Laterrière Smelter Experience During Low Amperage Operation Due to Rectifier Problems

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Abstract

During the summer of 2023, major breakdown failures at the potline electrical substation forced the Laterrière aluminium smelter to decrease the potline current by 20 kA (from 216 kA to 196 kA) for one month as well as operate at 200 kA for two and a half months before slowly increasing back to the normal amperage over two months. After this event, a root-cause analysis was performed that showed that the cause of the failures was due to a design problem on each rectifier of the substation. Other amperage decreases were necessary to perform a major overhaul on each rectifier. This paper summarizes the events from the point of view of potroom operation, and the lessons learned regarding the technical adjustments and operational targets during the different amperage changes and low amperage operation.

Keywords: Aluminum reduction potline, Low amperage operation, Rectifier maintenance.

1. Introduction

Consistent electrical power is critical for an aluminium smelter and the electrical substation must be reliable to avoid any potlines disturbances. In recent years (decades), many aluminium smelters have increased potline's amperage, which increased the electrical current load on substation equipment including transformers and rectifiers [1].

The Laterrière aluminium smelter is located in the Saguenay region in Quebec, Canada. The smelter has two P-155 potlines of 216 pots each (432 pots total); the annual aluminium production is around 250 kt/a.

The smelter begun to experience problems during the spring of 2022 when an electrical transformer (TR6) failed, which resulted in an amperage reduction of 13 kA (from 216.5 kA to 204 kA) for 10 days in both potlines. A second transformer (TR2) experienced the same kind of failure during the fall of the same year, but without impacting the potline as the external temperature was low enough to allow continuous operation at the normal amperage with a N-1 configuration. This breakdown was repaired in 8 days but showed the fragility of the substation. It was decided to launch a major overhaul project of all the electrical transformers of the substation, making certain to increase on-site the availability of critical spare parts.

However, in June 2023, during a heat wave, two rectifiers (R8B and R3A) failed in a short time interval which forced both potlines to operate at 196 kA. Inspection of the failure draw attention to the impact of the high operating temperature inside the rectifiers, which caused diodes failure. Both rectifiers were repaired within a month but, to minimize the risk of another rectifier breakdown, the amperage was limited to 200 kA for another 75 days. During the fall of 2023, during the preparation of the rectifier's major overhaul, the amperage target of the potlines was increased slowly (Figure 1) by controlling the internal temperature inside the rectifiers - which is strongly dependent on the external ambient temperature that was cooling down during that period.

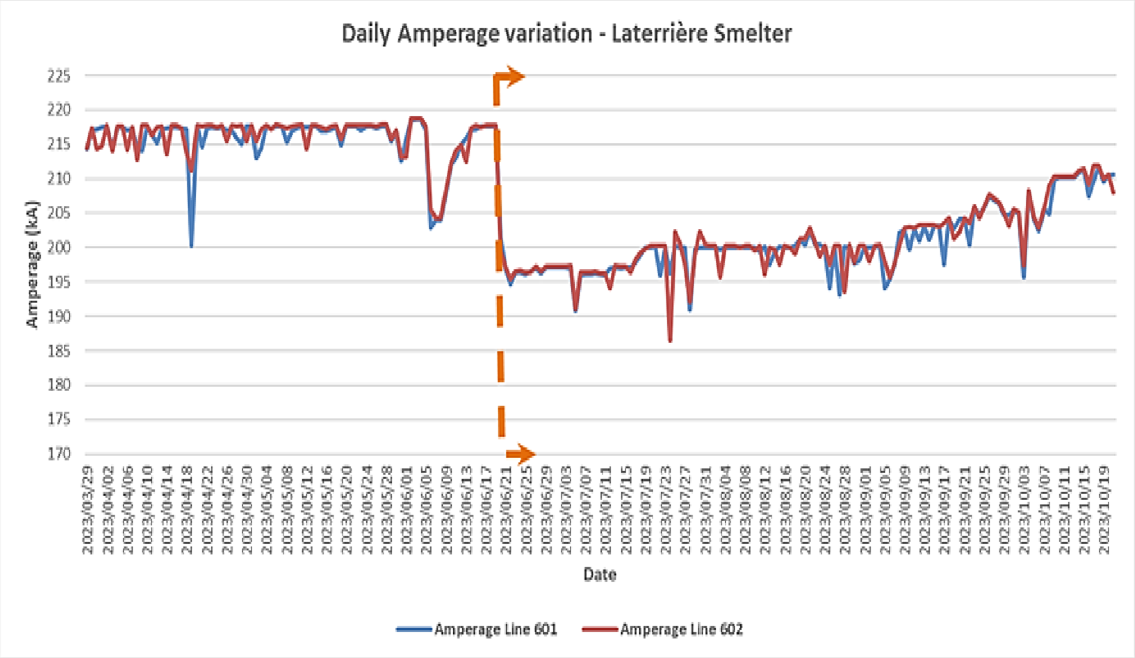


Figure 1. Daily amperage of the two potlines.

The amperage was not brought back to the initial target because the major overhaul of the rectifiers required frequent amperage drops to 195 kA.

This paper explains what was accomplished to operate the potlines during this period and to be ready for any further amperage drops (risk to operate at 185 or 195 kA, in case of another rectifier breakdown failure). A complete review of the emergency response plan was also conducted.

2. Substation

The investigation of the breakdown failures of the two rectifiers demonstrated that operation temperature inside the equipment was above the maximum recommended by the supplier. An underperforming cooling system of the units was found to be the root cause of the diode failures in the equipment (Figure 2).

Each half-rectifier has 6 wheels of 12 diodes (total 72) and the substation has 16 half-rectifiers for a total of 1152 diodes to replace. It was found during the inspection that the break-down failure of an old diode impacts the life of a new diode. The project had to improve the air circulation of the 16 half-rectifiers. The illustration of a rectifier and its 6 diodes wheels is presented in Figure 3.

Figure 2. Illustration of the type of damage found in the rectifiers due to overheating.

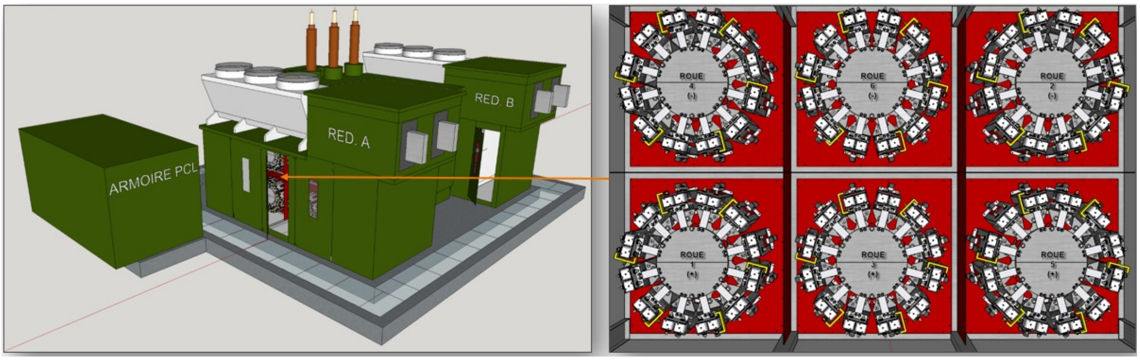


Figure 3. Rectifier and the diode wheels.

3. Amperage Management

The internal operating temperature is a key factor to limit any potential breakdown of the rectifiers and the relation between the operation temperature at the junction of the diode wheels and the external temperature was known. A table was produced to provide a guideline to the Reduction department for the maximum amperage target in regard of the number of rectifiers in service and the maximum temperature difference between the junction temperature and the temperature target set by the supplier (Table 1). Considering the state of the asset, it was recommended to operate the rectifiers 30 °C below the recommended temperature.

Table 1. Amperage guidelines in regards of the seasons of the year.

Season and process	**N 8 rectifiers**	**ΔT junction**	**N – 0.5 7 rectifiers**	**ΔT junction**	**N-1 6 rectifiers**	**ΔT junction**
Summer	200.0 kA	-29 °C	190.0 kA	-19 °C	185.0 kA	**8 °C**
Fall	212.0 kA	-35 °C	190.0 kA	-31 °C	185.0 kA	-7 °C
Winter	217.5 kA	-56 °C	207.0 kA	-40 °C	185.0 kA	-32 °C
Spring	212.0 kA	-35 °C	190.0 kA	-31 °C	185.0 kA	-7 °C
Average	210.4 kA	-39 °C	194.3 kA	-30 °C	185.0 kA	-9 °C
Production loss, t	8 550		27 900		39 000	

3.1 Daily Amperage Management During Ramp-Up (Fall Period)

To minimize production losses while limiting the risks on the rectifiers, a table was agreed on by the potline electrical substation and the reduction department to adjust the amperage target twice a day based on the external temperature. Table 2 is based on the number of rectifiers in service: the table on the left has 8 rectifiers and the table on right has 7 rectifiers.

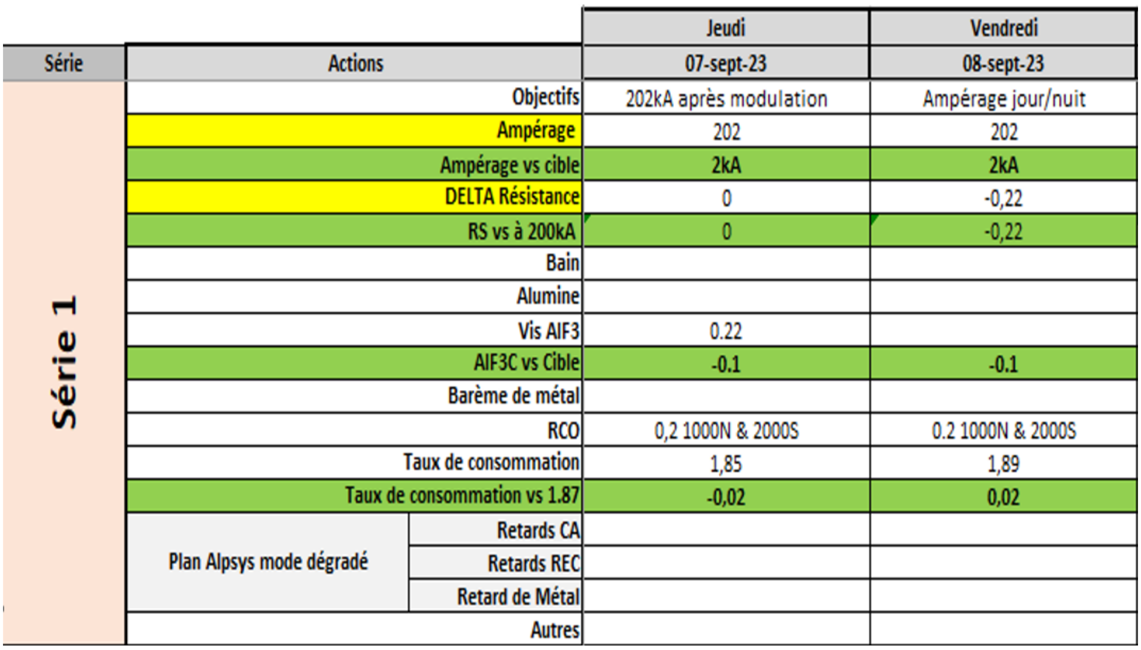
Twice a day, the amperage target was set according to the maximum temperature forecast by the local weather channel for the next 12 h.

Table 2. Amperage target table based on the external temperature and the number of rectifiers in service. Left: 8 rectifiers, Right: 7 rectifiers.

Ave. gap of 5 °C between ambient and external		# of running rectifiers		Ave. gap of 5 °C between ambient and external		# of running rectifiers
External temperature, °C	Rectifier current with N diodes, kA	8		External temperature, °C	Rectifier current with N diodes, kA	7
		Potlines current setpoint, kA				Potlines current setpoint, kA
15	**26.00**	**208.0**		**15**	**27.14**	**190.0**
16	26.00	208.0		16	27.14	190.0
17	25.88	207.0		17	27.14	190.0
18	25.75	206.0		18	27.14	190.0
19	25.63	205.0		19	27.14	190.0
20	**25.50**	**204.0**		**20**	**27.14**	**190.0**
21	25.38	203.0		21	27.14	190.0
22	25.25	202.0		22	27.14	190.0
23	15.13	201.0		23	27.14	190.0
24	25.00	200.0		24	27.14	190.0
25	**25.00**	**200.0**		**25**	**27.14**	**190.0**
26	25.00	200.0		26	27.14	190.0
27	25.00	200.0		27	27.14	190.0
28	25.00	200.0		28	27.14	190.0
29	25.00	200.0		29	27.14	190.0
30	**25.00**	**200.0**		**30**	**27.14**	**190.0**
31	25.00	200.0		31	27.14	190.0
32	25.00	200.0		32	27.14	190.0
33	25.00	200.0		33	27.14	190.0
34	25.00	200.0		34	27.14	190.0
35	**25.00**	**200.0**		**35**	**27.14**	**190.0**

4. Process Management

Dropping the amperage target has a major impact on the pot's thermal balance and many process adjustment must be made. A rigorous follow-up of the changes made or to be performed must be done. To do so, a daily follow-up has been created to follow the changes made in both potlines. Aside of the amperage target, discussed in the previous sections, the main indicators to follows are discussed the subsequent subsections. An example of the Excel sheet used to follow the KPIs (in French) is presented in the Figure 4.



			Jeudi	Vendredi
Série	**Actions**		**07-sept-23**	**08-sept-23**
Série 1		Objectifs	202kA après modulation	Ampérage jour/nuit
		Ampérage	202	202
		Ampérage vs cible	2kA	2kA
		DELTA Résistance	0	-0,22
		RS vs à 200kA	0	-0,22
		Bain		
		Alumine		
		Vis AlF3	0.22	
		AlF3C vs Cible	-0.1	-0.1
		Barème de métal		
		RCO	0,2 1000N & 2000S	0.2 1000N & 2000S
		Taux de consommation	1,85	1,89
		Taux de consommation vs 1.87	-0,02	0,02
	Plan Alpsys mode dégradé	Retards CA		
		Retards REC		
		Retard de Métal		
		Autres		

Figure 4. Example of the daily follow-up of the process parameters ***(extract of table – the original one has an additional set of lines for potline 2 and covers one complete week).***

4.1 Pot Resistance Setpoint

The resistance set point of the pots was adjusted to keep the internal heat as constant as possible with the amperage changes. It was important to decide what daily changes must be made and track what was the cumulative change from the reference.

4.2 Bath Height Target

The bath height target was increased right when the amperage dropped after the breakdown of the rectifiers coupled with the elongation of the anode cycle duration. The goal was to increase the anode-cathode distance (ACD) for an “as constant as possible” internal heat with the same anode bath immersion.

The bath volume increase was also a protection to limit low bath height excursion and to help the alumina dissolution with a colder cathode.

4.3 Alumina Feeding Parameters

Follow-up were made daily on the main alumina feeding indicators (anode effects rate and duration, number of feeding cycle, duration of no feed tracking, percentage of time in underfeed mode, etc.). According to the evaluation, feeding parameters were adjusted.

4.4 AlF_3 Addition Adjustments

In Laterrière potlines, the main addition is done by mixing the AlF_3 with the fresh alumina before the gas scrubbers. This represents roughly 80 % of the pot consumption. The remaining (20 %) is added with a bin on the individual pots by the pot tending machines, based on the sampling results from the laboratory.

As the pot heat balance is greatly affected by the amperage, the adjustment of the AlF_3 adding upstream is critical and needs to be followed daily.

4.5 Metal Tapping Table, Metal Level Target

The metal level decrease is a way to limit the heat losses when a pot is in thermal deficit. But metal level is also a way to minimize the MHD instability in a pot. So, depending on the temperature forecasts, metal level changes must be anticipated to minimize any upset created by the amperage change, and the tapping tables must follow as well.

4.6 Anode Consumption Rate

Laterrière smelter uses the Rio Tinto consumption rate method to set new anodes in pots [2]. The anode consumption rate is a key parameter that must be modified if there is an amperage change to set the anodes correctly and to have an exact reading of the metal level at the pot.

4.7 Operational Delays

The operational delays must be closely followed and prioritized for catch up, as metal tapping and anode covering delays can exacerbate the thermal balance deficit of the pots. As for anode setting delays, they can slow down any amperage increase opportunity.

4.8 Pot Start-up

During this kind of event, pot start-up parameters need also to be followed and adjusted accordingly:

- Pot preheating rate and duration;
- Bath flux period (Heat input, feeding parameters, flux duration);
- Early life start-up laws, etc.

5. Results

5.1 Operating Setpoint and Internal Energy

The 20 kA drop induced a decrease in the pot internal energy of 20 kW (Figure 5), even if the anode-cathode distance (ACD) was increased by 1 cm (Figure 6). Part of this energy drop is also imputed to the pot stability at higher ACD (Figure 7), generating less extra-resistance at the pot (Figure 8).

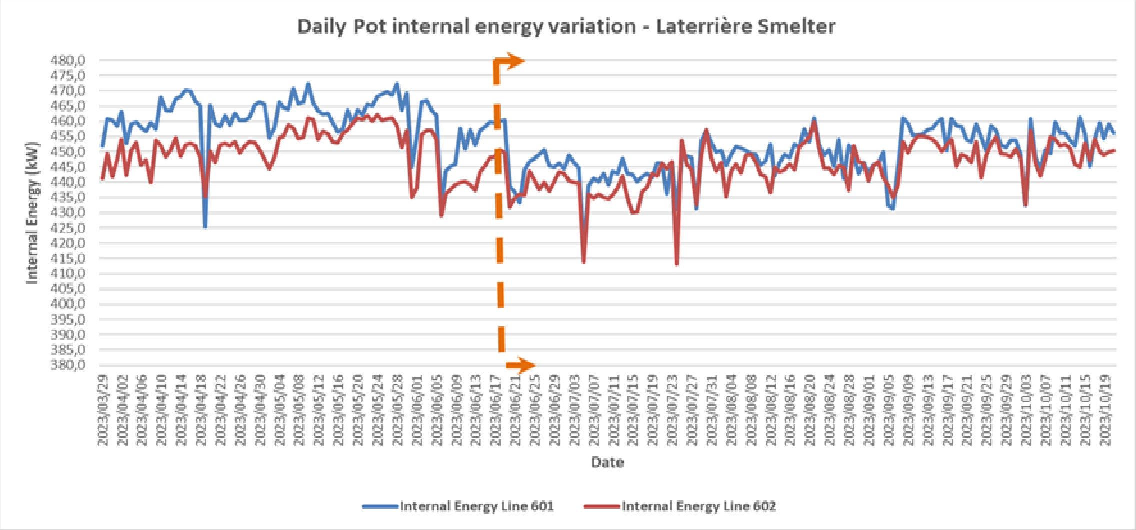


Figure 5. Daily pot internal energy (calculated at 94 % of current efficiency).

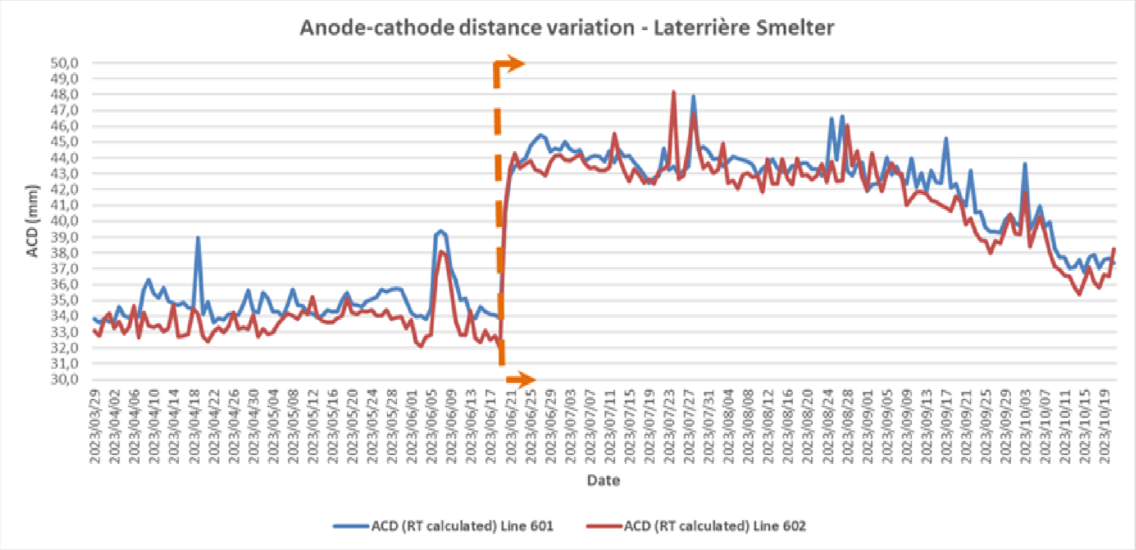


Figure 6. Daily anode-cathode distance (calculated).

Early in the process, an extra-resistance treatment was added after metal tapping to help limit the presence of excessive ledge under the corner anodes. A closer follow-up of the beam levelling after tapping (4 corners check) was also implemented to prevent any mechanical offset of the anode plan, due to corner anodes sitting on ledge at lower metal level

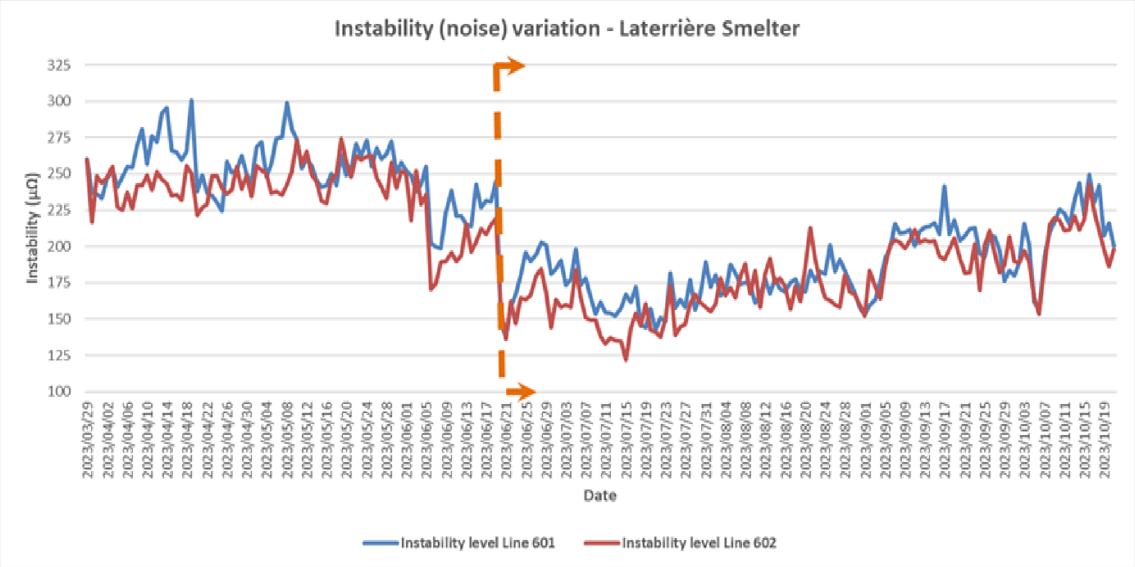


Figure 7. Daily pot instability (noise).

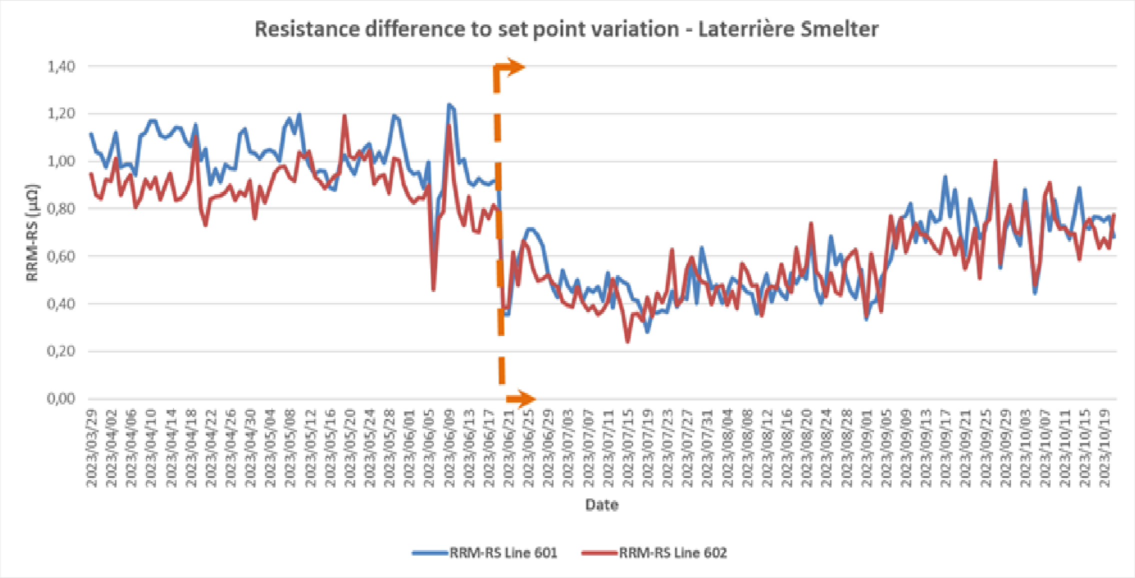


Figure 8. Daily difference between the pot resistance and set point.

5.2 Liquid Management (Bath and Metal)

When the event occurred, and the amperage was suddenly dropped, the ACD was increased rapidly to mitigate the heat loss, which created a shortage of liquid bath (Figure 9). To mitigate this, a contingency plan was put in place (see Section 6.2). To generate rapidly liquid bath, donor pots were put in place, where a special team was generating bath to be transferred to the other pots.

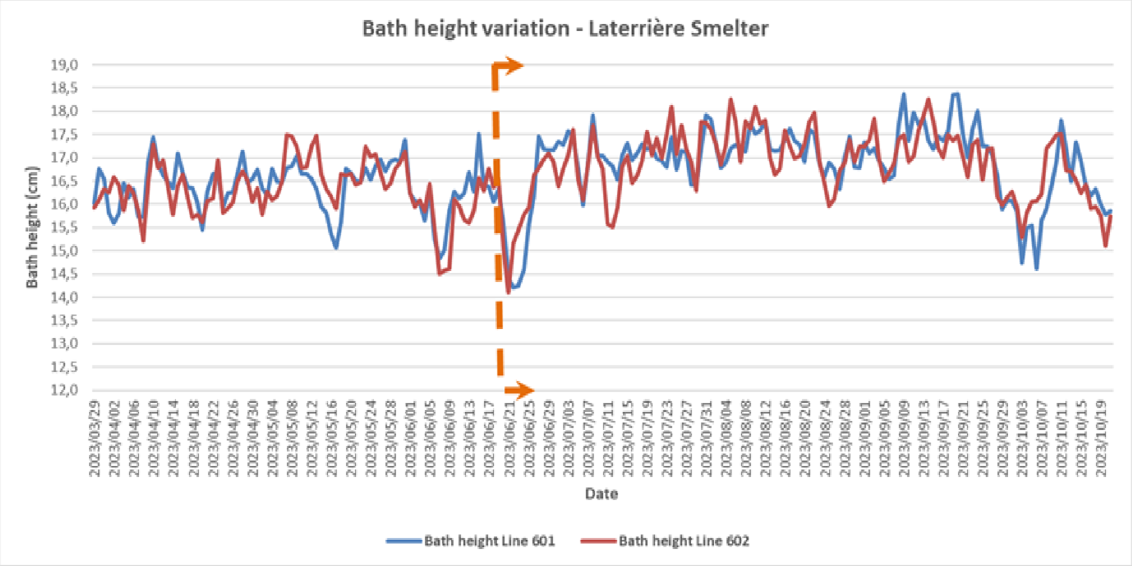


Figure 9. Daily variation of the bath height.

Also, alumina content in the anode cover material was slightly decreased to dope the pot’s natural bath generation. Finally, pot’s bath height target was increased by 1cm to compensate the high ACD (anode immersion) and the heat balance deficit.

Once the bath level measurement reached the new target, alumina feeding parameters were adjusted to consider the larger bath volume.

To compensate the heat balance deficit, the metal level target was decreased (Figure 10), but different events affecting actual metal level occurred during the summer. Metal flow problems coupled with crane breakdowns during the month of July put pressure on the pots for more than a week. Freeze on the cathode was the main problem observed during this period.

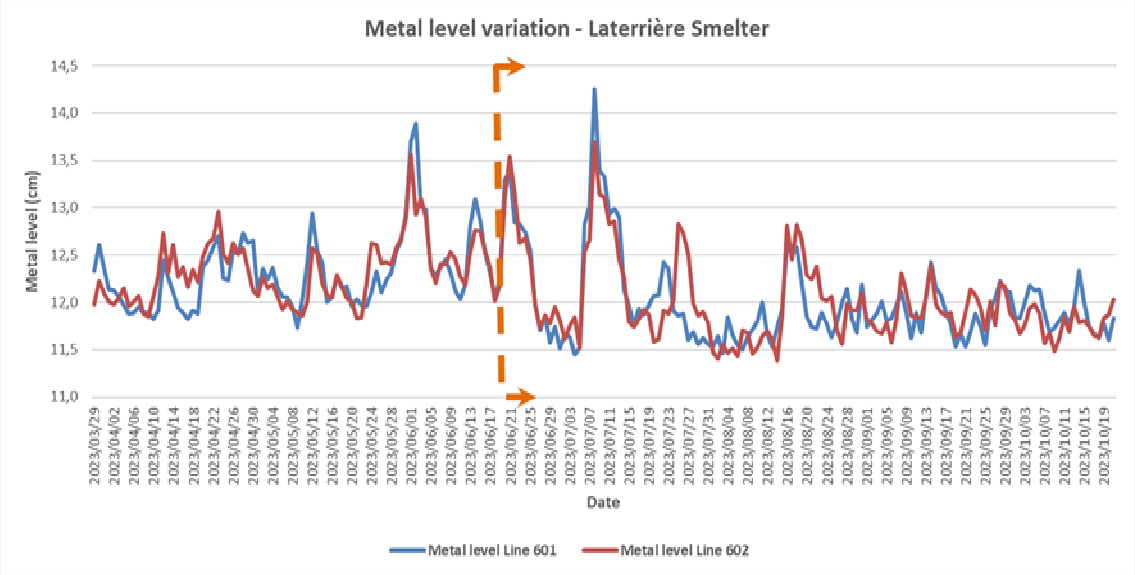


Figure 10. Daily variation of the metal level.

5.3 Thermal Behaviour

The event induced a sudden increase in the bath AlF_3 excess content (Figure 11) and standard deviation (Figure 12). This was rapidly mitigated by cutting the AlF_3 input in the fresh alumina. Sodium carbonate was also added to the pot with very high AlF_3 result which helped to lower the standard variation and generate bath.

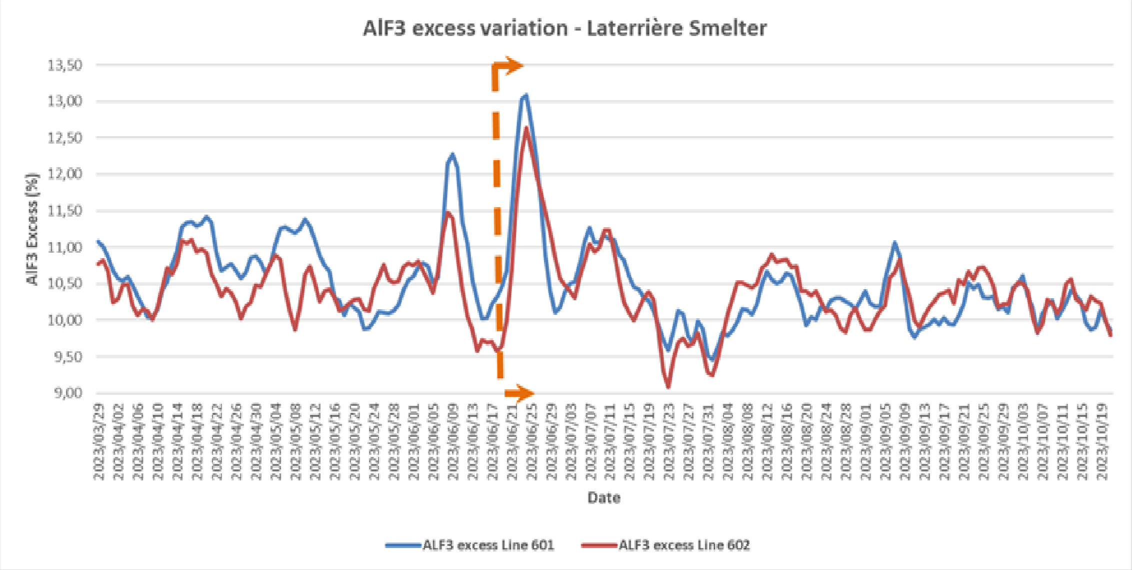


Figure 11. Daily variation of excess AlF_3 in the pots.

Later during the summer, considering the ledge observed in the corners of the pots and the different issues with the metal flow, the excess AlF_3 target was lowered, which helped to bring back the bath superheat to the normal operating values (Figure 13). Overall, the thermal state of the pots was brought back effectively in a timely manner despite the operations flaws that occurred.

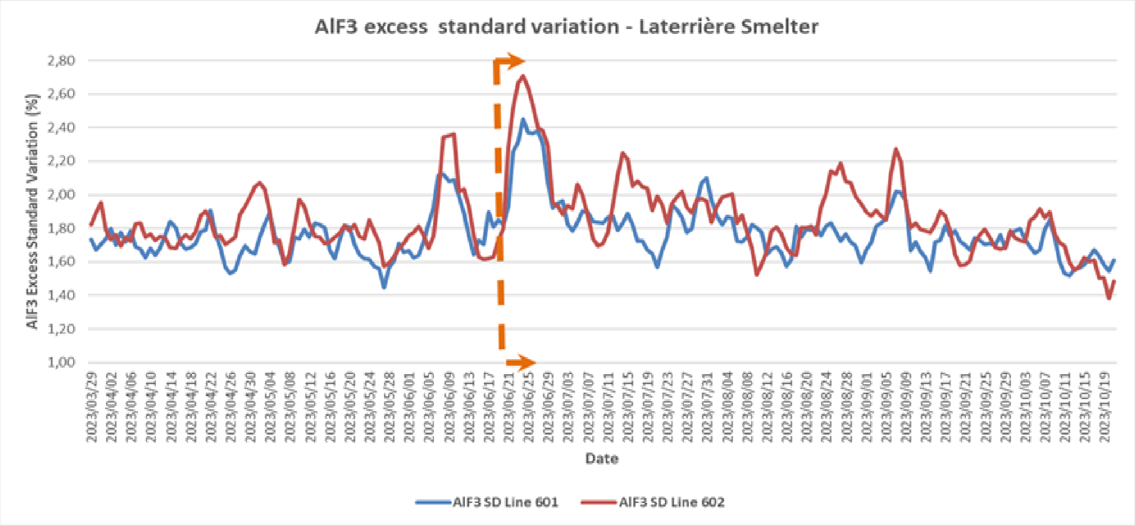


Figure 12. Daily variation of AlF_3 standard variation by potlines.

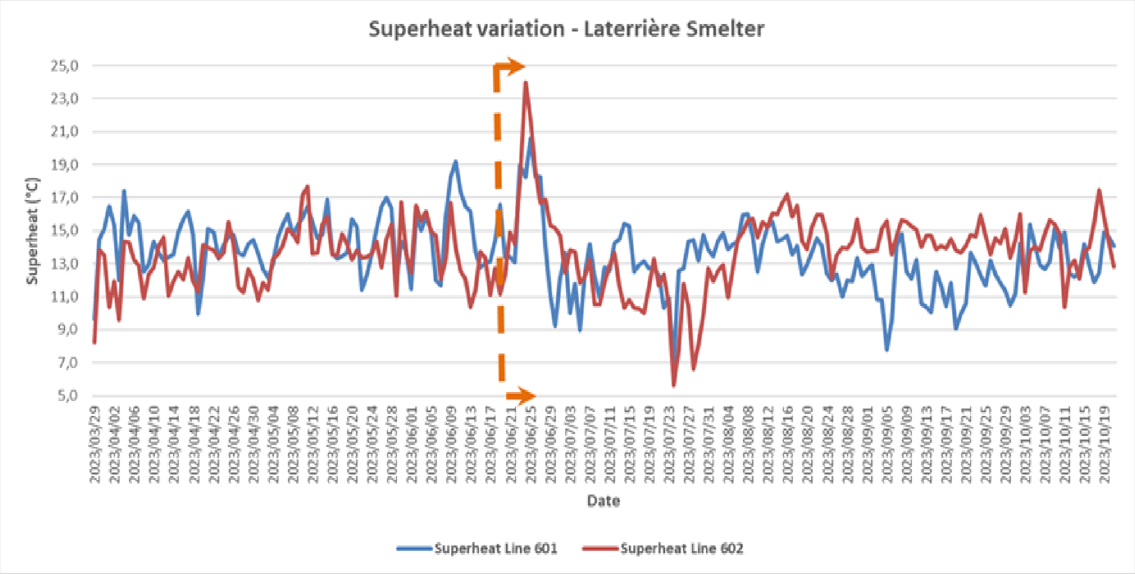


Figure 13. Daily variation of bath superheat (Rio Tinto calculation).

5.4 Current Efficiency

Despite the process upset created by the 20 kA drop at first, the potline recovery at higher ACD brought some process robustness as the pots became more stable (Section 5.1). First, at higher ACD, the current efficiency increased by 1 percentage point (Figure 14), which contributed to limit the economic losses induced by the lower amperage target.

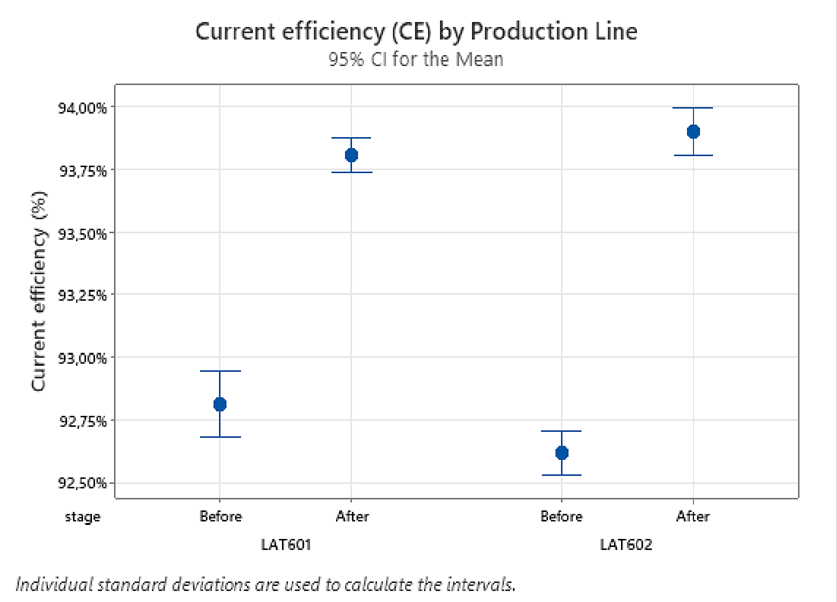


Figure 14. Potlines current efficiency before and after the event.

Pot stability brought other upsides on the alumina feeding control and a decrease of the anode effect frequency was observed (Figure 15). Because of the alumina transportation system is generating more attrition in line 602 than line 601, the impact was more significant in potline 602 gaining some robustness.

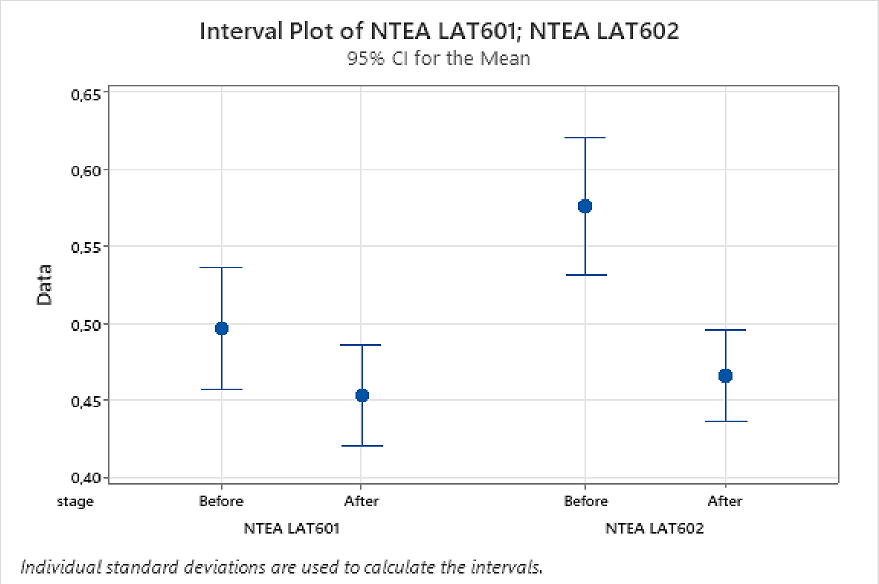


Figure 15. Potlines anode effect frequency before and after the event.

6. Emergency Response Plan

6.1 Pot Modelling

In parallel of the process management, the risk of breakdown on another rectifier unit was real and could have occurred at any time, which would have forced a lower amperage: either 185 kA or 195 kA, depending on the unit broken.

As it was an unknown if the pots in their actual form can operate at such low amperage, a request was made to the Rio Tinto Aluminium modelling team to evaluate options to limit the thermal losses knowing that the ACD cannot be raised indefinitely:

- What can help to generate more internal heat?
- What can help to limit the heat dissipation?

Six options were considered with an associated action plan in case of emergency:

1. **Remove anode slots:**
   This option helps to generate roughly 20 kW more for the same ACD (equivalent of 4 kA)

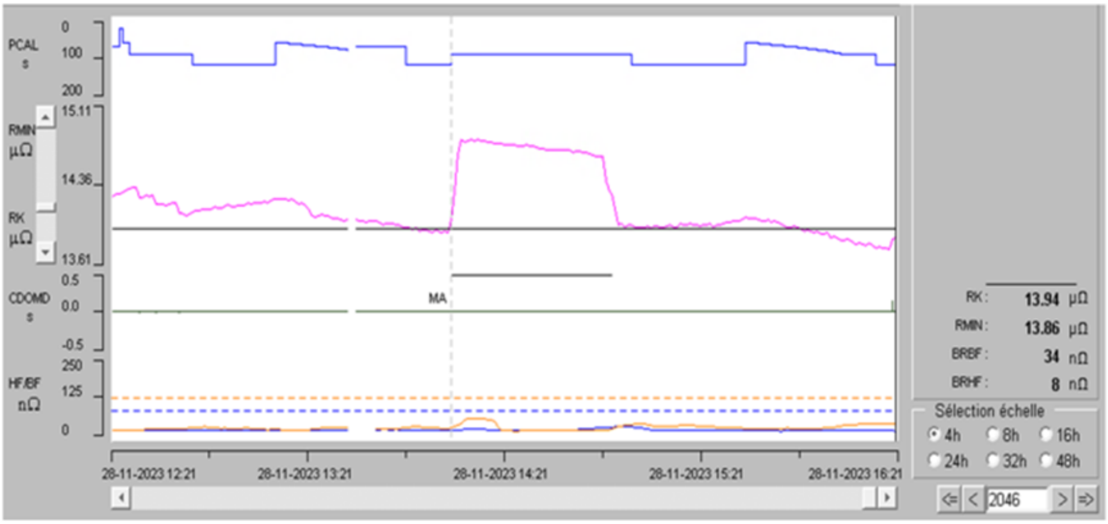
2. **Electrically Isolate 2 anodes:**
   This helps to lower the heat dissipation and generate heat by 20 to 35 kW (equivalent to 1.5 to 2.5 kA). To do this, many test were done with different materials and shapes. The use of a cardboard electrical insulator collar between the anode rod and the anode beam (Figure 16) was chosen.

Figure 16. Anode isolation system.

Tests made on four pots confirmed the potential of this option and the results obtained by modelling (Figure 17). An increase of pot resistance of 0.7 µΩ was obtained (Table 3) on average which is the equivalent of 24 kW at 185 kA.

Table 3. Pot resistance increases by electrically isolating two anodes (µΩ).

Pot	RMIN before	RMIN after	ΔRMIN
2045	14.04	14.61	0.57
2046	13.91	14.77	0.86
2049	14.30	14.88	0.58
2052	13.99	14.70	0.71
		Average resistance	**0.68**



RK : 13.94 µΩ
RMIN : 13.86 µΩ
BRBF : 34 nΩ
BRHF : 8 nΩ

● 4h ○ 8h ○ 16h ○ 24h ○ 32h ○ 48h

2046

Figure 17. Anode isolation test results.

3. **Decrease metal level:**
   The potential to reduce the metal level by 1 cm was evaluated (from 12 cm to 11 cm). This decreases heat loss by 3 to 5 kW.

4. **Increase anode cover height by 4 cm:**
   This decreases heat loss by 11 kW (equivalent to 3 kA) and is quite easy to implement.

5. **Reduce pot gas suction reduction by 15 %:**
   This mitigation has a low impact on the pot thermal balance (1 kW or 200 A equivalent).

6. **Rod 2 anode stubs instead of 3:**
   Another option is to rod only two anode stubs out of 3. The hole in the middle can be filled with packing coke to minimize the bath infiltration and sodium contamination. This option increases the heat generation and decreases heat loss. The impact on the thermal balance is equivalent to 15 to 20 kW (4 to 5 kA equivalent).

In total, the options evaluated can compensate for about 85 kW or 24 kA without increasing the ACD and keep the pot thermal balance nearly constant.

6.2 Donor Pots

When a sudden amperage decrease of this magnitude occurs, it became critical to keep the bath height nearly constant in pots in order to keep the pots operating. The standard plant method used by the Laterrière smelter at that time to generate bath in donor pots was time-consuming and inefficient. Afterwards, donor pots often become unstable, hot, and often have red pot shells. A demonstration was made using Rio Tinto's best practice to generate bath, a technique developed in AP technology. The new method was compared with the standard method on a group of pots. For the same time duration, donor pots using the new method generated nearly 4 times more bath than the standard method (3400 kg versus 900 kg on average on 12 h shifts). Additionally, pots using the new method had no excursion to high temperatures (above 985 °C) and stayed stable. As a result, the new method was imbedded into the emergency response plans.

6.3 By-Pass Bridge

Due to the apparent fragility of the electrical substation for failures, another asset refurbished was the half-potline by-pass bridge (Figure 18).

Figure 18. Half-potline by-pass bridge.

The last time this equipment was used,-was during the restart of Potline 1 in 2010, following a problem with the electrical transmission line. It was installed when the electrical current in Potline 1 was completely stopped (0 voltage on the potline).

A Kaïzen (Continuous Improvement philosophy) was conducted to make certain the emergency response plan was adequate in case of need to stop a group of pots. Several activities were completed:

- A complete review of the procedures; some flaws were identified for the electrical safety of the people working to install the bridge.
- A complete review of the maintenance plan and its execution as the bridge was not maintained for many years.
- Procurement of missing parts of the bridge and equipment; a special cabinet was dedicated to store the bridge parts and equipment.
- Development of a document explaining the roles and responsibilities of each employee involved.
- Testing of the motion of the moving bridge part to ensure the correct motion and the correct grabbing point for the crane to manipulate it.
- SMED (Single Minute Exchange of Dye) activity to reduce as much as possible the installation time.

The maintenance of the by-pass bridge was put back in the plant maintenance calendar and the emergency response plan was modified with all of the changes.

7. Conclusions

The Laterrière aluminium smelter was able to operate successfully after major extended amperage decreases caused by two potline rectifier breakdown failures. After the upset, the process was stabilized, and pot production was above expectations despite excessive ledges found in the corners of pots. Due to the fragility of the electrical equipment, many actions were taken to improve the emergency response plan and preparations for any further amperage decreases with minimum impact on potline performance.

8. References

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