1 INTRODUCTION

This research report documents the creation of a benchmark sample to facilitate gap etching analysis of pre-payment meter primary surge arresters removed from the field. The latter is beyond the scope of this document but forms part of a larger research project, undertaken by the author, aiming to assess whether the specification for pre-payment meter primary surge arresters adequately reflects the LV surge environment.

1.1 Background to the Problem

With the advent of Eskom's "Electrification Drive" circa 1989, protection from lightning surges was not specified for pre-payment meters. Numerous field failures led to the introduction in 1990/1991 of a primary surge arrester specification covering gapped Silicon-Carbide (SiC) and Metal Oxide Varistor (MOV) surge arresters for differential application (L-N) within the low voltage (LV) pre-payment meter installation. Although the MOV has seen increasing use as the primary surge protection device in recent years, a vast proportion of Eskom's installed pre-payment meter population still utilises the gapped SiC arrester. But this proportion is shrinking as the older meter installations are upgraded to standard meter base types utilising MOV's.

Whilst lightning-related failures decreased dramatically upon introduction of the primary surge arresters, there is no concrete evidence that the devices are adequately specified in terms of their surge protection capability. This is because the specification is based on engineering judgement through experience of the MV lightning surge environment, in the absence of the recording of lightning surges during numerous summer seasons to quantify the LV environment, which is expensive and time-consuming. Furthermore, perceptions exist in the South African industry that the specification does not adequately reflect the harsh LV lightning surge environment.

Broadly speaking the main research question is as follows: does the primary surge arrester specification for pre-payment meters adequately represent the LV lightning surge environment? This leads to further research questions:

- What is the frequency distribution of surge currents that the primary surge arresters experience?
- What is the expected failure rate of the primary surge arresters (gapped SiC and MOV)?
- Is this failure rate acceptable, and if not, what should it be?
- What should the kA rating of the surge arrester be?

In answering these research questions, the expected benefit is to ensure that pre-payment meters are adequately protected against lightning surges, by ensuring that the specification is amended to adequately reflect the operating environment. Of course it is possible that the present specification is too stringent – then the expected benefit is more cost-effective primary surge arresters in accordance with a relaxed specification.

1.2 Problem Statement

As mentioned previously, recording of lightning surges during numerous summer seasons to quantify the LV environment is expensive and time-consuming. However an inexpensive alternative is the inspection of the gap surface material of gapped SiC surge arresters, where the size of the gap etching yields a measure of the peak Coulomb-charge discharged through each arrester, following years of field service.

Therefore each gap effectively functions as a "peak recorder" – in the South African pre-payment meter context, these peak recorders are present in the majority of installations. The field gap etchings may be interpreted through comparison with standard pre-conditioned, laboratory-created gaps i.e. a benchmark sample.

If the sample of inspected field gaps is sufficiently large, the arrester lightning discharge current distribution will emerge. This may be statistically compared to the lightning stroke current distribution, enabling the extrapolation of the arrester lightning discharge current distribution into the high current (low probability) regime that ultimately determines the primary surge arrester current rating.

Originally Geldenhuys (1997) initiated the need for gap etching analysis of gapped SiC surge arresters in the pre-payment meter context, based on the work of Gaibrois, Mashikian and Johnson (1979) on Distribution class surge arresters. This led to the visual inspection by Evert (1998a, 1998b) of 219 gapped SiC arresters removed from the field for signs of gap arcing and possible damage. He compared the etchings to the benchmark sample created by Gaibrois, Mashikian and Johnson, and tentatively concluded that the gap etchings do not indicate a high frequency of surge currents in excess of the limits dictated in surge protection specifications.

Subsequently Geldenhuys (1999) stated the need for a benchmark sample specifically pertaining to pre-payment meter gapped SiC surge arresters, and hence further analysis of the gap etchings analysed by Evert.

1.3 Objective of this Work

The specific objective of the work documented in this research report is the creation of a benchmark sample to facilitate gap etching analysis of pre-payment meter surge arresters removed from the field.

The benchmark sample must reflect the LV operating environment, and can only be created with some knowledge of the expected surge arrester discharge currents that depend on the nature of the lightning surges impinging upon the surge arresters. These in turn depend on the direct and indirect coupling of lightning events onto the MV/LV system and the resulting surge propagation. To create a benchmark sample therefore requires the appropriate selection of two discharge current parameters:

- Applicable waveforms
- Peak-current range

In summary, the connectivity between naturally occurring lightning events and gap etching analysis is illustrated in Figure 1.1, where the specific objective (or focus area) of this work is the creation of a benchmark sample for the gapped SiC surge arrester utilised in pre-payment meters.

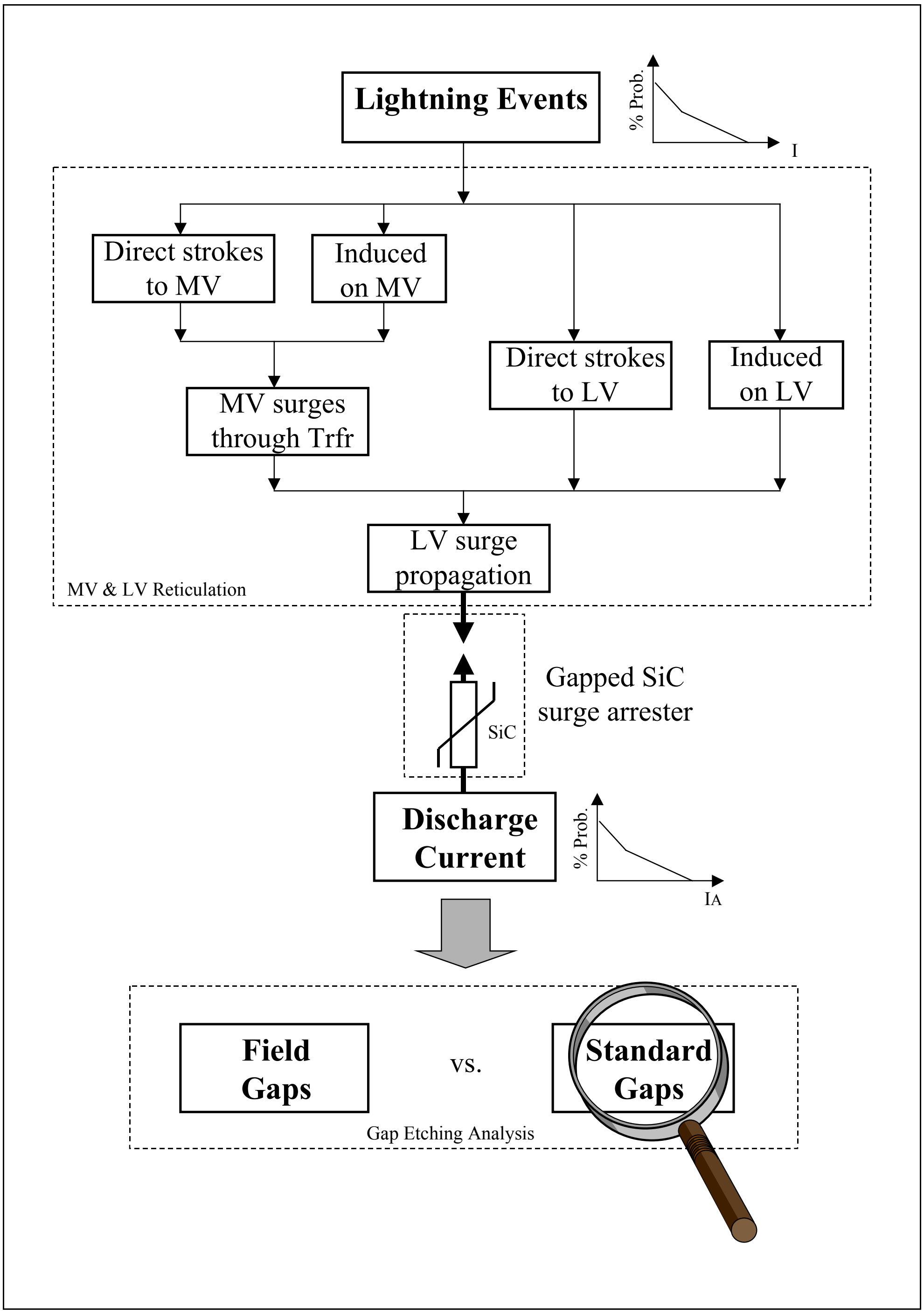

Figure 1.1: Connectivity between lightning events and gap etching analysis

Therefore the scope of this work does not include the actual coupling of the lightning events onto the MV/LV reticulation, nor the propagation of surges from the point of coupling to the primary surge arrester, but relies on the work of other researchers and specifications in this regard. Furthermore, the analysis of field gaps is not included in the scope of this work, but is the subject of further research work by the author.

Passing a wide range of lightning impulse currents through the gap sets - in the absence of the SiC blocks - creates the benchmark sample. The benchmark sample therefore cannot be used as proof of the arrester's surge handling capability.

Finally, the field performance of the gapped SiC and MOV primary surge arresters utilised in pre-payment meters is excluded in the scope of this work, but may be the subject of future research.

1.4 Gapped SiC Surge Arrester - Principle of Operation

The active part of the pre-payment meter gapped SiC surge arrester comprises a spark gap in series with a SiC block. The spark gap comprises identical gap plates separated by an insulating washer. The SiC block provides the clamping characteristic of the surge arrester due to its non-linear voltage-current characteristic curve that is temperature dependent i.e. as the block temperature increases, its resistance decreases. However at system voltage, the SiC block conducts power-frequency current[1] that will result in thermal runaway and hence its destruction; therefore the spark gap isolates the SiC block from the system voltage.

When a sufficiently large (voltage) lightning surge impinges upon the surge arrester, the spark gap flashes over such that the surge arrester conducts the surge discharge current, as the SiC block clamps the surge voltage. Whilst the spark gap conducts, the SiC block is also exposed to system voltage, and the surge arrester may conduct power-frequency (follow) current. Once the surge

[1] The ZnO block in gapless MOV arresters conducts very low power-frequency current.

has passed, the typically lagging power-frequency follow current arc is interrupted at the first subsequent zero-current crossing, where the system voltage across the SiC block reduces the likelihood of spark gap re-ignition i.e. the surge arrester reseals.

The current discharged through the surge arrester produces an etching on the gap surface material, which is of prime interest in this work.

1.5 Approach to Creating a Benchmark Sample

The work commenced with a literature review of the gap etching analysis technique, and topics relating directly to the gapped SiC surge arrester (utilised in pre-payment meters) and its immediate operating (lightning) surge environment – this is presented in Chapter 2.

The test space is defined in Chapter 3, with due cognisance of the limitations imposed by the impulse generator available at the University of the Witwatersrand. This resulted in the selection of four waveforms each having three peak current ranges, requiring 12 resistive inductors.

Chapter 4 presents the design approach for the resistive inductors, incorporating the quantification of stray resistance and stray inductance of the impulse generator and the thermal capability requirements of the components. The main challenge was the construction of low-inductance components – a novel inductance-reducing method was devised and utilised. Due to time constraints, only six resistive inductors out of the required 12 were constructed pending creation and analysis of a reduced benchmark sample.

Chapter 5 describes the quantification of the relationship between peak-current and impulse generator set-point voltage - and the approach used to define the peak-current range - per constructed component, prior to creating the reduced benchmark sample. Select gap etching examples are shown, and preliminary visual inspection leads to a set of observations. Although the original aim of the benchmark sample was to facilitate the categorisation of field-gap etchings according to the closest visual match, further analysis is undertaken to explore the relationship between gap etching area and peak current through measurement and analysis of the benchmark sample etchings.

Finally, Chapter 6 presents a summary of this report with conclusions, and recommendations for future work.