COPPERBELT ENERGY CORPORATION EXPERIENCES ON TWO FAILURES OF MERLIN GERIN TYPE SB6 – 72 CIRCUIT BREAKERS

Author & Presenter: John O Silweya BEng Elect – Senior Maintenance Engineer at Copperbelt Energy Corporation

Co-author: Emmanuel Sampa Katepa, BEng (Hons) Mech, MEng, MBA – Asset Strategy Manager at Copperbelt Energy Corporation

1. BACKGROUND

The Copperbelt Energy Corporation Plc is an electrical transmission and distribution company operating in the Copperbelt Province of Zambia. We supply a total load of approximately 550MW to the copper mines and 250MW for other industries and domestic use. We operate an electrical network comprising 220kV, 66kV and 11kV substations, transmission lines and associated switchgear. Of the 433 circuit breakers that we maintain and operate, eighteen (18) 66kV circuit breakers are the SB6-72 SF₆ type manufactured by Nuova Magrini Galileo (NMG), now Siemens S.p.A. of Italy.

On Thursday, 2 August 2007, one of the SB6 – 72 66kV SF₆ circuit breakers failed whilst it was being taken out of service for routine maintenance at Mill substation. The blue phase interrupting column of this circuit breaker was ruptured approximately 1 minute after opening the circuit breaker. This circuit breaker was installed and put to service on 30 January 2004.

On Sunday 10th August 2008, we experienced another failure of a SB6 – 72 66kV SF₆ circuit breaker at Luano Switching Station when the feeder on which it is installed was de-energized to allow a high load to pass under the line. The blue phase interrupting column completely shattered approximately thirty seconds after de-energizing the concerned transmission line. In this case, when the abnormal load (truck) was passing under the line, there was a flashover when the truck got near to the blue phase conductor resulting in the snapping of the conductor and catastrophic failure of the circuit breaker. This circuit breaker was installed and put to service in April 2003.

There were no injuries or fatalities as a result of the two incidents.

The aim of this paper is to share our experiences on these failures and some of the actions we are taking to prevent these failures and ensure the reliability of these circuit breakers for continued use on our 66kV transmission network. This paper also aims to solicit ideas on any
further actions and learning points that can be derived from Technocrats in the industry who may have had similar experiences.

2. EQUIPMENT DETAILS

The breaker at Mill Street Substation is on a 5km 66kV line with a calculated fault level of 19.7kA at the Mill 66kV busbar. Average loading on this line is 400A, and is mainly three phase mine load. The environment is heavily polluted with dust and acidic fumes.

The Luano Substation breaker is on a 38km, 66kV line with a fault level calculated at 5kA at the point of fault along the 66kV line. Average loading is 300A, and is mainly three phase mine load. The environment is fine with no pollution, though the area experiences high lightning activity in the rainy season (November to April).

The nameplate details for the two breakers are as follows:

<table>
<thead>
<tr>
<th>Make</th>
<th>Circuit Breaker at Mill</th>
<th>Circuit Breaker at Luano</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Rating</td>
<td>800A</td>
<td></td>
</tr>
<tr>
<td>Voltage Rating</td>
<td>72000 Volts</td>
<td></td>
</tr>
<tr>
<td>Serial Numbers</td>
<td>20000 1855</td>
<td>DLJ 1999 0049</td>
</tr>
<tr>
<td>Type</td>
<td>SB6 72</td>
<td></td>
</tr>
<tr>
<td>Rated Impulse Voltage</td>
<td>325kV</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>50Hz</td>
<td></td>
</tr>
<tr>
<td>Rated short circuit breaking current</td>
<td>78kA</td>
<td></td>
</tr>
<tr>
<td>Short term current</td>
<td>31.5kA for 3 seconds</td>
<td></td>
</tr>
</tbody>
</table>
3. MODE OF OPERATION – BREAKING PRINCIPLE

Breaking principle
The SB6 circuit breaker uses the rotating arc current interruption technique combined with auto-expansion.

The current to be interrupted passes through a coil oriented along the same axis as the contacts.

The resulting magnetic field guides the arc and causes it to rotate rapidly over the whole surface of the arcing contacts. As the temperature rise in the arcing contacts is well distributed and moderate, wear is restricted.

The pressure rise is used to blow out and extinguish the arc.

The main opening sequences are shown in figure 1 to 4:

- Fig. 1: circuit breaker closed; path for continuous flow of current.
- Fig. 2: start of opening: opening of the main contact diverts the current via the excitation coil and the arcing contact.
- Fig. 3: arcing period; the current passes through the coil, the arc forms between the contacts and the magnetic field in the coil causes the arc to rotate.
- Fig. 4: end of opening; the arc is extinguished and the dielectric strength is restored.

1 - extinction chamber
2 - excitation coil
3 - fixed arcing contact
4 - moving arcing contact
5 - separator
6 - main contact
7 - sliding contact, fixed part
8 - sliding contact, moving part

Figure 1: Merlin Gerin SB6 – 72 SF6 gas insulated circuit breaker Instruction Manual 5482 482 - D
4. SERVICE HISTORY

<table>
<thead>
<tr>
<th></th>
<th>Circuit Breaker at Mill</th>
<th>Circuit Breaker at Luano</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date commissioned</td>
<td>Jan 2004</td>
<td>April 2003</td>
</tr>
<tr>
<td>Number of circuit breaker operations</td>
<td>372</td>
<td>392</td>
</tr>
<tr>
<td>Number of fault clearances</td>
<td>5</td>
<td>44 (mostly due to lightning)</td>
</tr>
</tbody>
</table>

5. CIRCUIT BREAKER MAINTENANCE HISTORY

SF₆ circuit breakers are inspected and tested annually. The tests are primarily insulation resistance and contact resistance tests. Additionally, there are quarterly trip tests to confirm the operational availability of the entire protection set-up, from the relays to the circuit breaker.

Timing or motion tests are often only done at commissioning or when due to a defect or as a result of work on the breaker mechanism, it is suspected that there may be a potential failure in the mechanism.

Both of the failed breakers had 100% compliance to this test regiment and the recorded results are presented in the tables that follow.

5.1 Circuit Breaker at Mill substation

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Resistance - CB Open [GΩ]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U – E</td>
<td>48</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>L – E</td>
<td>69</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>U - L</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

| Contact Resistance - CB Closed [μΩ] |      |      |      |
| RΦ      | 25   | 26   | 23   |
| YΦ      | 19   | 16   | 12   |
| BΦ      | 92   | 92   | 94   |
It must be noted that the insulation level varies due to the level of dust pollution that affects the circuit breaker outer porcelain rain-sheds / insulators

5.2 Circuit Breaker at Luano Switching Station

<table>
<thead>
<tr>
<th>Year</th>
<th>Opening Time [ms]</th>
<th>Closing Time [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RΦ</td>
<td>YΦ</td>
</tr>
<tr>
<td>2004</td>
<td>29.6</td>
<td>29.8</td>
</tr>
</tbody>
</table>

The opinion of the authors is that these results were not sufficient to predict the type of failures that were experienced.

6. DESCRIPTION OF FAILURES

6.1 MILL SUBSTATION – INCIDENT OF 2ND AUGUST 2007
The blue phase of the 66kV circuit breaker interrupting chamber was shattered, with the fixed contact assembly left hanging on the flyover conductor (see picture in Appendix 2). The other phases’ columns remained intact.

The porcelain pieces resulting from the circuit breaker disintegration were spread over a wide area in the substation HT yard. One of the flying porcelain debris hit the HT yard wall fence and broke one of the slab blocks. However, the adjacent electrical equipment did not sustain any damages.

No loss of supply was experienced by any of our customers as a result of this incident.

6.2 LUANO SWITCHING STATION – INCIDENT OF 10TH AUGUST 2008

The Bancroft No.2 66kV line SF6 circuit breaker at Luano Switching Station had completely shattered.

The flying porcelain debris from the circuit breaker damaged post insulators for the Bancroft No. 2 66kV line isolator, Solwezi line isolator, Solwezi line main & reserve bus bar insulators and the conductors to transformer 2 66kV main bus bar isolator. The flying porcelain debris from the circuit breaker also damaged insulator discs for the bus bar flyovers on the Bancroft No. 2 and Solwezi 66kV line bays. In addition, the red phase VT on the Bancroft No. 2 66kV line had an oil leak and cracked porcelain from the flying debris. The blue phase VT on an adjacent line bay was also affected and had an oil leak.

The Bancroft No.2 66kV line SF6 circuit breaker interrupting columns and support insulators were completely shattered (see Appendix 2). The blue phase assembly components i.e. fixed and moving contacts were found on the ground. The red and yellow phase fixed contact assemblies were still attached to their respective bus bar fly over conductors.

Circuit breaker and Line earth switch control cables were damaged as a result of the explosion.

It was evident that the blue phase suffered the explosion and the yellow and red phases suffered consequential damages. The explosion on the blue phase was vented in all directions and also downwards through the circuit breaker operating mechanism and control cabinet.

317MW of load was lost on the electrical network as a result of this incident.

7. DISCUSSION ON THE POSSIBLE CAUSES OF FAILURE

7.1 Defects in the interrupting chamber components

In the case of the circuit breaker at Mill, this is highly likely since the waveforms obtained from the circuit breaker trip test in June 2007 show that when the circuit breaker was opened, the blue phase still showed signs of conducting (see waveform in appendix).

There may have been a defect in the blue phase interrupting column of the Luano circuit breaker on account of the numerous incidence of lightning related trip-outs experienced (44 times since commissioning). One may suggest that the circuit breaker contacts in the blue phase interrupting column did not open, or did not fully open and hence when the abnormal load was crossing the line, it made contact with the blue phase conductor thus generating a fault current. The protection relays at Luano operated, meaning the breaker was closed and thus giving the current and voltage signals, through the closed circuit breaker primary contacts, to the CTs and VTs on the line side of the circuit breaker. Therefore, it is thought that the fault current thus generated in the blue phase, with a condition of not contacts that are not fully separated, led to arcing, heating and
decomposition of the SF6 gas in the circuit breaker blue phase column, leading to high pressure in the column and the eventual explosion.

**7.2 Mechanism failure**

This appears unlikely for the circuit breaker at Mill substation because investigations after the failure revealed that moving contact travel was established and the mechanism and its components were functioning properly.

However, for the circuit breaker at Luano, the explosion originated from the blue phase interrupting column, and spread out to the yellow and red phases. The explosion on the blue phase was also directed downwards, and the blue phase bearing housing was found cracked and operating cranks / levers were found out of position / detached. It has to be ascertained whether this was as a result of the explosion or there was a mechanical defect.

**7.3 Loss of SF6 gas insulating properties**

In view of the fact that there were numerous trip outs on the line associated with lightning (44 since commissioning), the SF6 gas properties may have been compromised due to SF6 gas decomposition after arcing across the contacts during fault clearing operations. Products of SF6 gas decomposition include hydrogen fluoride, carbon tetra-flouride and hydrolysable fluorides, all of which are corrosive in nature and can lead to loss of insulating properties and arcing across open circuit breaker contacts. These corrosive by-products can also degrade insulating materials that are present in the circuit breaker interrupting columns.

**8. INTERACTION WITH THE EQUIPMENT MANUFACTURERS OF THE SWITCHGEAR**

The switchgear manufacturers, Siemens S.p.A of Italy, were contacted after the 1st circuit breaker failure on 2nd August 2007. The aim was to have Siemens investigate the failure ascertain it's cause(s) so that remedial measures could be put in place to prevent a recurrence. These efforts did not bear fruit as Siemens offered to replace the damaged circuit breaker pole, at CEC’s cost. CEC felt this was not appropriate – what was appropriate was to investigate the cause of the failure. It was only after the 2nd circuit breaker failure of 10th August 2008 that Siemens agreed to send technical experts to investigate the causes of the two failures and test the remaining circuit breakers to determine their reliability for continued use on the electrical network. These tests will be carried out, at CEC’s cost, commencing in mid October 2008.

Our opinion of the response shown by Siemens is that the investigations and testing of the remaining circuit breakers in service should have been done at Siemens’ cost, or the costs could have been shared. We feel this would have been the prudent action for Siemens to take.

**9. PRELIMINARY CONCLUSIONS**

The failure experienced on the circuit breaker at Mill substation is most likely due to a defect in the interrupting chamber, on the insulating separator.

The failure at Luano Switching Station is thought to be either due to lack of proper moving contact separation in the blue phase (either contact jamming or mechanism failure) or loss of insulating properties of the SF6 gas. These factors, with the fault current caused by the contact of the abnormal load with the blue phase line conductor and resulting high fault current, led to the circuit breaker explosion, originating from the blue phase. The fact that the protection relays operated at
Luano lends credence to the thought that the circuit breaker remained in closed position, probably the blue phase contacts only.

10. ACTIONS CURRENTLY BEING UNDERTAKEN

1. Procure an SF6 gas analyzer to determine the condition of SF6 gas in circuit breakers.

2. Improve the lightning performance of our transmission lines

3. Engage Siemens in investigating the circuit breaker failures to understand their causes and hence put forth preventive measures

4. Engage Siemens in testing the remaining circuit breakers that are in service so that their reliability for continued use can be ascertained.
5. APPENDICES

1. WAVEFORM ON THE MILL LINE CIRCUIT BREAKER AFTER TRIP TEST IN JUNE 2007
2. MILL CIRCUIT BREAKER PICTURES

Damage to blue phase shown on site

Blue phase breaking cylinder showing the melted and deformed side where tracking and arcing across to the moving contact might have occurred.

Main Fixed contact on red/yellow phase

Checking the operating mechanism. A straight edge is placed on top of the three contacts to check for any discrepancies. Breaker in open position
Checking the operating mechanism. A straight edge is placed on top of the three contacts to check for any discrepancies. Breaker in closed position

3. LUANO CIRCUIT BREAKER PICTURES

![Piece of blue phase fixed arcing contact on the ground](image1)

![Failed circuit breaker on site](image2)

Piece of blue phase fixed arcing contact on the ground

Failed circuit breaker on site
Piece showing blue phase fixed & moving contacts stuck together

Deformation to mechanism housing

Operating shaft with linkages off

Detached linkage for blue phase column