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Earthing of MV and LV Distribution Lines: A multi-faceted problem.

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Abstract

Earthing and bonding of systems and the components of (HV-) MV-LV power supply systems require a balancing act between various possible stresses on the system and various fault conditions that can occur in such a systems.

This include step and touch potentials under fault conditions, clearing of faults, inability of LV systems to clear certain faults, lightning protection, wood pole shattering, leakage current ignition of wood pole members, HV and MV fault GPR transferred to the LV system etc.

This paper discusses some of the aspects that have to be taken into consideration when bonding and earthing is done in a system and illustrate these choices at the hand of some examples.

Introduction

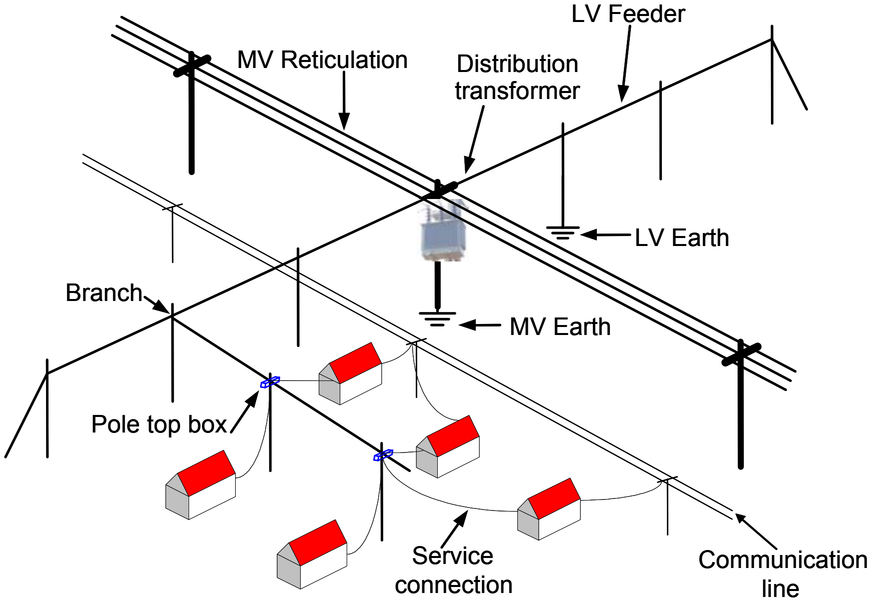


Figure 1. Ensuring safety and optimum performance: The environment in which a distribution supply system operates includes the service to customer and his installation (home), and the exposure of the public (in the street), this is impacted by environmental factors such as pollution, lighting, accidents, vandalism, other services etc. (Artwork: A Dickson.)

Figure 1 sets the scene of the environment in which safe power system earthing and bonding is to be achieved. The paper discusses the specific issues Eskom has to take into consideration when making such design choices. Eskom's uses 22kV system technology primarily for new networks (as well as 11kV technology where it exists and 33kV in rare cases) that are earthed through Neutral Earthing Compensators (NECRT) which limit the earth fault current nominally to 350A. The LV system is earthed according the SANS 0292 (Code of Practice for the Earthing of LV Distribution Systems). Close to the transformer installation to a separate earth electrode with a resistance around 70 or 30 ohm (system voltage and protection dependant) aimed at clearing a MV system fault- contact to the LV system by mean of the MV earth fault protection.

Power system safety and power system supply reliability

There is primarily personal and animal safety as well as system continuity of supply and system reliability considerations to be thought about when designing power system earthing.

Transferred Power Frequency potential from the MV system

IN the case of open wire overhead MV systems (not cables) Eskom uses a neutral arrester to separate the MV earth from the LV earth at a transformer. This is done to isolate any ground potential rise (GPR) voltage emanating from the MV network to the LV earth system, as this will be transferred directly to the customers on the LV feeders if there is a direct connection between the MV and LV earth. The MV GPR voltages can be a few kV and would be lethal if it occurred wile a customer was touching the power safety earth and the local ground at the same time.

This paper focuses on considerations on achieving an optimally safe and (power system) optimal reliable bonding and earthing of a wood pole structure that carries MV, LV and other services at the same time.

LV Fault - Ground potential rise:

LV to MV-LV transformer tank fault.
In the case where a LV to transformer tank occurs, a fault condition occurs on the LV system that is currently not protected for in overhead power systems. This is however a quite rare event. This is not discussed in this paper.

LV feeder neutral break.
Considerations around the risk of the LV neutral break are not discussed in this paper. This is a very significant risk and has to be dealt with by the utility in addition to the issues discussed here.

Use of wood poles:

Wood (compared to steel and concrete) has advantages as a structure material for power systems:

Wood poles are extensively used in Eskom for distribution of electricity. Wood's benefits are its mechanical strength and relative low cost, additionally because wood is not an electrical conductor it allows designers more flexible designs with respect to the management of bonding and earthing of power systems:

As an example in the case of Single Wire Earth Return (SWER) systems separate earthing of electrodes as well as making contact to earth electrodes inaccessible to the public is essential for safe design. Wood structures make this easy to do. On steel structures it is impossible to achieve such designs.

This article focuses on the use of wood poles in a village / town or urban, densely populated MV-LV supply installation environment.

Environmental factors to be taken into consideration in bonding and earthing of MV-LV power systems:

Lighting on MV systems: 300 kV BIL in high Lightning areas.

Lightning causes equipment damage, wood pole shattering, short duration interruptions and long term interruption due to equipment failure. Lighting can also cause deaths of customers connected to power systems and failure of customer equipment connected to the grid.

300 kV BIL Philosophy:
- Do not allow strikes to the ground close to a line to cause a flashover on the line. - However in the case of a direct strike to the line it is desirous to have flashover of the line at as low spark over voltage as possible, this will divert the lighting strike energy away from terminal equipment such as transformers and the arresters on the transformers. It is to be noted that the lighting arresters at the transformers is not rated to withstand the full lighting current (it will be very expensive to withstand the full lighting current). In this case a power frequency fault will occur which is to be cleared by the protection and power is to be resorted quite quickly and automatically by the auto reclose function on the protection. In high lighting density areas such as the average High Veld around 1 direct strike per km of line occurs. This implies that there should be around 1 auto reclose interruption per km of line per year. This sets a benchmark performance for the line with respect to lighting induced auto reclose operations.

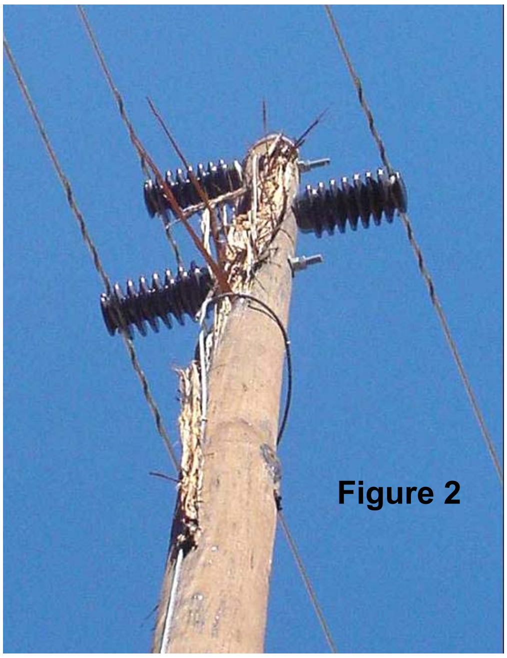


Figure 2

This concept of using wood insulation to enhance the insulation level of MV distribution lines dates quite far back in South Africa. (ref. 1).

Shattering of wood by lighting

Lighting can cause severe damage to wood poles as shown in **figure 2.** When the arc travels on the surface of the wood the damage is normally not serious and do not effect the mechanical integrity of the pole. However when the lighting arc travels inside the pole it shatters the wood badly often destroying the pole completely.

Pole shattering is associated with poorly dried wood in the first year of the line's life and again at the end of the wood pole's life if the core become rotten and moist and create low breakdown internally to the pole.

It is therefore imperative that wood pole lines are build with poles which are properly dried.

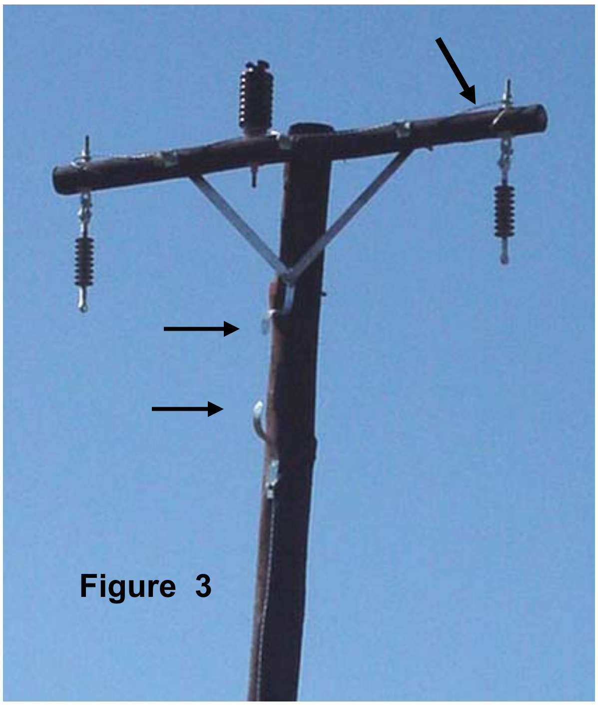
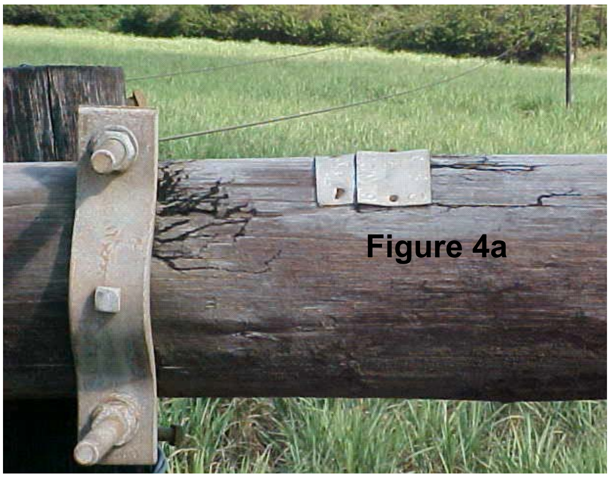


Figure 3

Recently experiments has been done in Eskom with protective spark gaps; attempting to have the lighting spark over arc away from the surface or core of the wood to flash through the air. See the structure in **figure 3**. The hardware on top of the structure is bonded with a steel wire running between the insulator mounting brackets. Between this common bond of the insulators to the pole BIL earth wire a spark gap has been fitted.

Wood poles in polluted environments:

A second problem that wood poles experience in high pollution (and even low pollution areas such as the Kalahari with low rainfall) is tracking which in severe cases turn into combustion of the pole and even outright pole fires.



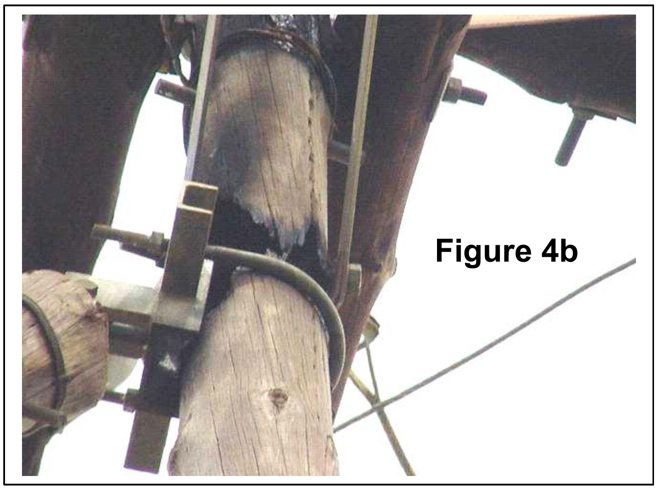
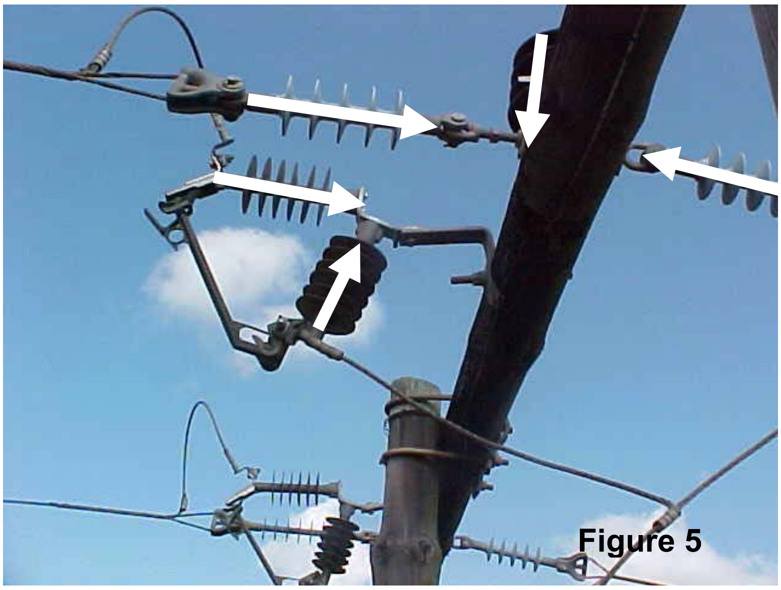


Figure 4. The initial tracking on wood surface in areas where pollution plays a role can be seen in figure 4a. The ignition of the wood and destruction of the structure can be seen in figure 4b.

The leakage current is a function of the pollution in the area, the type of insulators used on the structure and the number of parallel leakage paths that are available on the structure.



In figure 5 a structure with 5 parallel paths per phase to ground can be seen with three different kinds of insulators used. This leakage current occurs in each of the phases and runs along the wood surface (if there were no bonding conductors) between the three phases.

In areas where leakage currents are significantly high the designer has additional issues to consider:
The hardware at the top of the structure should be bonded to ensure that leakage currents between phases have the opportunity to follow conductors rather than leaking across the surface of the wood. Care has to be taken so that the leakage current at the base of the

insulator is effectively "collected" by bonding conductors and should not be allowed to run on the surface of the wood before it leaks into a conductor medium. All the different parts of the structure have to be earthed not only some of them.

The sum of the leakage currents between the three phases are not necessarily zero.

$$Sum\ of\ leakage\ current = \sum_{n=a,b,c} Phase\, n\,(pollution\ severity,\ type\, of\ insulator, number\, of\ insulators)$$

The type of insulators between the outer and middle phase is often not the same. The number of insulators is often also not the same. This lead to a net leakage current to ground. In this case a BIL gap may well be the point where such leakage current- tracking and combustion of wood may occur for this reason BIL gaps in high pollution areas may cause problems and may well not be used.

Bonding of parts of concrete structures

Even concrete structures does not escape the effects of the environment; incorrectly bonded concrete structures suffers form damage to the concrete as well as burning off of spindles of insulators and the reinforcing steel in the pole.

Where no bonding exists, lighting can flash to the reinforcing of the pole and do structural damage to the concrete.

Where poor bonding contact exist the primary flashover is often caused by lighting (that do not do the damage) but due to the secondary power frequency fault current, do welding damage to the spindles of insulators and to the reinforcing in the pole.

Lightning personal safety considerations

When lightning strikes terminate on power systems close to points of supply it does endanger the life of persons (and animals) that are accidentally connected between the power protective earth and the "local earth".

A direct strike to the power line flows into the system and the lightning caused ground potential rise (GPR) is proportional to the lighting current (median value of 34 000A) and the system resistance (typically 10 ohm), which produces easily a GPR of 340kV on the LV protective safety earth!

This problem is alleviated by the combined BIL down wires on the line. However it will only be eliminated if the BIL wire earthing was extremely low (much less than 1 ohm per pole; which is not practically possible) so the problems remain. The only effective counter measure is to couple an extensive protective ring trench earth around the property supplied. (This is the responsibility of the customer.) In addition off course if there is no contract between a person and the remote earth, there will not be any risk either; which implies that contact with the power system during lighting storms should be avoided.

In general it has been shown that communities at large are more safe from lightning risk in areas where power system are present compared to a community without the overhead power system. The air termination system and earth electrodes of the power system protects more effectively against the lightning risk, but does not eliminate it and relay the (reduced) risk in a different way.

Example of the bonding and earthing of a Shared Structure in a densely populated area with High Lighting activity:

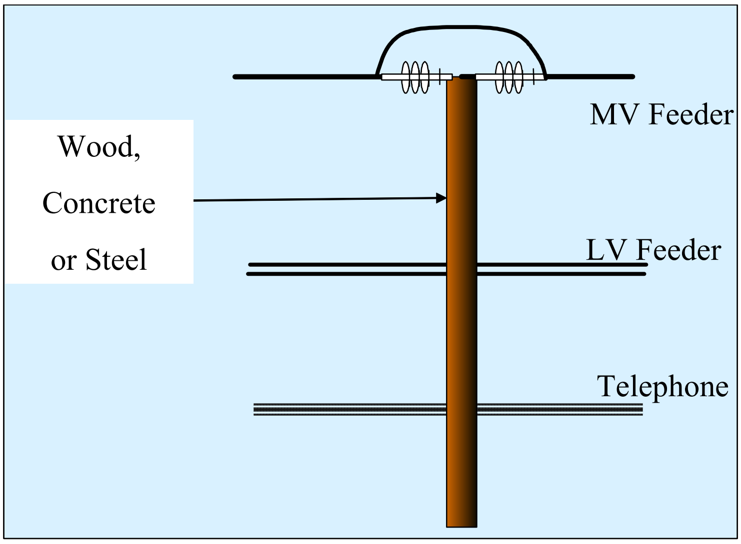


Figure 6: How do you bond and earth a wood pole structure shared by MV, LV and other services safely and with the lowest network risk?

This section of the paper examines the consequences of the impacts listed above on designing a safe shared services structure, where the MV, LV and other services such as telephone lines shares the same structure.

The choice a designer is faced with is examined by means of a matrix shown in tables 1 and 2. Table 1 examines the AC safety risk impacts and table 2 examine the impact of lighting on the safety and reliability of the system.

The design approach is listed in the first column of the table. The choices that designer has are the following:

- To have a BIL down wire on the pole or not to have one at all (fully insulated pole.)
- Not to install BIL wires on structures that already of “accidental” BIL wires such as stay wires.
- To insulate the bottom 2m of the BIL wire.
- To install more effective lightning protection on the line such as the use of double arresters etc.
- To have additional gaps on the BIL down wire.

All these options are examined in table 1 and 2 and the consequences are shown. Finally in table 3, table 1 and 2 are thrown together to show which option provides the best choice: The best choice structure (which still carries risk) is where a double gap is used above and below the LV bundle. This layout is shown in figure 7.

IN the case where lighting activity is low, the lighting risk is not a consideration which then allows the “fully” insulated option.

Table 1: The AC power system related risks on a shared services wood pole structure bonded in different ways

<table>
<tr><th>Table 1</th><th colspan="3">AC power system related risk</th></tr>
<tr><th>Design Philosophy</th><th>MV Conductor drop onto LV system</th><th>MV conductor contact to BIL down wire only</th><th>LV contact to BIL down wire</th></tr>
<tr><td>BIL wires on all shared structures (no gap no insulation of BIL wire.)</td><td rowspan="2">Fast clearing of MV fault (1sec). Auto Reclose repeat to lock out. High GPR on LV Protective Earth. Exposure to all LV installations and BIL wire locations Med risk</td><td rowspan="2">Slow clearing of fault (10 sec) even a small risk of not clearing fault. Very High GPR on BIL wire. Med risk</td><td>Fault not cleared BIL wire stay live High risk</td></tr>
<tr><td>BIL wires only on suspension structures with no stays (no gap no insulation of BIL wire.)</td><td>Fault not cleared Fewer BIL wires stay live High risk</td></tr>
<tr><td>No BIL wire</td><td rowspan="6">Fast clearing of MV fault (1sec). Auto Reclose repeat to lock out. High GPR on LV Protective Earth. Exposure to all LV installations Med risk</td><td>No risk</td><td>No risk</td></tr>
<tr><td>BIL wire on all shared structures- insulate bottom 2m of down wire</td><td>Slow clearing of fault (10 sec) even a small risk of not clearing fault. Very High GPR on BIL wire.</td><td>Fault not cleared BIL wire not accessible Med risk</td></tr>
<tr><td>No BIL wire- Double arresters on transformers on MV side</td><td>No risk</td><td>No risk</td></tr>
<tr><td>BIL wires on all – Move gap down below LV</td><td>BIL wire will remain live until it flashes to LV protective earth. If Fault to LV occurs- clearing of the fault is the same as column to the left. Med risk</td><td>Low risk</td></tr>
<tr><td>BIL wires on all – Split air gap above & below LV to prevent LV Faults</td><td>Low risk</td><td>Low risk</td></tr>
</table>

Notes:

LV conductor system: Eskom currently uses LV bundle conductor with a bare neutral or open wire LV on bobbin insulators. In the case of insulated neutral bundle conductor, it cannot be assumed that the MV fault current will go flash to the LV neutral and clearing of the fault will be subject to the local earth resistance conditions, it may be unable to clear the MV conductor on the ground.

MV earth and LV earth referrers to the earth electrodes at the pole mounted distribution transformer.

BIL and BIL down wire:

"BIL" and "BIL down wire" refer to the practice in Eskom to install a wire on the surface of MV wood pole structures with a plus minus 300 mm gap. This gap is normally constructed by applying two banded straps at the end of the wire 300mm apart. The top of the structure is normally bonded and brought down on the BIL down wire. The aim is to increase the lighting impulse spark over voltage from around 170kV of the insulator to 300 kV from the three phases to ground

Table 2: The lightning related risks on a wood pole shared structure bonded in different ways.

Table 2		Lightning risk	
Design Philosophy	**Effective earth**	**Consumer lightning risk**	**Equipment Damage**
BIL wires on all shared structures (no gap no insulation of BIL wire.)	MV earth + LV earth +BIL wire earths.	Best practice (not totally safe)	Best Practice
BIL wires only on suspension structures with no stays (no gap no insulation of BIL wire.)	MV earth + LV earth +fewer BIL wires	Best practice (not totally safe)	Best Practice
No BIL wire	MV earth+ LV earth only	High risk	High risk
BIL wire on all shared structures- insulate bottom 2m of down wire	MV earth + LV earth only	Best practice (not totally safe)	Best Practice
No BIL wire- Double arresters on transformers on MV side	MV earth + LV earth +BIL earths	High risk	Medium risk
BIL wires on all – Move gap down below LV	MV earth + LV earth + BIL earths	Best practice (not totally safe)	Best Practice
BIL wires on all – Split air gap above & below LV to prevent LV Faults	MV earth + LV earth + BIL earths	Best practice (not totally safe)	Best Practice

Table 3: The overall risk: AC power and lightning combined. Where a "high" appear the philosophy is discarded outright, the most attractive option is the bottom philosophy option with only 1 Medium risk.

Table 3	**AC power risk**			**Overall Risk**	**Lightning Risk**	
Design Philosophy	**MV Conductor drop onto LV system**	**MV conductor contact to BIL down wire only**	**LV contact to BIL down wire**		**MV conductor contact to BIL down wire only**	**LV contact to BIL down wire**
BIL wires on all shared structures (no gap no insulation of BIL wire.)	MED	MED	HIGH	**HIGH**	LOW	LOW
BIL wires only on suspension structures with no stays (no gap no insulation of BIL wire.)	MED	MED	HIGH	**HIGH**	LOW	LOW
No BIL wire	MED	LOW	LOW	**HIGH**	HIGH	HIGH
BIL wire on all shared structures- insulate bottom 2m of down wire	MED	LOW	MED	**2 MED**	LOW	LOW
No BIL wire- Double arresters on transformers on MV side	MED	LOW	LOW	**HIGH**	HIGH	MED
BIL wires on all – Move gap down below LV	MED	MED	MED	**3 MED**	LOW	LOW
BIL wires on all – Split air gap above & below LV to prevent LV Faults	MED	LOW	LOW	**1 MED**	LOW	LOW

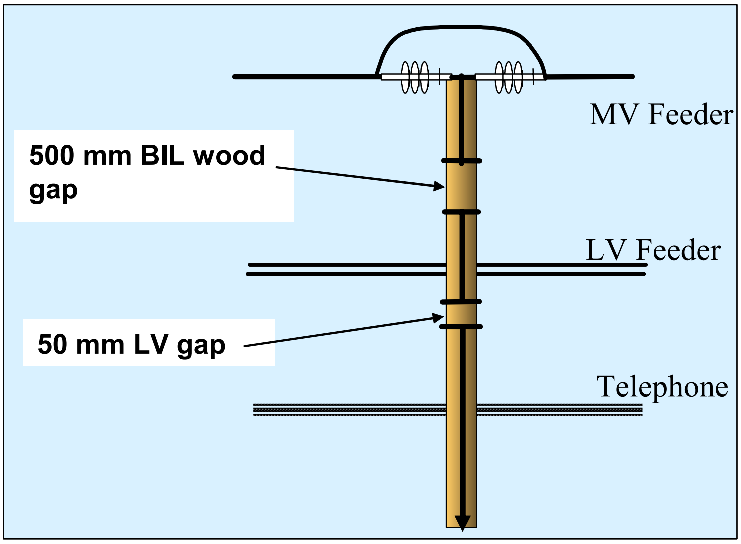


Figure 7: Optimal bonding and earthing of shared structures in densely populated areas with high lighting density.

As a general rule for the use of BIL down wires and bonding of hardware on wood pole structures, Eskom uses table 4 as guideline. There is no good structure of all situations; it depends on the pollution and lighting environment and the reliability target that has to be achieved.

Table 4. General rules for the use of BIL wires and bonding of hardware on wood pole structures

	Pollution Low	Pollution High
Lighting Low	No BIL down wire or bonding of hardware	Bonding of hardware (no BIL down wire)
Lighting High	BIL wire and co-ordinated gap	Bonding of total structure, no gap, high insulator BIL.

Finale

What appears to be a simple decision has many possible impacts and has to be considered carefully. After applying careful consideration to all the factors as shown above, some risk remains. (There are unfortunately no power systems that do not have risk to it.)

It should be noted that this paper is not comprehensive and has focussed on specific issues. Significant issues not discussed here include breaking of the LV neutral as well as HV and MV GPR fault potential transferred via the LV protective earth.

Reference

1) Insulation co-ordination of unshielded distribution lines from 1kV to 36 kV. C T Gaunt, A C Britten, H J Geldenhuys. Prepared for the HVCC task force on the Lighting protection of Distribution Lines. Published in association with the SAIEE.

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Acknowledgements

Bruce McLaren for the development of the MV structure wood pole protective spark gap. Andrew Dickson for the artwork of figure 1.