CHOICE OF MV FEEDER BIL TO MAXIMIZE QOS AND MINIMIZE EQUIPMENT FAILURE

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ABSTRACT

A high BIL (300 kV) on a MV feeder ensures that no backflashovers occur due to indirect strikes (lightning that does not terminate on the line itself). This results in the possibility of high surge voltages and currents on the feeder that can cause excessive equipment failures. In many cases the BIL is increased by using wood as part of the insulation. Direct strikes (lightning that does terminate on the line itself) can damage the wood and this can result in pole failure and electrocutions.

According to calculation, a lower BIL (150 kV) may result in a small increase in the number of backflashovers due to indirect strikes. Continuous measurements over 6 years revealed that no flashovers occurred due to indirect strikes on a test feeder. This paper investigated an optimal BIL in favour of both acceptable Quality of Supply (QOS)(in particular voltage dips) and acceptable Network performance (interruption of service to customers). Attention was also given to making a pole mount installation lightning proof.

INTRODUCTION

In some Eskom MV networks, up to 78% of equipment failures have been attributed to lightning. In the case of MV feeders, the insulation to earth typically consists of a 150 kV Basic Insulation Level (BIL) insulator in series with a 150 kV BIL wood gap on the bonded wood-pole [1] as shown in Figure 1. The wood also provides some power frequency arc quenching properties [2]. The 300 kV BIL philosophy was implemented to ensure that no indirect lightning strikes caused a phase-to-earth flashover. Unfortunately, the higher the BIL, the higher the amplitude of the voltage and current lightning surges on the feeders and this causes fuse, surge arrester and transformer failures during lightning storms. Direct strikes will cause a flashover across the wood gap and this will very often split the wood as shown in Figure 2.

The pole-mounted supply points are an integral part of the feeder and the most optimal configuration and protection of the equipment was established. It has been found that MV drop-out fuses cannot be graded for both lightning and power frequency faults [3] and for that reason nuisance fusing during storms or incorrect protection operation during equipment faults occurred frequently. Due to practical reasons, blown surge arresters were not always replaced promptly and the pole-mounted transformer became unprotected against lightning during that time. A new design in the pole-mount transformer configuration has resulted in eliminating safety risks (work at heights and in close proximity to high voltages) when changing distribution surge arresters. The transformers and fuses are also protected against lightning even after the arrester has failed. Furthermore nuisance fuse failures and protection grading are also addressed. Future research will include measurements on a 22 kV feeder to determine the most optimal choice of BIL.

Figure 1. MV pole top configuration

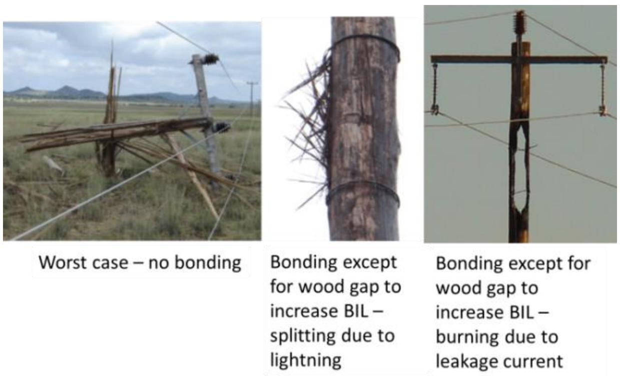

Figure 2. Wood damage due to lightning and leakage currents

THE LIGHTNING THREAT TO MV FEEDERS

The objective of the study was to minimize the BIL of unshielded MV feeders up to the point where faults on the feeder initiated by indirect strikes are limited to single figures annually. The advantage will be that the amplitudes of the surges on the feeders are reduced, resulting in less equipment (surge arrester, fuse and transformer) failures. Secondly, should it be possible to use the insulator only to provide the BIL, the rest of the structure can be fully galvanically bonded and earthed, avoiding wood-pole damage such as wood splitting and power frequency leakage current causing pole-top fires.

A study was done over 6 years on feeders with the BIL varying between 150 kV and 300 kV. The polarity of GPS time-stamped recorded lightning surges on a 22kV feeder were matched with Lightning Detection Network (LDN) data to determine whether the strikes were direct or indirect. The LDN consist of 23 sensors and has a specified geographical accuracy of a 500m radius for a 90% detection rate. The average (over 6 years) lightning ground flash density across the feeder was 7.9 ground flashes/km²/year. Part of the study also showed that many power frequency fault arcs were quenched before any breaker operation.

INFORMATION ON STUDY

Test feeder

The Ganspan – Kgomotso (GAKG) test feeder is 156 km long and supplies 5 small towns (total of 4350 customers) and 158 agricultural (irrigation) customers. A total of 372 pole-mounted transformers are connected to the GAKG feeder.

Pole-mount transformers

The pole-mount installation configuration is shown in Figure 3. Both the lightning surge current and the power frequency current flow though the fuse. The fuse cannot be graded for both currents. A higher fuse rating results in less nuisance fuse failures due to lightning, but then the fuse cannot be graded to isolate faulty installations before the Sensitive Earth Fault (SEF) protection operates.

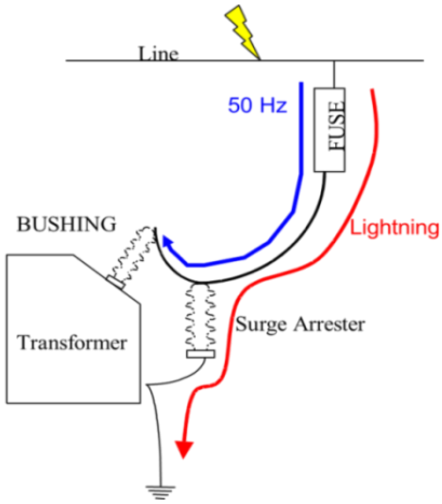

Figure 3. Pole-mount installation configuration. Both lightning surge current and power frequency current flows through the fuse.

Measurement circuit

A Class 4 QOS logger was installed on the line side of the GAKG 22 kV overhead MV feeder breaker. A resistor divider was used for voltage measurements while the breaker's CTs were used for power frequency current measurements. A capacitor divider was also installed in parallel with the resistor divider to verify that it did not filter out high frequencies. Figure 4 shows the layout of the measurement circuit.

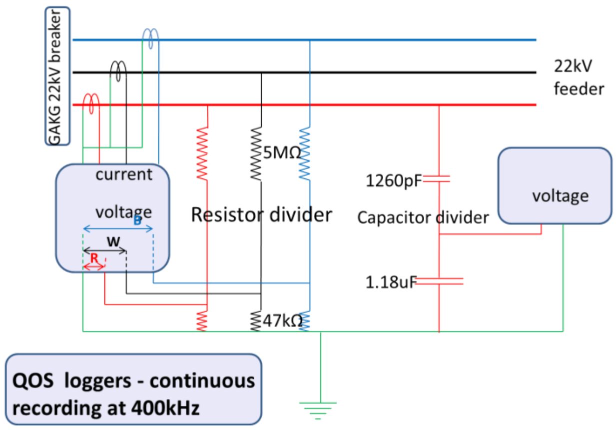

Figure 4. The measurement circuit at the substation

ANALYSIS OF MEASUREMENT DATA

Differentiation between direct and indirect strikes

An indirect strike is defined as any strike to a distant object within 1 km of the feeder. Only those indirect strikes that had both a high amplitude and were very close to the feeder produced an induced voltage surge that could be seen on the voltage logger. The rest of the indirect strikes within 1 km of the line were however still captured on the LDN.

The current and voltage waveforms were measured continuously. If there was a disturbance in the waveform, it was analysed to determine the cause. When a match with the LDN data was found, the polarity of the strike was compared with the polarity of the first half-cycle of the measured lightning voltage surge. Should the polarity be the same, it meant that it was a direct strike – if not, it was an indirect strike.

The waveforms of the voltages and currents showed whether the lightning surge current was followed by a power frequency fault current. SCADA data was used to verify any breaker operations caused by a subsequent power frequency fault current. Some direct-to-feeder flashes did not result in breaker operation. In these cases the power frequency fault current arc was quenched before any breaker operated as shown in Figure 5.

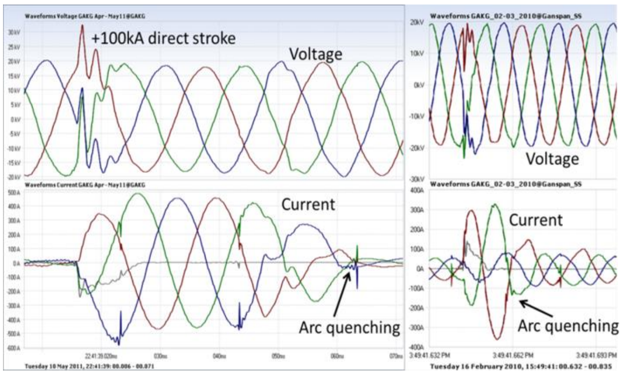

Figure 5. An example of arc quenching before breaker operation

Results

No incident could be found where an indirect flash caused insulation breakdown on the test feeder as shown in **Erreur ! Source du renvoi introuvable.**. During the 6 year period, 62% of the single-phase faults and 39% of the phase-phase faults quenched. According to [2], the wood path can assist in quenching arcs up to 20 A. The minimum AC fault current that was quenched, was 80 A_{rms} and the average was 179 A_{rms}. According to these values, no contribution to arc quenching would have been made by the wood path.

High amplitude strikes

A study was done to determine the effect of all flashes with strikes above 65 kA in a buffer zone within 1 km of the feeder as shown in Table 2. The specific interest was to ensure that no high amplitude indirect strikes close to the feeder were missed.

There were 11 strikes between 120 kA and 179 kA in the vicinity of the test feeder over the past 6 years. Most of them were too far from the feeder to cause a noticeable surge on the feeder. None of them caused insulation breakdown.

Table 1. A summary of the faults caused by lightning on the GAKG feeder. All indirect flashes within 1 km of the feeder were tabled.

	DIRECT FLASHES			INDIRECT FLASHES		
Year ending in Febru-ary	Phase to phase faults	Single phase faults	Did not cause faults	Phase to phase faults	Single phase faults	Did not cause faults
2009	15	0	18	0	0	1603
2010	34	9	9	0	0	2062
2011	30	2	28	0	0	1983
2012	26	3	14	0	0	2471
2013	14	0	22	0	0	1091
2014	7	1	11	0	0	887

A particular case where a negative 120 kA strike terminated 15 m from the feeder (Figure 6) where the BIL was 180 kV was analysed. The induced voltage can be calculated as:

$$Um = \left(1 + \frac{v/c}{\sqrt{2-(v/c)^2}}\right)\left(\frac{h*I_p}{d}\right) \qquad 1$$

- where v is the speed of the travelling wave in m/s, c is the speed of light in m/s, h is the height of the feeder in m, I_p is the lightning amplitude in A and d is the distance between the strike and the feeder in m. Adding values for the specific case:

$$Um = \left(1 + \frac{10^8/3*10^8}{\sqrt{2-(10^8/3*10^8)^2}}\right)\left(\frac{10*120}{15}\right) = 2.98\text{ MV}$$

However, there were surge arresters 100 m away from the point where the induced voltage was measured. The surge voltage on the line will then be:

$$V = \left(V_{IR} + \frac{L}{c}\frac{IZ_0}{2t_f}\right) \qquad 2$$

- where V_{IR} is the surge arrester voltage discharge level in V, L is the length of line section in m, c is the speed of light in m/s, I is the induced current in A, Z_0 is the line surge impedance in Ohms and t_f is the surge rise time in s. Substituting the values in equation 2, results in an induced voltage of:

$$V = \left(40 + \frac{100}{3\times10^8}\frac{7.4\times400}{2\times5.3\times10^{-6}}\right) = 133.7kV$$

The surge arresters that were close prevented a flashover in this case. This was the case in all such incidents in the past 6 years.

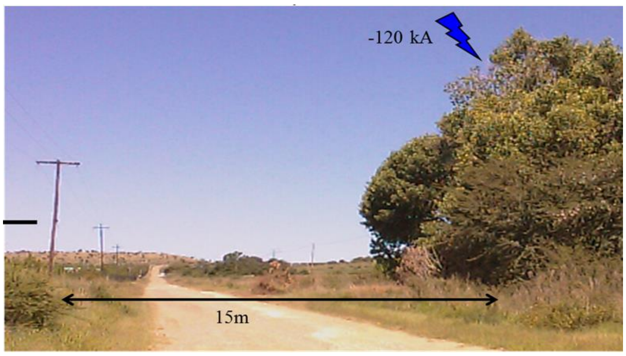

Figure 6. A -120 kA strike terminated 15 m from the feeder.

Table 2. A total of 72 strikes above 65 kA were recorded along the feeder.

Direct strike = 8		Indirect strikes = 55		Line out
Resulted in faults	Did not cause any faults	Resulted in faults	Did not cause any faults	Line not energized at time of strike
7	1	0	55	9

PROPOSED WAY FORWARD

BIL of feeder

Direct strikes to the GAKG feeder should cause a total of 121.6 flashovers annually according to Equation 3 [5].

$$N_s = N_g(28H^{0.6} + w) * L * 10^{-3} \qquad 3$$

- where *Ng is the* average ground flash density (7.9) in ground flashes/km^{-2} /year, *w is the* line width (1.2 m) in the absence of shield wires in m, *L is the* line length (156 km) in km and *H is the* average tower height (8 m) in m.

There were on average 40.5 flashovers annually over the 6 year period of which only 23.5 resulted in breaker operation. This may have been due to significant shielding by trees in the vicinity of the feeder and requires further investigation.

For the GAKG feeder with length of 156 km, ground flash density of 8 ground flashes/km²/year, 10% of the line insulated at 180 kV and 90 % at 300 kV, 5.06 flashovers should have occurred annually along the feeder due to indirect strikes as seen in Figure 7 [4]. No flashover occurred due to indirect strikes to the GAKG feeder and it could possibly be due to surge arresters and other equipment that were always in close proximity of the indirect strikes.

According to [2], a wood path can also prevent a power frequency arc follow through caused by a lightning strike. However these tests were only done for lightning currents up to 3500 A. All the strikes direct to the GAKG feeder were more than 3.5 kA and would therefore not have applied to this research.

Should the feeder's BIL be lowered to 150 kV, it is possible that the amount of flashovers might increase from 40.5 by an additional 5.06 flashovers. According to the measurements, 42% of these flashovers will quench before breaker operation. It will be acceptable to have only about 3 additional flashovers annually for the benefit of much smaller lightning surge voltage and current amplitudes and less equipment failures.

Pole mount transformer configuration

A Combi unit was designed. A failed arrester drops out and then the fuse opens as well. Subsequent strikes will flash over to earth while in the process of replacing the broken arrester. Both transformer and fuse are therefore protected against lightning. Fuse grading challenges with protection were also addressed. Both the arrester and the fuse can be replaced safely from ground level.

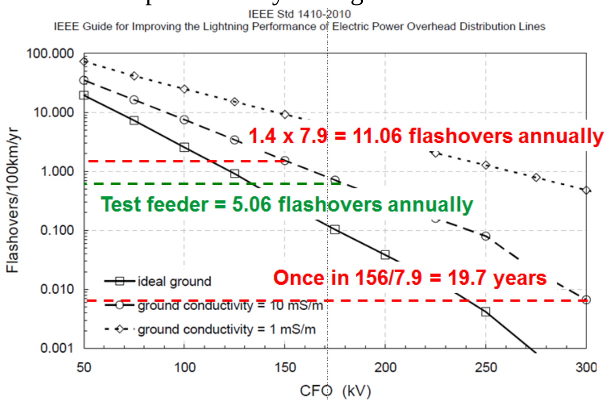

Figure 7. Flashover rate for different BIL standards

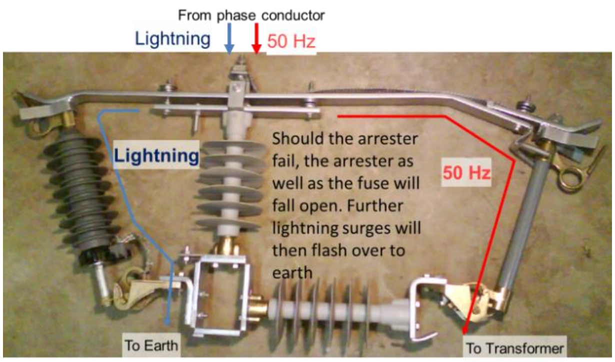

Figure 8. The Combi unit to protect the transformer and fuse after surge arrester failure.

CONCLUSION

Based on the actual measurements of induced voltages on the feeder, the BIL of the feeder could possibly be lowered. It would be beneficial to lower the feeder BIL to a level (150 kV) where no unprotected wood is present. This will eliminate wood damage and will lower the surge energy and voltage amplitudes. Equipment on pole-mount installations, will benefit significantly.

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