POWER FAILURE, TEMPORARY POT SHUT-DOWN, RESTART AND REPAIR

Harald A. Øye
Department of Materials Science and Engineering
Norwegian University of Science and Technology
N-7491 Trondheim, Norway

27th International Aluminium Conference
Metal Bulletin Events, Moscow Sept. 12-14 2012
POWER DISTURBANCES
Types of Power Disturbances

Power modulation.
Partial shut-down.
Full shut-down.
Planned or unplanned.
Time is an important parameter.
Most smelters have auxiliary power, but if not

Full shut-down including auxiliary power creates a dangerous health situation due to possible CO poisoning.

Plants need to have instruction manuals for all the situations and combinations listed above.
Basis: Reports from other smelters or own experience.
Should trial experiments be carried out?
Power Modulation

- Power modulation is used when the grid power is not sufficient during peak hours (dinner preparation). Will give a better power contract.

- **ALCAN BRAZIL:** Up to 30 – 34 % reduction for 3 hours without adverse effect.

- **VALESUL:** 30 % power modulation without adverse effects.

- **EASTALCO:** 30 % power modulation for 3 hours without adverse effects.

- The power is increased before and after power curtailment.
HIBERNATION

• Hibernation is a solution by severe but not total loss of power or lack of operators due to labour conflict.
  – The anode is lowered into the aluminium.
  – Cell voltage should be 1.8 – 2.2 V.
  – Increased cover with alumina.
  – Can be kept for weeks.

• Figure VI-205. Predicted and measured metal temperature during full line load hibernation of a 116 kA VSS Søderberg pot (from Tørklep [88]).

• The cell stabilized at about 760°C.
First Action during Power Cut-out

• Lower the anode into the metal pad (if possible).

• Tap aluminium

• Raise the anode after electrolyte is solidified.
Søderberg versus Prebake

- Søderberg will cool slower than prebake and tolerate larger power losses.

- Modern prebake (300 – 400 kA): Designed to have high heat loss through the sides.
  Manning is lower
  Hence more vulnerable to power loss.
Power Interruption

- 10 – 30 minutes to change cathodes: No problem
- 2 hours: Usually still manageable.
- 3 – 4 hours: Also manageable but recovery time increases
- 4 – 6 hours: Electrolyte is frozen. (Cell life decreases, Complete restart may be necessary, Qatalum 2010.
- 6.5-7 hours, gradual to 9.5 hours Aluar 2011. 50% of pots restarted directly
- 30 – 50 hours: Metal has also solidified. (Cell life decreases).
Figure VI-193. Measured bath temperature response to full power loss for a period of 3 hours on a 240 kA cell (redrawn from Dupuis et al. [86]).
Figure VI-194. Modeled responses of pot operation parameters during a 3 hours power curtailment and restart. a) Pot voltage, bath temperature and superheat. The pot is given some extra voltage (about 30 minutes into the timeline) to increase bath temperature in anticipation of shutdown. b) Concentration of excess AlF$_3$ and alumina. c) Bath level and bath resistance (redrawn from Dupuis et al. [86]).

Effects:
No MHD and the aluminium pool gets flat.
No movement, heat transfer changes, ledge grows.
AlF$_3$ concentration increases.
Al$_2$O$_3$ concentration increases.
Bath resistance increases.
Actions for Anticipated Power Interruption (Taberaux [84])

Before Interruption
- Increased pot voltage and/or amperage prior to the event.
- Increased alumina feed control setting prior to event.
- If possible tap metal from cells.
- Increase bath levels in pots with low bath levels.
- Adjust bath chemistry to lower excess AlF$_3$ (higher ratio).
- Increase anode cover depth.

During Curtailment (reduce heat losses)
- Disable automatic alumina control and resistance regulation.
- Stop changing anodes.
- Inspect and manually cover open holes in pots.
- Reduce fan suction.
- Stop forced cooling of cathode sides (where they exist).
- Close basement shutters (where they exist).
- Kill anode effects as soon as possible.
- Select a group of pots to stop (if necessary) in order to provide sufficient power to remaining majority of pots.
Effect of Complete Cool-down

- Total shrinkage in longitudinal direction
  - 200 kA: 25 mm
  - 400 kA: 50 mm
- Total shrinkage in transverse direction
  - < 10 mm
- Cooling cracks at the weakest points
  - Block – small seam
  - Block – large seam

Figure VI-196. Cooling crack in cathode bottoms. The objects next to each crack gives an impression of crack width. a) From Tabereaux [89], b) From Dias [90].
Damage Due to Complete Cool-down

- **Cooling cracks:** Usually not so serious as they will close by heat-up. Refractory barrier is often formed that can stop aluminium intrusion.

- **Cracks present before cooling:** The weaknesses are exacerbated during cooling and heat-up.

- **Unprotected cathode surface:** Harmful oxidation of $\text{Al}_4\text{C}_3$ will take place.

- **Very young pots:** More vulnerable as ledge, bath chemistry and refractory barriers are not stabilized. Strong Sodium gradient. Started last.
Stopping of a Young Pot

Young pot stopped for an unrelated reason. Horizontal cracking and detachment of almost the entire top layer of the bottom carbon pane caused by a gradient in sodium swelling. Pot life was 1.5 days.

Probable Reason:
Strong Sodium Concentration Gradient
Effect of Oxidation

The reaction

\[ \text{Al}_4\text{C}_3(s) + \text{H}_2\text{O}(g) = \text{Al}_2\text{O}_3(s) + \text{CH}_4(g) \]

gives volume expansion.
Worst in hot and humid climate.

Figure VI-198. The result of exposing a cleaned cathode surface to air. a) Alumina powder formed by reaction between aluminium carbide and moist air. The ridges are reaction products being pushed up from the narrow joints. b) A view of the same cathode surface after most of the powder has been removed. The cathode was 468 days old when it was stopped.
LOSS OF LIFE
Loss of Life Due to Power Cut-out

• Very dependent of how the power loss happened and the skill of the pot operators.

• Will inevitably lead to increased anode effects, increased iron content and high temperature excursions.

• Power shut-down becomes often an insurance issue.
Reported Loss of Life

• Rao [81]: 500 days from 1 to 2 restarts.

• Tabereaux [89]: 100 – 200 days. Low number >0-2 % of premature failures. Normal age distribution. Controlled shut-down and restart.


300 – 400 days. High number of premature failures > 5 %, high age distribution, long extended cool-down prior to shut-down, uncontrolled shut-down, rapid restart.

• Residual (remaining) life concept: Nolan Richhard in Reynolds did post analysis and found 31%.

• I have used 30-35 % of remaining life for outage more than 7 hours depending on the situation.

• (30 % remaining life for cells with life 2500 days): (2500 ∙ 30/2) / 100 = 375 days.
Power Loss Incidents Reports
Cells covered with electrolyte during stop.

Cells were cleaned, checked and patched before start-up.

Covered with a plastic sheet after cleaning to hinder oxidation.

Some oxidation was however observed. It had probably been better to cover the cell with solidified aluminium during the stop.

Due to capacity reasons
1. Cold restart. Use of hot butts and addition of hot bath (cold anodes cracked).
2. Hot restart. Use of preheating devices and/or shunt.

Faced some operational difficulties: Joint failure, high burn-off rate, anode cracking and hot pots.
• Rectifier blow-up and fire affected 247 pots.

• All anodes were raised above bath level.

• Some pots were tapped, some not.

• Anode and superstructure were removed and bath removed. Tried to keep the side ledge.

• Butts selection was critical. Discharged all butts older than 22 days or with cracks.

• The anode sidewall channel was filled with crushed bath to protect sidelining and give heat insulation.

• Start-up by the crash method, i.e. the bridges were lowered until contact with the solid metal pad, liquid bath poured in and the current cut in.
Features Noted by ALUMAR during Start-up

• The ACD during restart was kept higher to melt the metal pad and heat the cathode.

• Enough bath should be poured in to allow the higher ACD.

• No liquid metal should be added with the bath.

• A lowering of the line load may be necessary if the number of anode effect got high.

• Increase of metal pad depth may help with ledge formation and pot stability.

• Additional liquid metal should not be added before the bath is completely melted.

• Keep the bath ratio above target to compensate for sodium absorption.

• Alumina feed is turned on when pot noise reaches a low level.

• The restart of the 247 pots took 32 days. (Shorter than first anticipated).
TRIMET 2007 (Reek et al. [97])

- The Hamburg plant was shut down in 2005 and restarted by Trimet in 2007.
- Metal and bath that could not be tapped was left in the pot. This proved to be an excellent protection for the mothballed cathode.
- The first pot was started dry using coke bed and with a lot of difficulties.
- Cryolite and temperature of 1150°C was chosen. Cryolite contains much less Al₂O₃ than crushed bath and anode effect started much faster.
- After 3 pots were started. One pot a day was started with a mixture of coke bed and flame preheating.
- From the 8th pot on, two pots a day were started.
- A special feature was cooling of the bimetal joint to avoid burn-off.

Figure VI-204. Cooling device for the bimetallic connection installed on an anode during dry start.
ELKEM Aluminium, Mosjøen 1982 (Brekke [79])

- An arctic hurricane hit and line II lost power for 7.5 hours and 1/3 power for an additional 6 ¾ hours. Auxiliary power was available.

- The anodes were lowered into the metal pad and covered with extra crushed bath. The gas cleaning system was run on 1/3 capacity.

- A hole in the frozen bath was chiseled out in the middle of the aisle side for inspection and possible bath addition.

- The pots were on normal load and 1.5 – 2 volts with anodes in the metal pad. Temperature 875°C - 925°C.

- The anode was lifted to the top of the metal pad to give 4 – 7 volts and left for preheating for 6 – 8 hours.

- The anode was lifted further to give an unstable voltage of 5 – 30 volts.

- Bath started to melt out from the sides, and after some bath production the voltage stabilized at 15 – 25 V.
• After 1 hour sufficient bath had melted and the cell was operated with wooden poles. The voltage dropped to 7 – 9 volts.

• The pot was operated manually for 12 – 16 hours and then set to ”auto” with a set point 3 $\mu\Omega$ higher than normal for 24 hours.

• Two days after restart the average bath temperature was $\approx 1010^\circ$C and went down to normal 1 week after restart.

• The cryolite ratio was stabilized after 2 weeks.

• Two pots were lost in the end of the month probably due to the accident. No anode problems were encountered.
Two properly functioning 140 kA vs. Søderberg pots were stopped (age 33.8 and 32.1 months.

The cathode surface was cleaned by increase of the cryolite ratio and temperature.

Metal was tapped to two levels, A: 3 – 5 cm, B: 17 – 19 cm.

As much bath as possible was siphoned off by temporarily lowering the anode into the metal.

The anode was raised out of the molten aluminium after all bath had solidified.

The cell was left for 20 days for complete cooling.
The pots were resistance preheated on liquid aluminium. When all the metal had been added the current load was gradually restored, reaching the nominal value in 80 minutes for pot A and 50 minutes for pot B (Figure VI-208). The ramp-up speed was determined by the time it took to reach maximum pot voltage. Cryolite was added to the side channels to reduce heat loss. Both pots were preheated for three days with metal temperatures reaching 855°C in pot A and 893°C in pot B. The cells were then started by adding bath and raising the anodes.

Figure VI-208. Current ramp-up and voltage responses during the first couple of hours preheat of Søderberg cells on metal. a) Pot A with only 3.5 cm of frozen untapped metal left. b) Pot B with 17-19 cm of frozen untapped metal left (redrawn from Buzunov et al. [100]).
The following conclusions were drawn from the tests, of which some are specific to Søderberg operation:

- **Cell preparation with maximum metal tapped is more labour intensive than preparation with only partial tapping.**
  - Requires more time to clean the cathode (high temperature, high cryolite ratio).
  - Run risk of damaging lining during removal of bottom ridge.

- **Required metal left in cell determined by height of bottom ridge.**
  - Bottom ridge should not protrude above metal level to interfere with target anode-metal distance at start of preheat.
  - Unevenness, cracks and cavities in anode surface requires more metal to be poured.

- **Amount of metal left in cell does not influence the preheating process significantly.**
  - Strict control of current distribution in anode studs necessary in all cases.
  - Cracks in anode face require additional effort to level out anode current distribution.
  - Target metal temperature after preheating must be higher than 850°C.

- The startup process is not significantly affected by cell preparation and preheat.
A heavy rainstorm at night Nov.6 resulted in flooding of the electric power transformation and distribution room

Potline D: Current increase started after 2;50 hours and full power was established after 4;30 hours.

Potline C: Auxiliary power restored after a few hours, but power for the pots was not available for several days.

Potline A/B: Auxiliary power was restored after 5;40 hours; Line power after 6;30 and 7 respectively with 20kA increments until 190 kA was reached after 9;30 hours after the start of the outage.

Potline D: All 238 pots restarted directly
Potline A/B: 188 pots restarted directly. 207 pots shut down
Potline C: All 142 pots shut down

The number of restarted pots were unexpectedly high in view of the severity of the outage
Pot Repair
Pot Repair

- Complete reline or partial repair dependent on age, condition and nature of failure.
- Criteria for restarting Cells
  - Irregular past operating history
  - Iron content
  - Cathode and sidewall conditions
  - Stability
  - Temperature
  - Cell age (Not above 2000 days ?)
  - Plant economics, metal price
Incidents That May Justify Partial Repair

- Tapout through sidewall.
- Metal leak through collector bar port.
- Sudden iron contamination caused by pot hole.
- Local surface wear under the tap position.
- Local damage in a bottom block or the peripheral seam.

But partial repair is not carried out if the cell is too old or have other problems than the specific incidents.

Partial repair may lengthen cell life by several years.
Partial Repair Procedures

• **Hole under the tap position or pothole** may be mended by adding flake alumina. If the hole is due to tapping, the tap position should be changed if possible.

• **Leak through the upper sidewall.** Reduce bath level temporarily, clean the failure area and tamp ramming paste against the steel shell. Sometimes a hole has to be cut and later mended in the steel shell.

• **Red hot sides.**
  Can be **counteracted by air pipes but root cause should be found.**

• **Tapout through collector bar port.**
  If localized to a crack or pothole. It can be mended with flake alumina. It may be necessary to cut the strap to the collector bar.
  If the leak is due to a failed specific block, the cell can be stopped and sidewall or block changed.

• **Excessive paste shrinkage** and high iron due to a greater number of minor cracks.
  This failure can sometimes be counteracted by breaking side crust along the sides for some time. Paste shrinkage will however, often lead to strong heaving due to aluminium penetration.
Conclusion

Total power failure:  
- < 2 hours are not problematic.
- 2 – 4 hours are manageable.
- > 4 hours electrolyte freezes and loss of potlife is expected.

Loss of life for a fully stopped pot may be from 100 – 500 days dependent on the conditions of the potline and how it was stopped.

Partial repair is in many instances economic provided that the pot is in general good condition and not too old.