POLE-TOP FIRES RISK ASSESSMENT: A SOUTH AFRICAN PERSPECTIVE

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ABSTRACT

Pole-top fires on 22 kV overhead woodpole electricity distribution lines are addressed. The mechanism covered is where, under certain conditions, the surface of one or more phase insulators collects pollution, which conducts leakage current when lightly wetted. This leakage current can flow into and onto the wood of the structure and can, in certain cases, cause the wood to track, char and ignite. Experiences from tests and the field are used to perform a risk assessment of different mitigation options using criteria such as pollution (leakage current) performance, lightning performance and bird safety. A proposal for different structure configurations for use in different areas is made. The rationale behind the proposal is described, practical considerations and limitations are discussed and further research is recommended.

INTRODUCTION

Pole-top fires on 22 kV overhead woodpole distribution lines are addressed in this paper. The mechanism covered is where, under certain conditions, the surface of one or more phase insulators collects pollution, which conducts leakage current when lightly wetted. This leakage current can flow into and onto the wood of the structure and can, in certain cases, cause the wood surface to track, char and ignite. Fires can also start inside the wood.

Fig 1 illustrates a typical overhead woodpole distribution structure. Un-energised metal hardware is bonded together and is connected to earth, with an insulation coordination gap inserted into the earth downwire. Field experience has shown that fires occur most frequently on the cross-arm. The risk of cross-arm burning is reduced by the bonding illustrated in Fig 1 [2, 6], as leakage current is diverted away from the cross-arm. However, there is still a risk of burning at the insulators (marked “1” in Fig 1), as in some cases leakage current must flow through or on wood to reach the bonding [6], and in the insulation coordination gap (marked “2” in Fig 1), as some leakage current flows to earth.

Examples of other mitigation measures from literature are:

1. Fully bonded and earthed structures to divert leakage current away from the wood of the structure entirely and conduct it directly to earth [1] – similar to Fig 1, but with no insulation coordination gap in the earth downwire;
2. The use of insulators with suitable conductive end fittings to collect leakage current onto the bonding without having to flow through or on wood [5, 6];
3. Use of low leakage insulators, e.g. silicone rubber, to limit the magnitude of the leakage current [4, 6];
4. Local bonding to bridge out zones where sparking is most likely to occur [1, 7, 8];
5. Bonding of un-energised insulator ends together to a common point via insulated bonding cables [3];
6. The use of steel cross-arms to eliminate cross-arm fires (but not necessarily pole fires) [2, 3, 4];
7. Use of timber preservative to reduce wood decay, and hence to better maintain metal-wood contacts [1];
8. Ensuring solid metal-wood electrical contact by the use of galvanized steel springs [1] or the use of gang nails and spring washers [4];
9. Maintenance to maintain solid metal-wood electrical contact [1, 4];
10. Regular testing, washing and/or silicone coating or greasing of insulators [1, 4];
11. Insulator plastic hood or protective creepage [3].

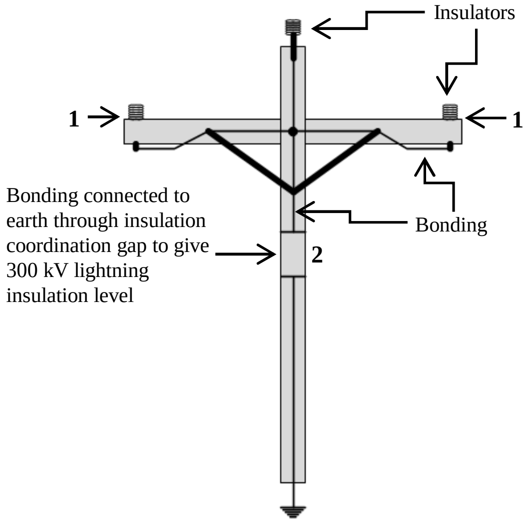

Fig 1: Partially bonded distribution woodpole structure [6]

There are therefore different measures to choose from. Some have been tested in the field, with various degrees of success, while others are still conceptual. Certain measures may be applied simultaneously, e.g. low leakage insulators and some form of bonding.

PROBLEM DESCRIPTION

While certain mitigation strategies are expected to be successful in significantly reducing the number of pole-top fires, their impact on other aspects of line performance is not always positive. An example is the fully bonded and earthed option applied together with suitable insulator end fittings: wood is completely removed from the leakage current path, but the result is lower impulse insulation strength, reduced arc quenching capability and, in some cases, a threat to bird safety because earth potential is transferred to the pole top. Also, the dangers of full bonding and earthing have not yet been studied particularly with respect to human safety. The various measures also have differing components, installation and maintenance techniques and costs. Other questions that should be answered are in which areas the risk of pole-top fires is sufficiently high that specific mitigation measures need to be applied, whether a network-level or pole-level approach should be adopted and what else needs to be taken into account to not introduce other problems.

A pole-level risk assessment tool is given in [4]. This comprehensive approach covers every pole in a network, with poles meeting certain low-risk criteria being excluded. It has the advantage that network reliability is the main focus and it is based mainly on simple information such as pole age, network voltage and structure type. The present paper proposes a network-level risk assessment approach, as an alternative, that also takes other (non-pole-top fire) factors into account. The risk assessment is based on two sources of information: long-term tests performed in a severe natural pollution environment and field experience in various conditions prevalent in South Africa. The following two sections deal with those sources. The risk assessment is then applied to different mitigation options, by assessing them against criteria such as pollution and lightning performance and bird safety. They are also compared to a basic woodpole structure configuration. A proposal for structure configurations for use in different areas is made next, followed by conclusions and recommendations.

SELECTED TEST RESULTS

Long-term tests in a severely polluted marine environment were performed at Eskom's Koeberg Insulator Pollution Test Station (KIPTS). Details of the site may be found in [9]. Tests have been running for over two years, with modifications made at various times as needed.

A number of mitigation measures were evaluated, such as:

1. Fully bonded and earthed structures, with wood and steel cross-arms and with different types of insulators, to verify that this prevents pole-top fires from occurring due to leakage current, as is expected theoretically;
2. Structures bonded and earthed through insulation coordination gaps: as illustrated in Fig 1;
3. Leakage current collection mechanisms (end fittings) on all insulators: post insulators with conductive metal caps or conductive metal plates (Fig 2) and longrod insulators with standard conductive metal end fittings;
4. Silicone rubber coating on porcelain insulators, compared to the performance of an adjacent structure with the same insulators, but not coated.

Space limitations at the site meant that not all measures in the literature could be tested. The above measures are those most pertinent to South African conditions for reasons such as lightning performance, bird safety, cost effectiveness and practicality. The following has been learnt from the tests:

- No signs of tracking have thus far been found on any structure that was fully bonded and earthed;
- Tracking of various degrees of severity has been identified on the pole surface in all insulation coordination gaps – the most severe is shown in Fig 3a;
- The tracking in the gap of the structure with coated insulators was much less severe than that found on the adjacent structure with uncoated insulators;
- No tracking has thus far been found on the surface of any cross-arm at an insulator that was bonded (all insulators employed suitable conductive metal end fittings);

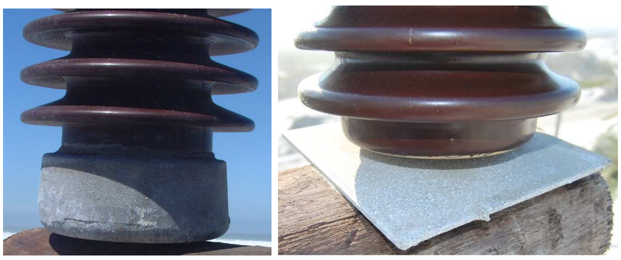

Fig 2: Post insulator end fittings tested: conductive metal cap (left), conductive metal collector plate (right)

Fig 3: Tracking observed at KIPTS: a) in insulation coordination gap (left), b) at uncapped insulator without conductive plate (right)

- When a collector plate was not included with one uncapped post insulator for a short period, surface tracking was observed on the cross-arm at that insulator – this is shown in Fig 3b.

It must be noted that it was not possible to inspect cross-arms and poles internally, where field experience shows many pole-top fires start. However, the experiences gained with the tests have added significant confidence to the understanding of the mitigation against pole-top fires.

FIELD EXPERIENCES

Lessons learnt from investigation of pole-top fires in South Africa have served both to inform the testing and to confirm what was observed during the tests. Examples are:

- The majority of pole-top fires occurred on structures which were not bonded or where bonding was not complete [6].
- Only one fire was verified as having occurred in the insulation coordination gap or at the junction between pole and cross-arm of a tightly bonded structure [6].
- These observations are line with the results of previous South African work; the same study also found tracking underneath an uncapped post insulator [2].

The conclusion from South African field experiences, coupled with test observations, is that solid electrical bonding of un-energised metal hardware reduces the risk of pole-top fires occurring due to leakage currents, even if not earthed directly. However, this does not eliminate the risk completely, as any wood in the leakage current path, due to unsuitable insulator end fittings or gaps in the earth downwire for example, place structures at risk of burning.

RISK ASSESSMENT

Mitigation measures are compared in Table 1. Note the following when interpreting Table 1:

- The use of suitable conductive metal insulator end fittings has been assumed for all options.
- The comparison is a general one, and is not necessarily for specific embodiments of particular methods.
- Safety of the public, workers and ground-based animals also needs to be taken into account when applying any pole-top fire mitigation, or other, measure.
- Only intermediate structures without auxiliary equipment have been considered, for simplicity; structures with stay wires, multiple cross-arms and auxiliary equipment also need to be taken into account.
- The impact on protection settings needs to be investigated for all mitigation measures chosen.

Table 1: Comparison of structure options – wood leakage current ignition risk

Option[1]	Lightning performance	Pollution (leakage current) performance	Bird safety[4]	Workmanship & maintenance[5]	Cost[6]
a. Fully insulated: no bonding whatsoever (basic configuration)	Poor (BIL > 1 MV)[2]	Poor (much wood in leakage current path)	Good	Errors least likely (simplest structure)	Inexpensive
b. Bonded & earthed through gap: all un-energised metal hardware bonded together & earthed via downwire with 500 mm gap (Fig 1)	Good (BIL ≈ 300 kV for 170 kV BIL insulators)[2]	Better (less wood in the leakage current path)	Acceptable	Errors more likely (greater complexity), incomplete connections may result in substandard performance	More expensive
c. Fully bonded & earthed: all un-energised metal hardware bonded together & earthed directly	Average[3] (BIL ≈ 170 kV)[2]	Best (no wood in the leakage current path)	Problem for some configurations	Similar to option b, but effect of incomplete connections may be more severe	Similar to option b
d. Low leakage insulators: silicone rubber insulators	Not applicable	Leakage current is limited (KIPTS), not solution on their own	Not applicable	Not applicable	Depends mostly on the structure configuration
e. Insulator treatment: regular testing, washing and/or silicone coating or greasing of insulators	Not applicable	Least effective [4][7], but little information available	Not applicable	Labour-intensive: risk of errors occurring	Labour-intensive: can be expensive
f. Local bonding: bridging out of zones where sparking is most likely to occur	Poor	Very good [1]; good [2]; not all methods trialed in the field	Not applicable	Depends on the specific type of local bonding, but errors may be likely	Moderately expensive
g. Bonding of un-energised insulator ends to a common point using insulated bonding cables	Unknown	Promising results at conceptual stage	Not applicable	Moderately complex	Moderately expensive
h. Steel cross-arms: eliminate cross-arm fires (but not necessarily pole fires)	Depends on earthing arrangement	Promising [2]; unknown in long-term [3]; most cost-effective [4]	Depends on the earthing arrangement	Moderately complex; care needed [4]	Moderately expensive

1 The options are divided into complete structure options (a-c) and options applied only to certain parts of structure (d-h).
2 BIL is the basic impulse insulation (lightning withstand) level of a structure in phase-to-earth mode.
3 Flashovers were found to theoretically be more frequent than for 300 kV BIL insulated structures, but the increase is not significant.
4 Phase-to-earth mode only. Phase-to-phase mode also needs to be considered, but is independent of pole-top fire mitigation measures employed.
5 Likelihood of incorrect construction or incomplete bonding or earthing occurring. Severity of effects of errors occurring are also included.
6 Cost refers to the amount of material required and labour needed for construction; this is a qualitative and relative estimate.
7 This appears to contradict some of the KIPTS test results, but since little information is available this may in fact not be the case.

PROPOSED STRUCTURE CONFIGURATIONS FOR USE IN DIFFERENT AREAS

The options listed in Table 1 were reduced to preferred options for South African conditions. Several options were eliminated due to lack of available sufficient field experience, complexity, cost or lack of suitability for South African conditions. The most important criteria specific to the country are acceptable lightning and pollution performance and safety of large birds (other constraints such as human safety obviously need to be considered in all cases). However, not all areas have significant levels of lightning, pollution or great numbers of large birds. The structure configurations in Table 2 are therefore proposed. Table 2 shows that for a low risk of pole-top fires occurring the structure configuration is determined by lightning level and bird risk. For high pole-top fires risk, the most attractive configuration when considering only pole-top fires is a fully bonded and earthed structure with low-leakage insulators that have suitable end fittings. However, further investigation is required before this can be confidently applied, e.g. selection of appropriate configurations with adequate bird safety and confirmation by field trial of all aspects of structure performance.

It is therefore proposed that structures with bonding, earth downwire with a gap and insulators that are low-leakage and have suitable end fittings are used. This configuration does not completely eliminate pole-top fires, but offers the best compromise available at present, as discussed previously in this document.

The configurations proposed are for new networks. For existing networks, a plan is needed for retrofitting, depending on the risk in each applicable area. Further compromises, additional to those already listed, may need to be made.

CONCLUSIONS AND RECOMMENDATIONS

A proposal for structure configurations for use in different geographic areas has been made. The rationale was described and practical considerations have been discussed. The approach is based on the fact that while certain mitigation measures may be successful in significantly reducing the number of pole-top fires, there are other important considerations that also need to be taken into account. A trade-off between different aspects may, in many instances, need to be made. Also, further details need to be added to this proposal, as discussed in the paper. Further research should be performed into the feasibility of and practical aspects associated with fully bonded and earthed structures, and generally into ways of reducing or eliminating pole-top fires while taking all other aspects of line design into account.

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Table 2: Proposed structure configurations

Pole-top fires risk [1]	Lightning level (flashes/km^2/year) [2]	Bird risk [3]	Structure configuration[4]
High	**High**	**High**	b + d
High	**High**	*Low*	b + d
High	*Low*	**High**	b + d
High	*Low*	*Low*	b + d
Low	**High**	**High**	b
Low	**High**	*Low*	b
Low	*Low*	**High**	a or b
Low	*Low*	*Low*	a or b

[1] Determined from previous experience on networks in the area concerned.
[2] High is defined as > 2 flashes/km^2/year; low as ≤ 2 flashes/km^2/year.
[3] High is defined as a significant risk of large birds bridging phase-to-earth clearance; low as an insignificant risk of the same. The option is chosen according to the number of large birds anticipated in the area concerned.
[4] As defined and discussed in Table 1.