Design of power lines poles that will be safe even when a phase has come in contact with crossarm.

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SUMMARY

Previous work has shown that it is possible in some situations to get currents with high enough amplitude to be lethal flowing through a wooden pole [1, 2]. For a current to flow through the pole there has to be a connection of a phase conductor with the cross arm i.e. the insulator has to be damaged. When the live conductor has a connection to the metal cross arm, it might be dangerous climbing or even touching the pole. The magnitude of current flowing through the pole during a fault depends on several parameters, among others: preservative of the wood; and the precipitation during the days leading up to the occurrence of the fault. Some parameters affecting the poles ability to conduct current have been identified under partially controlled situations. However, the identified parameters seems to interact in several ways and in a real life situation it is nearly impossible to determine if a pole can be considered as an insulator. It is therefore important to have a well-developed method, when work has to be done in a pole.

The impedance characteristic of wooden poles has been proven to be something between an insulator and a conductor. In which situation it will be one or the other is very difficult to distinguish.
This paper will show that this is the case, even when power lines are built with composite material.
When new power lines are built there is a need for new tools and methods to create a safer situation in case of a phase - ground connection regardless of material used for the pole.

KEYWORDS
Wood poles, personnel safety, electricity distribution

1. 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 concluded that a current flowing through the pole could 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, thus creating a path for the current to flow through the wooden pole. This accident triggered a detailed investigation to determine under which conditions currents with harmful amplitude can flow through a wooden pole [3]. 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.

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 damaged the resistance will drop. 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 or more 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 [4]. 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. Thus, the voltage across the pole and the current through a person climbing the pole will be presented for times over 2 s.

2. METHOD

For these measurements eight poles have been raised at a substation located in the northern part of Sweden and all poles have been equipped with a metal cross arm. The 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 the project start.

Table 1

Preservative	Age	Drying method
Arsenic	20 years	Slow dry
Arsenic	50 years	Slow dry
Creosote	50 years	Slow dry
Creosote	New	Slow dry
Creosote	New	Dried with heat (fast dry)
Creosote	20 years	Slow dry
Wolmanit CX (salt)	1 year	Dried with heat (fast dry)
Wolmanit CX (salt)	New	Slow dry

In Figure 1 the schematic and the setup of the experiment are shown. The voltage and current was measured between the top of the pole and the ground, and over the resistor. These values were used to calculate the impedance of the pole. For the study, one phase carrying 6 kV was connected directly to the metallic cross arm simulating a broken insulator. A 3 kΩ resistor was used to simulate the human body and "Scandinavian Climbers" was used to connect the resistor to the pole. The space between the "hand" and the "foot" were chosen equal to two meters and the Scandinavian Climbers was moved along the pole while keeping the distance between them.

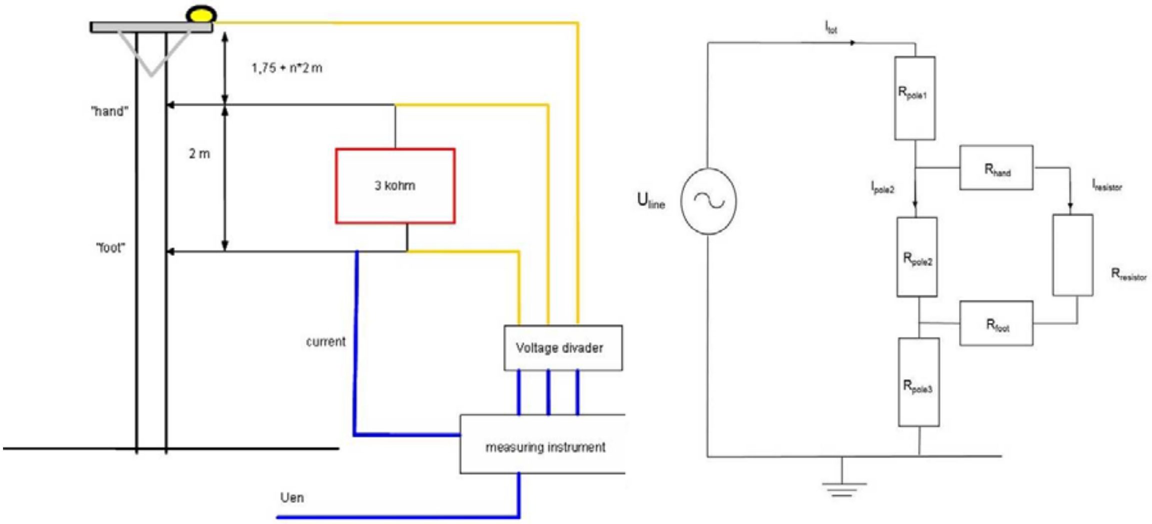

Figure 1. Experimental setup (left) ad equivalent circuit (right)

3. RESULTS

The identified parameters can be divided into two types; one type can be known beforehand and one cannot. One type of parameter can be the choice of preservative, drying method and how the lines are built, while the other type can include precipitation, humidity and outside temperature.

3.1 Type one parameters

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 during the measurements shown the highest resistance to electrical currents.

Prior to applying preservatives the wood has to dry and this is done in two different ways; simply leave the wood outside for about one year until it is sufficiently dry or 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 hewed can also be a factor to consider. It is difficult to determine the condition of the wood pole with regard to cracks and knots without intrusive methods. In Figure 2 the scanned images of two different poles are shown. The images were obtained using a CT-scanner fitting the pole. The image on the left hand side in Figure 2 shows a new pole that is dried during a short time. The pole in the right hand side in Figure 2 is an old pole from the time before accelerated drying methods were introduced.

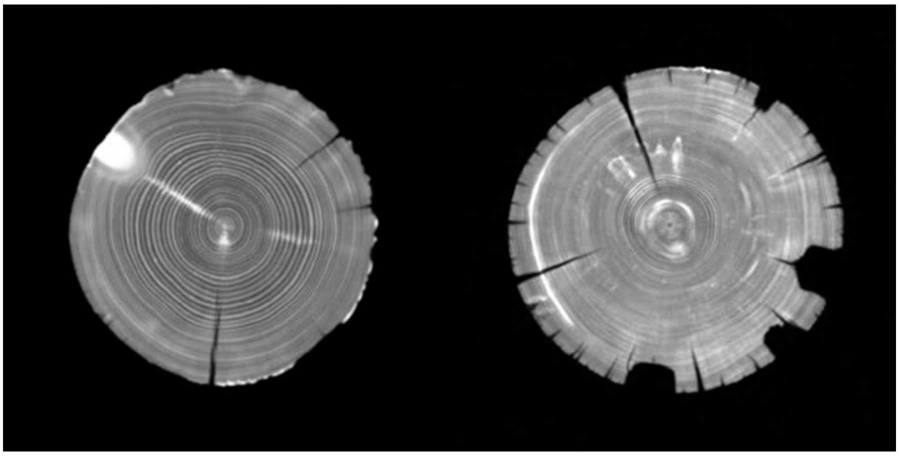

Figure 2 Two examples of scanned images of wood poles. The white areas indicate where knots are located and the dark areas where cracks have formed.

How the lines are built will have an impact as well. Sometimes the pole holds additional cables that are connected with a metal bolt through the pole. Occasionally the pole is supported by a stay wire connected to the pole or a sign used during air inspections of the line as seen on left hand side in Figure 3. The right hand side in Figure 3 shows the head of a metal nail that is used to indicate preservative and year of erection of the pole. Incidents have occurred when maintenance workers have felt a small electrical shock when touching the nail. As the nail can be reached from the ground, also the general public is exposed to this risk.

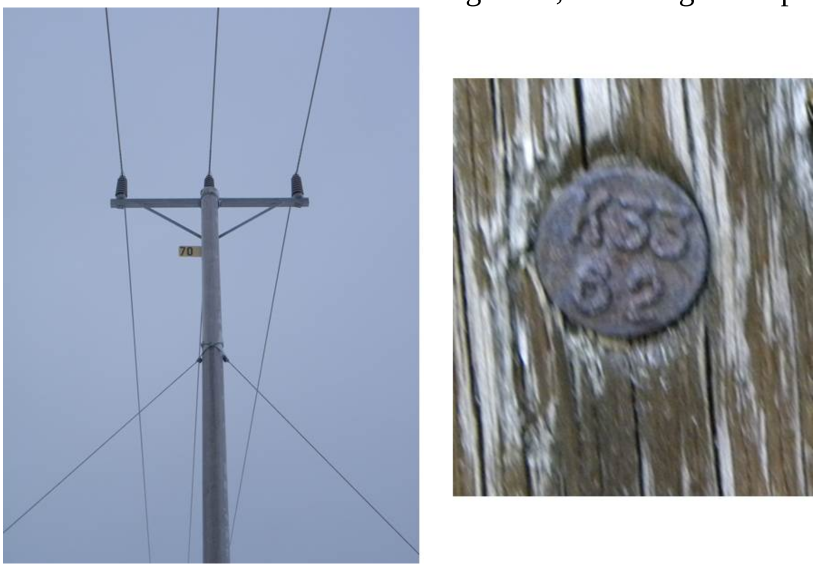

Figure 3 Pole with stay wires and metal sign (left hand side) and identification nail (right hand side)

3.2 Type two parameters

The moist content of the pole will influence the resistance. Work done by [5] show that the leakage current through a wet wooden pole is increased up to a factor of 6 compared to under dry conditions. These experiments were performed on wood specimen not common in Scandinavia, but measurements done by our group on Swedish poles support this finding. Experiments shows that for instance wet snow covering the pole for a period of time will lower the resistance. Even though the precipitation impacts the resistance it cannot be used as the sole parameter when evaluating the resistance in the pole. The linear correlation between

the precipitation during a seven day period prior to the measurement and the measured resistance has been obtained for the measurements carried out during one year and was found to be slightly negative but overall weak.
The ambient temperature will affect the poles ability to conduct current and in Scandinavia the variation in temperature during the year can be significant. During the time period of the experiment the environmental temperature varied between -18° C and +12° C but temperatures as high as +30° or as low as -30° are not uncommon. The linear correlation between ambient temperature and the resistance in the pole have been calculated and in the same way as with the precipitation the correlation is again weak. If the two extreme values for January and February (-18° and -15° respectively) are removed the correlation coefficient between temperature and resistance for the 20 year old arsenic pole is 0.36. During the measurements performed in May, June and August the temperature was identical, +10° C, but the resistance in the 20 year old arsenic pole varied between 172 kΩ (May), 620 kΩ (June) and 1.3 MΩ (Aug).

As can be seen in Figure 4 the variation of the impedance of one pole during the year is significant. During the time frame of one year the same pole can show values ranging from 28 kΩ to 1.3 MΩ (arsenic). The reason for the large variations is likely a combination of, among others, ambient temperature and precipitation. The bar in the far right in Figure 4 indicates the impedance of the poles after they have been intentionally watered for a period of time. This might not give a good representation of a real life condition, but gives an indication on the impact of heavy precipitation. Note also that the lowest values measured during natural circumstances, were of similar magnitude as the valued obtained after artificial watering.

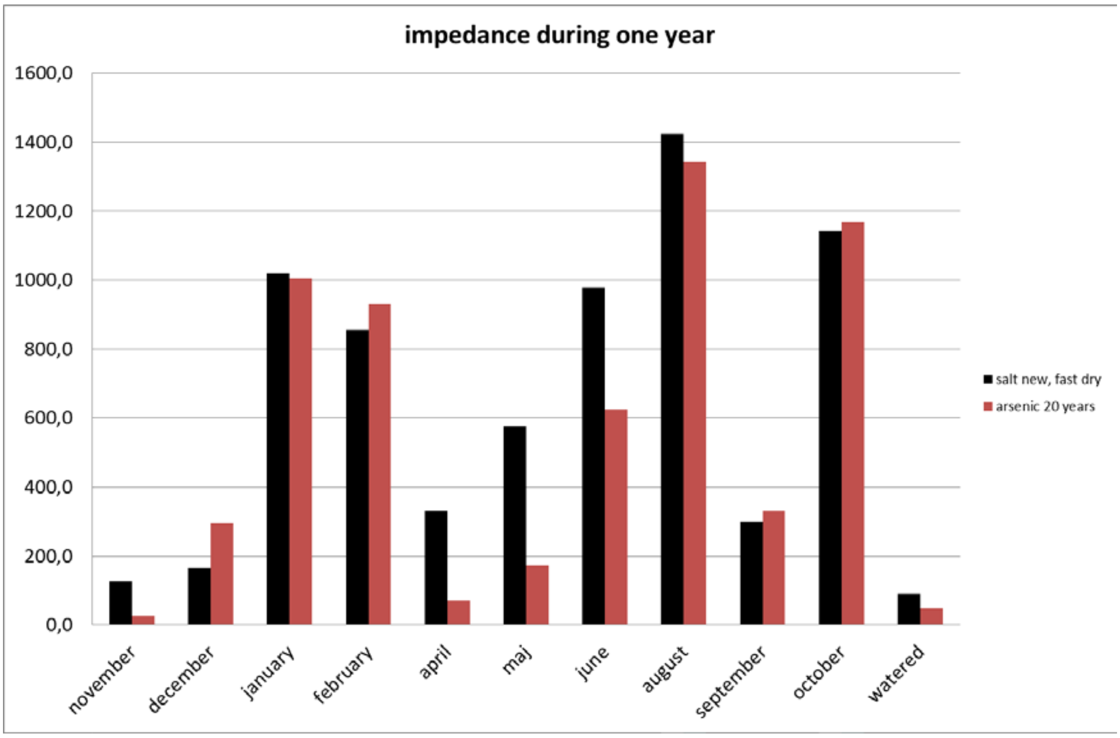

Figure 4 Variation in impedance for two poles during one year, vertical scale in kΩ

The measurements shown in Figure 4 were carried out once a month and the results only reflect the conditions during the moment of the measurements.
A period of rain followed by a period of cold weather will result in a pole that contains ice. A current that starts to flow through the frozen pole will cause the pole to thaw thus decreasing

the impedance. This phenomenon was tested during the above mentioned conditions, rain followed by temperatures below zero. Measurements were carried out once every minute for 20 minutes as the live wire was connected to the crossarm. Figure 5 presents the current flowing through the pole, which increases linearly close to a factor 2 as the pole warmed up.

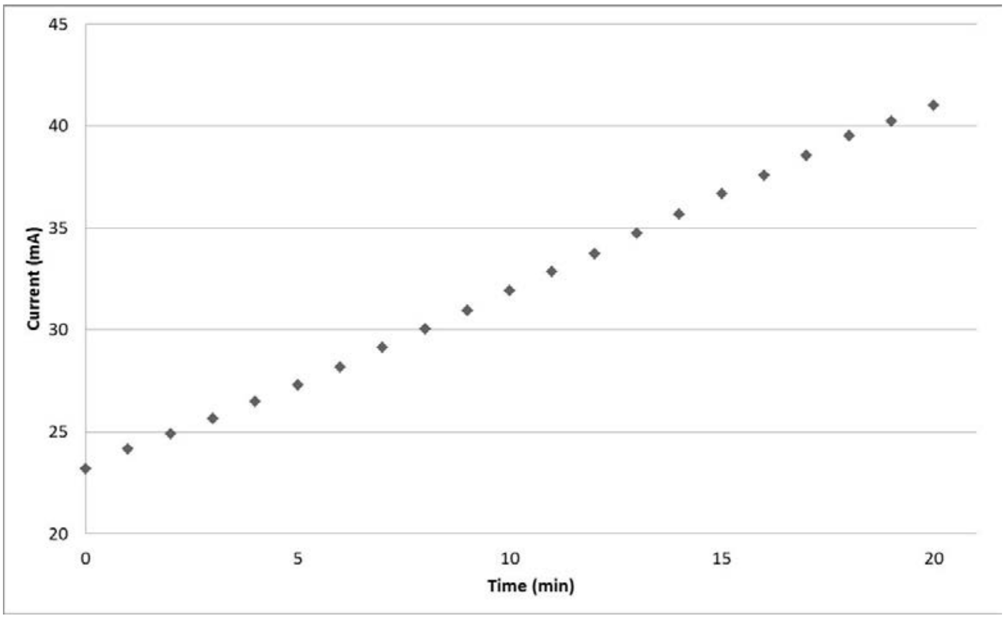

Figure 5 Increase in current flowing through a pole due to thawing

4. FIRES

In addition to the safety risk for the public and for maintenance workers, a current flowing through the pole can cause a fire. In [6] a pole fire in Australia was investigated and one conclusion was that a current of only 4 – 5 mA is enough to start a fire. Fires in wood poles are far more common than hazardous currents injuring a person touching the pole. Moreover, a pole that brakes due to a fire could fall down and in a worst case scenario leaving the live wires hanging low enough to be reached from the ground.

During the field measurements in Sweden a new wolmanit CX impregnated pole was equipped with an earth wire connected 50 cm below the brace. In Sweden it is not common practice to connect all metal parts in the pole to ground as it is in other countries, for instance Norway. The live wire was connected to the metal cross-arm as would be the case of a broken insulator, thus creating a voltage potential of 6 kV between the brace and the earth wire. This created a fire in the pole in less than an hour. The line was tripped manually before the fault was detected by the protection relay. On the left hand side in Figure 6 a scanned image of the pole is shown, the dark spots in the lower side if the pole indicates where wood is “missing” due to the fire.

Figure 6 Scanned image of the pole after the fire (left hand side). During the fire (right hand side)

5. COMPOSITE POLES

Even if wooden poles are by far the most common poles in Sweden some lines have been built using composite poles. One composite pole was erected at the test site in Sweden and measurements showed that it can be considered as an insulator. However; voltage potentials between metal parts connected to a composite pole can reach high levels and the space between them should remain at a safe distance or all metal parts should be bound together.

6. CONCLUSION

Some parameters influencing the resistance of a wooden pole have been identified. However, the identified parameters appear to interact and no one parameter can be said to have highest significance. The age of the wood also seem to affect the result and work done in [5] shows that as the wood decay the resistance decreases.

An important conclusion from the measurements is that the resistance of the pole varies over a wide range of values, more than a factor of 10.

The weak correlation between the resistance of the pole and any single parameter tells that the question of when it is safe to touch or climb a pole is complex. As a consequence, a pole that under certain conditions have been determined as an insulator might under different conditions pose a risk for a person touching the pole. From a safety viewpoint the only conclusion appears to be that it is never safe to touch or climb a pole when a live non-insulated conductor is resting on a crossarm without securing an extra high resistance for R_{Hand} and R_{Foot} (indicated right hand side in Figure 1).

When new power lines are built there is a need for new tools and methods to create a safer situation in case of a phase - ground connection regardless of material used for the pole. Also is it important that more measurements are performed, for example continuous long-term measurements of the resistance of different types of poles.

7. ACKNOWLEDGEMENT

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BIOGRAPHY

Mats Wahlberg is currently working at Skellefteå Kraft Elnät, Skellefteå, Sweden as research engineer. He has been with the company for about 30 years. He has a long experience obtained from involvement in a wide range of tasks. Some examples are calculations of constructions, losses and protection relays. In the last 15 years the main focus of his work has been with power quality issues and different kinds of communications. He is also a member of working group CIGRE C4:33 and CEATI Lightning & Grounding. He is also senior research engineer at Luleå University of Technology, Skellefteå, Sweden.

Sarah Rönnberg received the Licentiate degree and PhD degree from Luleå University of Technology, Skellefteå, Sweden in 2011 and 2013 respectively. Currently she is working as an associate senior lecturer in electric power engineering at the same university. Her main research contributions are in the study of emission in the frequency range 2 to 150 kHz and in understanding the interaction between power-line communication and end-user equipment in this frequency range.

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