This paper deals with the application and experience of Line Surge Arresters (LSA) on seven 275 kV Eskom Transmission overhead lines. It presents a way forward in establishing and achieving optimum levels of power quality through application of line surge arresters. It has become evident that use of LSAs is necessary in special circumstances. These circumstances are in high lightning density areas, mountainous areas with poor tower footing resistance, and areas with power electronics driven industry. This has necessitated the compilation of a well engineered process for the future application of Line Surge Arresters in South Africa. This paper attempts to address these issues by proposing a process using the experience gained from recent LSA applications.

Lightning occurrence in South Africa

In Southern Africa over 95% of ground flashes transport negative charge to the ground in the first return stroke. These are called negative strokes. The first stroke may be followed by subsequent strokes along the same ionised channel. The subsequent strokes generally carry a lower current than the first, but exhibit a higher rate of rise of voltage. The intervals between strokes have a median value of 30 ms [1] and may be as much as 800 ms. The total duration of a multiple stroke flash rarely exceeds one second. Strokes with up to 18 strokes have been measured on an 11 kV test line. However, fewer than 25% of lightning flashes have more than four strokes. The rarer positive flashes are likely to have only a single stroke, but this often has a higher current and is of longer duration than most negative strokes. The authors acknowledge that a more appropriate measure than lightning stroke density (Ng) for lightning performance of overhead lines would be the lightning stroke intensity to the line or in the vicinity of the line. Due to their height, spanning along high topography and good earthing; transmission lines would expect to attract higher incidences than indicated by Ng.

Lightning related faults on the Eskom transmission network

Lightning plays a significant part in the overall performance of overhead power lines. In particular, two types of line faults are associated with lightning strikes to lines, namely, back-flashovers and shielding failure. In the case of a back-flashover, a direct lightning strike to a tower, or the ground wires, causes the voltage on the tower to rise above the insulation strength of the line, causing insulation breakdown and a fault on the line, typically at the tower. In the case of shielding failure, the location of the ground wire at the time of the lightning flash, is inadequate to protect the phase conductors, resulting in the flash terminating on one of the phase conductors. Shielding failure typically happens at locations between towers. Alternatively, a lightning strike in the proximity of an overhead power line (up to several hundred meters and more) will induce over voltages of opposite polarities. As such voltages rarely exceed 300 kV, induced surges do not cause flashovers on 132 kV and above. From data captured over a ten year window, Eskom Transmission has revealed that the system voltage with the highest frequency of lightning faults is 275 kV. Furthermore, data shows that lightning causes 33% of the total number of faults experienced on the 275 kV network, with the others being unknown (17%) and under investigation (50%).

Lightning performance improvement strategies

Lightning performance of overhead lines is defined as the number of annual faults per 100 km that the line exhibits due to lightning. Eskom Transmission has annual targets for performance of overhead lines operating at the different system voltages. For 275 kV lines, the 2005 cumulative annual target is 3.5 faults per 100 km per annum as shown Fig. 1.

The main driver for Eskom to reduce the number of faults on its overhead lines is twofold. Firstly, line faults cause costs to those of Eskom’s customers sensitive to voltage dips. These costs are difficult to ascertain as each industry process and electricity dependency is different. Secondly, faults cost Eskom in the form of network outages, damage to substation terminal equipment and excessive switchgear operation. Eskom Transmission pays particular attention to power quality and hence the continuous drive to reduce voltage dips and unplanned outages on its transmission lines. Lightning performance of a transmission line can be improved by reducing the back-flashovers and shielding failure flashovers. In order to successfully improve the lightning performance of a transmission line the following design parameters have to be taken into consideration:

- Existing design insulation level.
- Existing position of the overhead shield wire.
- The tower surge impedance.
- The tower footing resistance.
- Design application of line surge arresters (LSA).

This report concentrates on the application of LSA on Eskom transmission’s lines, and the benefits that have been realised, and proposes an application process to be followed when implementing future performance enhancement projects.

Use of LSAs in general

Today, many electricity utilities worldwide use LSAs, mainly for quality of service improvement...
and for double circuit outage reduction (there are also some other applications: safety of people, compact line design, switching surge control, live line working) [3]. LSAs are used on shielded and unshielded lines. Internationally the majority of LSAs are installed on lines having voltages of between 46 kV and 138 kV, some utilities are using LSAs on 220 kV, 275 kV and 400 kV lines. Different utilities have different approaches when LSA selection is in question. Some very important characteristics / parameters to be taken into account when selecting LSA are:

- Gapless or gapped design.
- Single piece housing or multi-unit design.
- Polymer housing (silicone, EPDM, etc.).
- Installation details (installed on the cross arms, in parallel to the insulator string, suspended from the phase conductors, fixed to the structure or free moving, etc.).
- Selection of the rated voltage (the same as for station arresters or higher).
- Selection of the energy capability (heavy duty distribution, intermediate or station, IEC Class I – III).
- Creepage distance.
- Mechanical performance.
- Use of a disconnector or fault indicator.

General experience from most international electricity utilities using LSAs is that they are performing well, line lighting performance is improved and double circuit outage rate is reduced or eliminated. At present there are no existing guidelines within Eskom regarding pre-engineering and installation of LSAs, but the aim is to have such a document in future. It is noteworthy that certain utilities have experienced some problems with LSAs (disconnector failure, installation problems, arrester failure due to the wrong energy capability or rated voltage selection).

Where LSAs are installed on each phase conductor and each tower lightning caused flashovers are completely eliminated. However, this installation configuration is not a financially optimal choice. It is possible to install LSAs on particular line sections, and on less than all phase conductors to achieve the expected line performance. To achieve an optimum arrester installation configuration it is necessary to perform an appropriate software simulation. A number of applicable software packages are commercially available. The software simulations should be performed during the pre-engineering stage of any LSA installation project and some results from simulations performed recently are mentioned later in this paper.

LSA energy duty depends on many factors:

- Lightning activity of the region where arresters are installed.
- Arrester installation configuration.
- Line design (shielded or unshielded).
- Tower footing resistance.
- Tower footing resistance distribution.

Use of line surge arresters on Eskom’s transmission lines

Of the seven Eskom transmission grids, only North West, Central and Northern grids have LSAs. This paper will concentrate on these three grids and report on their experience with LSAs on their lines. In brief, Eskom has two types of arresters on its lines - gapped and gapless. No information could be sourced on the gapped type, but more information on the gapless type can be found in [4]. In addition, the Essellen – Pelly line has a mix of two different energy class rated arresters with other lines having only one. Table 1 represents the seven 275 kV Eskom Transmission lines which have gapped type LSAs installed on various towers. The table represents the line lengths, dates of installation of the LSA, and number of units installed.

This table shows the enhanced line performance that Eskom Transmission has experienced with the use of LSAs. The Glockner – Olympus line performance was not available for inclusion in this paper. The following section will detail the methodology followed for the implementation of these projects and hence highlight the need for a revised and more structured approach to similar projects in future.

Application criteria used for implementation of LSA projects

The process followed in implementing the LSA installation projects is similar to the process summarised in Fig. 2.

The process presented in Fig. 2 is generic and was used in designing the LSA system for the three grids mentioned. Considering the results shown in Table 1 it becomes clear that the application of LSAs is effective.

However, considering the following, it is clear that there is scope for further development of the LSA application process:

- There were no pre-determined improvement targets, which could be linked to the budget for executing the project.
- The application of LSAs varied among all the projects, but the most effective installations were the applications that had in the order of one LSA per km of line.

![Fig. 2: Generic lightning performance improvement process.](image-url)
There was lack of consistency and value added pre-engineering studies, as only one grid had completed them for two lines. Despite this, there were varying performance improvements achieved by these two lines, with one having 82% improvement while another one achieved only 14%.

The use of LSA suppliers in pre-engineering studies did not optimise on installing LSAs on alternating tower installations, installations on one or two phases per tower. Instead LSA were installed on all three phases on consecutive towers.

Future application of line surge arresters

This section of the paper discusses the future application of LSAs with the use of a different application process and a case study from recent Northern grid pre-engineering work. Having studied the previous process that was followed for LSA application, a new process has been proposed. This process is shown in Fig. 3.

It should be noted that, even in implementing this proposed process in the case study to be discussed, some modifications were needed, as stage 11 was not undertaken due to time constraints. The transmission line on which the above process was applied is the Foskor – Merensky 275 kV in the Northern Grid [5]. This line is 129 km long, with an average span length of 375 m. It has had tower footing resistance improvements carried out in the past, but the line’s lightning performance seemed to vary seasonally. There were no improvements in performance recorded from the interventions.

The study was carried out taking the following into consideration:

- The expected lightning performance improvement.
- The budget available for the project.
- Historical performance of the line.
- Measured tower footing resistance values.
- The simulation studies included proper selection of LSAs with LSA energies being monitored.
- The pre-engineering work done was carried out by Eskom employees through cooperation with international specialists on the topic of lightning performance improvement.
- The pre-engineering work done was carried out by Eskom employees through cooperation with international specialists on the topic of lightning performance improvement.
- The expected lightning performance improvement.

The four options investigated were:

- No LSAs installed.
- One LSA installed on the outer phase.
- Two LSAs installed - on the outer phases.
- Three LSAs installed - on all phases.

The most effective solution which eliminated all the flashovers was where all the phases were equipped with LSAs. But this option was not financially viable. The study concluded with the option that met both financial constraints and a predicted lightning performance improvement of 82.1%. This option was with LSAs on the outer phases of the affected sections of the line. The methodology followed in the simulation was that detailed in [6 - 7]. The LSAs will be installed during 2005 and the next lightning season will verify the expected versus the actual performance of the line.

Conclusion

The paper highlights the effects that lightning has on overhead transmission lines and how electricity utilities such as Eskom can minimise these effects. What must be taken into account is the costs incurred by the electricity utility in order to achieve improvements to lightning performance measured against the costs to the utility and its customers for poor performance. Eskom’s experience with the use of LSAs has been positive for the purposes of improving power quality and return on investment purposes. However, it has been realised that for the future implementation of LSA projects, the generic process needs to be revised.

The revision means that pre-engineering studies have to be a mandatory part of the project initiation as this identifies the key engineering issues from the beginning. Issues such as identifying expected performance, the available finance for project implementation and historical performance trends. The suggested process provides for the standardisation of LSAs and the identification and quantification of engineering benefits prior to the application. The concept of optimised installation also gets introduced. The core of this process is to establish and achieve optimum levels of power quality through the application of LSAs on overhead transmission lines.

Acknowledgement

This paper was presented at the 5th Southern Africa CIGRE Regional Conference in October 2005 in Somerset West, and is published with permission.

References