TRIPLE SEGMENTED INTERCELL BAR: A CONTRIBUTION IN COPPER ELECTROWINNING

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ABSTRACT

The original segmented intercell Optibar succeeded in reducing the magnitude and occurrence of short circuits. It also improved the specific energy consumption of the process. This paper expands the load current source concept introducing a triple segmented bar. This new bar adds immunity to dirt contacts and open circuits. Moreover, it further improves the standard deviation of current densities. As compared with industrial practices this development should accomplish an 8% specific energy reduction. Also, a plant implemented with BBS should be able to work with 12.5% higher process currents than Walker without compromising the operation.
INTRODUCTION

In 2011 the technology based on current mode was implemented at industrial scale. The success of this technology moved CIM Magazine (Lanktree, 2011) to write in the Jan 2012 issue an upfront story of this technological innovation. To cover the story, the technical reporter Graham Lanktree was appointed by Peter Braul Editor of the upfront section. The article tells that “More than 40,000 tonnes of copper have been refined in a year-long test run of Optibar Inc.’s new technology at Barrick Gold’s Zaldívar copper plant in northern Chile. The new segmented intercell bars being used in the Compañía Minera Zaldívar refinery have slashed energy costs, reduced short circuits during refining and allowed the production of heftier, purer sheets of copper – gains that all promise to boost the plant’s margins. A copper refining tank house containing the cell circuits typically consumes 2,000 kWh of electricity to produce a single tonne of grade-A copper. Yet, monitoring the energy efficiency of the Optibar technology after increasing the weight of harvested copper sheets, the project’s engineers recorded a 92 kWh-per-tonne cut in energy consumption, a savings of 4.6 per cent. “Today, with the power prices we have, Optibar technology represents a potential savings for the whole plant of US$1.5 million per year,” says Robert Mayne-Nicholls, executive general manager of Barrick Gold’s Chilean operations.”

Moving forward by these successes and a large number of onsite measurements the search of better technologies capable of surpassing challenging and relevant industrial scenarios is on. To properly size the challenge it should be noted that a medium size industrial facility typically use 26,000 cathodes requiring current balance. Newer technologies should be friendly with full automation, reliable, fail proof, free of sensitive devices and instrumentation, and above all, free of human inspection and intervention. Any solution should offer minimum standard deviation of current densities. This is required because low 6 transfers to high current efficiency ηL (larger copper deposition), high specific energy efficiency ηE and negligible occurrence of short circuits. All technologies based on voltage mode or Walker suffers with short circuits and current density deviations. This is because currents seek lower resistance paths. In turn, current mode technologies are sensitive to “dirt” contacts and open circuits.

Figure 1 – Zaldívar’s electrowinning cells working with segmented intercell bars

This paper presents a triple segmented bar capable of ensuring short circuit immunity and better current equalization than previously reported systems. It has a bypass property that offers a current path to bypass “dirt contacts” boosting energy efficiency. In addition, it possesses a backup property to “jump” over open circuits, so blanks are not longer produced. At last, but not least important, the intercell bar configuration presented in this paper ensures that a specific issue within a cell is not reflected on contiguous cells. Four relevant scenarios are examined to evaluate the performance of the proposal; I Normal Operation, II Short Circuit, III Dirt Contact and IV Open Circuit. All the parameters used in the
computer model are “hard” industrial data collected by processing the measurements performed throughout 150 harvest cycles in the Zaldivar’s site. The average operational current was 330 A/m². The following key parameters are computed; standard deviation of current densities, short circuit occurrence, current efficiency, energy efficiency and number of blanks produced by open circuits.

WALKER INTERCELL BAR CONFIGURATION

The Walker intercell bar is up to this day is the most common industrial practice. This technology connects all the cathodes of one cell (outgoing currents) with all the anodes of the next cell (incoming currents) (see Figure 2a). Thus, each cell has a common voltage for their anodes (+) and a common voltage for their cathodes (-). Therefore, the current is free to seek lower resistance paths. The drawback of this approach is that the current distribution in each cell is highly dependent on resistance deviations. Among the factors affecting these deviations are; electrode position and separation, electrolyte conductivity and contact resistance between electrodes and intercell bars.

OPTIBAR INTERCELL BAR CONFIGURATION

This bar connects a single cathode of an upper cell to a single anode of a lower cell. This “current source” connection of the load forces the current out-flowing from a cathode to flow to one anode (see Figure 2b). With this connection slight voltage differences among cell electrodes partially compensate contact resistances dispersion and electrode misalignment. Furthermore, the arrangement generates preferred paths for the electrical currents or current channels. These channels share similar circuit equivalent resistances producing balanced currents throughout the cell. Each equivalent circuit resistance is comprised of a number of contact and electrolyte resistances in series. This also means that current path resistances will be more balanced as the number of series cells increases. Finally, current mode intercell bars are intrinsically protected against short circuits. Despite these positive characteristics these segmented bars produce unnecessary energy losses when operating with dirt contacts. Also, if an open circuit is produced the cathodes affected do not deposit copper at all. For worst, if the number of open circuits in a cell is high some severe imbalances may occur. Despite these disadvantages, industrial results prove that current mode bars produce a better performance than: Walker bars (Wiechmann, Morales, Aqueveque and Mayne-Nicholls, 2011). This is particularly true for high current operation.

TRIPLE SEGMENTED INTERCELL BAR CONFIGURATION

The triple segmented intercell Bar (Backup Bypass System, BBS) innovation is intended for current mode intercell bars. In this new configuration, the connection between two cells (n and n+1) is made from each single cathode to the next cell left adjacent single anode (@). The next intercell between cells (n+1 and n+2) connects each single cathode to the next cell right adjacent single anode (\@). So, the current flowing follows a zig-zag pattern (Aqueveque, Wiechmann and Burgos, 2009).

The innovation is the addition of two segmented side bars (see Figure 2c). These side bars act as bypass when a dirt contact is encountered in the main path of the current and as current path backup if a contact is open (connection failure). This segmented side bars interconnect in groups the otherwise electrically insulated cathode and anode hanger ends. Figure 3c shows one configuration of the side bars where each segment connects 2 anodes in one side and 2 cathodes in the opposite side. This configuration has been selected to minimize short circuit occurrence and magnitude. Other possible alternatives are: sidebars connecting three anodes and cathodes, sidebars connecting four or five electrodes and so on. In short, BBS retains the positive characteristics of current mode bars while adding bypass for dirt contacts and backup for open contacts.
PROCESS ELECTRICAL MODEL

Due to the slow dynamics of the electrochemical process a steady state model represents the voltage distribution behavior with enough accuracy (Aminian, Bazin, Hodouin and Jacob, 2000; Barton and Scott, 1994). In EW the electrolyte resistance produces a relevant voltage component. Additional voltage components are: cathode and anode polarization and over-potential for the current to flow. For copper electrowinning (CuEW) these polarization voltages are approximately 1.230 mV. Finally, a voltage drop is produced by the contacts between the intercell bar and the electrodes. These contacts are produced by hanging the anodes and cathodes on the intercell bar (see Figure 4). The contact resistance follows a Gamma type distribution with an average value of 70 μΩ. All these values match the data collected in the Zaldívar’s site (see Figure 5).
CIRCUIT ANALYSIS

A 7-cell electrowinning plant containing 66 anodes and 65 cathodes per cell was simulated. Random variations were applied to resistance parameters (contact resistance $R_c$ and electrolyte resistance $R_e$). The same resistances values were used to simulate the Walker, Optibar® and BBS connections. All these parameters were acquired on the Zaldívar’s Copper Mine. The current level was chosen to be 660 Amps per cathode (or 330 A/m² per cathode face).

For simulation purposes the same resistance values ($R_c$ and $R_e$) were used for all the connection configurations. The simulations were performed using the nodes method for matrix networks resolutions, by building the admittance matrix ($Y_{BUS}$) and the current matrix of the network $I_{NET}$ (Equation 1).

$$V_{NET} = Y_{BUS}^{-1} \cdot I_{NET}$$ (1)

Normal Operation

The electrochemically deposited metal quantity and quality, depends on the applied current. In addition, a modern plant will obtain its better performance when all the cathodes operate at nominal value. Three configurations are examined: Walker, Optibar and BBS. They exhibit standard deviations of 15.5% (measured), 10.2% (measured) and 9.9% (projected), respectively. These results are shown in Figure 6.
Figure 6 – Cathode current distribution results using; (a) Walker, (b) Optibar and (c) BBS

Short Circuit Anomaly

This anomaly is characterized by an abnormal copper deposit in a very small area of the cathode (~1 cm² out of 1 m²). This reduces the distance between adjacent electrodes and consequently the electrolyte resistance. It also reduces the current of the neighboring cathodes reducing their copper deposit. Therefore, the copper production is compromised. The origin of this anomaly was simulated reducing the electrolyte resistance (Re), between cathode-anode couples.

Walker connection fails in preventing short circuits producing over currents in excess of 1,000 Amps. For worst the current reduction in remaining cathodes reaches 2%. Optibar succeeds in reducing the magnitude and occurrence of short circuits at industrial scale (Wiechmann et al., 2011). Compared with Walker, reduces the over current level around 200 Amps. This is enhanced with a reduction in short circuit occurrence to 33%. Comparing BBS with Walker, short circuits over current levels are quite similar to Optibar in the 200 Amp range. However, it is predicted that the frequency of occurrence will be reduced to 25%. This is based on the absence of blanks on top of a low standard deviation of currents. Moreover, the hanger over-current during short circuits is reduced from 1,460 Amps to zero. This property enhances the energy efficiency and lifetime of BBS intercell bars.

Dirt Contact Anomaly

The exposition to dust, temperature and sulfuric acid evaporation is a highly aggressive environment for proper electrical contacts. The term used for impaired contacts is “dirt contacts”. These contacts are between the electrodes hanger bars and the intercell bar. The dirt phenomenon increases the contact resistance value (Rc). In turn extra energy losses follow (I²Rc). The dirt contact anomaly was simulated increasing 20 times the nominal value of the contact resistance (Rc). Industrial measurements show increases in contact resistances up 100 times the nominal value.

The Walker connection ensures that only the cell with dirt contacts is affected. Successfully, the current through that contact is reduced from 660 to 87 Amps. This value is within the range of acceptable standard deviation (σ) (see Figure 7a). However, the deposit of copper is compromised. In contrast, results using Optibar® show that two cells are affected with a dirt contact in one cell. For worst, the cathode current is barely reduced only to 190 Amps producing extra losses in that contact resistance. This bad result is because of the current source nature of the segmented intercell connection that injects current through the dirt contact. Further, it also reduces the current density per plate face avoiding the correct copper deposit in the compromised cathode (see Figure 7b).
With BBS the current through the dirt contact is reduced to 99 Amps within the range of acceptable standard deviation. This is accomplished by the bypass property that offers an alternative current path to dirt contacts allowing a good copper deposit with 72% (465 Amps) of the nominal current (Figure 8). Both, the low current through the dirt contact and the copper deposit provides immunity to this anomaly (see Figure 7c).

![Image](https://example.com/image1.png)

**Figure 7** – Current distribution with dirt contact anomaly: (a) Walker, (b) Optibar and (c) BBS

Notes: Electrodes with blanks are shown in dark. Also, the softer contrast of BBS system shows its balance property.

![Image](https://example.com/image2.png)

**Figure 8** – Bypass property of BBS facing a dirt contact

Notes: The small arrow shows the current (99 Amps) through the bad contact. The large arrow shows the current using the bypass 465 Amps.
Open Circuit Anomaly

An open circuit occurs when an electrode hanger to intercell bar contact fails. This anomaly can be caused by a polymeric sphere (used to reduce acid fog in some facilities) trapped in the space between the bar and the capping board or by a bad cathode positioning after harvest. It could also happen if contacts are deformed or too dirty to produce conduction. For simulation purposes the open circuit was simulated by increasing the contact resistance ($R_c$) to a very high value.

![Graphical representation of current distribution with open circuit anomaly]  

**Figure 9** – Current distribution with open circuit anomaly; (a) Walker, (b) Optibar and (c) BBS

Notes: Blanks are shown in black. The BBS system shows no blanks and better current balance.

![Diagram of backup property of BBS facing an open circuit]  

**Figure 10** – Backup property of BBS facing an open circuit

Note: The green arrow represents the current through the backup path.
Results using Walker connection show that open circuit phenomenon does not produce secondary effects on contiguous cells. However, a double face blank is produced (see Figure 9a). Compared with Walker, OptiBar® connection shows higher sensitivity to open circuits. The phenomenon affects two cells. Four blanks are produced. One double face blank in the cathode compromised cell and two single face blanks in the next cell due to anode zero current (see Figure 9b).

BBS presents immunity to the open circuit phenomenon (backup property) offering an alternative route to the current. The circuit is closed through the opposite hanger bar end of the open cathode connection (see Figure 10). This also implies that the next cell is not affected (see Figure 9c). The cathode copper depositing current is only slightly reduced to 500 Amps. Therefore, blanks are not longer produced.

**DISCUSSION**

Table 1 show a comparison of the technologies examined. Walker and OptiBar results are industrial data. BBS results are projected by computer simulation. The use of OptiBar reduces the standard deviation from 15.5% to 10.2%. Respective industrial results also show a 5% better efficiency in specific energy consumption (Wiechmann et al., 2011; Wiechmann, Vidal, Muñoz and Castro, 2011). Close examination of these results confirm that every single point accomplished in standard deviation improvement is tied to similar improvement in specific energy. Since BBS reduces standard deviation from 15.6% to 9.9%, it follows that an improvement of 5 to 6% should be expected. On top of that, BBS offers depositing current with open circuits and dirt contacts without important energy losses. The absence of blanks should also reduce the occurrence of short circuits since industrial data shows a direct correlation between blanks and short circuit occurrences. Moreover, the over-current through the intercell bar during short circuits is reduced to zero. In summary, it is conservative to estimate an 8% of better specific energy efficiency when compared with Walker based systems. Finally, a plant implemented with BBS should be able to work with 12.5% higher process currents than Walker without compromising the operation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Walker</th>
<th>OptiBar</th>
<th>BBS</th>
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<tbody>
<tr>
<td>Normalized Standard Deviation</td>
<td>15.6%</td>
<td>10.2%</td>
<td>9.9%</td>
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<tr>
<td>Dirt contact copper depositing current</td>
<td>13%</td>
<td>28%</td>
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<td>Open circuit copper depositing current</td>
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<td>0%</td>
<td>65%</td>
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<td>Blanks per open circuit</td>
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<tr>
<td>Short circuit frequency per cell/cycle</td>
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<td>0.13</td>
<td>0.10</td>
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<tr>
<td>Short circuit over-current in cathode-hanger contact</td>
<td>800 Amps</td>
<td>156 Amps</td>
<td>0 Amps</td>
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</table>

Note: Results with Walker and OptiBar are industrial data while BBS are projected.

**CONCLUSION**

The Backup Bypass System is capable of successfully surpassing major industrial phenomena exhibiting low short circuit occurrence and immunity to dirt contacts and open circuits. An 8% better energy efficiency should be accomplished. Finally, a plant implemented with BBS should be able to work with 12.5% higher process currents than Walker without compromising the operation.

**REFERENCES**


