Integrated Power Outage Restoration Capability System (IPORS) in Potlines

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Abstract

Power outages and poor recoveries are costly, damaging for environment and cell life and are also stressful for the personnel involved in the recovery. It is fundamental to strengthen the power-outage restoration efficiency while minimizing relapses and production losses as well as sustaining the reliability of the cells and safety of the staff affected. In this paper, we report the enhancement of the power outage-recovery agility through computerized capabilities. We recommend Integrated Power Outage Restoration Capability System (IPORS), a comprehensive, cost-effective outage-recovery management system that helps reduce the recovery duration and enhances the coordination by providing adequate information for directing responses. The IPORS is an advanced prediction and coordination capability that allows power outage recovery in a more informed and efficient manner.

Keywords: Power outage, power recovery agility, aluminium reduction potline.

1. Introduction

Whether caused by aging assets, extreme weather, natural calamity, shortage of energy, or open circuit, power outages are increasingly challenging to manage by potline personnel due to an increasingly high cooling tendency of modern aluminum cells. For instance, unplanned power outages could be particularly difficult to recover due to lack of companies' readiness and electrolytic cell preparedness to such thermal variation. Admittedly, as modern aluminum cells are designed to have a high heat loss capability, recovering from a prolonged power outage may be challenging and potentially damaging to the power plant utilities, if the personnel fails to control the recovery rate and efficiency.

Outages are costly, damaging for the environment and cell life and are stressful for the personnel involved in the recovery. It is essential to minimize the power outage relapses and costs while sustaining the reliability and safety of the cells and staff affected. In this paper, we aim to improve critical situation management and the recovery agility from a power outage through computarized capabilities.

In the event of a planned or an unplanned power outage, the cells lose heat rapidly, which results in the electrolyte cooling and beginning to freeze beyond the reasonable limits. During power restoration, multiple faults, abnormal voltages, and anode effects often occur. These occurrences are a burden to fix during the line load ramp-up phase. The amount of information facing the decision makers can be overwhelming to digest and interpret. Too often, some of the information might not be needed for decicion making to ensure rapid recovery. The following questions usually come to mind of managers: Which faults should the personnel attend first? How do operational and technical teams decide to move forward? When to increase the line load given the voltage capacity limits? How to minimize pot failure? How to avoide power outage relapse? Each operational decision may have a significant or detrimental impact on the business. As the reaction time is critical for success, reduction personnel need to act fast and coordinate activities cost-effectively.

To best manage the recovery efficiency and avoid pot loss, we propose Integrated Power Outage Restoration System (IPORS), a comprehensive, cost-effective outage-recovery management system that helps reduce the recovery duration by providing better information for directing responses. The IPORS is an advanced coordination capability to power restoration in a more informed and efficient manner. It tracks historical and real-time information such as cell voltages and age, anode effects, cathode voltage drop, iron and silicon content to predict cells at high risk of failure. Based on this information, operations personnel could make accurate decisions by evaluating how to prioritize responses, assign crews, and better determine possibilities for power creeps. IPORS also allows high agility recovery, minimizing the restoration time and improving communication with the power plant personnel. The remainder of this paper is organized as follows: first, we provide the purpose, the research question and the methodological framework of this study. We then outline a succinct background and the motivational framework for writing this paper. Next, we focus on three critical perspectives of the power outage and restoration; we describe the power outage and provide some knowledge of the currently available practices. Second, we discuss the challenges in high amperage cells; finally, we define the value proposition of IPORS and demonstrate how the system could maximize potential benefits.

2. Purpose

The power interruption and restoration in the aluminum production are addressed. Response to a long-term power outage involves two operational concurrent efforts; the efficient restoration of power and the prevention of collateral damages of a company’s assets. The purpose of this paper is to describe the integrated power outage restoration capability function and illustrate the extent to which it increases the restoration agility through computerized capability. The scope of this paper applies to response and recovery capabilities of the pot line personnel in the event of a long-term power interruption.

3. Research Question

What computarized capability would the reduction personnel appreciate in the middle of the power outage restoration to increase recovery agility and minimize relapses and faults?

4. Motivational Framework and Background

Nearly all aluminum smelters experience power outages and power restoration at any given time of their lifespan. The power outage often results in a temporary loss of power and shutdown of reduction lines. For instance, from 2008 to 2017 most aluminium smelters in the Gulf Cooperation Council (GCC) countries - Ma’aden, EGA, Sohar and Aluminum Bahrain had major power outages ranging from partial to complete shutdown of the potlines. The power outage and restoration failure are primarily the result of the complexity of the Hall-Herault process as well as the lack of some companies’ readiness and preparedness to such emergencies. For example, while most companies focus on reducing cost through utilizing rationalization and cheap labor, they often fail to align long-term contingency plans to power interruptions and restoration. Estimate of annual production losses due to power outages might amount 3 % to 10 % of the total production in many cases. The restoration efficiency affects the magnitude of the production loss. Modern aluminum plants now have an annual production of more than 1 - 2 million tonnes [1]. The loss of the 10 % of production could have a detrimental impact on a company’s revenues and fixed costs. Aging assets, natural calamities, rising appetite to business productivity through amperage increase, lack of experienced personnel, and open-circuit incidents are situations that contribute to the power outage. In the meantime, there is limited ability in managing power outages restoration in most aluminum production companies; this paper suggests that adequate preparedness through competently trained personnel and technological capabilities may allow preventing the occurrence and mitigating the restoration duration, which is the principal cause of production and asset losses and the most challenging step of power interruptions.

5. Methods

The IPORS was developed subsequently to the lessons learned from lived power restoration cases, detailed risks analyses and repeated emergency drills. The IPORS concept is the result of many years of experience in power interruptions, in which in-context actions, active observations, the analyses of risks, causes and effects of restoration failures across many companies are the primary sources of learning. We assumed that we could turn most of the past failures and misunderstandings into wisdom from which further generations of smelters should take inspiration. Furthermore, theoretical reflections suggest that cumulative experience and experiential learning could be a source of practical knowledge and development [2] that could help strengthen the restoration models and minimize losses.

6. Aluminum Smelting Process

Aluminum smelting uses Hall–Héroult electrolytic process to reduce aluminium oxide to metallic liquid aluminum. The process takes place in an electrolytic cell at high temperatures, typically in the range from 955 – 965 °C to maintain the electrolyte and metallic aluminum in liquid form. The amount of aluminium made per unit time is proportional to DC electric current passing through the cell, which can range from less than 100 kA in the oldest technologies to over 600 kA in the newest technologies. An electrolytic cell is made of different materials ranging from steel casing, refractories, silicon carbide, carbon cathode and anode, which contain a pool of liquid aluminum and electrolytic bath. The electrolytic bath is made principally of cryolite and some additives for which the solidification depends on the bath temperature and bath chemical composition, which determine the superheat in an operating cell. The refractories are made of materials having high thermal conductivity to allow operating at high DC current and power which increase the cell productivity. However, these material characteristics are detrimental in power interruptions due to the rapid cooling tendency of the electrolytic bath caused by high heat dissipation of the system. This is contrary to the requirement that the molten electrolyte and liquid aluminum should be maintained at high temperature for a long time during the power failure in order to avoid freezing and cause cell or potline shut-down.

7. Power Outage Description

Modern pot lines consist of 200 to 450 electrolytic cells operating continuously day in and day out. Power should not be interrupted for more than a certain time because power interruptions have detrimental effects on the optimal operation of the cells. Todd et al. [3] found that short duration power interruptions in potlines could be tolerated with manageable consequences. A power interruption, of few hours, can lead to relative turmoil, electrolyte bath freezing, productivity loss, pot life damage, and financial impediments should a company fail to have contingency plans for mitigating the impacts. Castillo [4] found that the effects of power outages include social, physical and psychological impacts as well as indirect and direct economic losses. Power outages have different causes, some of which include limited power or grid capacity, natural calamity, lack of the experienced and trained personnel, and electrical circuit failure. These incidents might occur without forewarning signals.

During the power interruption, the liquid bath temperature decreases rapidly towards its freezing point. The rate of decrease depends on the bath superheat, the overall cell heat loss and cell technological conditions. Figure 1 shows the bath height depletion measured before and during a power outage. The bath height was 19 cm measured 3 hours before shutdown. Because of the heat loss and high cooling tendency, the bath height decreased to approximately 7.7 cm in about four hours and 30 minutes after shutdown. Figure 2 shows that approximately 62 % of the bath was semisolid and deposited on the cathode. This material has high density and high-electrical resistivity. It displaces the liquid aluminum upward, which comes in contact with anodes. This might cause anode failures during power restoration should production teams fail to adjust the voltage correspondingly. The quantity of the bath solidified provides critical information about the design capability limit and the likelihood to recover the pot line. The standard deviation of the liquid bath increased to 6.5 cm from 2. The high variance indicates that not all cells should be treated identically; special care should be placed on cells that had high cooling tendency before the outage or cells in which anode setting setting had occurred a few hours before the event.

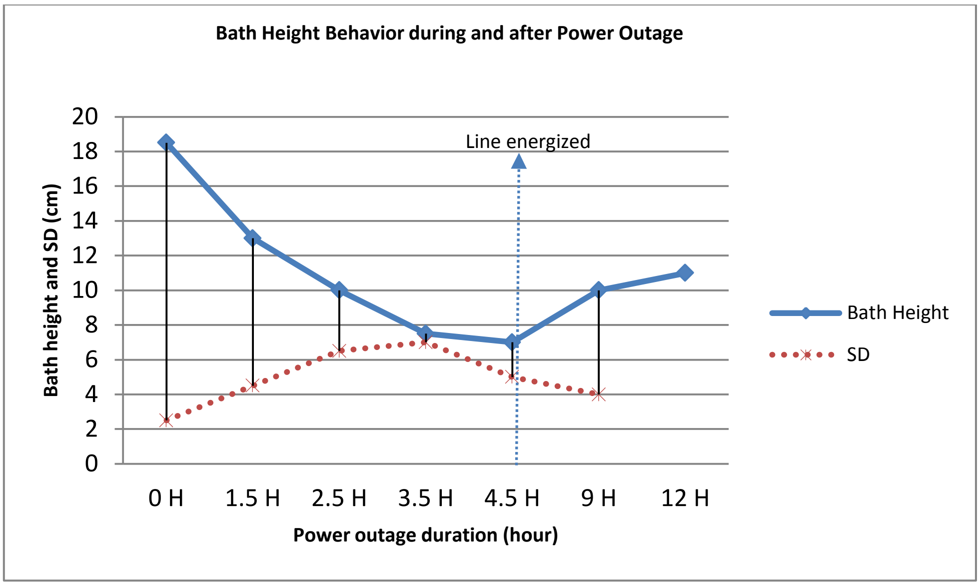


Figure 1. The variation of bath height before, during and after power shutdown.

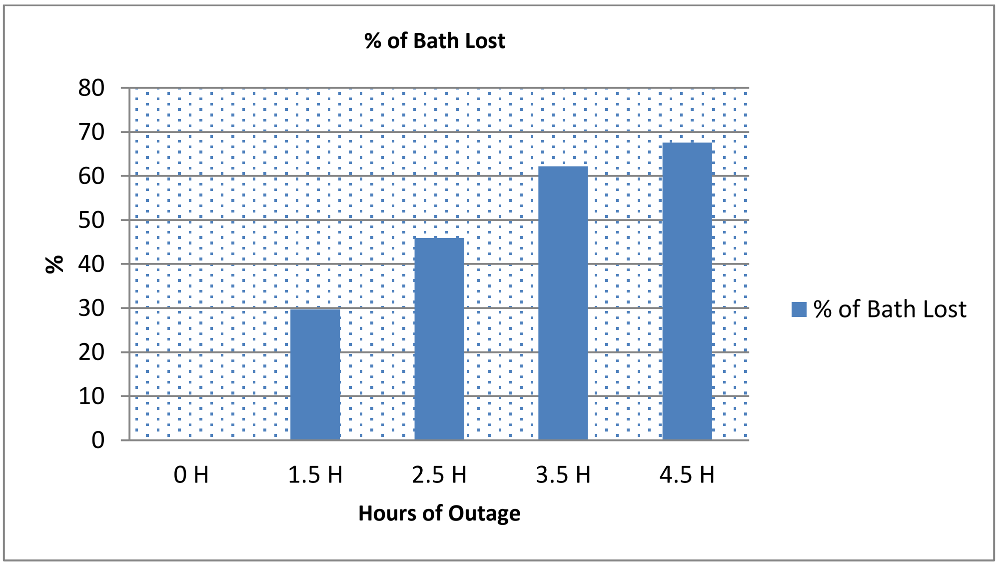
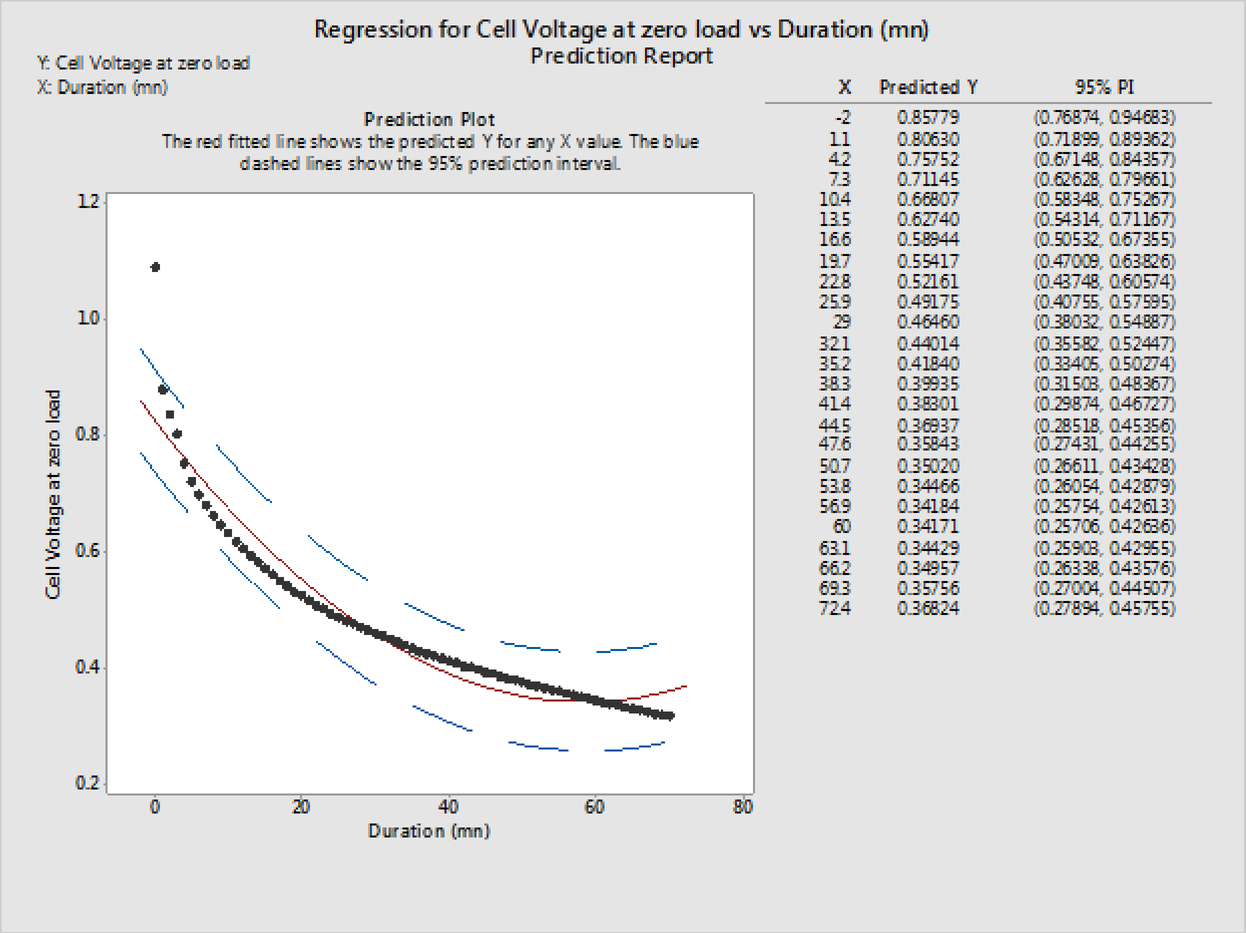


Figure 2. Percentage of bath frozen during power shutdown.

Figure 3 outlines the regression of the cell voltage exhibiting an exponential decaying scheme during zero load. One minute after the power outage, the volage of the cell dropped dramatically from 4.2 to 0.85V. This voltage is the value of the back electromotrice force (BEMF) of the cell. The value decreases over time as charges get separated due to the electrolyte bath freezing. Data indicate that the BEMF decreased by 50 % in about 1.5 hour. Reduced BEMF is indicative of the electrolyte changing the phases from liquid to semisolid.



Regression for Cell Voltage at zero load vs Duration (mn)
Prediction Report

Y: Cell Voltage at zero load
X: Duration (mn)

Prediction Plot
The red fitted line shows the predicted Y for any X value. The blue dashed lines show the 95% prediction interval.

X	Predicted Y	95% PI
-2	0.85779	(0.76874, 0.94683)
1.1	0.80630	(0.71899, 0.89362)
4.2	0.75752	(0.67148, 0.84357)
7.3	0.71145	(0.62628, 0.79661)
10.4	0.66807	(0.58348, 0.75267)
13.5	0.62740	(0.54314, 0.71167)
16.6	0.58944	(0.50532, 0.67355)
19.7	0.55417	(0.47009, 0.63826)
22.8	0.52161	(0.43748, 0.60574)
25.9	0.49175	(0.40755, 0.57595)
29	0.46460	(0.38032, 0.54887)
32.1	0.44014	(0.35582, 0.52447)
35.2	0.41840	(0.33405, 0.50274)
38.3	0.39935	(0.31503, 0.48367)
41.4	0.38301	(0.29874, 0.46727)
44.5	0.36937	(0.28518, 0.45356)
47.6	0.35843	(0.27431, 0.44255)
50.7	0.35020	(0.26611, 0.43428)
53.8	0.34466	(0.26054, 0.42879)
56.9	0.34184	(0.25754, 0.42613)
60	0.34171	(0.25706, 0.42636)
63.1	0.34429	(0.25903, 0.42955)
66.2	0.34957	(0.26338, 0.43576)
69.3	0.35756	(0.27004, 0.44507)
72.4	0.36824	(0.27894, 0.45755)

Figure 3. Regression of the cell voltage during zero load.

Operationally, the liquidus is the temperature in a phase diagram below which the material is crystallized. When the power outage lasts beyond the irreversible limits (4 - 6 hours), the bath and the liquid aluminum invert inside the cell due to the bath density becoming higher than that of aluminium (metal inversion). When the power returns, the cold bath reduces alumina solubility and the undissolved alumina deposits on the cathode (muck) resulting in high-electrical resistance and high voltage during the power ramp-up. Anode effect frequency increases. An anode effect can have a voltage of 30 - 40 volts (700 – 950 % of the cell nominal voltage [1]) due to extreme conditions in the cell. Depending on the power outage duration, the cell preparedness, and the power restoration management, the anode effect frequency may upsurge above 500 %. Failure to control the occurrence of anode effects may slow down the rate of restoration or lead to power shutdown relapse due to the limited rectifier voltage. The anode effect strength depends on numerous factors including the material nucleation or solidification, the alumina concentration, the horizontal current, and the electrical current density and distribution across the cell. Because of the metal-bath inversion and high-bath resistivity at the cathode, the Lorentz electromagnetic forces inside the metal pad change the direction and the cells become abnormally unstable.

The metal inversion causes the voltage to fluctuate abnormally between 1.6 V to 30 V. This is caused by the liquid aluminum oscillations, coming into contact with the anodes periodically and by the lack of dissolved alumina which causes anode effects. Depending on the technological condition and localized frozen bath, the Lorenz forces may distort the metal pad shape in the cell, leading to uneven current distribution across the anodes rods and the transition joint failure (see Figure 5). Should the potlines personnel neglect to handle the transition phase between the inversion and the normalization, anodes may fail causing open circuit, metal leak, power outage relapses, and loss of cells might occur.

Figure 4 is an illustration of a cell that had its electrolyte partially frozen at one end. The figure shows that the current distribution (CD) significantly distorted. The typical values of the CD should range from 1 – 1.4 mv. Correspondingly, the electrical transition joint (ETJ) temperatures range from 200 - 250 °C depending of the technological condition. Apart from the thermal diffusivity of the surrounding materials overheating, increased temperature of the ETJ is typically proportional to its current load. It has been observed that a cell that undergoes a long anode effect and persistent high voltage, could face increased ETJ temperature as shown in Figure 5.

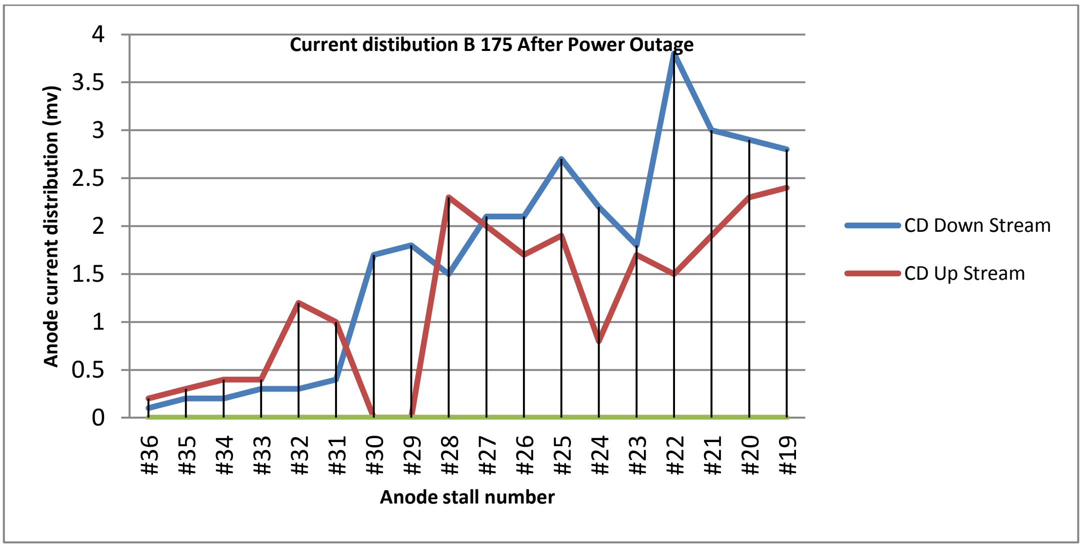


Figure 4. Anode current distribution in a cell with partially frozen bath.

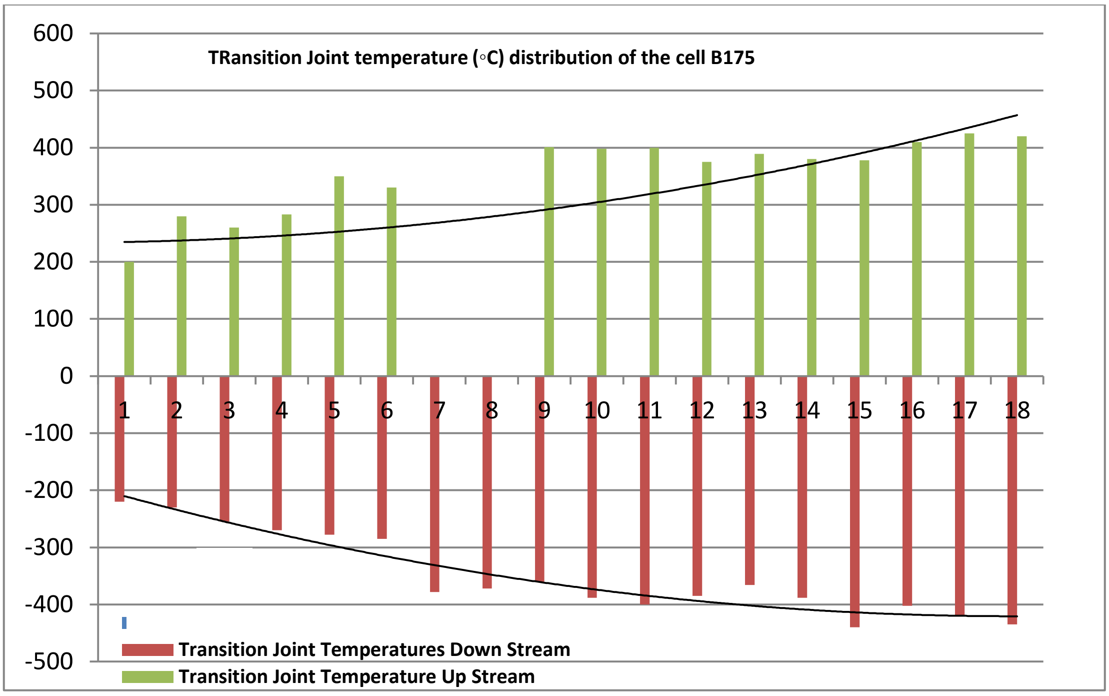


Figure 5. Electrical transition joint temperature distribution.

The transition phase is the most critical part of the power restoration; it generally lasts 30 - 90 minutes depending on the severity of the cooling, the material nucleation, and how effective the holistic case would be handled. During this phase, multiple events abnormal voltage, repeated anode effects, electrical arcing, alumina feeding failureand too low bath occur. The number of alarms and alerts from the control system might exceed the apocalyptic level of 200 000 per hour. It is improbable for potline personnel to concentrate on critical alerts. Castillo [4] discussed that restoration planning should rely on both domain expert knowledge and interpretation and the restoration coordination amongst stakeholders involved.

8. Power Outage and Restoration: Company Preparedness

Power-outage recovery efficiency varies from company to company. The main differences are related to the companies’ preparedness or lack of preparedness. For instance, trained personnel, information capability, and sound risk analysis and management might increase a company’s responsiveness during power restoration. The risk analysis to prevent catastrophic situations is a critical element of a successful power restoration, perhaps is one of the most complex tasks for a production manager. According to Haimes [5], modeling the risk analysis in a complex system might point to incommensurable and conflicting objectives leading to inaction. The risk assessment to prevent a catastrophic event such as power outages and to enhance the agility of recovery requires financial expenditure, skilled personnel, and potential investments in physical infrastructure. Conceivably, the costly financial investment involved and the hypothetical occurrence of such events spur the decision makers to consider their readiness and preparednessn as secondary priority. Haimes [5] recommended that risk analysis should be conducive to learning and based on explicit assumptions and propositions. In doing the risk assessment, a manager's aim is to allow preparing operational continuity and developing a disaster recovery strategy that might include such computerized capabilities as IPORS.

The IPORS could provide structured and standardized data for reducing and focusing the amount of information needful for a successful power restoration. The IPORS was designed subsequently to lived-power restoration cases, detailed risks analyses, and repeated emergency drills. It is a result of many years of experience and learning. Its focus is to increase clarity, reduce data confusion, and have concise information readily available from management right down to the process operators. Built-in flexibility allows for the response to other eventualities that can be expected during potline restoration events.

9. IPORS Value Proposition

The major functions of IPORS include:

- Prioritizing restoration efforts and managing resources based upon criteria such as abnormal cell voltage, reccurent anode effect and duration in high voltage, low bath level, cell age, and cathode risk to failure,
- Providing information on extent of outages and number of cells impacted to divert the personnel attention to critical issues,
- Outlines target voltage of the pot line and individual cells, amperage and compares them with actual values during restauration (see Figure 9),
- Shortens restoration times,
- Enhances personnel safety,
- Improves communication with power plant,
- Utilizes historical and current data of the cells to identify risk locations,
- Allows prioritizing decisions,
- Improves overall recovery agility and
- Shows exceptions (i.e., cells that are offline).

As an example, we show the monitoring of the wedge drop in cut-out cells. Due to an amperage outage, Figure 6 shows that the voltage of a cut-out cell increased from 0.44 V before the outage to 0.49 V after power restoration, by about 11 % compared to the initial value and to 10 % above the critical threshold level. Figure 7 shows that the wedge voltage drop increase of 35 mV is the main contribution to this, which comes from the cooling of the aluminum busbars when the power is off and subsequent loosening of the contacts between the wedges and busbars. The IPORS monitors the cut-out pot voltage and issues a warning if the voltage is above the safety limit. Failure to monitor and correct deviations of the wedge voltage drop might lead to open circuit, power outage relapse, and possible line loss.

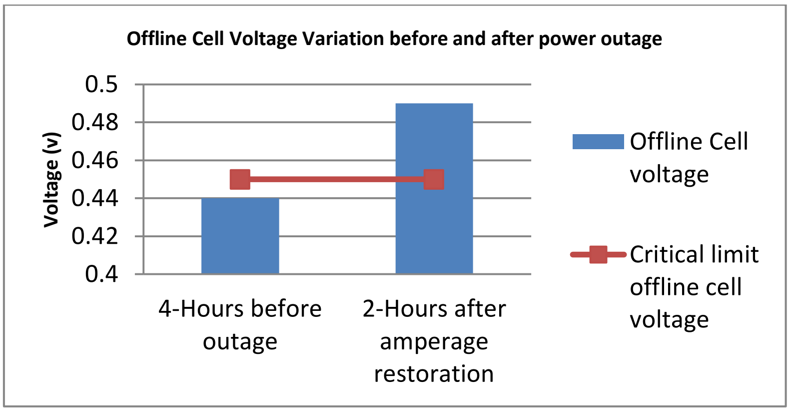


Figure 6. Measured voltage increase in an offline cell after power restoration.

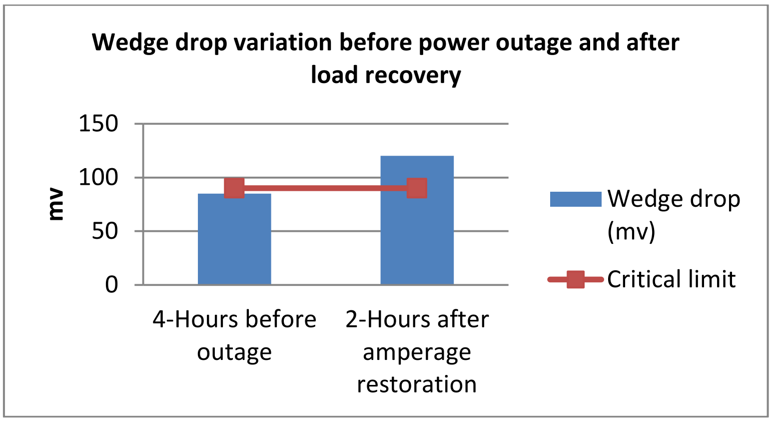


Figure 7. A real case of the wedge drop variation in an offline cell before power interruption and after power restoration.

10. Description of the Software

The software utility used to monitor the potlines is called iPOTS which is a web based application written in JAVA/JSP language and is hosted in Apache/Tomcat servers. To deploy and run JavaServer functions, a compatible server with a servlet container, Apache Tomcat was required.

One objective of this program was its portability, which means that the programs written in this platform run similarly on any combination of hardware and operating system with adequate runtime support. The execution part was achieved by compiling the Java language code to Java bytecode. Java bytecode instructions are comparable to machine code, but in this software, they were intended to be executed by a process virtual machine written specifically for the host hardware. This program does not use the database; the data are stored in binary files and are generated by Potline Interface Programs (PIP) written in C language.

iPOTS application reads these binary files to generate the line current, voltage, and anode effect graphs, reports and writes the files for changing parameters in the Parameter Change Request module. The graphs and data points represent real time data or the latest measured physical variables as entered into the application by the potline personnel. The advanced algorithms provide capabilities that were previously not possible with any standalone server. The level of control and synchronization offered by these features allows timeliness transmission of the power available at power plant as well as the security margin to open circuit potential. Based on these features, the best combination possible of the line load and voltage can be selected optimally.

It is a well known fact that power interruption relaps during the power recovery process would induce considerable harm to the pot line performance and particularly to the critical power plant functions. It also can induce damage to energy generation capabilities that might result in a long restoration timeframe. The IPORS is a tool to optimize power recovery efficiency and minimize its failures.

Evaluation of the line load and voltage data will be potline specific and based on the power recovery efficiency. Trends might vary from long pot line outages to short duration events. The human-machine interface application is remotely accessible at different terminals spread out through the pot lines, in the control room and from other workstations if the correct access has been granted.

11. Graphical Exhibits

Figures 8 – 10 give an example of a recent power failure in an EGA potlines. Figure 8 is a screenshot of the IPORS. It outlines the total pot line voltage and the line amperage that a manager should use in combination moving forward. The cumulative anode effect (Cum AE) indicates the number of anode effects occurring since the beginning of the power restoration. This capability allows reducing the restoration duration due to faster predictions and informed decision-making. This screen also helps the potline manager to efficiently identify causes of high voltage and communicate timeliness with the superintendent and shop floor to take corrective actions.

Figure 9 shows the potline voltage and amperage that a manager should use together when the power is being restored. The potline voltage increases proportionally to numerous factors including bath resistivity, the number of anode effects, and the amount of amperes passing throughout the cells. Knowing the rectifier voltage output limit, a manager can speed up the power restoration while comparing actual values to critical limits. Conversely, when the line voltage approaches rectifier voltage ouput limits, the line manager should slowdown the line load increment as a preventive measure of power outage relapse. Such features allow reducing the restoration duration due to faster predictions leading to informed and accurate decision-making.

Figure 9 indicates that 20 minutes after power restoration, the voltage increased beyond the nominal level whereas the line current only reached 65 % of its nomial value. Should a manager continue incrementing the line current without control, overcurrents may occur. When the combination of current and voltage is set above the equipment rated capacity, excessive heat is may be produced and the circuit may trip.

Figure 10 shows the cell-voltage tracking screen. Cell nominal voltage is about 4.2 V; depending on technological conditions and the time elapsed to normalize the potline the cell voltage may vary substantially. Voltage and amperage control is a crucial factor of success to minimizing risk to people and operational losses. The voltage tracking screen allows displaying exceptions based on certain preset criteria. The historical values of the cell voltage could also be displayed for different time series (t-15 minutes). This capability is particularly important because the line manager can sort and display the cells from low to high value. The manager handling more than one line can use these features for multiple selections.

Time Start: 15/09/2018 09:56 **End:** 16/09/2018 01:56

☑ Line Target ☑ Primary Amperage ☐ Secondary Amperage ☑ Line Volt ☑ Cum AE

Time (Day/Month/Year Hour:Minute) **Start:** 15/09/2018 09:56 **End:** 16/09/2018 01:56

Amperage **Min:** 415.0 **Max:** 425.0

Line Volt **Min:** 1570.0 **Max:** 1630.0

Cum AE **Min:** 0.0 **Max:** 60.0

Figure 8. Screenshot of IPORS output.

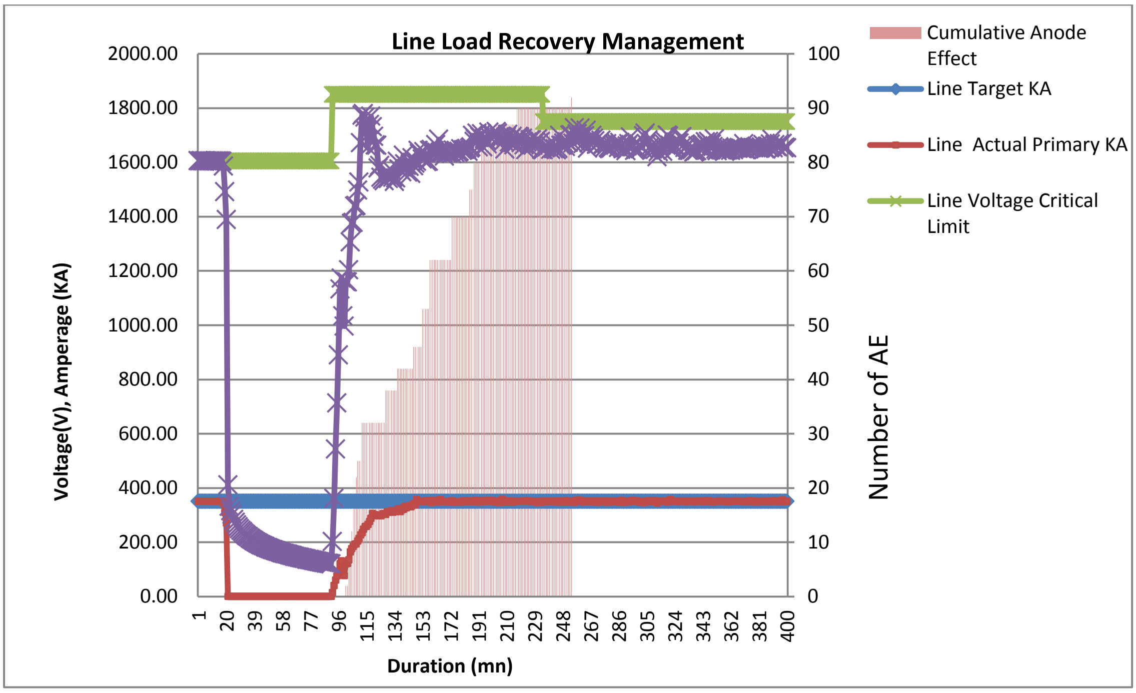


Figure 9. Critical KPIs for power restoration.

Select Pots to Show: Potline **Min Volts:** 2.0 **Max Volts:** 5.0

Select: Show All t=09/05/2018 09:01

Pot	t-15	t-10	t-5	t-2	t	State
167	5.621	5.637	5.628	5.645	5.631	
57	5.463	5.47	5.474	5.455	5.436	
131	4.479	4.504	4.495	4.652	4.768	
18	4.708	4.71	4.731	4.733	4.75	
181	4.784	4.748	4.712	4.689	4.729	
55	4.743	4.742	4.728	4.72	4.728	
160	4.702	4.703	4.714	4.722	4.719	
117	4.685	4.673	4.662	4.702	4.698	
11	4.645	4.655	4.67	4.653	4.675	
79	4.694	4.677	4.669	4.669	4.672	
84	4.483	4.586	4.635	4.659	4.669	
165	4.676	4.674	4.663	4.654	4.656	
253	4.626	4.612	4.591	4.613	4.636	

Figure 10. Sorting abnormal voltage of individual cells in descending order.

Figure 11 outlines critical variables that a manager could use to isolate or control cells in critical condition. For example, should the total power available at power plant facilities be restricted, a manager might decide to shut down or isolate particular cells based on the criteria outlined in Figure 11. Also, the bath temperature and the bath height of a cell before power outage could allow planning further actions. The cells that have lower temperature before the power outage should draw the attention about the risk of complete freezing of the bath. Similarly, pot line personel should have contingency plans for managing cells that have high anode beam position.

12. Concluding Remarks and Recommendations

Power outages and recoveries are costly, damaging from the environmental, production loss, and cell life standpoints, and stressful for the personnel involved in the recovery. Production and financial impacts that result from a long-duration power outage will vary depending on the duration and the recovery efficiency.

It is fundamental to minimize the power outage relapses and the restoration duration while sustaining the reliability of the cells and the safety of the staff affected. Aluminum producers should have contingency plans in place to moderating power failure impacts on the business. While a power failure can occur without forewarning signs, companies might improve the resilience of power restoration through integrated power outage restoration capability system, a comprehensive, cost-effective potline outage-recovery management system that helps reduce the recovery duration by providing better information for directing responses, coordinating resources, and increasing alertness. The IPORS is a tool that management can use to assess the efficiency of power restoration. Specific KPIs can be set to optimize the line load restoration rate as well as focusing on problematic cells. In addition, we found that the bath height and the cell voltage during zero load could be used as indicators to measuring the severity of the frozen electrolyte. While the bath height decreases by 50 – 60 % in three hours after the power outage, the pot voltage decays following an exponential scheme. The regression model shows that some cells would get their bath frozen entirely after 6 - 7 hours. Subsequently, the restoration of a planned outage could be controlled efficiently as a manager could increase bath height in most critical pots, adjust the cell chemistry, and reduce alumina feed during power restoration to minimize the risk of freezing the cells A manager might also increase anode cover in some pots in anticipation to reduce heat loss, given the high heat loss capability of modern cells.

Select Pots to Show: Potline

POT	AGE (Days)	COMBINED DROP (mV)	IRON (%)	SILICON (%)	TEMPERATURE (° C)	BEAM POSITION (mm)	METAL HEIGHT (cm)	BATH HEIGHT (cm)	POT STAT
5001	356	446	0.050	0.023	956	226	26.0	18.0	
5002	1701	568	0.058	0.031	955	229	27.0	17.0	
5003	1618	548	0.054	0.026	967	96	27.0	18.0	
5004	1543	566	0.417	0.031	960	198	26.0	17.0	
5005	16	515	0.023	0.081	955	92	27.0	13.0	
5006	1907	548	0.281	0.045	972	234	27.0	17.0	
5007	1671	581	0.054	0.041	954	118	27.0	17.0	
5008	1802	632	0.303	0.091	973	189	25.0	22.0	
5009	1839	591	0.043	0.025	960	118	26.0	19.0	
5010	213	521	0.060	0.023	965	140	28.0	13.0	
5011	1517	580	0.063	0.059	950	113	26.0	17.0	
5012	285	571	0.361	0.027	973	112	26.0	17.0	
5013	170	565	0.051	0.021	956	185	27.0	17.0	
5014	103	574	0.051	0.021	960	188	26.0	17.0	
5015	1608	569	0.087	0.027	963	241	26.0	17.0	
5016	1508	552	0.058	0.029	954	192	28.0	17.0	
5017	1782	573	0.089	0.035	976	220	26.0	14.0	
5018	1663	774	0.072	0.085	958	208	28.0	17.0	
5019	1638	626	0.169	0.034	980	108	25.0	19.0	
5020	1804	569	0.190	0.091	975	116	26.0	21.0	
5021	1627	557	0.052	0.026	965	94	25.0	13.0	
5022	203	535	0.062	0.024	960	82	25.0	19.0	
5023	311	546	0.077	0.025	960	127	26.0	13.0	
5024	1521	558	0.058	0.038	980	111	27.0	17.0	
5025	970	555	0.049	0.027	955	164	26.0	18.0	
5026	1368	556	0.162	0.028	975	141	26.0	16.0	
5027	1817	581	0.070	0.029	978	163	26.0	15.0	
5028	711	557	0.064	0.026	963	162	26.0	18.0	

Figure 11. Critical historical variables for a cell cut-out decision-making.

13. References

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