New protections against potline freeze for aluminium smelters

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During the past years, many smelters have experienced incidents leading to damage to their potrooms or worse, total shutdown of the potrooms, leading to very high financial loss and insurance claims. To protect such costly assets, the installed and available protection systems have proven to be inadequate: smelters need independent redundant, state-of-the-art and standalone systems, meeting the highest standards of protection in order to safeguard their multibillion assets. ABB has developed new protection systems which can prevent such incidents, and can lift up the protection concepts to state-of-the-art with Industry 4.0 expansion capability.

Events leading to potline shutdowns

There are several different categories of events, which can lead to a potline shutdown.

- Loss of power generation or power supply from the utility for more than about five hours
- Short-term power disturbance, leading to potline trip and to restart issues
- Potline operation issues leading to open circuit in the potroom
- Auxiliary power failure supplying medium and low voltage to potline services
- Power conversion station failure. (HV switchgear or rectiformers).

The power supply, distribution and conversion area must be designed to provide uninterrupted power to the potline. This requires installing backup systems with automatic changeover on all levels from utility overhead line, power generation, and high voltage switchgear, all the way down to 220 VAC distribution redundant systems. State-of-the-art power systems even have an N-2 design for critical areas. N-2 operation means that two circuits or subsystems can fail, but there is still sufficient power for 100% production of the potline.

Standard protection design for smelter power systems

Following on of the concept of N-1 or N-2 backups in power circuits and power conversion rectiformer, their sub systems, again have redundant protections circuits and overlapping protections. As an example, if the converter over-current fails to see the overcurrent, then the transformer protection would take care to clear the fault. But should both protections fail to operate, then the switchgear protection is set up to disconnect the unit from the substation.

In a utility grid, it is now standard to have redundant protection systems from different suppliers. Even when the input parameters and function description are the same, the purpose is to ensure that although one system may be disabled or hacked, the other will more likely survive.

Another example would be that if one has an voice-activated house door in the Artic, then one should still carry a key to open the door in case the voice activation has failed.

Potline protection

The potlines, historically and traditionally, have been protected by conventional voltage and current measurements, such as increasing voltage indicating anode events, increased impedance in the potroom, but also any signs of open circuit. In line with the increasing voltage, the reduced potline current confirms an open circuit. The conversion station will try to maintain current and voltage, which can result in arcing and high power density in a single pot, or arcing to bus bars on a leaking pot.

ABB's new protection detects changes of the potroom resistance within milliseconds, and it detects the different potroom disturbances like anode effect, tapping error, leaking pot and others. Potlines need redundant open circuit protections (OCP). Combining the OCP protection with the potroom ground fault supervision (PERMS, see below) allows the automatic differentiation of even more possible potroom disturbances.

Weaknesses in the design and limitation of existing potline protections

A thorough review is called for if the current potline protection relies on any of the following situations:

- Only one protection system, no backup
- Dual system only looking at the same parameter
- Limited performance during potline restart. (This is the most important time

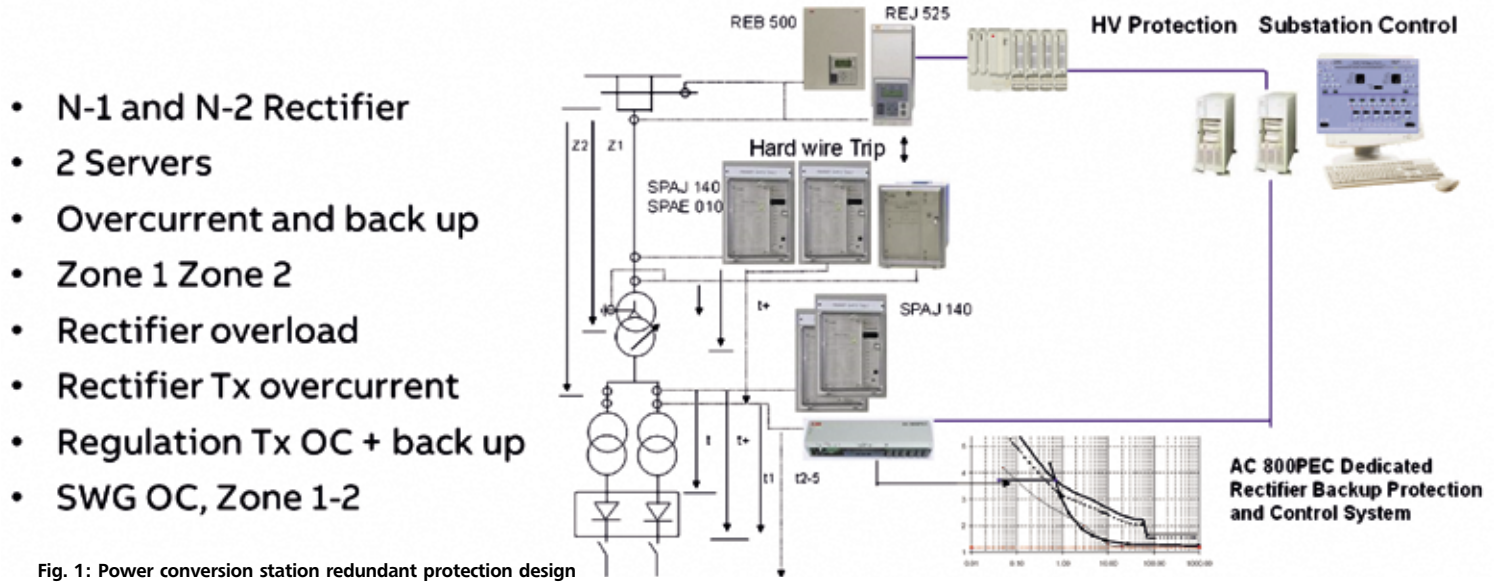


Fig. 1: Power conversion station redundant protection design

Fig. 3: High speed PLC with five microsecond sampling rate and Industry 4.0 capabilities

when they should work!)
- Slow sampling rates, limited of data analyses and trending
- Limited ability to distinguish different operation and failure modes
- No standalone, independent protection
- OCP protection systems and ground fault detection not available or not optimized.

Design requirement for open circuit protection (OCP)

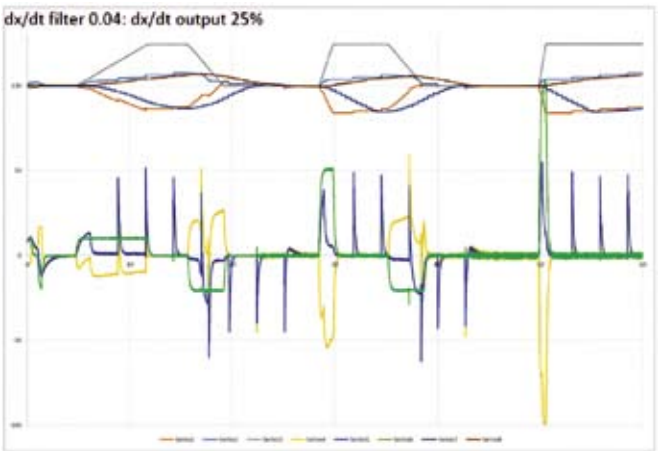
Many different potroom disturbances are possible, and one disturbance may lead to another. Industry feedback sums them up in following categories:

- Leaking pot with ground connection
- Leaking pot without ground connection
- Tapping error by human
- Pot control error
- Pot busbar connection failure
- Multiple anode disconnect
- Other.

The OCP needs to be able to detect any potroom disturbance, or the trend to one, as early as possible. At the same time no false alarms or even pot line trip shall be allowed, as operation staff then will not trust the protection. As most disturbances happen during restart or start-up of the potrooms the OCP needs to be active and reliable during this phase of potroom operation.

New open circuit protection design

ABB's new protection detects changes of the potroom resistance within milliseconds, and distinguishes the different potroom disturbances. To be able to recognize and differentiate between the disturbances, the OCP needs to receive high quality input signals: potline voltage, potline current and ground resistance need to be available on the same time base and with a very high sampling rate per second. ABB's potline DC measurement with Fibre Optic Current Sensor (FOCS) technology allows such high accuracy, same-time measurements. These signals then connect the I/O cards of the OCP high speed processor. Here again, the I/O cards are capable of the same high speed, same-time sampling rate. The processor then uses these signals to determine the current state of the potroom operation and differentiates the different disturbances. High speed and real-time data acquisition is required to predict risks of these anomalies, well before they develop into serious potroom disturbances. →



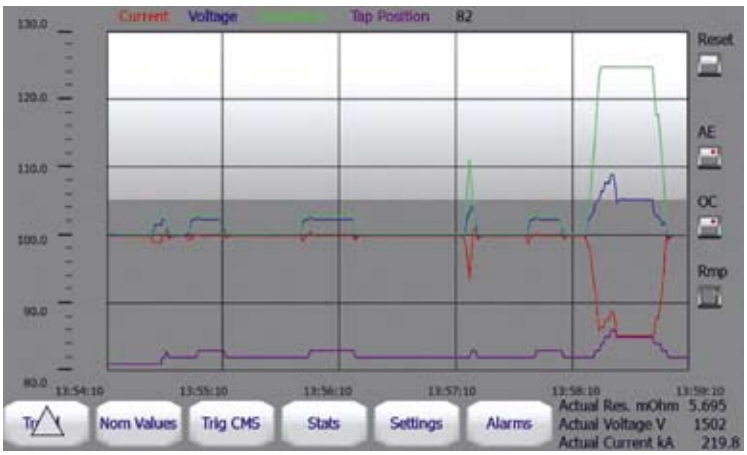


Fig. 4: Potline simulator with real event comparison

Potline simulation and event management OCP

The OCP has a built-in potline simulator which allows testing during normal operation as well as simulation of new operation points or of operation modes of the potline before these are implemented.

The new protection system detects changes of the potroom resistance within milliseconds. The graphs in the upper part of Fig. 4 show OCP reaction to the potline simulator input signals, with the master regulation set points and return loop signals already compensated. The graphs in the lower part of Fig. 4 show the tap up and tap down response to different step inputs. The dynamic functions of the OCP will override or complement/supplement the traditional potline current and voltage trip set points if they are seen as not compatible with the detected potline operation status. After the installation, the OCP will be run in the voltage and current mode, with the addition of a dynamic (potline operation) learning mode. The learning mode will send a trip signal to the data logger but will not activate a trip of the potline.

Tuning: After the learning period and templating has been completed, our commissioning expert will return to the plant (after 3-6 months). He will analyze the trip initiations and operation modes with the customer's expert team and then implement the trip matrix selection.

OCP addition with ground protection

The Process Earth Resistance Monitoring System (PERMS) is a unique monitoring system to measure the earth impedance of a floating potroom system. With PERMS it is possible to continuously monitor the resistance between the process and earth. The system will give a warning if the resistance value drops below a defined level, and it interfaces with the OCP to identify which potroom disturbances may develop.

In addition to the OCP protection inputs, the PERMS can be used as a safe working area monitoring device to protect personnel and potroom equipment such as cranes.

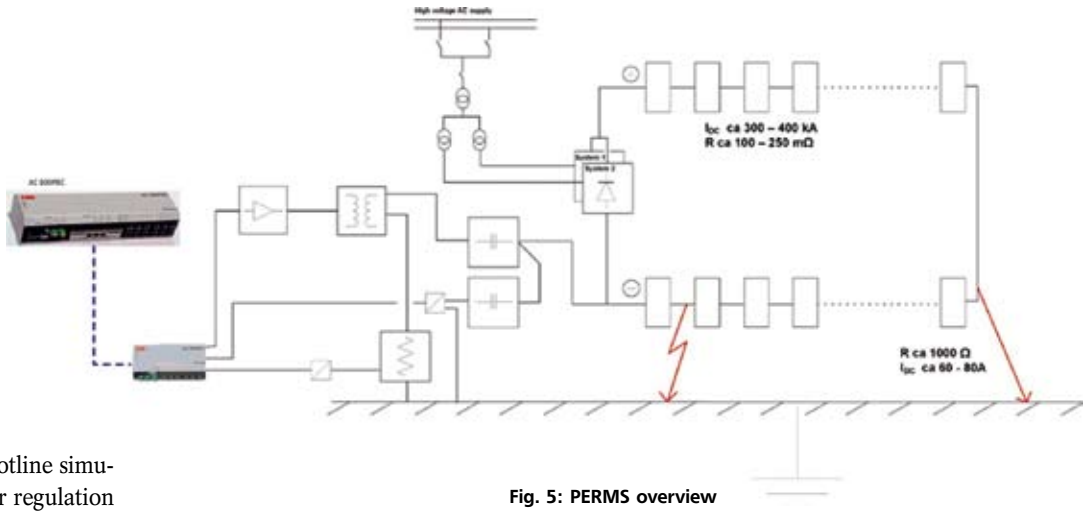


Fig. 5: PERMS overview

To detect earth fault currents, it is necessary to measure the impedance between the DC voltage system and earth. The continuous monitoring also helps to plan for predictive maintenance of the potroom insulation system.

The resistance to earth depends on the dirt, dust and moisture between the DC process and earth. Leaking of hot metal ('run out') can cause low resistance paths to earth. The insulation between high current carrying busbars ('collector busbars') and earth is critical for the safe operation of the smelter. The resistance values are recorded in the OCP historical memory.

Metering design

The metering principle of PERMS is based on a modulated AC voltage. This measuring voltage is generated with help of the AC 800PEC controller, and it is applied between the process and plant earth without making an earth connection for the DC process. There is a very low and safe current flowing through the process, to earth and back to the measurement system.

The measured impedance and the phase shift allow PERMS to calculate the real resistance and capacitance.

Design parameter of the PERMS monitoring

- Monitors resistance and capacitance to earth in the potroom, with signal exchange to the OCP for detection and trending of any potroom distortion evaluation
- Can be used for process voltages up to 2000 V DC
- Can detect an earth fault behind the active components (AC part of the rectiformers)
- High speed location of the leaking pot or of the busbar to ground connection.

Conclusions

Potline open circuit and pot-to-ground monitoring is crucial to prevent potline damage or shutdowns ending up in outrageous financial cost. Smelters need to install redundant monitoring and protection systems to supervise all aspects of the process. This electric power security has not been supervised in the past to the level which has been standard for years in other systems at the smelters. Almost all other areas within the smelters have been given a redundant and back-up system design. However in the potrooms such redundancy and multiple monitoring and protection has not so far been implemented. Independent, redundant and standalone potroom protections and monitoring systems with industry 4.0 capabilities will help to prevent or reduce pot line shutdowns.

Authors

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