Numerous pole mounted MV transformers fail during lightning conditions. Blown surge arresters are not always replaced promptly so the transformers remain unprotected against lightning. Changing distribution surge arresters on pole mounted transformers poses safety risks to operators where they are required to work at heights and in close proximity to high voltages. A MV pole mounted transformer installation consists of a combination of fuses, surge arresters and a transformer. In a standard installation the surge arresters protect the transformer against lightning and the fuses open to isolate a faulty transformer installation from the network. The lightning proof fuse (LPF) eliminates nuisance fusing on MV feeders caused by lightning while still allowing sufficient protection.

A detailed study was undertaken to determine the optimum placement and configuration of the equipment at a transformer installation to ensure reliable performance. The emphasis was placed on the use of technology to enforce operator discipline. A combination unit (combi), consisting of a drop-out fuse and a surge arrester, was developed to resolve the lightning surge challenges around MV pole mounted transformers installations. The unit also addresses and resolves the lack of discipline of operational staff.

The unit was constructed in such a way that both the pole mounted MV transformer and drop-out fuses are always protected against lightning by surge arresters. The unit also solves the challenge of grading fuses for both lightning and power frequency faults. Due to the configuration of the unit, all operating is done from ground level with an insulated operating stick thereby eliminating the need for the operator to climb up to the transformer. The installation of these units improves network performance, the safety of operating staff, and reduces operational costs.

### Equipment failure

Thousands of MV drop-out expulsion fuses and pole-mounted MV transformers are lost each year especially during lightning storms. Table 1 gives an indication of the annual amount of failures. The cost of replacing a pole-mounted transformer (including labour, material and transport) is estimated to be about R40 000, resulting in huge financial implications to the utility or distributor. The average once-off installation cost of a combi 3-phase set together with a 3-phase LPF is R31 000.

### Fuse operations at lightning frequencies

It is a challenge to avoid nuisance fusing on rural feeders caused by lightning impulses while also making proper 50 Hz protection grading possible. In order to minimise nuisance fusing, technicians insert 20 A fuses in many pole-mount installations. However when a fuse is rated too high it causes the Sensitive Earth Fault (SEF) protection of the upstream breaker to operate before the fuse blows, resulting in a line outage. In some cases where 20 A fuses were installed, only a single fuse operated (the one on the faulted phase). The other two fuses fed into the fault through the transformer windings, tripping the breaker on SEF before the fuses blew. It is evident from Table 2 that when higher graded fuses are fitted (to limit nuisance fusing due to lightning) more breaker operations occur.

It is relatively easy to grade fuses to operate correctly for power frequency

### Table 1. Average MV equipment failures per year.

<table>
<thead>
<tr>
<th>Area</th>
<th>Fuse sizes used</th>
<th>Number of breaker operations</th>
<th>Number of transformer faults</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 A</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>20 A</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>20 A</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>8 A</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>8 and 20 A</td>
<td>12</td>
<td>61</td>
</tr>
<tr>
<td>6</td>
<td>20 and 8 A</td>
<td>28</td>
<td>65</td>
</tr>
</tbody>
</table>

### Table 2. Number of breaker operations that occurred when transformers with different fuse ratings failed.

It is relatively easy to grade fuses to operate correctly for power frequency
TRANSMISSION AND DISTRIBUTION

faults, however fuses are also sensitive to high lightning currents. Normally, lightning consists of a first strike followed by several subsequent strikes as can be seen in Fig. 1. The illustration shows that lightning consists of three major components namely an amplitude component, the rate at which the current rises and an energy component that exists due to the DC current found within a lightning flash. The total surface area underneath the waveform represents the energy that needs to be dissipated by the fuse and surge arresters on the line.

The combination of all of the above given factors contributes to the reason why MV drop-out expulsion fuses blow for lightning impulses. In practice this means that since lightning flashes are of very short duration and consists of high peak values with the possibility of a DC component, the maximum RMS current handling capability of the fuse is reached almost instantaneously, resulting in a blown fuse (mainly due to the energy dissipated in the fuse). However, this problem can be avoided by the installation of a LPF where passive components are introduced into the circuit or by the installation of a combi unit where the fuse is protected against lightning by the surge arrester.

Lightning-proof fuses (LPF)

Circuit configuration and parameters

By introducing a spark gap in parallel with a MV drop-out expulsion fuse (which is in series with an inductor), with the inductor acting as a low impedance path at 50 Hz and as a high impedance device at lightning frequencies, it was found that the problems due to lightning frequencies can be avoided with great success. Fig. 2 illustrates the arrangement of the circuit components found in the fuse and Fig. 3 shows the operation of the LPF.

During normal 50 Hz operation the inductor acts as a low impedance path with low overall energy dissipation. The impedance of the inductor at power frequency is given by:

\[ X_L = 2 \cdot \pi \cdot f \cdot L_c \]  

where:

- \( X_L \) = Power frequency impedance
- \( f \) = Power frequency
- \( L_c \) = Inductance

This will ensure that the fuse will work correctly for normal over-current situations. However, from the above equation it can be deduced that the impedance of the circuit will be high for lightning frequencies resulting in the current attempting to find an alternative conducting path. The maximum volt-drop across the inductor is 75 kV at lightning frequencies and 0.15 V at 50 Hz (with a load current of 5 A). The power frequency will pass through the inductor and the fuse while the lightning impulses will flash over the spark gap, bypassing the fuse element.

Impulse test results

All current impulse tests have been performed at NETFA using 8/20 \( \mu \)s current impulses. The 8/20 \( \mu \)s current impulse test was done to determine the breakdown...
Advantages  
- The advantage of the LPF is that it eliminates nuisance fusing on MV feeders caused by lightning and still allows sufficient protection grading.  
- Standard Eskom fuses are used and the LPF fits in a standard fuse holder.  
- The LPF saves overtime, man-hours and transport costs.  
- It minimises supply loss, voltage unbalances and subsequent damage to customers’ sensitive equipment (such as pumps, electronics, and fridges).

Disadvantages  
- The LPF does not protect the pole mounted transformer from lightning.  
- Whenever the fuse blows for a 50 Hz fault at the transformer, a standing back-flash-over will occur across the spark gap while the fuse is falling open. The arc will be cleared by the upstream breaker. The breaker will
Compliance to distribution standard


Combi unit calculations

As can be seen in Fig. 7 the potential difference (voltage drop) across the transformer in the standard configuration will be 122 kV when lightning (34 kA 1,2/50 μs) terminates on top of the transformer pole. When combi units are installed 1.5 m above the transformer, the surge arresters are moved further away and the potential difference across the transformer increases to 137 kV, which is still well below the transformer BIL of 150 kV (Fig. 8).

When lightning terminates on the line close to the installation, the voltage across the transformer in the combi configuration will be at most 10 kV more than for the standard configuration.

Case study

A transformer, where a combi unit set had been installed, failed on 4 March 2011. A Fault Analysis and Lightning Location System (FALLS) was used to locate the lighting strikes which terminated near the transformer installation and it was found that a 14 kA subsequent lighting strike (indicated in Fig. 9 by a red-filled ellipse) was responsible for the transformer failure.

After site inspection it was found that the combi unit was mounted about 3.5 m above the transformer tank and it resulted in a potential difference (calculated at 206 kV) between the transformer windings and tank (greater than the transformer’s 150 kV BIL) when the lightning strike terminated at the installation.

Operating and safety

The only challenge so far was the weight of the surge arrester when it had to be lifted with a fully extended link stick. However, should the operator use the correct method (i.e. the telescopic function of the link stick) the installation of the drop-out surge arrester should not be more challenging than the installation of a MV drop-out expulsion fuse. To minimise the risk of falling objects, a tool was developed to replace drop-out surge arresters and drop-out fuses from ground level using a link stick. Fig. 10 shows the insertion tool.

Advantages of using the combi unit

- Replacing drop-out fuses and surge arresters from ground level.
- No risk of slip and fall from a step ladder.
- No risk of electric contact.

Continued on page 36....
Both the transformer and fuses are protected against lightning.

- No nuisance fusing due to lightning.
- A maximum size of 15 A fuses are used in the combi units to ensure correct protection grading.
- The transformer is always protected against lightning.
- A faulty fuse or surge arrester will fall open and is easily noticeable.
- The unit can be used as an isolation point.
- Standard Eskom fuse and fuse holder is used.
- The unit’s surge arrester has the same dimension as a drop-out line arrester.
- No outage booking is necessary for the replacement of a fuse or surge arrester.
- The replacement time of a combi unit surge arrester is much faster than replacing in a surge arrester in the standard installation.

Disadvantages of using the combi unit

- Cost of installation: it costs more to install a combi unit than a normal fuse and surge arrester arrangement.
- Should the surge arrester fail, the customer is without supply. A new surge arrester should therefore be installed as soon as possible.
- In the combi configuration the surge arrester is further away from the transformer, resulting in a 137 kV impulse level instead of a 122 kV potential difference across the transformer. However the transformer should be insulated to 150 kV.

Performance of the combi unit

A total of 1064 pole-mount installations were fitted with combi units over the past six years. At all of these installations at least one transformer failure occurred annually.

After the installation of combi units only six transformers were recorded to have failed in the last six years, instead of an expected 3000.

Transformer installations where combi units are installed can be seen in Fig. 11.

Lessons learned

The six installations where the transformer failures occurred were visited and the findings are as follows:

- Three installations had neither neutral arresters nor any connection between the 400 V neutral and earth, leaving the transformer without proper lightning protection.
- One installation was hit by a lightning flash consisting of 18 strikes. All the surge arresters failed and in the process the transformer was damaged.
- One transformer failed shortly after installation with no lightning in the vicinity – the failure was not lightning related.
- Incorrect installation – the combi unit was mounted too high above transformer tank, with an earth lead of 3.5 m instead of 1 m as indicated in the specification [2].

Summary of findings

Combi units should be installed at lightning problematic pole mounted transformer installations to minimise equipment failures (fuses and transformers), to improve network performance and to bring about operational cost savings. Proper protection grading is achieved and nuisance fusing is eliminated. All operating is done from ground level making operating safer and easier. These units can be installed at all transformer installations due to the safety features.

References

[1] C T Gaurt, A C Britten and H J Geldenhuys: “Insulation co-ordination of unshielded distribution lines from 1 kV to 36 kV”, SAIEE.

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