CURRENTS IN POWER LINE WOOD POLES

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ABSTRACT

Over the last few years some rather severe problems have arisen for poles used to support overhead power lines. A wooden power line pole is assumed to be a good electric insulator because of the basic properties of wood with its porous structure and cellulose compounds forming the major part of the cell walls. A fault during which an insulator is broken or a phase conductor has loosened, normally poses no danger. In rare cases a fire has started, but this has not been seen as a sufficiently dangerous situation to change maintenance practice. However, it has been noticed that under certain circumstances such poles can get conductive enough to result in hazardous or even lethal current for power line maintenance workers climbing the pole.

INTRODUCTION

In the summer of 2008 a maintenance worker in Sweden was killed when climbing into a wood pole supporting an 11-kV overhead line. The investigating done afterwards raised the suspicion that a current flowing through the pole might be sufficient to kill a person but insufficient for the protection to detect. Due to a broken insulator one of the phases of the 11-kV line had been resting on the metal crossbar. This accident triggered a more detailed investigation in order to determine if power line wood poles can conduct current and if so, whether this current can be sufficient to injure or kill a maintenance worker climbing into the pole. The study has been made at the 11 kV level on a pole while a live wire was resting on the metal cross arm as would be the case if the insulator was broken. A measurement method has been developed in order to determine under what conditions climbing should be prohibited.

In Sweden the use of wood poles as part of 11 kV overhead lines is fairly common. A three phase system is used to distribute 11 kV, one wire for each phase, and the three wires are supported by insulators mounted on a horizontal metal (or wood) cross arm. The poles are treated with some kind of preservative to protect the wood from rot and insects. Three kinds of preservatives are commonly used in Sweden: arsenic, creosote and wolmanit CX, the first and latter being salt based. In this study eight poles with different preservative and age varying from 40 years old to brand new have been examined in a realistic environment. The measurements presented in this paper support the earlier suspicion that a wood pole used for distributing power can conduct current if a fault occurs and a live wire comes in contact with the cross arm. It also shows that the current through a parallel, not connected to earth, resistor (representing a human climbing the pole) can reach potentially lethal amplitudes. Three main variables that affect the electrical characteristics of the pole have been identified: the preservation of the wood; the environmental temperature; and the amount and duration of the precipitation.

There are however other variables that can have an impact on the conductivity of the pole for example how the pole was dried before preservation.

EFFECTS ON A HUMAN BODY, EXPOSED TO ELECTRICAL CURRENT

The total impedance of a human body consists mostly of the skin resistance which will vary from person to person. As long as the skin is dry the resistance is high but if the skin gets wet or broken the resistance drops. The resistance of a body is also dependent of the voltage level and will decrease for increased voltage levels. For 95% of the population the body impedance will be 3125 Ω when exposed to a voltage level of 100 V. For this study, 3000 Ω was selected as a typical value for a human. It is the amplitude, duration and path of the current flowing through the human body that will determine if the current is harmful. The current threshold for perception is less than 1 mA and for current levels over 15 mA a person can no longer control the muscles [1]. Respiratory problems occur in the range of 20 to 40 mA. When exposed to electrical current for duration over 2 s, the ventricular fibrillation threshold is considered as low as 50 mA. The protective relays at the substation are tested for faults over 3 or 5 kΩ and will not trip or even detect a fault of this kind where the resistance at the fault could be up to several MΩ. The voltage across the pole and thus the current through a person climbing the pole will as a consequence of this be present for times long over 2 s.

VARIABLES THAT CAN INFLUENCE THE POLE RESISTANCE

A number of variables have been identified and tested in order to examine their influence on the pole-resistance.

- ***Preservative of the pole***

In Sweden there are three different preservatives used for wooden poles; creosote, arsenic and wolmanit CX. The three preservatives have been found to have different impact on the conductivity of the pole. Creosote preserved poles have in this project shown the highest resistance to electrical currents. Creosote however contains high levels of polycyclic aromatic hydrocarbons. Discussions are ongoing to change the use of creosote as a preservative as it might have an adverse impact on the environment and on the people handling the poles.

- ***Drying method of the pole***

Traditionally there has been only one way to dry wood, simply leave the wood outside for about one year until it is sufficiently dry. Nowadays some also use heat in order to significantly speed up the process; a wood pole can be dried in three days using this technique. There will be a difference in how cracks form in the pole depending on the method of drying. The characteristic of the cracks can have an influence on how the preservative enters the wood and also on how the rain can be absorbed. The age and density of the tree when it is felled can also be a factor to consider.

- ***Temperature of the surroundings***

In the northern parts of Sweden the temperature can vary between -40 and +35°C depending on the season. It was decided that the measurement were to be repeated at least once a month during the winter and slightly more often during the spring, summer and fall, the reason being that the weather and temperature shift is greater in those seasons. In order to keep track of the changes in the weather an automatic weather station that logged the temperature, precipitation and sun radiation was installed at the substation were the measurements were done.

- ***Precipitation type and duration***

During the wintertime the precipitation will be in the form of snow and the snow can rest on the cross arm. In the spring, summer and fall the precipitation will be in form of rain. One variable thought to have different impact in the pole resistance is if the rain is consistent for a number of days or if it rains heavily for only a short time.

- ***What is mounted in the pole and how it is done***

The wood poles can be used for supporting optical cable as well. Sometimes an optical cable is connected with a metal bolt through the pole. Occasionally the pole is supported by a stay wire which can be connected to the pole without an insulator. These conditions can make it possible for a worker climbing the pole to come in contact with different voltage potentials.

MEASUREMENT SETUP

For these measurements eight poles have been raised at a substation and equipped with a metal cross arm. All eight poles have a copper wire twisted around the base and connected to ground in order to eliminate the influence of different condition of the soil where they are raised. The age in Table 1 indicates the time from when the pole was made to when the project started.

Table 1

Preservative	**Age**	**Drying method**
Arsenic	20 years	Dried during a year
Arsenic	50 years	Dried during a year
Creosote	50 years	Dried during a year
Creosote	New	Dried during a year
Creosote	New	Dried with heat
Creosote	20 years	Dried during a year
Wolmanit CX	1 year	Dried with heat
Wolmanit CX	New	Dried during a year

The measurement setup can be seen in Figure 1**.** For the study one phase carrying 6 kV was connected directly to the metallic cross arm as would be the case if the isolator was broken. A 3 kΩ resistor was used to simulate the human body and "Scandinavian Climbers" was used to connect the resistor to the pole. Different techniques were tested and the Scandinavian climbers were found to be suitable even thou they will go in deeper into the wood than for instance a hand touching the surface. Voltage dividers with an input impedance of 1 MΩ were used simply to get the voltage down to a level where the instrument (HIOKI HICORDER 8855) can operate. Three voltages were measured; the phase voltage on the faulty phase, the voltage on the upper Scandinavian Climber representing the hand and the voltage on the lower Scandinavian Climber representing the foot. The two latter was used to calculate the "climbing voltage".

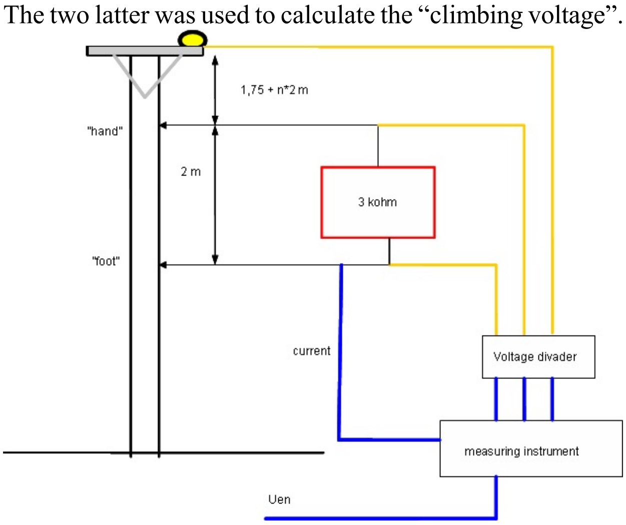

Figure 1 Experiential setup

The current through the resistor and the total current through the setup were also measured. The space between the "hand" and the "foot" were chosen to two meters and the Scandinavian Climbers was moved along the pole while keeping the distance between them. To apply an equal force to the Scandinavian climbers two petrol cans filled with water to achieve a total weight of 25 kg were connected to the climbers

RESULTS

Measurements have been made over a 12 month period to get values for different temperatures and precipitation type and duration. The measurements have been repeated at least once a month. The total current flowing through the pole and the voltage across it has been measured and the total resistance of the pole has been calculated. The resistance variations over a year for a 20 years old arsenic impregnated pole, 20 years old creosote pole and a one year old wolmanit CX impregnated pole are shown in Figure 2, Figure 3 and Figure 4 respectively. The resistance varies between 28 kΩ in November for the arsenic pole and 1450 kΩ for the wolmanit CX pole in August. The overall highest values and the least variations are found for the creosote pole. The precipitation and outside temperature during the measurements were logged and are shown in Figure 5 and Figure 6 respectively. The precipitation from November to February is in form of snow. The low value for the resistance in November could be explained by the fact that the temperature were close to zero and the snow was very wet and as it "stuck" to the pole the wood was exposed to moist for a long period of time with no chance to dry.

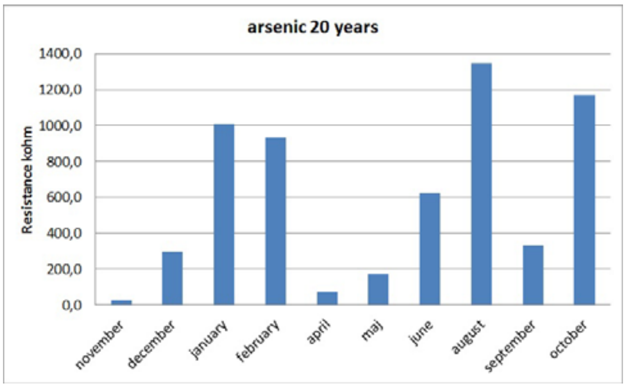

Figure 2 Yearly variation of the resistance in a 20 years old arsenic impregnated pole

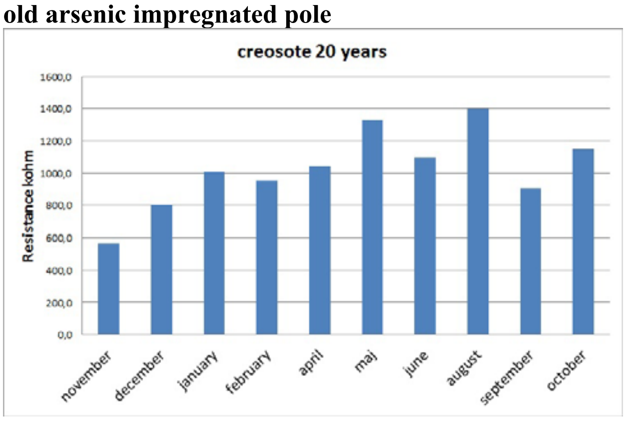

Figure 3 Yearly variation of the resistance in a 20 year old creosote impregnated pole

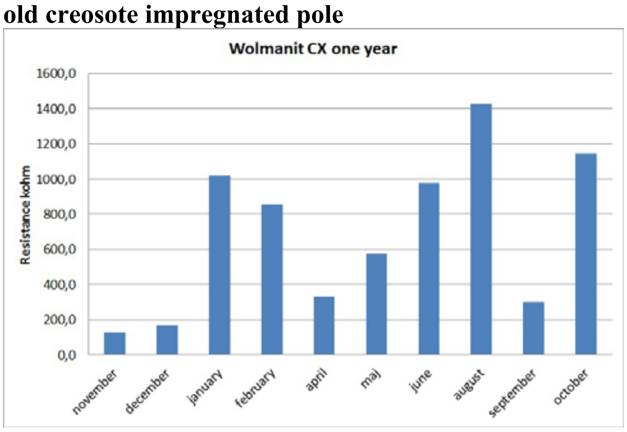

Figure 4 Yearly variation of the resistance in a one year old wolmanit CX impregnated pole

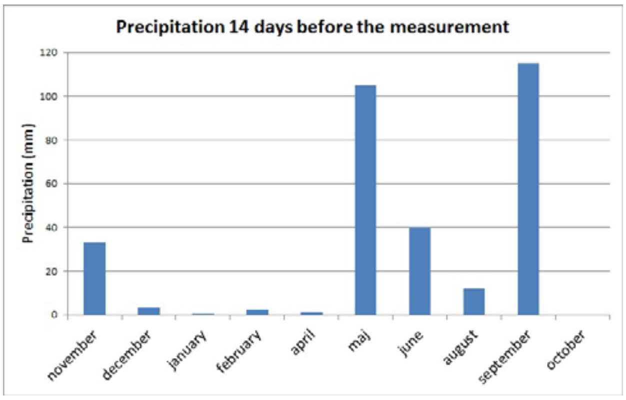

Figure 5 total precipitation 14 days before the measurement

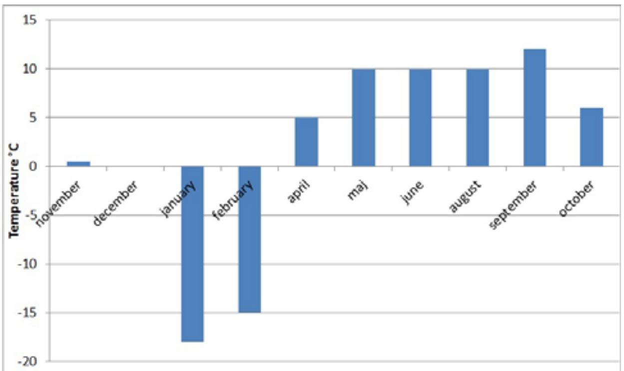

Figure 6 outside temperature when the measurements were made

When comparing the resistance values with the curves for the temperature and the precipitation one can easily see that the correlation is low, clearly other factors also have an impact on whether the pole is safe to climb in.
The voltage over the 3 kΩ resistor was measured as well as the current going through it. The result for the November measurement in a 20 year old arsenic impregnated pole is presented in Figure 7 and Figure 8 respectively.

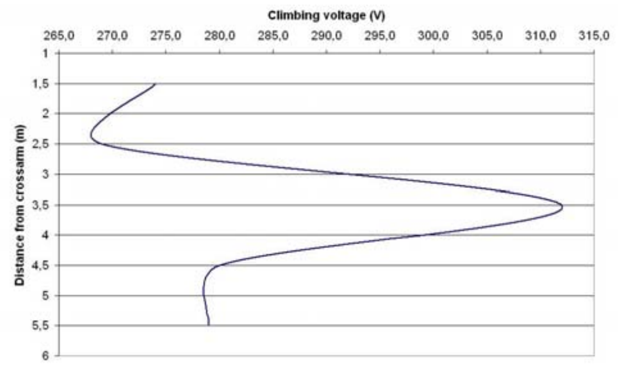

Figure 7 Voltage over a 3 kΩ resistor when moved along a wooden pole

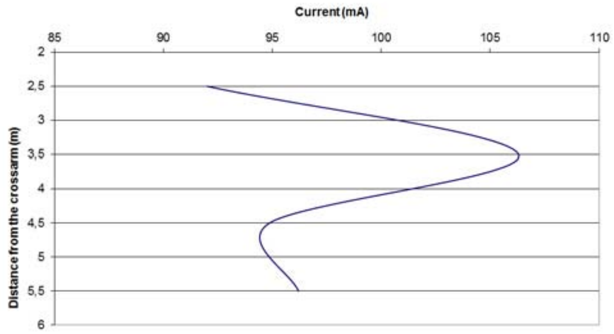

Figure 8 Current through a 3 kΩ resistor moved along a wooden pole

The current through the 3 kΩ resistor vary between 92 mA and 106mA. A remarkable observation is that the highest value is not closest to the cross arm but in the middle of the pole.

CONCLUSIONS

The measurements conducted in this project clearly shows that currents with high enough amplitude to potentially be harmful to a human climbing the pole can occur. A number of variables that can affect the conductivity of the pole have been identified but the project clearly shows that the impacts from these variables are complex. No single variable can be identified to alone have a strong impact on the conductivity. A combination of many factors has to be considered. Some factors like temperature, precipitation and exposure to sunlight has to be tested in situ. For others like drying method and density of the wood as well as preservative the impact on electrical conductivity should be considered in advance.
There are indications that the resistance along the pole can't be considered linear. The climbing voltage and the current through the resistor differ for different heights on the pole. There are differences between the poles but they all show this non-linearity
A testing method for electrical characteristics of the pole has to be considered. This testing method should be a part of an electrical specification of requirements for the pole manufacturers

REFERENCES

[1] P. W. Zitzewitz, R. F. Neff *Merrill Physics, Principles and Problems*. New York: Glencoe McGraw-Hill, 1995