

Pot Control Systems and Safety - Lessons Learned from Real Potline Incidents

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Abstract

In aluminium smelters, safety training is one of the first and foremost trainings delivered to the reduction staff. It generally covers risks associated with pot line operational activities and risks related to electricity. The standard operating procedures and risk analysis normally covers the risks associated in performing the operations. However, the risks associated with use of the pot control systems are not exhaustively covered.

In the recent past, several of our customer smelters worldwide using ALPSYS have reported significant incidents related, closely or remotely, to pot process control and/or their process control system. Those incidents were critical or potentially critical incidents resulting in very sick pots, pot open circuits and, at times, damages to the pot equipment.

Each incident has been thoroughly analysed to identify root causes and mitigation actions were put in place. In some cases, the pot control system (PCS) has been modified to integrate the mitigation actions. In most cases, the incident could have been avoided, or its consequences greatly reduced, with a proper action from the plant staff. In rare cases, the incident was the direct result of a wrong action.

In this paper, several real cases are presented and discussed, and the lessons learned from those incidents are explained. These lessons learned are relevant for potlines controlled by any kind of control system, not only for potlines controlled by ALPSYS.

Keywords: Pot Control System (PCS), ALPSYS, Safety incidents, Potline open circuit, Sick pots.

1. ALPSYS Pot Control System for Safety

ALPSYS is the AP Technology™ solution developed and owned by Rio Tinto Aluminium Pechiney. This pot control system (PCS in short), in addition to control of the pots and of the pot line, has monitoring tools that not only monitors the pot process status, but also the safety of the pots and of the pot line. The protection system primarily employs three actions – detection, declaration, and a treatment wherever possible.

Many kinds of detections can be done by PCS. Some of the detection systems employed in ALPSYS are:

- Pot voltage monitoring
- Amperage monitoring
- Open circuit protection through the sub-station
- Anode beam movement monitoring – Electrical cabinet monitoring
- Anode beam movement monitoring – Process monitoring
- Pot and potline alarms management

However, a PCS capacity to detect faults are limited. It is limited by what the PCS can measure or by what it can detect. Some typical situations that it cannot detect include:

- An anode beam too high or too low (when pots are not equipped with beam position measurement sensors or limit switches).
- Anode heeling or when anodes movements are physically blocked (when there are no sensors present on the motor mechanisms).
- Faults in the pot control electrical cabinet, depending on its design (some protections are not available in all smelters [1]).

When a fault is detected, the PCS will try to treat the issue. In cases where the pot control system can action, the system triggers direct actions. It can also trigger actions through external interfaces:

- Upon detecting an anode movement fault, the PCS stops the power to the anode motorization to stop any movement.
- If a trend to open circuit is detected, the PCS can send a potline shutdown request to the substation.

But the PCS capacity to treat an issue is also limited by the existing equipment:

- Typically, when an open circuit is detected, the PCS is not able to identify the cause (clad failure, pot tap out, excessive anode movement, etc.). It then cannot do anything to treat the issue as an unsuitable treatment could make the situation worse.

These limits, if not well known and understood, can lead operators to take a wrong action when faced with a difficult situation. It can then worsen the situation instead of improving it. In the worst cases, it can turn an under-control situation to an out-of-control incident.

2. Case Studies

Over the last 10 years, several of our customer smelters worldwide using ALPSYS reported significant incidents related, closely or remotely, to pot process control and/or their process control system. Those incidents were critical or potentially critical incidents: open circuits, damage to pot equipment or very sick pots. The intent of this paper is to share some of the critical incidents that have happened in the pot. The real events are explained to understand:

- The incident
- The consequence and the cause
- What could have been done to avoid the incident occurrence?
- Improvements made to the ALPSYS pot control system.
- What smelters could do to prevent such an incident?

2.1 Incident 1 - Open Circuit on a Pot

2.1.1 The Incident

Smelter A experienced an open circuit creating arcing on the pot, which eventually caused liquid bath overflow and damages to the pot. Fortunately, there were no injuries to the personnel. The pot was stopped, and the resulting restart was difficult due to a high number of anode effects. This resulted in a total of 2 successive line shutdowns of approximately 90 minutes.

2.1.2 The Causes

An investigation following the incident concluded that the resulted open circuit was due to excessive reduction of anode immersion in liquid bath. In other words, it was due to too many up movements of the anodes given by the pot control system. It was also confirmed that no fault was

2.1.4 Lessons Learned

Several lessons were learned from this incident.

First, of course, the anode beam movement monitoring function was improved in the pot control system to detect these cases more efficiently. It also triggered important lessons about alarm management in a smelter. The open circuit could have been avoided if the existing alarm had been raised earlier, and this is highly dependent on the set-up of the monitoring logic. It is tempting to use a “loose” set-up which would trigger an alarm early and would supposedly detect “all” cases. It will allow to not miss any case; however, it may raise so many alarms that people will tend to ignore it.

On the other hand, a smelter can opt for a very “tight” setup which would trigger an alarm only when an incident is absolutely sure. There will be no false alarm, but the real alarms might be triggered late. Sometimes, so late that it could be too late to give enough time to react. The right set-up is a balance between these two extreme cases. It is difficult to adjust, but it is very important to do it carefully.

During this incident, the alarm had been raised 13 minutes before the open circuit. It was late, but not too late to avoid the incident. Just putting the anode movement in manual or shutting down the anode motor power would have avoided the incident.

The other lesson is that all alarms should be investigated. Even an alarm which normally has a low criticality level should be checked, especially when it is coming from a disturbed or sick pot or a pot that is out of a normal operation state.

2.2 Incident 2: Several Pots Going to an Open Circuit During a Potline Shutdown

2.2.1 The Incident

A curious incident happened in Smelter B: during a normal potline current shutdown, anodes were raised by the PCS when the current was shut down. Anodes were raised several times, resulting in some anodes almost out of the bath when the current was restored. No open circuit happened - thanks to the quick reaction of the staff, but it was a very close call.

This was the first known occurrence of such an event in a potline. The investigations quickly showed that the problem was because the PCS on those pots did not detect the power shutdown.

2.2.2 The Causes

The analysis revealed certain interesting findings of how a past change management, could impact the life of a smelter. The root cause of this particular incident was to be found in an operation that happened months before, when this smelter decided to operate several pots in their pot line at a lower voltage – under 2.5 V – for an extended period. This is termed by several smelter as pots on sleeping mode, where the pots are operated at very low voltages, to keep the pot alive without any electrolysis happening [2]. This is mainly performed when there is a shortage of available power or shortage of key raw materials required to operate the pots and/or long-term operational difficulties.

The sleeping mode operation provides a window of opportunity to overcome the difficulties the smelter is undergoing without the need to stop a pot or a group of pots. The sleeping mode of operation requires however a very closer monitoring and observation of the pots.

In a normal situation, with the line operating at the set amperage and with a pot voltage abnormally low for a running pot, the pot control system detects a fault (called a pot voltage acquisition fault) and triggers an alarm. This alarm is a normal behaviour of the pot control system. In a pot line with several pots in sleeping mode, because of their abnormally low pot voltages, the PCS will declare this fault on all sleeping pots. This is an unnecessary alarm that will be likely to disturb operation people.

To limit the number of pot alarms arising, months before the incident, the corresponding threshold limit to trigger a pot voltage acquisition fault alarm was adjusted to a much lower voltage: it has been reduced from a value of 2 V to 0.25 V.

Regarding pot line shutdown, ALPSYS detects a pot line shutdown when the amperage and the pot voltage are both below two set minimum threshold limits. During this specific incident, the pot line amperage was below the set minimum threshold, but pot voltages of the impacted pots were not below the threshold (pot voltage during a pot line shutdown is normally of an order of 1.4 volts approximately; so well above the modified threshold limit of 0.25 V). Due to this, several ALPSYS pot micros did not detect a pot line shutdown, instead an amperage acquisition fault was detected, which was as per the system specification.

It is a standard practice when an amperage signal is lost, or if an amperage acquisition fault is declared, to continue to regulate the pot but calculating the pot resistance using the programmed amperage instead of the actual amperage. So, the pot micros that detected an amperage acquisition fault instead of a power shutdown did continue to regulate the pot as normal; but using a pot resistance calculated with a very low pot voltage.

The pot micro computed the pot resistance and detected it to be lower than the set lower threshold, which lead the pot micro to give up orders to regulate the pot resistance. This eventually un-squeezed the anode beam of the impacted pots when the pot line was in a shutdown state.

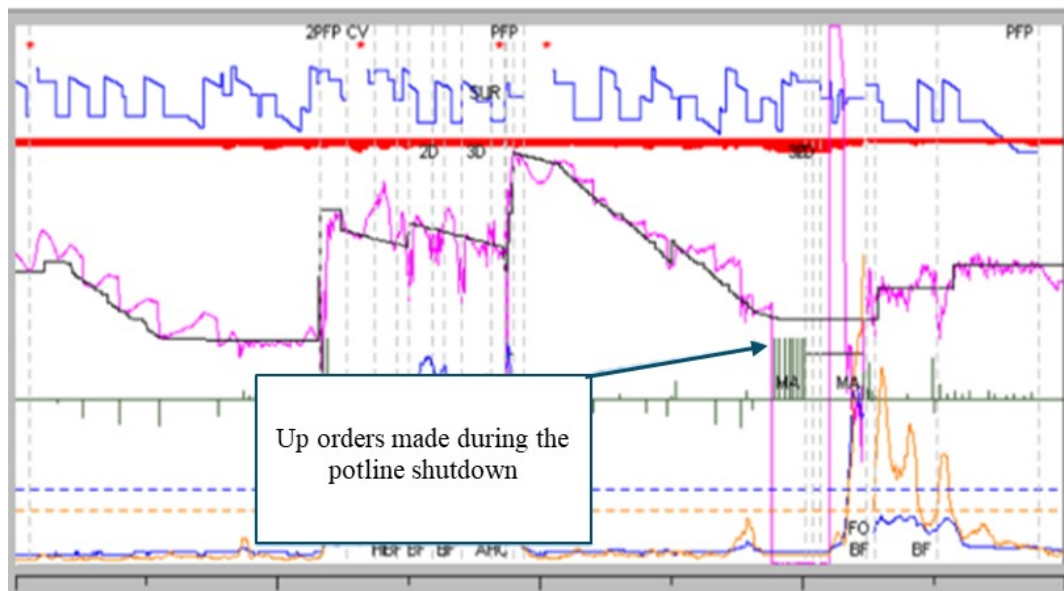


Figure 2. Pot graph indicating anode beam up orders made during pot line shutdown on pots where adjustments were made to the voltage lower threshold limit.

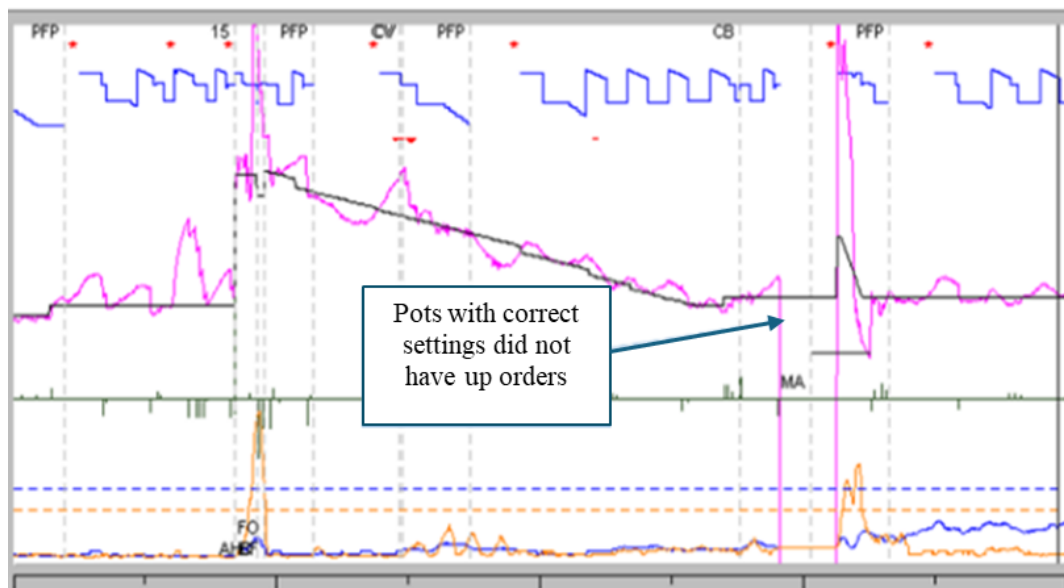


Figure 3. Pot graph indicating no anode beam up orders made during pot line shutdown on pots with no adjustments made to the voltage lower threshold limit.

The repetitive up movements were enough to reach a situation that could have been dangerous at the end of the power shutdown. Fortunately, the solution as mentioned above about incident 1 was already in place in this smelter. It prevented the anode beam movements after a certain time and avoided the anodes from separating from the liquid bath.

The lessons learned from this incident have a very general scope that goes far beyond just dealing with sleeping pots.

Changes occur frequently in potlines. To deal with an unexpected event, it is perfectly legitimate to adapt parameters or a set-up to adapt the PCS functioning to the new reality. In our case, changing the pot voltage threshold to avoid untimely alarms is a good practice as keeping false alarms could lead people to disregard alarms whether false or real. However, special care should be taken when conducting specific trials and operations. Operating sleeping pots is not a standard practice in a smelter. The decision to modify the thresholds to avoid untimely alarms was correct, but it needs to be followed up until the end of the event along with the changes implemented. It is important to track the changes made to the different parameters to restore the proper setting at the end of the event.

2.2.3 Lessons Learned

Modifying a pot control system parameter or set-up is a normal and frequent practice in a smelter. Most of the time this is done on a limited number of well-known parameters. They are frequently modified, and people know well the consequences of those changes. As it has been the case in this incident, an unusual situation can lead to change parameters that are very seldom modified in the plant. Then the consequences of the change may not be known or properly understood.

Before modifying a pot control system parameter or set-up, especially if it is not a common practice in the smelter, ensure to take the time to analyse thoroughly all the potential consequences of this change: in the present situation (pot in sleeping mode) but also in any future situation (pot line shutdown, equipment fault, pot operation, etc.). This will enable you to set up the right measures to deal with any future situation.

2.3 Incident 3: Open Circuit on a Pot Due to Equipment-Human Interaction

While some incidents are cases that happen rarely in some smelters, others happen regularly in most smelters, because they are due to some general causes.

2.3.1 The Incident

This incident happened in Smelter C, where an alarm started on a pot because of a contactor fault. When the operator intervened on the pot, all anode movements had already been stopped by the PCS following the declaration of the contactor fault. However, the pot voltage was high. The operator, seeing a pot at high voltage with an ongoing anode movement fault decided to put the anode movement in manual mode to deal with the issue, but the anode beam started to move upward without the operator noticing. An open circuit happened a short while after, damaging the pot, and fortunately no personnel were injured.

ALPSYS pot micro has inherent safety systems that could detect an abnormality with the electrical contactors that control the anode beam movements. If certain abnormal conditions are detected, the potmicro reacts and declares a fault. This prevents the system from performing a wrong action, thereby protecting the personnel and the infrastructure [1].

2.3.2 The Causes

During this incident, the impacted pot experienced a contactor fault following a change in the physical state of the contactors housed inside the pot control cabinet. The contactor responsible for the up movement of the anode beam became stuck, meaning the contactor was closed permanently. It was not responding to opening command from the PCS and would make the beam move up without any control. The ALPSYS pot micro continuously monitors the state of the contactors and in this case reacted to cut off the power to the anode motor. Without power, anodes movements are stopped even though the upward contactor remains closed. The reaction time was a few tenths of a second. This is termed as an “Order Discrepancy Fault” in ALPSYS.

The person who intervened to diagnose the issue changed the pot to a manual operation mode through the pot control cabinet. Turning the pot control cabinet to manual mode does not allow any control by the pot micro and all the existing safety features relating to the beam movements are bypassed. With the contactor still in a stuck condition (closed state) and the pot micro control bypassed, the anode beam started to move up continuously until the open circuit situation and eventually leading to a pot line shutdown.

There is a common belief in smelters that putting the anode movement in manual is a way to protect the pot from the risk of untimely anode movement; that it would stop any possible anode movement. This is a mistake that can have serious consequences. A pot in manual mode is not inherently safe: the result is only that pot safety monitoring has been transferred to the electrical cabinet. If an anode movement is ordered by the potmicro, switching the anode to manual will effectively stop the movement. But if the anode movement is due to an electrical fault, there is no guarantee that the switching to manual will stop it. Safety functions in the pot control cabinet are highly dependent on the design of this control panel. Some plants will have a fairly good level of safety, while others not.

2.3.3 Lessons Learned

Switching the anode beam to manual mode on the pot control cabinet must be used with caution and its consequences must be known to those involved. Any intervention on a pot following an

electrical fault in the pot control cabinet is a critical task and thus must be identified as such in individual site's management systems.

All ALPSYS pot control cabinets are equipped with a power switch which cuts off the anode motor power supply. The proper way to stop anode movement in a safe manner is to act directly on this switch. The type of switch might not be exactly the same for all the smelters (see examples of ALPSYS switches in Figure 4 but all smelters should have at least one such switch.



Figure 4. Left: Example of an anode beam motor switch, Middle: Example of a pot control cabinet, Right: Example of an anode beam motor switch. The type of switch differs by the smelter.

If a contactor is stuck or permanently closed, opening this switch will completely stop the anode movement and effectively remove the risk. This raises a frequent concern in smelter regarding the PCS: in many instances, the operators do not have a clear understanding of how the electrical cabinet works. This knowledge is what can make the difference between limited or serious consequences.

Some of the key lessons learned from this incident include:

- Know the limits of the pot control system's safety features (a pot with anodes in manual is not a safe pot)
- Be aware of the existing features (power switch to cut anode motor power off)
- Train the front-line personnel on how to react to alarms and faults, especially the faults which are not common.

2.4 Incident 4: Open Circuit and Potline Shut Down During an Anode Effect Treatment

2.4.1 The Incident

In Smelter D, a pot was unstable, and the operators did several interventions to try to treat the pot including switching the anode beam in manual for a while and setting it back to automatic mode. The intervention was rather successful, and the pot instability significantly reduced.

The pot disturbance was however not completely treated, and an anode effect started on the pot a few hours later. Two minutes after the beginning of the anode effect, smoke started coming out of the pot, and 6 minutes later, arcing occurred as the pot was in open circuit, with metal and bath projected around the pot. The potline was shut down in about 10 minutes after the beginning of the anode effect.

2.4.2 The Causes

During the initial investigation, it was discovered that the anodes were at a very high position, much higher than the neighbouring pots. It was also discovered that, around 1 hour before the open circuit, the pot did not respond to downward movements - the pot resistance was not reduced after several down movements. The movements were not enough to breach the set threshold to trigger an alarm, so it remained unseen before the anode effect.

It was then confirmed that, when the potmicro was requesting an upward anode movement, the anode beam moved up. However, when the pot micro was requesting a downward anode movement, the anode beam did not move.

During an automatic anode effect treatment, the potmicro lowers and raises the anode beam several times to expel the gases produced by the anode effect. With the pre-existing problem on the anode movement, during the sequence of anode effect treatment, only the raise commands were performed. The lowering commands were not performed, and no alarm was raised. This eventually continued until the open circuit.

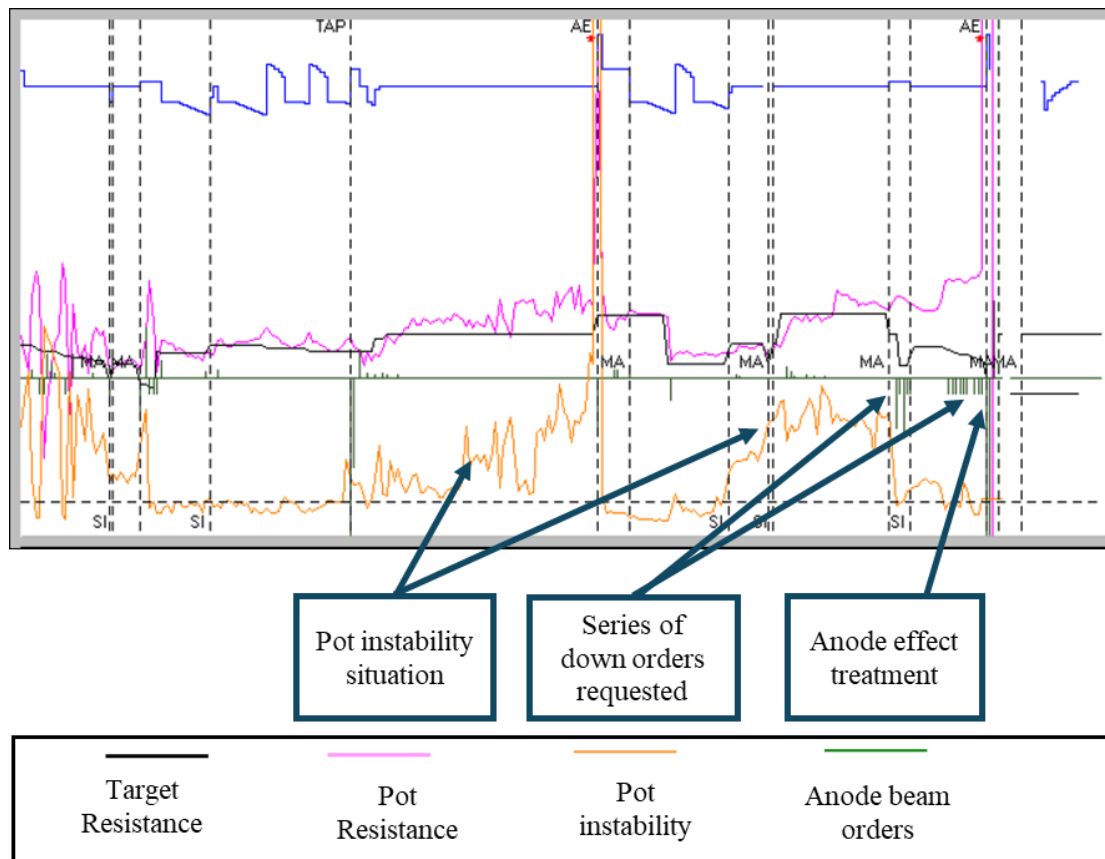


Figure 5. Pot graph indicating different pot states and start of potline shut down.

The origin of the problem was finally identified to be a malfunction of the Auto/Manual switch on the front panel of the pot control cabinet. A spring inside the switch ensures that the button can only be on one of two positions: automatic or manual. This particular switch was in poor condition and the spring retention did not work anymore. In short, the button stayed in the position it was left in.

The last time the pot was switched from manual to automatic, the switch did not rest in a proper position, and instead rested in between automatic and manual. In this particular position, the downward anode movement were switched off, while the upward anode movement were sent to the motor.



Figure 6. Auto/manual switch present on the pot control cabinet.

2.4.3 Lessons Learned

This incident happened in a potline with an old pot control cabinet design, where the contactors are not monitored. With a contactor monitoring, the pot micro would have detected that downward movements were not performed, and an alarm would have been raised. Without this monitoring, the potmicro was unable to detect that commands were not performed.

This incident emphasizes that even a small part of the system can have a significant impact on its behaviour, particularly when this part is an electrical component. All parts of the electrical cabinet play an important role in the pot safety and good maintenance of this equipment is a must. All essential components need to be checked regularly. It can be done with a regular preventive maintenance plan. By maintaining a high level of awareness among the people who work in the potline every day, it is also possible to get very useful feedback on such kind of potential problem via the operators.

It also shows the limits of using equipment not at the best standard. Many smelters are still using electrical control panels designed several decades ago, which do not include some improvements that were made in pot control systems since then. This incident is a good example of the possible consequences. Smelters with old equipment should consider upgrading their equipment to integrate the new features that would secure the personnel and the infrastructure [1].

2.5 Incident 5: A High-Risk Operation

2.5.1 The Incident

Anode beam raising is, most of the time, considered as the riskiest operation on pots. Because of the size of the beam raising device, and the fact that all anodes are disconnected from the beam during the operation, it can indeed lead to some very difficult situation if an incident happens.

In our experience, this is however not the operation with the highest number of incidents. The operation with the highest number of incidents is metal tapping.

Many cases of incidents during metal tapping were reported to us from many plants and they were initiated by a wide range of different causes, but these causes can be summed up in a few main issues.

- The metal tapping logic in the potmicro has been stopped by an event with a higher priority
- The potmicro cannot activate the anode motor
- The potmicro can activate the motor but anodes do not move

2.5.2 The Causes

The first case is typically what happens when an anode effect starts during the metal tapping with an anode effect in progress, it becomes impossible for the PCS to adjust the anode position while tapping the metal. So, the PCS stops the metal tapping logic. If the operator continues to tap metal, then an open circuit is likely to happen.

The second case is generally caused by an electrical fault in the Pot Control Cabinet - PCC or by a loss of the anode motorization power. Depending on the PCC design, the fault may be detected or not. If the fault is detected, the metal tapping logic will be stopped, and an alarm will be raised. If the fault is not detected, then the metal tapping logic will continue to run and should declare an alarm because the pot resistance would increase too much. Once again, if the operator continues to tap metal, then an open circuit is likely to happen.

The last case is what happens if the anode beam is stuck. It could be caused by anode heeling (anodes touching the ledge in the pot cavity). We also saw a case where the anode beam came to rest on a pile of alumina deposited inside the superstructure, due to alumina overflow from the top of the superstructure. In this case, the contactors were working correctly so the pot control system did not detect any anode movement fault and the consequences of the incident were different from the two previous cases. As the operator continued to tap metal, the pot control system forced the anode beam to go down, and the force of the beam mechanism was strong enough to damage the beam mechanism.

Smelters those experienced similar cases have witnessed:

- Bending of the long pieces (struts)
- Twisting of the anode beam
- Breaking of one/more of the supports of the anode jack mechanism

Depending on how the beam is damaged, the PCS may detect that pot resistance cannot be adjusted correctly and raise an alarm, but it is not always possible. We have seen cases where a mechanical part broke before any alarm was raised.

In all those cases, heavy and difficult work was needed to repair the pot superstructure.

2.5.3 Developments and Improvements

There were two different monitoring actions implemented in addition to the existing monitoring and control actions available in ALPSYS pot control systems.

- Implementation of too long up and/or down movements triggered by the pot micro: The pot control system continuously cumulates all the anode beam movements triggered and when it breaches a set threshold of cumulated duration, the pot control system triggers an alarm alerting the operator to check the pot for any abnormal situation present.
- Interlock with the pot tending assembly (PTA): ALPSYS pot control system and the PTAs continuously exchange information regarding the metal tapping operation and whenever an abnormal situation is declared by the pot micro, the PTAs shut down the tapping operation by switching off the compressed air supply to the tapping ladle.

The beam movement cumulation is now included as a standard safety feature within the ALPSYS pot control system. The PTA interlock for metal tapping operation, is available on the existing ALPSYS pot control system. However, the interlock system works based on a fast communication between the PTAs and ALPSYS which requires additional modifications on the PTAs.

2.5.4 Lessons Learned

Several important lessons are to be learned from these incidents.

When tapping metal, the operator should always monitor the pot closely because the metal tapping logic can stop unexpectedly at any time. In this case an alarm will be triggered. The operator should then immediately discontinue the metal tapping before checking the alarm. By doing the opposite (checking the alarm before stopping metal tapping), the operator may react too late and there could be possible damages to the pot.

An incident can also happen even if no alarm is triggered. The operator should watch the pot resistance to ensure that it is maintained close to the target. If not, metal tapping should be stopped immediately before investigating the issue.

It is always recommended for smelters to incorporate active exchanges between the pot control systems and the PTAs to integrate the safety interlock for metal tapping.

3. Conclusions

ALPSYS has always been an evolving technology keeping up pace with the real-world needs, prioritizing safety over and above all, ensuring safe operational systems and maximizing efficiency of operations. A very strong hardware and software design, coupled with a robust testing methodology has always been the backbone of ALPSYS. In addition, an active research and continuous exchanges with the users have led to several improvements to be developed and deployed. Several other improvements are also under research and development with a prime objective to safely operate the pot line and minimize the occurrences of an abnormal situation effectively.

However, relying solely on the pot control system to handle all sorts of abnormal situations would introduce additional risks. A pot control system is designed to detect and act on most known scenarios and conditions that arise during a pot and/or pot line operation but there are certain limitations to what the system could deliver in each case. These are determined by the capability of the detection system, the user settings, and the thresholds. Following a fault detection, if a corrective action triggered by a pot control system is overridden by a human action, all or most of the inherent security controls may be bypassed and at times this could worsen the situation, if not properly handled. This emphasizes the need of a strong knowledge of how a pot control system works and what must be done when the automatic systems are overridden.

Independent of the pot technology, a periodical maintenance of all the equipment associated to the pot control system ensures the risks to be minimized and maintained at an acceptable level. Smelters with limited safety protection systems should consider upgrading their protection systems to integrate the latest developments.

A rigorous and periodical training for pot line personnel on all routine/non-routine scenarios, and pot control systems is key to ensure a high level of competent work force that can understand the different situations and handle any abnormal situation that may arise.

4. References

1. Pierre Marcellin and Antoine Garnier, Protection against open circuit in ALPSYS pot control system, Proceedings of 39th International Conference of ICSOBA, Online, 22 – 24 November 2021, Travaux 50, 877-888.

2. Alton T. Tabereaux, The survivability of aluminum potlines after lengthy electrical power outages, *Light Metals 2022*, 448-457.
3. 3. Dominique Duval et al., Potline open circuit protection, *Light Metals 2012*, 913-916.
4. Didier Lamant et al., Potline open circuit auto-adaptive Protection, *Proceedings of 35th International Conference of ICSOBA, Hamburg, Germany, 2 – 5 October 2017, Travaux 46*, 915-924.