Abstract
Major strides have been made in understanding and preventing the undesirable consequences of arc flash incidents in the power utility. Fault level studies using some of the advanced software models, e.g. DigSilent and estimating incident energy and arc flash boundaries with some degree of accuracy using IEEE1584 model, are some of the greatest developments. Controlling exposure to arc flash is the last resort once the means to eliminate, or engineering means to reduce have all proven counterproductive or cost-ineffective. To achieve the right level of control, the solution of PPE has been implemented. This, together with other interventions to limit exposure to electric arc may significantly reduce the risk of exposure. The paper seeks to explain the studies leading to the decisions on Arc Flash PPE.

Introduction
The Occupational Health and Safety Act seeks to ensure our safety as workers and the safety of the communities affected by our work activities. The object of the Act is to provide for the health and safety of persons at work and for the health and safety of persons in connection with the use of plant and machinery. [1], among other things. It is in this quintessence that employers have taken the necessary steps to eliminate hazards, reduce exposure or provide the necessary protective equipment. The state power utility is arguably the spring of all economic development in South Africa and as such has a responsibility towards the vast mix of stakeholders in all its endeavors to generate, transmit and distribute to end-users flawlessly. It is expected then, that they should lead the pack in the prevention of power related incidents, that is to say, electric arc flash incidents, among others.

Body
The MV and LV Switchgear installed at Kendal Power station is an older generation, designed and installed in the 1980’s and are not capable of containing or diverting an explosion. This is the case in many installations elsewhere around the country, in municipalities, ICT facilities and even some big corporate buildings. In these, non-arcproof switchgear, arc propagates waves radially around the source, with the obvious distortion effects due to reflection, refraction as it passes from one medium to another. Internal arc-
proof switchgear, on the contrary, is designed to divert the explosion in a safe direction away from personnel, usually upwards. The ultimate solution is to divert the arc away from the position where personnel would normally be when they do their normal duties of operating and maintenance. The damage has to be contained within the boundaries of the substation while venting out the pressure to minimize the damage. Only recently, manufacturers such as ABB, ALSTOM, GEC and SIEMENS are offering a range of switchgear that is capable of diverting an explosion in the event of an internal fault.

Kendal power station is no exception to other business units in Eskom, as they took up the challenge with a great success. A successful roll-out of a safety concept is easily measured in compliance which is subject to audits and in auditable records of awareness training interventions, which is a requirement in the Occupational Health and Safety Act, Section 13 (Duty to Inform), paragraph (a).

In the Health and Safety Incident statistics, electric flash incidents are found not to have a distinct classification, they fall under a broader class of Electrical contact injuries. This may be caused by the fact that they are not well understood. They are also few due to effective protective relaying that reduce the probability of such incidents.

Flash suits, as they are called, don’t come cheap. It is a huge expenditure that management has to justify to the stakeholders. We have thus included this account on the adverse impact on human life. Arc flash related injuries can result in burns to body tissues and damage to eyes – cataracts [2]. Arc temperatures can reach levels of 35,000 °F (about 19000 °C) caused by ignition of materials. These include molten metal, copper vapour and heated air. These high temperature levels are typical for plasma. Light intensity levels are known to reach several thousand times the normal ambient lighting levels. [4]

The different degrees of burns and the typical thresholds are given in table 1. Burn is a function of tissue elevated temperature and time, for example, tens of degrees Celsius for an hour can result into a similar degree of burn as hundreds of degrees Celsius for tens of seconds. For our fast operating electrical protection, the operating time is typically in the order of hundreds of milliseconds, therefore the typical temperatures of a few thousands of degrees Celsius will cause the same degree of burn.

Table 1: Burns, temperature and typical damage

<table>
<thead>
<tr>
<th>Degree of Burn</th>
<th>Temperature</th>
<th>Duration</th>
<th>Incident Energy</th>
<th>Typical damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>&lt; 2nd degree</td>
<td></td>
<td></td>
<td>Epidermis only – no blistering</td>
</tr>
<tr>
<td>2nd</td>
<td>80 °C</td>
<td>0.1 sec</td>
<td>1.2 cal/cm²</td>
<td>Partial thickness burn, affecting both epidermis and dermis (known as blister burns)</td>
</tr>
<tr>
<td>3rd</td>
<td>96 °C</td>
<td>0.1 sec</td>
<td>Full thickness burn – damages both epidermis and dermis often also affecting subcutaneous tissue.</td>
<td></td>
</tr>
</tbody>
</table>

In simple terms fault current results in power dissipated in the form of heat energy according to equation the following equation:

\[ \text{Energy} = \text{Power} \times \text{Time} \]

The focus of this study was on internal faults or busbar faults – 3 phase bolted faults were used as they are the most conservative. Such faults are cleared by the incomer breaker which trips due to the operation of busbar protection. The different medium voltage levels encountered at a typical power station like Kendal are 3.3kV, 6.6kV, 11kV and 22kV. It is important to understand the type of protection applied on the incomers to each MV or LV board as the speed of operation is essential in clearing the fault.

![Figure 2: The flow diagram showing the process followed in carrying out the analysis of the system faults and determining the level of personnel protection required](image)

Time to clear a fault is dependent on the operating time of the protective relay (depends on fault magnitude) plus the breaker operating time (typically around 100ms). In our calculations, breaker operating time of 100 ms was applied in the IEEE1584:2002 model.

The boards on the units at Kendal Power Station (i.e. generator auxiliaries), are all equipped with low impedance buszone protection. This is important to note as the buszone protection operates instantaneously, thus limiting the fault current duration in the case of a busbar fault. In such cases, the study shows that Category 2 PPE clothing is sufficient protection should there be a breaker explosion.

Where there is no buszone protection, the next fastest protection for a three phase bolted fault is considered. In the protection schemes that were considered, the next protection in the hierarchy was the instantaneous overcurrent protection (O/C), typically applied on ASEA 2PA900 scheme. The
last one is the Inverse Definite Minimum Time (IDMT) overcurrent, depending on the Fault Current. In case of IDMT O/C, only the standard inverse is applied. Relay operating time for standard inverse is given as:

\[
t = \frac{0.14 \times TM}{(\frac{If}{CTR \times PS})^{0.02} - 1}
\]

TM=Time Multiplier,
CTR=CT Ratio,
PS=Plug Setting,

An important observation is that where there is no buszone protection, we start to encounter farther arc boundaries, typically in the range of 10-20m. This poses no danger to the passer-by as these substations are housed in solid wall rooms – these solid walls would then be regarded as arc boundaries. This situation arises in instances where the incomer is protected by an upstream transformer. This is common to the 380V boards, as they are ordinarily not equipped with busbar protection and rely on definite time overcurrent protection, eg., CAG relay.

This results in long fault clearing times and the Arc Rating required is above 8 cal/cm\(^2\) specification for Category 2 PPE.

The ultimate solution is to replace these boards with arc-proof boards, which is in Eskom’s plans. This solution poses the following challenges:

- Prolonged outages due to the massive scope of work,
- Potential loss of production,
- The massive cost of the project due to high price of equipment,
- High cost of specialised services for design, implementation and testing.

Engineering measures to reduce exposure include:

- Buszone installation - This may not be feasible considering that it may require long plant outage which interferes with production.
- A modification to the protection whereby an Instantaneous O/C would be installed but this would possibly give grading problems.
- Also where feasible, a solid wall can be built to isolate (physically) the high arc-flash zones with the low arc flash zones within the same
substation. This would also require long outages of plants and interruption of production.

- Building complete new substations could be considered but this would also require long period outages during cut-over.

In most substations, Hazard Risk Category (HRC) 2 provides sufficient arc flash protection and in all the problematic substations, HRC 4 PPE is sufficient as established in the study. HRC 4 is, however, very cumbersome to work with and strict measures are in place to enforce compliance.

For effective arc flash protection, isolation of fault must be reliable and selective. This calls for a good maintenance strategy, e.g. Reliability Based Maintenance (RBM) or a variation thereof (e.g. Reliability Basis Optimisation) to ensure that the integrity of protection is kept in check as it is key to the time duration of electric fault. All these steps are taken with ours and our loved ones’ lives in mind. As the saying goes: “No urgency of work can justify endangering a person’s life.” These are the great strides in ensuring safe delivery and use of the product, electricity, which is central to our daily living. Should we expect more?

Case Study

The 380V Coal Stock Yard Service Board 2A is protected by a CAG Relay with the following settings: CTR 2500/1, xIn=2, PS=2, The reduced arc flash current though the switchgear is 9.6kA. The CAG relay pick up calculated from this information is 10kA, therefore it won’t pick up for a 9.6kA arc current. Upstream there is a 1.6MVA transformer with the following protection settings: HV O/C Settings: CTR=300/1, PS=1.8, TM=0.1 on the ASEA 2PA1000 protection scheme.
The LV side has only undervoltage and Earth fault protection. These are slower than the HV O/C, we consider the HV O/C for our calculation. Using the trip time formula for a normal inverse curve, the calculated trip time is 0.964 s. Applying these in the IEEE1584:2002 model gives Incident energy of 31.9 cal/cm², Arc Boundary of 4.22m and PPE required of HRC 4.

References
3. www.osha.gov
5. IEEE GUIDE FOR PERFORMING ARC-FLASH HAZARD CALCULATIONS