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Lightning and Power Frequency Performance of MV Pole Mounted Transformers

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SUMMARY

During lightning storms a large amount of transformers, drop-out fuses and surge arresters fail which result in extensive unplanned outages. Properly grading MV drop-out fuses with upstream feeder protection, to ensure correct protection operation during both lightning and power frequency faults, is a great challenge and for this reason nuisance fusing during storms or incorrect protection operation during system faults occur frequently. Numerous MV pole mounted transformers fail during lightning conditions. Blown surge arresters are not always replaced promptly and the pole mounted transformer are unprotected against lightning for that time. Changing distribution surge arresters or 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 and isolate a faulty transformer installation from the network.

The Lightning Proof Fuse (LPF) was developed, constructed, tested and implemented at several test sites. The installation of LPFs eliminates nuisance fusing on MV feeders caused by lightning and still allows sufficient protection grading. A detailed study was done to determine the optimum placement and configuration of the equipment at a transformer installation to ensure an improvement in performance. A strong emphasis was placed on the use of technology to enforce operator discipline. A Combi unit, 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 Combi unit was constructed in such a way that both the MV pole mounted transformer and drop-out fuses are always protected against lightning by the surge arresters. The Combi unit also solves the challenge of grading fuses for both lightning and power frequency faults. Due to the configuration and operation of the Combi unit all operating is done from ground level with an insulated operating stick eliminating the risks of falling from heights and inadvertent electrical contact. The installation of Combi units at problematic pole mounted transformer installations does not only improve network performance and the safety of operating staff, but also bring about operational cost saving.

KEYWORDS

Combi unit, lightning, drop-out surge arrester, drop-out expulsion fuse, pole-mounted transformer.

1. INTRODUCTION

During lightning storms a large amount of transformers, drop-out fuses and surge arresters fail which result in extensive unplanned outages. It is a great challenge to properly grade MV drop-out fuses with upstream feeder protection to ensure correct protection operation during lightning and power frequency faults and for this reason nuisance fusing during storms or incorrect protection operation during system faults occur frequently. Numerous MV pole mounted transformers fail during lightning conditions. Blown surge arresters are not always replaced promptly and the pole mounted transformer will be unprotected from lighting for that time. Changing distribution surge arresters or pole mounted transformers poses safety risks to operators where they are require to work at heights and in close proximity to high voltages.

A Lightning Proof Fuse (LPF) was developed to reduce fuse failures due to lightning. A Combi Unit was developed to resolve the lightning surge challenges around MV pole mounted transformers installations. The Combi unit ensures that both MV pole mounted transformer and drop-out fuses are always protected against lightning and solves the challenge of grading fuses for both lightning and power frequency faults. All operating is done from ground level, eliminating the risks of falling from heights and inadvertent electrical contact. The installation of Combi units at lightning problematic pole mounted transformer installations improves network performance and greatly reduces operational costs.

2. EQUIPMENT FAILURES

Annually many thousands of MV drop-out expulsion fuses and MV pole-mounted transformers in the old North Western Region are lost particularly during lightning conditions. Table I gives an indication of the annual amount of failures. If the labour, material and transport cost to replace a pole-mounted transformer are taken into account (estimated average of R40 000), it is not difficult to see the large financial implications as well as the negative impact on customer satisfaction. Whereas the average once off installation cost of a Combi unit 3 phase set is R28 000 and the installation cost of a Lighting Proof Fuses 3 phase set is R3 000.

Table I Average MV equipment failures per year

Average failures per year	Total amount	Due to lightning
MV Fuses	16 502	12 789
MV/LV Pole Mounted Transformers	1212	939

3. FUSE OPERATIONS AT LIGHTNING FREQUENCIES

It is a challenge to avoid nuisance fusing on rural feeders caused by lightning impulses while also making proper 50Hz protection grading possible. In order to minimize nuisance fusing, Field Services inserted 20A 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 II below that when grading fuses higher (to limit nuisance fusing due to lightning) results in more breaker operations.

Table II Amount of breaker operations that occurred when transformers with different fuse ratings failed.

Area	Fuse sizes used	Number of breaker T&L/O operations	Number of transformer faults
1	20 A	11	11

2	20 A	3	3
3	20 A	8	8
4	8 A	1	18
5	8 & 20 A	12	61
6	20 & 8 A	28	65

It is relatively easy to grade fuses to operate correctly for power frequency faults, however fuses are also sensitive for high lightning currents. Normally lightning consists of a first stroke followed by several subsequent strokes as it can be seen in Figure 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 wave form represents the energy that needs to be dissipated by the fuse and surge arresters on the line.

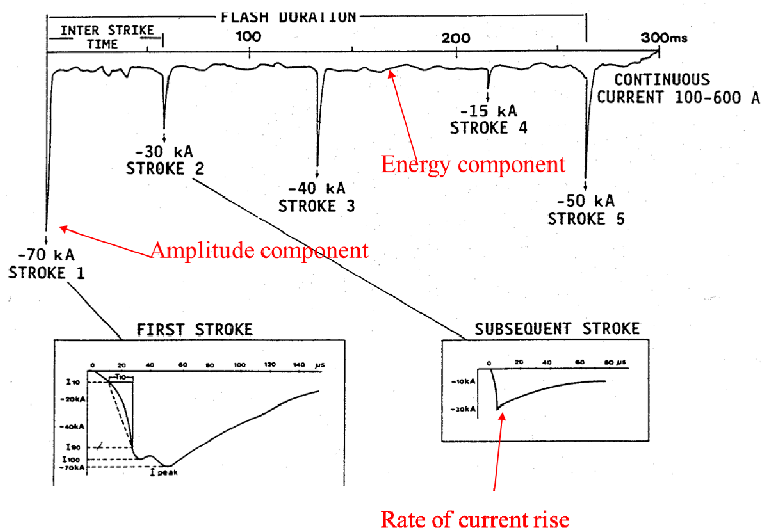

Figure 1 Three basic components found in a lightning flash [1]

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 (this is mainly due to the energy dissipation in the fuse).

However, this problem can be avoided by the installation of a Lightning Proof Fuse 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.

4. LIGHTNING PROOF FUSE (LPF)

4.1 *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 arising problems due to lightning frequencies can be avoided with great success. Figure 2 illustrates the arrangement of the circuit components found in the fuse and figure 3 shows the operation of the Lightning Proof Fuse.

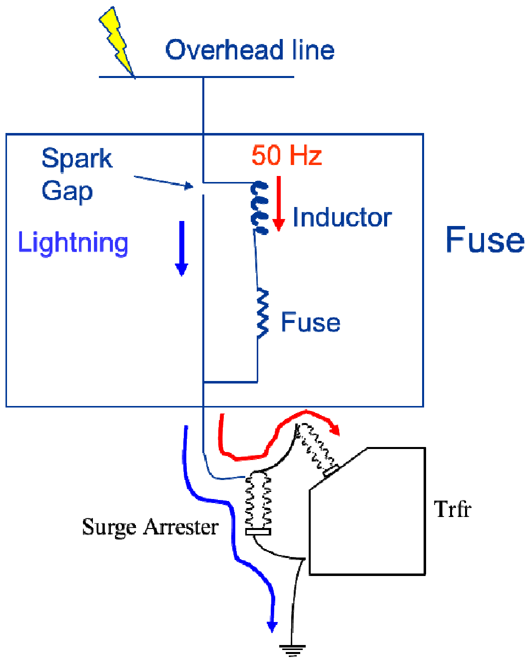

Figure 2 Circuit configuration using a Lightning Proof Fuse

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

$$X_L = 2 \cdot \pi \cdot f \cdot L_c \qquad (1)$$

Where:
X_L = Power frequency impedance.
f = Power frequency.
L_c = Inductance.

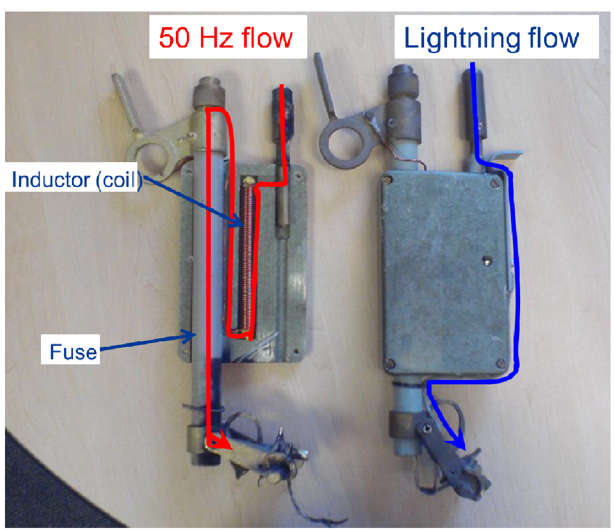

Figure 3 Illustration of the Lightning Proof Fuse operation

This will ensure that the fuse will work correctly for normal over current situations. However, from equation 1 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 (load current = 5 A) at 50 Hz. 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.

4.2 *Impulse Test Results*

All current impulse tests have been performed at NETFA using 8/20 µs current impulses. The 8/20 µs current impulse test was done to determine the breakdown currents of the 3 A and 5 A fuses. The 3 A fuse lasted for 5 tests in succession (without blowing on the last test) with current varying from 20 kA to 70 kA.

4.3 *Advantages*

- The advantage of the Lightning Proof Fuse 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 minimizes supply loss, voltages unbalance and subsequent equipment damage (pumps, electronics, and fridges) to customers.

4.4 *Disadvantages*

- The disadvantage of the LPF is that it does not protect the pole mounted transformer from lightning.
- Secondly, 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 auto reclose in about 3s and the faulty transformer is isolated from the network.
- The LPF is more costly than a standard fuse.
- The LPF cannot be used as a line fuse (coil heats up for load current greater than 15 A).

5. **THE COMBI UNIT**

The Combi unit consists of a post insulator in the middle with a drop-out type surge arrester on the one side and a drop-out expulsion fuse on the other side, see Figure 4.

Figure 4 Combi unit consisting of a drop-out expulsion fuse and drop-out surge arrester.

5.1 Development and Operation of the Combi unit

The Combi Unit was primarily developed to minimize the MV drop-out expulsion fuse and MV pole-mounted transformer failures during lightning activities.

In the standard configuration, the MV fuses are exposed to lightning as it is installed line side of the surge arrester. The surge arrester only protecting the MV transformer as illustrated in Figure 5 (A) Therefore an alternative configuration was proposed where the surge arrester is connected across the fuse and transformer to provide lightning protection to both, as can be seen in Figure 5 (B).

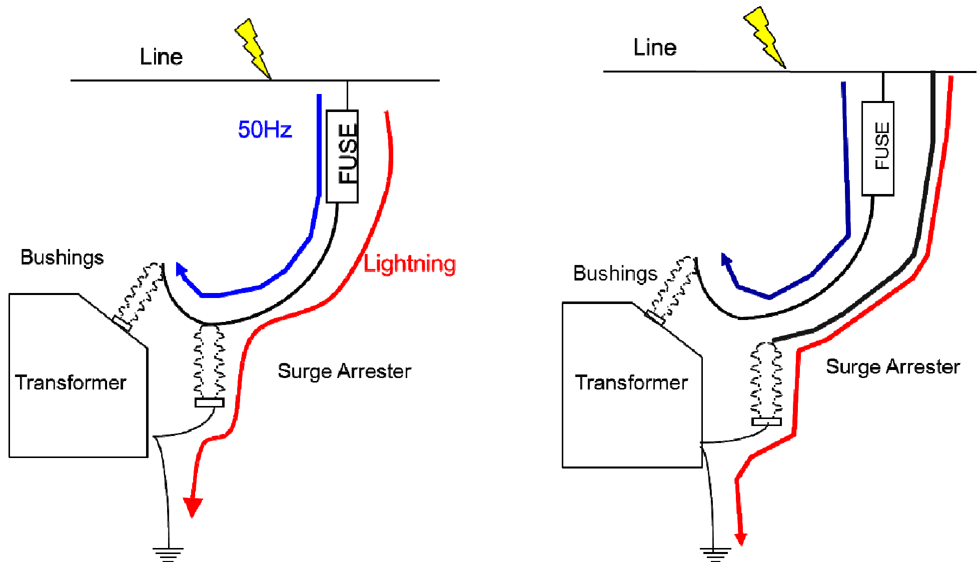

Figure 5 (A) Standard pole mounted transformer configuration and **(B)** Combi unit configuration

The Combi Unit was developed to implement the proposed configuration. Should the fuse blow, only the fuse will fall open while the arrester stays closed. In the case where the surge arrester GLD (ground lead disconnect) operates, both the fuse holder (fuse element still healthy) and the surge arrester fall open. Figure 6 illustrates the operation of the Combi unit.

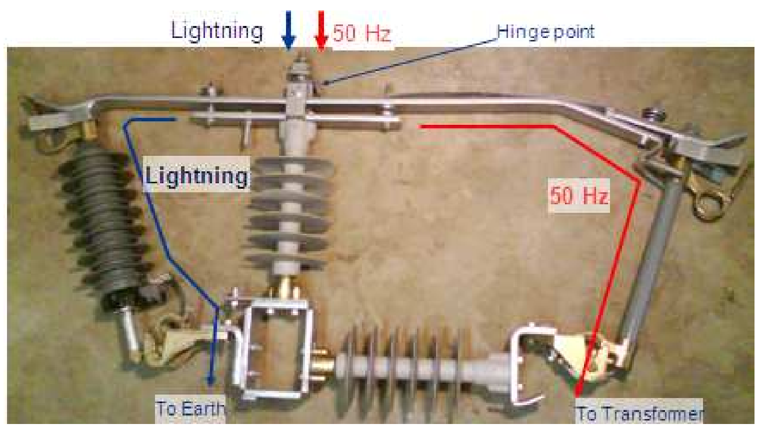

Figure 6 Illustration of the operation of the Combi unit

5.2 Compliance to Distribution Standard

The Combi unit complies with the DSP 34-1962: Distribution Specification – Part 4: Specification for a combined cut-out fuse and drop-out surge arrester unit.

5.3 Combi unit Calculations

It can be seen in Figure 7 that the potential difference (voltage drop) across the transformer in the standard configuration will be 122kV when lightning (34kA 1.2/50µs) terminates on top of the

transformer pole. When Combi units are installed 1.5m above the transformer, the surge arresters are move further and the potential difference across the transformer increases to 137kV, which is still well below the transformer BIL of 150kV, see Figure 8.
When lightning terminates on the line close to the installation, the voltage across the transformer in the Combi configuration will be at most 10kV more than for the standard configuration.

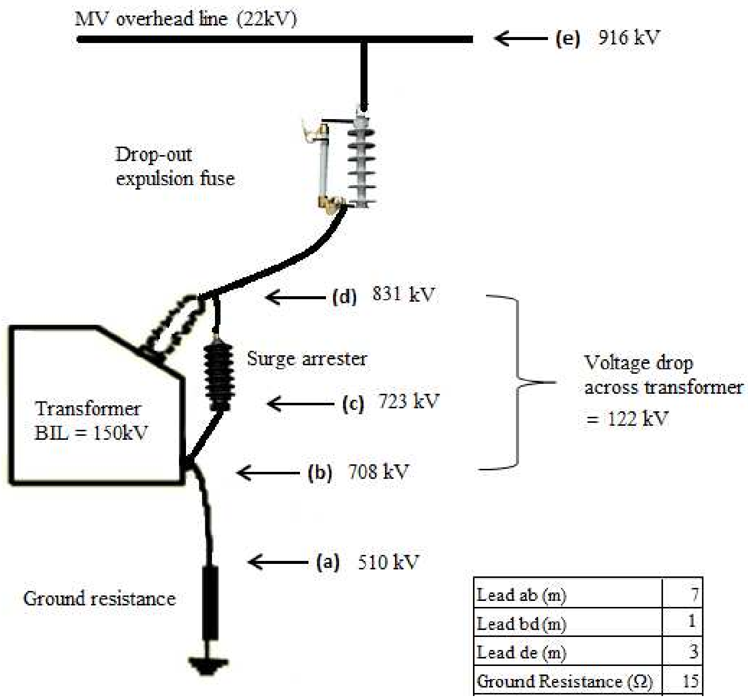

Figure 7 Voltage drop calculations of standard configuration

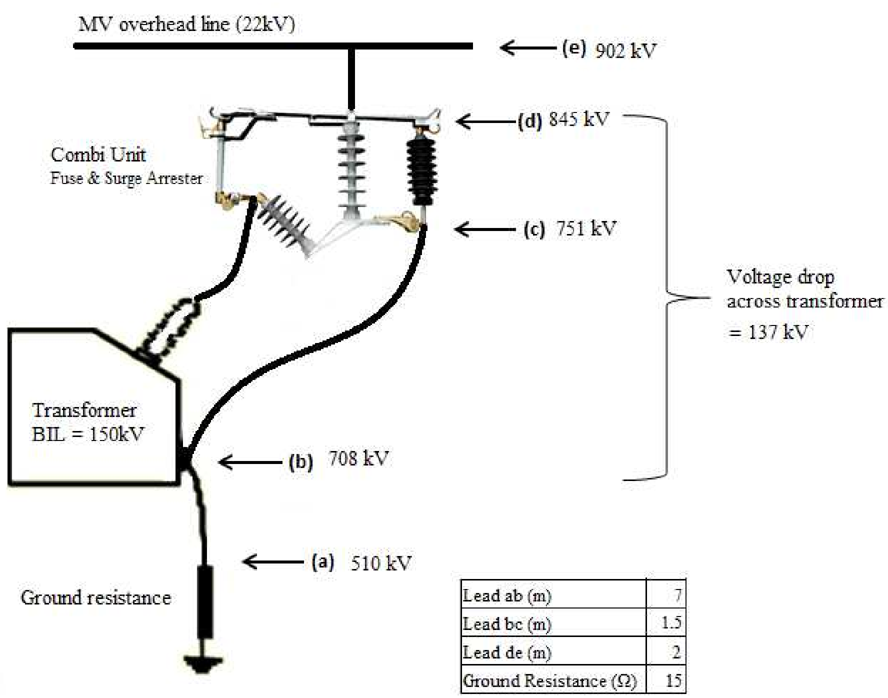

Figure 8 Voltage drop calculations of Combi configuration

5.4 Case study

A transformer where a Combi unit set was installed failed on 4 Mar 2011 at 19:07. FALLS (Fault Analysis and Lightning Location System) was used to locate the lighting strokes that terminated near the transformer installation and if was found that a 14 kA subsequent lighting stroke (indicated in the Figure 9 by a red filled ellipse) was responsible for the transformer failure.

Time GMT+02:00	PkCurr(I	NumSen	Latitude	Longitude
2011-03-04 19:01:33.635	-21	9	-30.1494	27.3355
2011-03-04 19:07:18.557	-22	10	-30.1846	27.3674
2011-03-04 19:07:19.454	-14	8	-30.1742	27.3549

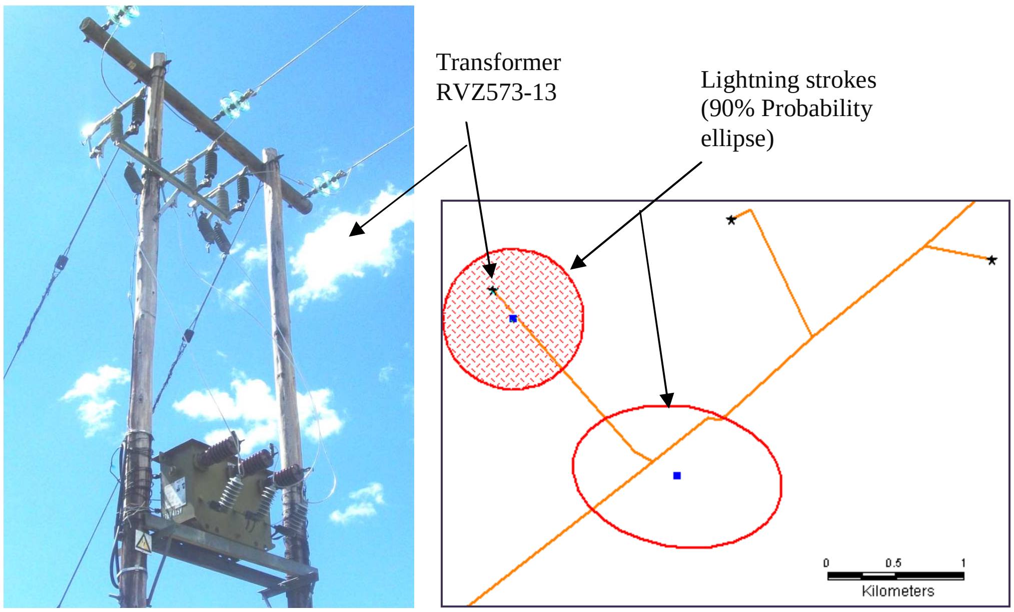

Figure 9 Transformer installation and lightning study results

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

5.5 Operating and safety

The only challenge so far was the weight of the surge arrester when a petite operator needs to pick it up from ground level with a fully extended link stick. However, should the operator uses the correct method (use the telescopic function of the link stick) the installation of the drop out arrester should not be more challenging than the installation of a MV drop-out expulsion fuse.

To minimize 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. Figure 10 shows the insertion tool.

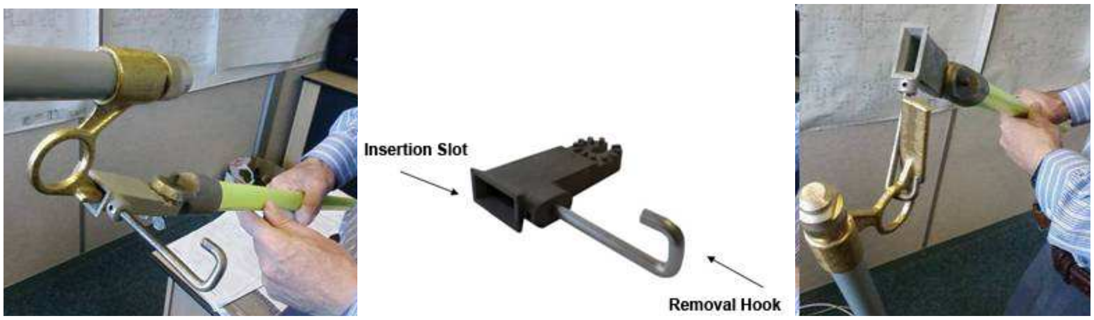

Figure 10 The insertion tool to replace drop out surge arresters and fuses

5.6 Advantages

Using the Combi unit, the following advantages can be expected:

- Replacing drop-out fuses and surge arresters from ground level.
  - No slip and fall from step ladder
  - No risk of electric contact
- Both the transformer and fuses are protected against lightning.
- No nuisance fusing occurs due to lightning.
- A maximum size of 15A 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 Combi unit can be used as an isolation point.
- Standard Eskom fuse and fuse holder is used.
- The Combi unit 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.

5.7 Disadvantages

- 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 137kV impulse level instead of a 122kV potential difference across the transformer. However the transformer should be insulated at 150kV.

5.8 Performance of the Combi Unit

A total of 1064 pole mount installation were fitted with Combi units over the past 6 years. At all these installations at least one transformer failure occurred annually. After the installation of Combi units only 6 transformers were recorded to have failed in the last 6 years, instead of an expected 3000 transformer failures in 6 years' time. Transformer installations where Combi units are installed can be seen in Figure 11.

Single pole arrangement Double pole arrangement

Figure 11 Combi unit installations

5.9 Lessons learned

The 6 installations where the transformer failures occurred were visited and the findings are as follow:

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

5.10 Recommendations based on Findings

Combi units should be installed at lightning problematic pole mounted transformer installations to minimize equipment failures (fuses and transformers), improve network performance and bring about large operational cost saving. Proper protection grading is achieved and nuisance fusing is eliminated.

Safety: All operating is done from ground level making operating safer and easier. It can be considered to install Combi units at all transformer installations due to the safety features.

6. **BIBLIOGRAPHY**

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[2] Specification for a combined cut-out fuse and drop-out surge arrester unit, Distribution Specification DSP 34-1962 Part 4, Mar. 2009.