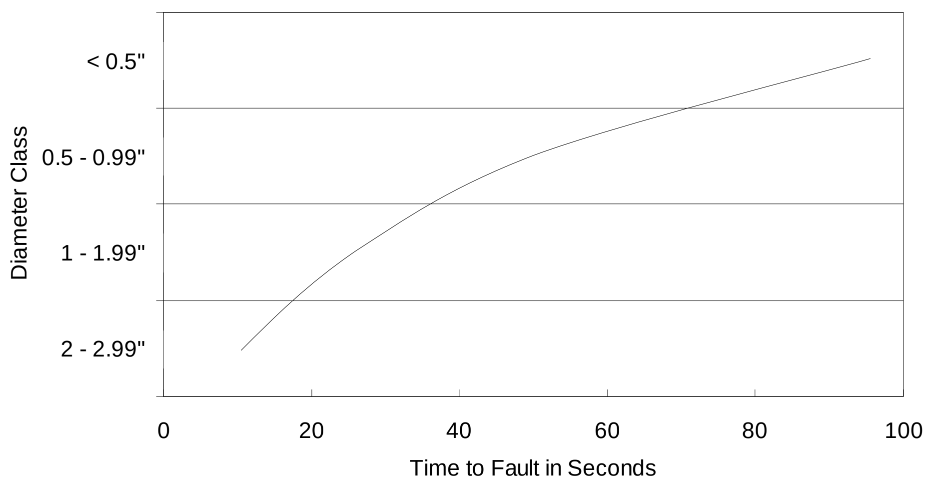

Figure 3. An example of mean variability in measured conductivity observed over the range of diameter classes for a single species (red alder) at 3kV per foot voltage stress gradient.

- Voltage gradient is the most important factor in determining the risk of tree-initiated, low impedance, high current faults. Figure 4 clearly demonstrates the importance of voltage gradient as a factor in determining the risk of a tree contact providing a low impedance pathway and resultant high current fault.

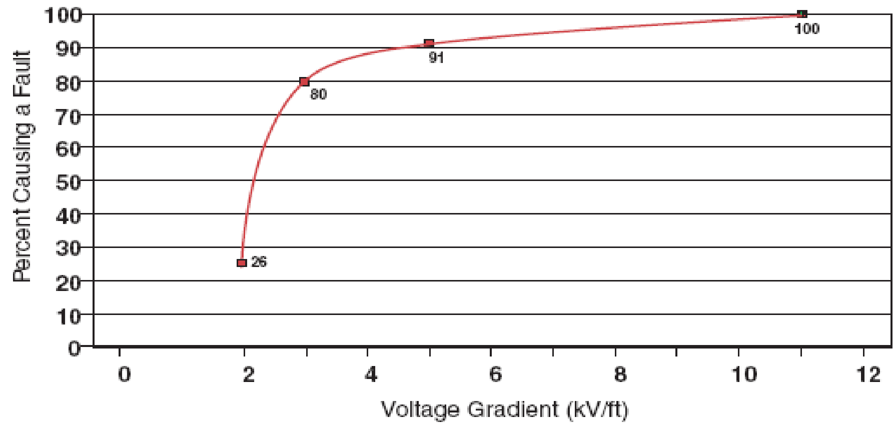

Figure 4. The percent of samples that resulted in a fault increased with voltage gradient

- There appears to be a voltage gradient threshold below which a tree branch will not provide a low impedance fault pathway. Figure 5 suggests that tree initiated fault pathways subject to voltage gradients less than 2kV/ft are much less likely to result in high current faults.

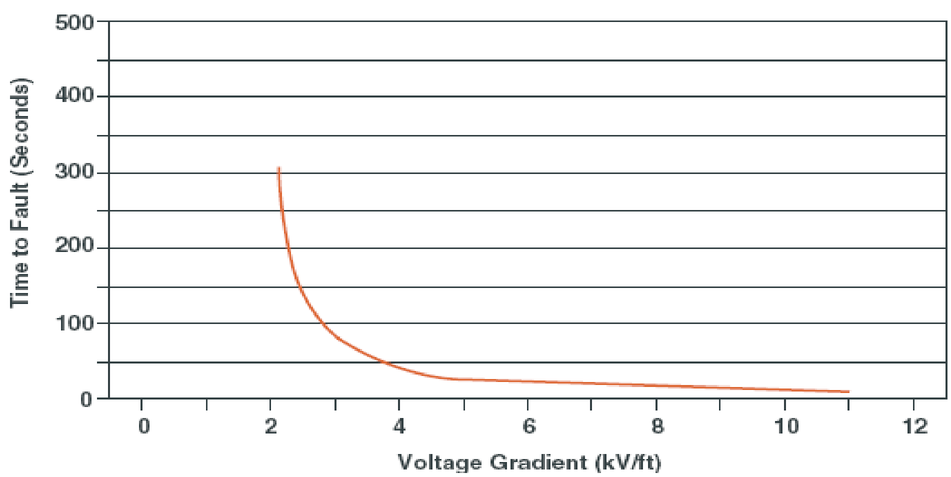

Figure 5. Time-to-fault decreases as voltage stress gradient increases.

CONCLUSIONS AND RECOMMENDATIONS

Species Considerations

This project clearly establishes that electrical impedance varies by species. The variability between species appears great enough to warrant consideration in evaluating risk to reliability posed by trees on overhead electric distribution circuits.

Overhead Circuit Considerations

This study emphasizes the point that multi-phase lines, which typically have substantially higher voltage gradients than do single phase lines, have greater risk exposure to tree-related interruptions than do single phase lateral taps. This increased risk is due to the higher voltage gradients created by the close proximity of areas of unequal electrical potential. These elevated voltage stress gradients are impressed across a branch when it provides a phase-to-phase fault pathway. Voltage gradients may vary by nearly an order of magnitude on an overhead distribution circuit, and should be considered in developing vegetation maintenance prescriptions.

Construction Framing Considerations

The findings of this study demonstrate that the relative risk of tree-related interruptions varies by construction framing standards. Changes may be possible in standard structure design which could reduce the voltage gradient, or change the orientation of energized equipment to reduce or eliminate the likelihood that a broken or deflected branch would make contact with two or more areas of unequal electrical potential.

Diameter Considerations

Branch diameter was shown to play a major role in conductivity, with the largest branches being much more conductive than small shoots. This factor should be considered in developing risk assessment criteria. In terms of tree morphology, larger branch diameters occur closer to the main stem. By definition then, conductor contact with larger diameter branches will more often occur with trees in very close proximity to overhead lines. These high-risk contacts will also develop over a long period of time. Branches of only a few growing seasons in age represent relatively lower risk. The implication is that periodic assessment should allow identification of higher risk tree-conductor contacts before they are manifest as an interruption.

Growth Considerations

This project adds to an understanding of the high impedance pathway provided by small diameter new growth, and provides an important piece of information useful in scheduling periodic preventive maintenance. Basically, the incidental branch-conductor contacts that develop as a circuit "ages" and trees grow back into the cleared area is of low risk to reliability. Simply stated, it is unlikely that trees cause interruptions on 15kV class distribution lines merely by growing into contact with a conductor. The brown foliage that has traditionally been described as "burning" is more probably leaf wilt. This is due to the effect of resistance heating, desiccation and subsequent death of the living tissues of new shoots and leaves. Wilted foliage is a poor indicator of a tree's threat to reliability. Since these new contacts do not appreciable affect the risk of an interruption, some level of contact can be tolerated. The preventive maintenance cycle period can be based on an economically optimal period, rather than strictly on the basis of maintaining line clearance.

Overcurrent Protection Considerations

The project also confirmed that once formed, the low impedance/high-current fault pathway provided by a tree branch is persistent. This confirmation presents a potential opportunity in re-thinking tree caused faults in the context of system overcurrent protection. If the fault pathway provided by a branch remains, subsequent faults will occur when the circuit is reenergized. The decision to make application of "fuse sacrifice" or "feeder selective relaying" overcurrent protection coordination philosophies on distribution circuits with elevated risk exposure to tree-caused interruptions needs to be made with this in mind. Furthermore, the overcurrent protection scheme in place at many utilities today is designed to protect against faults that occur within a cycle or cycles (60 Hz). This study suggests that tree-related faults often develop over extended periods. This reality may require changes in the design of system protection schemes.

APPLYING THE RESULTS

Based on the enhanced understandings of how trees cause interruptions and documented differences in impedance between tree species, there are considerable situational differences in risk of interruption due to tree contact with energized conductors. Factors such as species, diameter, and voltage gradient discussed in this paper are readily observable in the field. Consequently, this information can be incorporated into risk assessment criteria, maintenance specifications, maintenance planning and scheduling strategies, and site-specific vegetation maintenance prescriptions.

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