Point-on-Wave Closing Method to Reduce Transformer Inrush Current Used at Southern Peru Copper Corporation

Rolando Jesus
Southern Peru Copper Corporation

Hernan Flores and Eduardo S. Palma
Schweitzer Engineering Laboratories, Inc.

Presented at the
XXII Conferencia Doble Latinoamericana
Lima, Peru
May 12–14, 2025

Originally presented at the
50th Annual Western Protective Relay Conference, October 2023

Point-on-Wave Closing Method to Reduce Transformer Inrush Current Used at Southern Peru Copper Corporation

Rolando Jesus, *Southern Peru Copper Corporation*
Hernan Flores and Eduardo S. Palma, *Schweitzer Engineering Laboratories, Inc.*

Abstract—Generally, when energizing unloaded power transformers, the precise electrical closing time of each phase of the circuit breaker is not considered. Inrush currents created due to the residual flux in the transformer, the instant of closing, and the characteristics of the core can be significantly reduced by using point-on-wave (POW)-controlled closing. Transformer inrush current is characterized by a high magnitude and harmonic content, which are harmful for the electrical system.

A record of the current and voltage signals at a 1 MHz sampling rate directly from the secondary values of the instrument transformer while closing the breaker can be manually analyzed to determine the exact moment for closing each phase of the breaker with microsecond precision.

This paper presents the state of the previous implementation of POW-controlled closing for a paralleled group of power transformers. Then it discusses the recommissioning of POW closing by analyzing 1 MHz records and applying timing values to a POW control device. Lastly, it reviews the benefits of POW closing for a mining company in southern Peru.

I. Introduction

A private mining company located in the southern part of Peru is dedicated to the exploration, exploitation, transportation, and processing of copper. It is one of the largest copper producers in Peru and its operations have two main networks, at 220 kV and 138 kV. The mining company's transmission network connects several substations, which are very important to keep all facilities operating properly.

At one of the mining company substations, several 138 kV transmission lines converge, and two 120 MVA, 138/34.5 kV power transformers operate in parallel. In 2021, each time one of the paralleled power transformers was energized, high currents and voltage drops resulted in the loss of sensitive loads.

For the mining company, it is very important to avoid voltage drops that consequently stop production. A method to manually prevent voltage drops is to energize one power transformer in an electric islanded topology, separating it from the other power transformer. This special topology electrically separates the two buses by opening the bus-tie breaker at 138 kV, as shown in Fig. 1. Under this special topology, when the power transformer is energized, the voltage drop is directly on Bus A and minimized on Bus B.

This special topology for transformer maintenance had several disadvantages, such as the time required for each of the several switching maneuvers and the risk that a switch or disconnector may be unavailable, which impact the total time allotted for maintenance of the transformer.

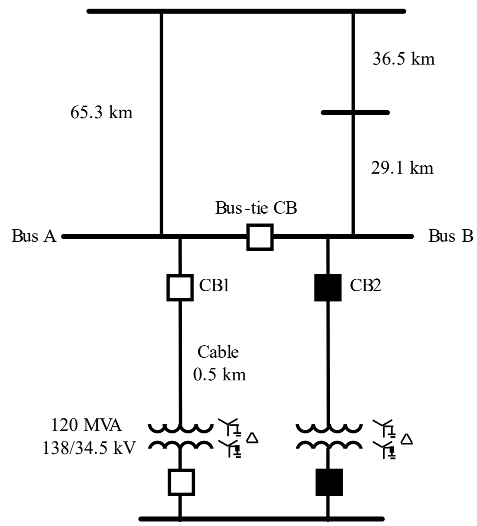

Fig. 1. Special topology during transformer maintenance.

The other method the mining company used to prevent the loss of sensitive loads following transformer energization is point-on-wave (POW)-controlled closing [1] [2]. For POW closing, the mining company had an existing device, but it was not working correctly and resulted in inrush currents of 2.5 pu and voltage below 0.83 pu during transformer energization. The controller for a sensitive load, a rock crushing mill, has a ride-through characteristic that does not allow voltage below 0.85 pu for several milliseconds (ms) or down to 0.83 pu at all. Fig. 2 shows this characteristic.

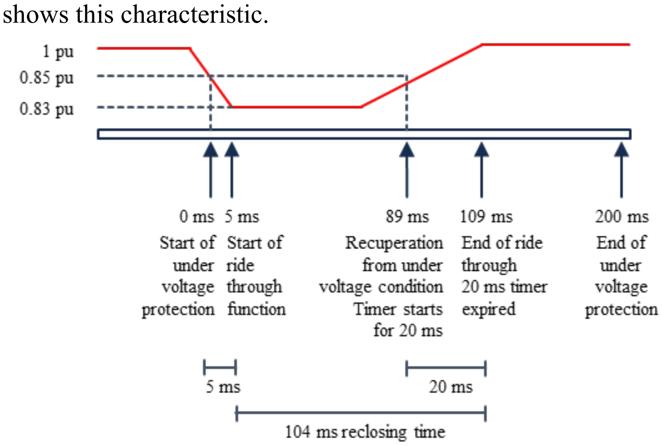

Fig. 2. Ride-through characteristic of a rock crushing mill.

This paper discusses the improvements in POW-controlled closing performance at this mining company.

II. POW-Controlled Closing

The POW-controlled closing application at one of the mining company's substations is discussed in this section. In this substation, when one of two power transformers is energized under the special topology, the current magnitudes rise to two or three times the nominal values and a voltage drop occurs in the 138 kV busbar and in neighboring buses.

Fig. 3 shows the one-line diagram of the power transformer and the two circuit breakers associated with their voltage level. On the 138 kV side, Circuit Breaker 1 (CB1) is connected to the power transformer through a 0.5 km underground cable. Analog secondary signals are available through an inductive voltage transformer and a 5P20 class / 100 VA current transformer.

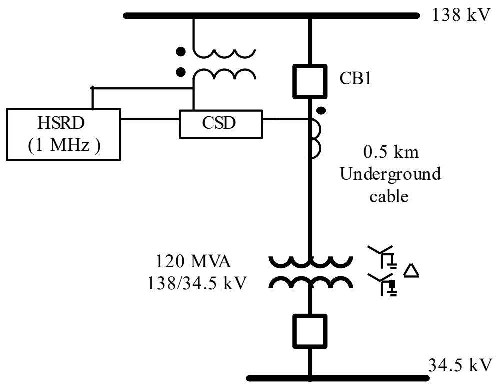

Fig. 3. One-line diagram of the transformer.

As seen in Fig. 4, current leads voltage, which indicates that the capacitive charging current of the cable is greater than the inductive excitation current of the transformer.

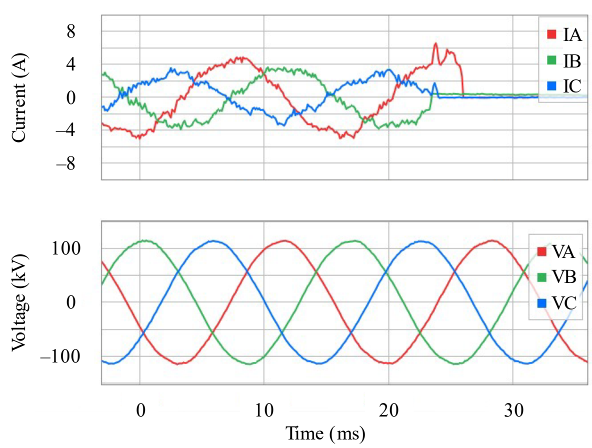

Fig. 4. Current and voltage of the transformer.

Fig. 5 shows a simplified one-line diagram of both transformers: two 138 kV circuit breakers (CB1 and CB2) each with a controlled switching device (CSD) and high-sampling recording device (HSRD) that records POW closing for this application [3]. The CSD has a sampling rate of 64 samples per cycle, and the HSRD has a sampling rate of 10 kHz and 1 MHz [3].

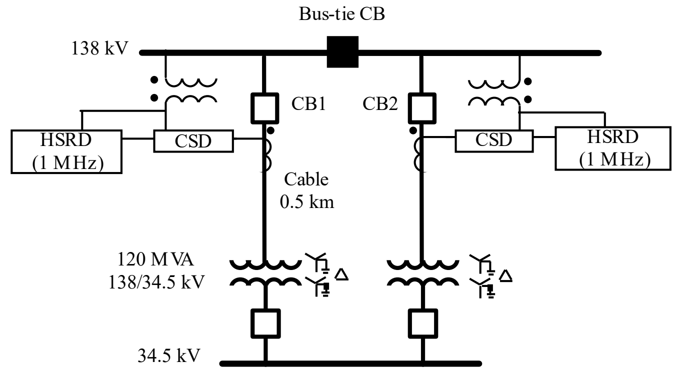

Fig. 5. Controlled switching devices (CSDs) in 138 kV.

COMTRADE analysis software was used to manually verify the exact time each circuit breaker pole closes at precommissioning, in April 2021, and during commissioning, in November 2021.

Table I shows closing angles that were used from [1] to implement and test POW closing for the 60 Hz system.

TABLE I
OPTIMUM POW CLOSE ANGLES FOR A GROUNDED WYE-DELTA TRANSFORMER AFTER AN A-PHASE VOLTAGE ZERO CROSSING.

Pole	Closing angle	Closing time (ms)
A	90°	4.17
B	180°	8.33
C	180°	8.33

The mining company decided to implement the CSD only for closing control, since this was the main concern for its operations. These transformers are rarely de-energized since the rock crushing mills must work 24 hours a day, 7 days a week throughout the year, other than during annual maintenance. For the purpose of testing the performance of POW-controlled closing with CSD, the transformers were de-energized in an uncontrolled manner. While uncontrolled de-energization can leave an unpredictable level of residual flux in the transformer, this was preferred by the company.

III. Controlled Closing Cases

On November 10, 2021, the following POW close operations were recorded by the HSRD, and the CSD settings were tuned.

A. *Case 1*

The event recorded during the first energization of the transformer shows that the inrush current reaches a value of 2.48 pu, as shown by the dotted line in Fig. 6. The nominal current for the power transformer at 138 kV is approximately 500 A rms.

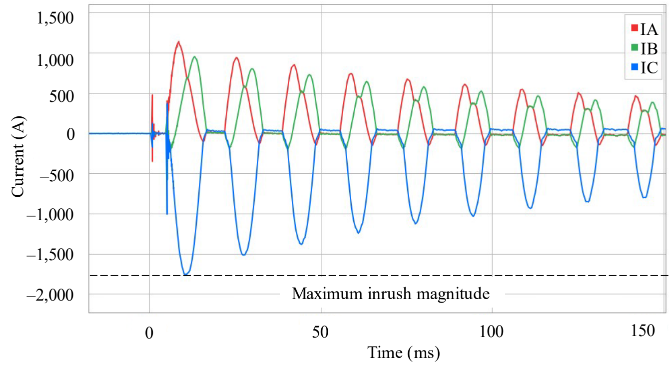

Fig. 6. Inrush current for Case 1.

Fig. 7 shows the 1 MHz recording of three phase currents and voltage Phase A (VA). VA is the reference signal used for the time calculation. In Fig. 7, the dotted line, or t = 0, points to the exact moment when VA is at zero crossing.

The optimum POW close angle for a grounded wye-delta transformer is 90º for Phase A, or 4.17 ms after a VA zero crossing for Phase A, as shown in Table I. The time difference between Pole A inception and 4.17 ms is 3.3 ms (3,327 µs), which is circled in Fig. 7. The time to close CB Pole A should be shifted by 3.3 ms from the actual time the pole was closed.

For Phases B and C, the optimum POW close angle is 180º, or 8.3 ms after a VA zero crossing for IB and IC, as shown in Table I. The time difference between Pole B and Pole C inception and 8.33 is 3.2 ms (3,202 µs), which is circled in Fig. 8. The time to close CB Poles B and C should be shifted ahead 3.2 ms from the actual time the pole was closed.

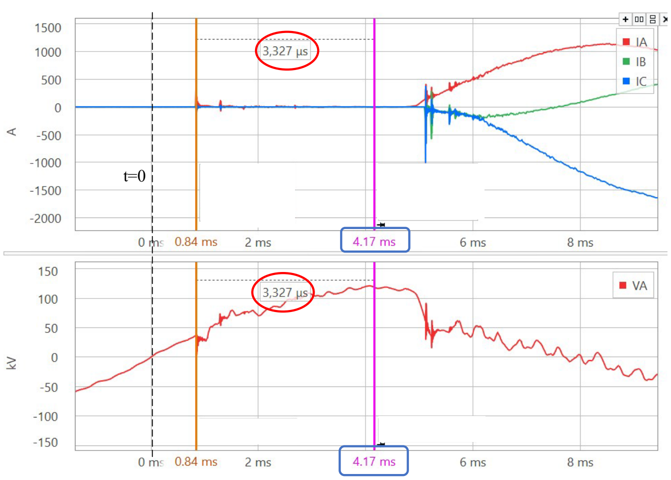

Fig. 7. Current Phase A and Reference VA for Case 1.

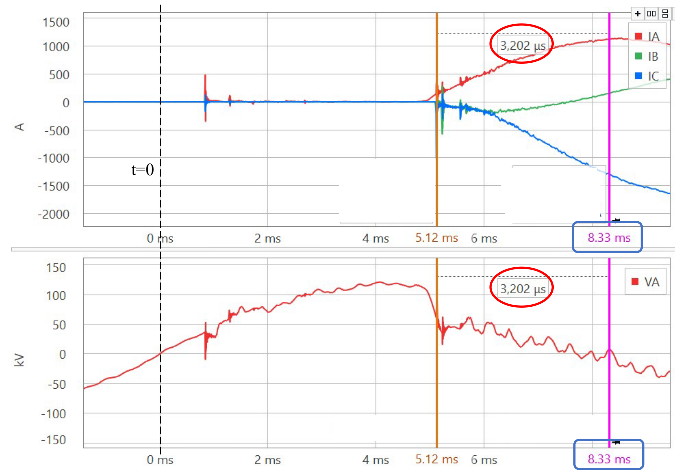

Fig. 8. Currents of Phases B and C and Reference VA for Case 1.

This first energization of the power transformer showed that it was necessary to correct the time setting for circuit breaker closing of all three phases.

B. Case 2

The second closing was performed by the CSD after modifying its circuit breaker closing time setting by approximately 3 ms. The event recorded during the second energization of the transformer shows that the inrush current reaches a value of 0.76 pu, as shown by the dotted line in Fig. 9, so the energizing current was reduced.

Following the same time calculation performed in Case 1, the Case 2 time difference between Pole A inception and 4.17 ms is 1.1 ms (1,064 µs), which is circled in Fig. 10. The time difference between IB and IC inception and 8.33 is 1.3 ms (1,295 µs), which is circled in Fig. 12.

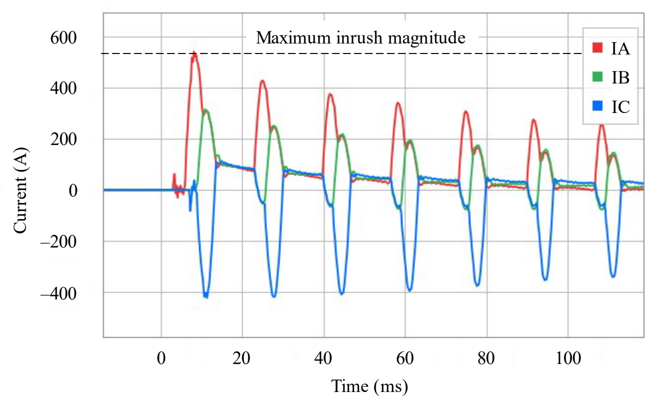

Fig. 9. Inrush current for Case 2.

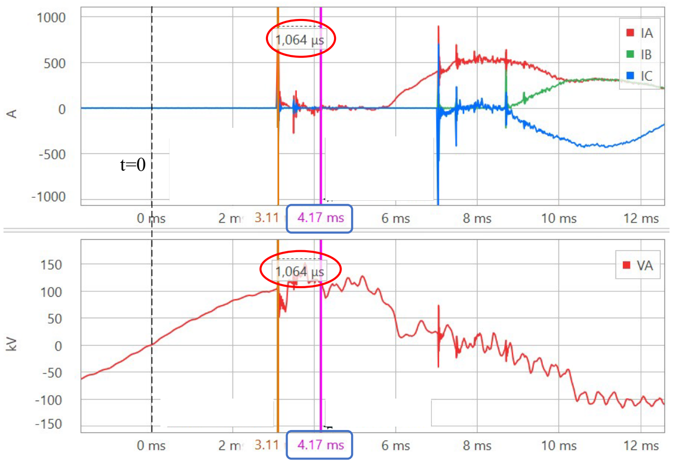

Fig. 10. Current Phase A and Reference VA for Case 2.

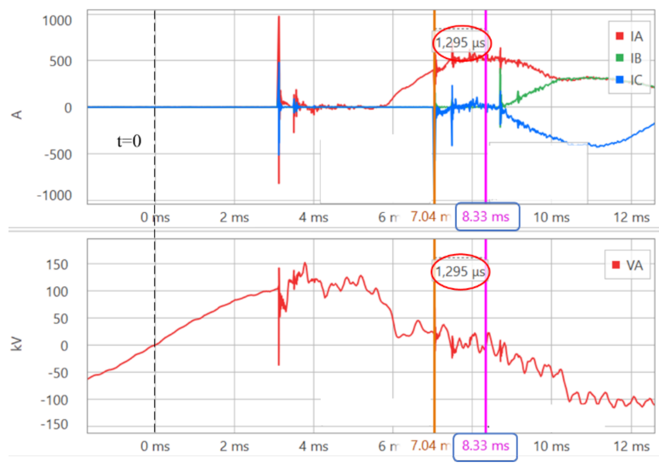

Fig. 11. Currents of Phases B and C and Reference VA for Case 2.

Using the zoom features and vertical time cursors of the COMTRADE analysis software helped with the time difference calculation and expedited commissioning of the transformer.

C. *Case 3*

The third closing was performed by the CSD after modifying its circuit breaker closing time setting by approximately 0.5 ms. The event recorded during the third energization of the transformer shows that the inrush current reaches a reduced value of 0.63 pu, as shown by the dotted line in Fig. 12.

For the first, second, and third cases, a special topology was used to energize one power transformer in an electric islanded topology, separating it from the other power transformer.

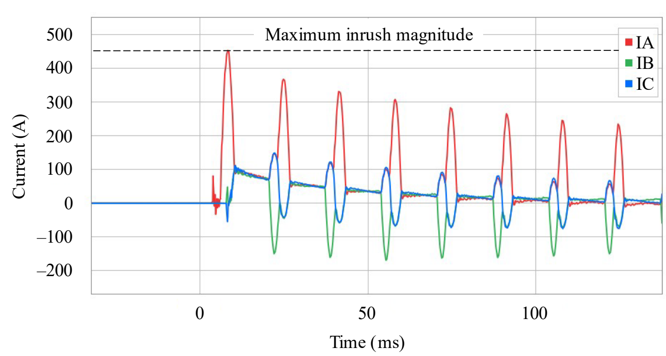

Fig. 12. Inrush current for Case 3.

In Case 3, the time difference between Pole A inception and 4.17 ms is 0.4 ms (393 µs), which is circled in Fig. 13. The time difference between Pole B and Pole C inception and 8.33 is 0.2 ms (215 µs), which is circled in Fig. 14.

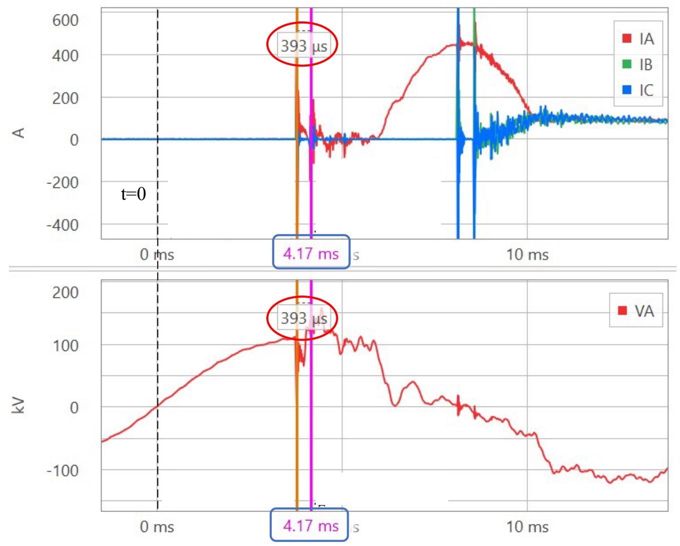

Fig. 13. Current Phase A and Reference VA for Case 3.

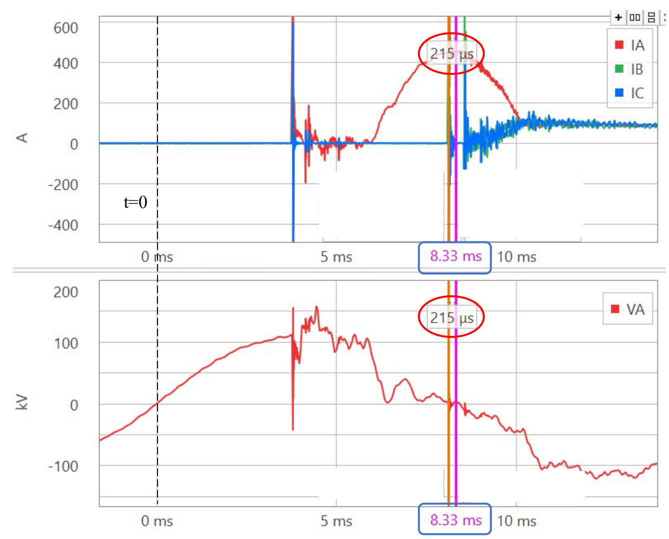

Fig. 14. Currents of Phases B and C and Reference VA for Case 3.

D. *Case 4*

The fourth closing was performed with minimal modifications from the previous cases. The POW closing recorded during the fourth energization of the transformer shows that the energization current reaches a value of 0.49 pu, as shown by the dotted line in Fig. 15.

For this case and for the first time, the topology of the transformers was not the special topology. The second transformer in parallel was in service and electrically connected to the transformer to be energized.

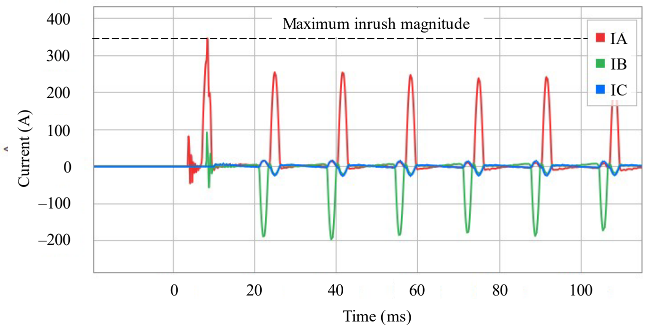

Fig. 15. Inrush current for Case 4.

In Case 4, the time difference between Pole A inception and 4.17 ms is 0.4 ms (387 μs), which is circled in Fig. 16. The time difference between Pole B and Pole C inception and 8.33 is 0.081 ms (81 μs), which is circled in Fig. 17

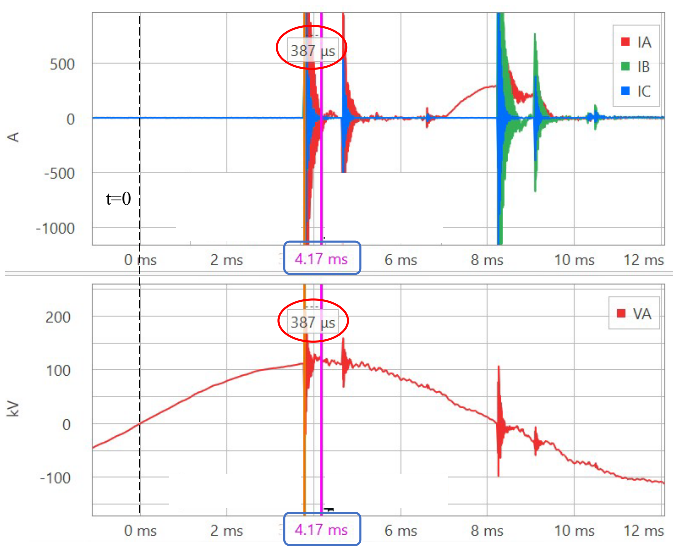

Fig. 16. Current Phase A and Reference VA for Case 4.

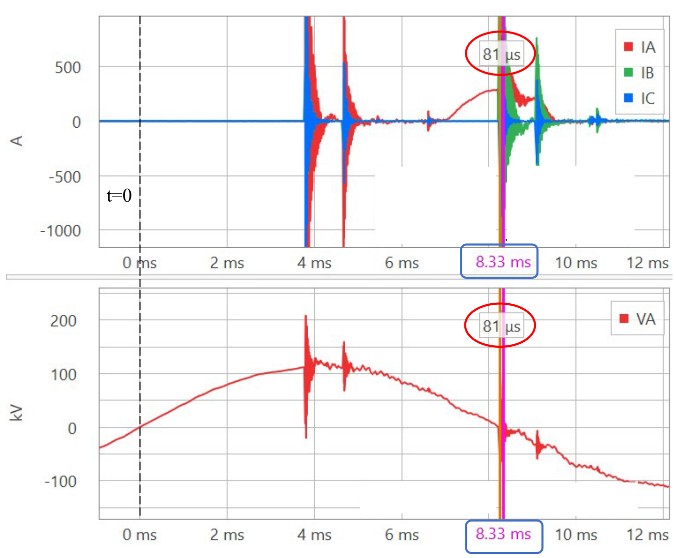

Fig. 17. Currents of Phases B and C and Reference VA for Case 4.

E. Case 5

The fifth closing was performed with the same time setting as the fourth case, and the topology was in normal conditions. The event recorded during the fifth energization of the transformer shows that the inrush current reaches a value of 0.63 pu, as shown by the dotted line in Fig. 18.

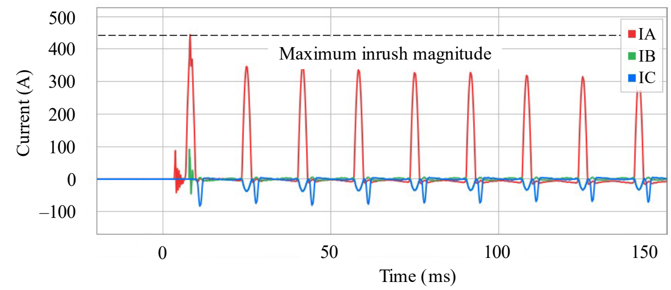

Fig. 18. Inrush current for Case 5.

In Case 5, the time difference between Pole A inception and 4.17 ms is 0.5 ms (539 μs), which is circled in Fig. 19. The time difference between Pole B and Pole C inception and 8.33 is 0.4 ms (450 μs), which is circled in Fig. 20. In the fourth and fifth energization, the energizing currents are low, and the voltage signal is not deformed. This allows the voltage signal at the 34.5 kV levels not to be distorted; therefore, there is no loss of sensitive load.

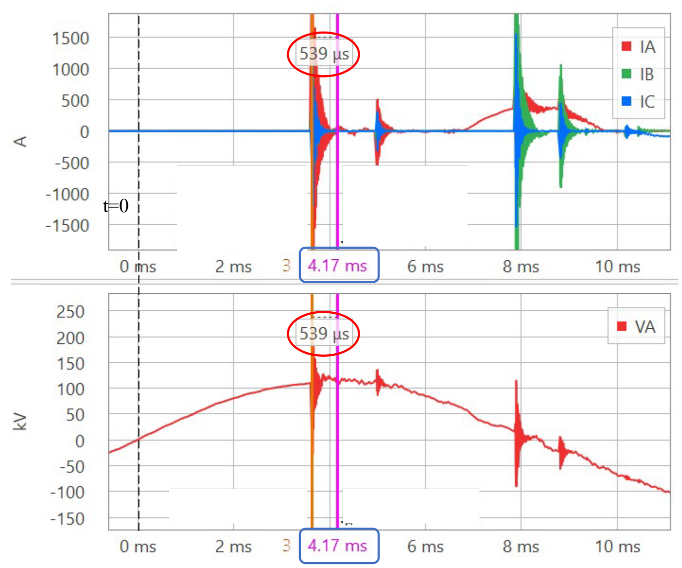

Fig. 19. Current Phase A and Reference VA for Case 5.

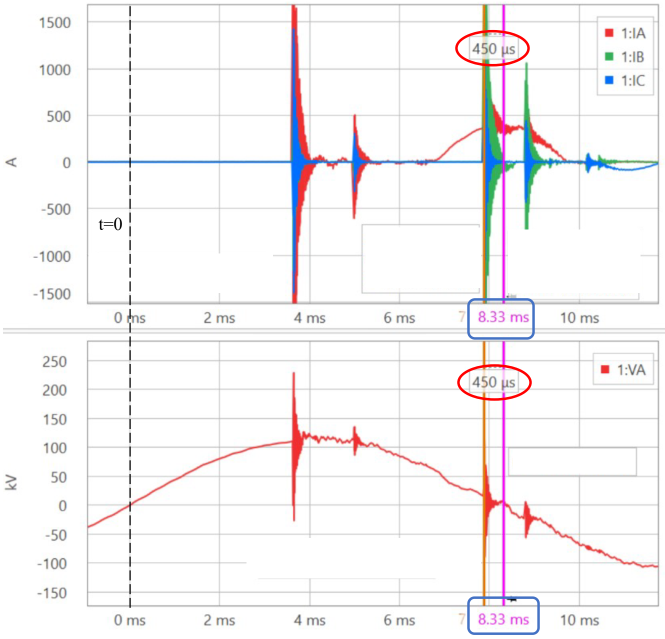

Fig. 20. Currents of Phases B and C and Reference VA for Case 5.

Table II is a summary of inrush currents of all cases.

TABLE II
SUMMARY OF CLOSE SWITCHING CASES

Case	Inrush current	Comment
1	2.48 pu (1.76 kA peak)	Special topology
2	0.76 pu (0.54 kA peak)	Special topology
3	0.63 pu (0.45 kA peak)	Special topology
4	0.49 pu (0.35 kA peak)	Normal topology
5	0.63 pu (0.45 kA peak)	Normal topology

IV. CONCLUSION

This paper presents an application of POW-controlled closing for a paralleled group of power transformers at a mining company in southern Peru. The existing POW closing system was causing significant inrush currents of 2.5 pu and voltage sags to 0.83 pu due to incorrect closing time settings that resulted in the loss of sensitive loads.

In 2021, the POW closing was improved by using 1 MHz records from an HSRD during POW closing and applying new single-pole closing times in the settings of a CSD. The new transformer energization POW control reduced inrush current to less than 1 pu and resulted in improved operations availability and power quality for the mining company.

If the rock mills are out of service, working hours are lost before they go back in service, which translates into production and revenue losses. The most important objective for the mining company is to keep the rock mills in service. Other industrial sites may use this application as a reference to economically solve power quality challenges, such as loss of sensitive loads, using POW-controlled closing.

V. REFERENCES

[1] D. Goldsworthy, T. Roseburg, D. Tziouvaras, and J. Pope, "Controlled Switching of HVAC Circuit Breakers: Application Examples and Benefits," proceedings of the 61st Annual Conference for Protective Relay Engineers, College Station, TX, April 2008.

[2] G. Benmouyal, N. Fischer, D. Taylor, M. Talbott-Williams, and R. Chowdhury, "A Unified Approach to Controlled Switching of Power Equipment," proceedings of the 44th Annual Western Protective Relay Conference, Spokane, WA, October 2017.

[3] V. Bala, B. Hampson, and R. Chowdhury, "Using High Resolution Oscillography to Improve the Performance of Controlled Switching of Transformers," proceedings of the Electrical Engineers Association Conference, Wellington, New Zealand, June 2019.

VI. BIOGRAPHIES

Rolando Jesus received his Bachelor of Science from UNCP University in 1996, a Master of Business Administration from ESAN University in 2007, and a MgSc in Management Energy from San Agustin University in 2022. Upon graduating, he worked at IANSA Consulting as a designer engineer, then at ABB Peru as a commissioning engineer, and then in the transformer factory CEA as a testing engineer. He has worked nearly 20 years at Southern Peru Copper Corporation (SPCC), a copper mine in Peru, as power system chief. He is a senior engineer, and his areas of interests are: operation and maintenance of transmission lines and substations; system protection, control, and automation; SCADA substations and SCADA; cybersecurity; and improving the reliability and energy efficiency of electric power systems. He is a member of CIP (College of Engineers of Peru), member of IEEE, and member of AEP (Peruvian Electrotechnical Association).

Hernan Flores received his Bachelor of Science from UNI University in 2010. Upon graduating, he served nearly four years at Peru's system operator as a technical assistant in electrical studies. Prior to joining Schweitzer Engineering Laboratories, Inc. (SEL) in 2015, he worked at Abengoa Peru for four years as a protection specialist for substations in 500 kV, 220 kV, and 138 kV. He is presently an application engineer at Schweitzer Engineering Laboratories Peru SAC. (SEL Peru). He is the leader in protection and control systems in the market of Peru and Bolivia. In 2021, he received the degree of instructor from SEL University. He is interested in power system protection and new technologies such as traveling-wave protection and fault locating and controlled switching.

Eduardo S Palma received his Bachelor of Science in electrical engineering from the University of South Florida in Tampa, in May 2003, and his Master of Business Administration with a concentration in globalization and international business, in May 2012. Eduardo joined Schweitzer Engineering Laboratories, Inc. (SEL) in January 2003 and is the regional technical manager for the Latin America region and a Certified Information Systems Security Professional (CISSP). Eduardo conducts and provides international technical seminars, technical sales presentations, and training to introduce and implement SEL solutions and services worldwide.