

Fault Locating and Proactive Monitoring of Transmission Lines: ENDE Bolivia Experience

Daniel Caballero and Jonathan Titichoca
ENDE Transmisión S.A.

Armando Guzmán, Michael West, Hernan Flores, Yajian Tong, and Mangapathirao V. Mynam
Schweitzer Engineering Laboratories, Inc.

Presented at the
53rd Annual Western Protective Relay Conference
Spokane, Washington
October 27–29, 2026

Fault Locating and Proactive Monitoring of Transmission Lines: ENDE Bolivia Experience

Daniel Caballero and Jonathan Titichoca, *ENDE Transmisión S.A.*

Armando Guzmán, Michael West, Hernan Flores, Yajian Tong, and Mangapathirao V. Mynam, *Schweitzer Engineering Laboratories, Inc.*

Abstract—To improve transmission line availability, reduce restoration times, and lower fault-locating costs, Empresa Nacional de Electricidad Transmisión S.A., the state-owned electric transmission utility of Bolivia, deployed dedicated fault-locating devices. These devices use traveling-wave (TW)-based methods for high-accuracy fault locating. In addition, the devices include a line-monitoring function to detect and locate precursor activity and generate an alarm when multiple low-energy events occur at the same location. This paper presents the TW-based fault-locating and line-monitoring functions of these devices and evaluates their performance in detecting transmission line faults and precursor events on 230 kV and 500 kV transmission lines. We discuss precursor events detected and located on the monitored power lines and describe how this information is supporting the utility's evolution toward condition-based maintenance. Field inspections confirmed conditions, including missing insulator disks, bird contamination, and lightning-related activity, at locations identified by the line-monitoring system, demonstrating the practical value of TW-based condition monitoring.

I. INTRODUCTION

Empresa Nacional de Electricidad Transmisión S.A. (ENDE-T) is the state-owned electric transmission utility of Bolivia, which operates and maintains approximately 90 percent of the National Interconnected System, including 6953 km of transmission lines and 74 substations. The Bolivian transmission backbone operates primarily at 230 kV and 115 kV, with additional networks at 500 kV, 132 kV, and 69 kV. In a limited meshed transmission network, system reliability depends strongly on transmission line availability. As a result, permanent faults on transmission lines may significantly reduce power-transfer operating margins. To mitigate these faults, the utility has deployed dedicated traveling-wave (TW)-based fault locators to achieve high-accuracy fault locating. These devices have also provided line-monitoring functionality that enables the detection and localization of precursor activity and generates alarms when multiple precursor events originate from the same location.

In this paper, a precursor event refers to a low-energy transient detected and located by the line-monitoring system that may indicate abnormal activity or a developing line condition. Detection of an individual event does not establish that a permanent fault will occur. Identifying and mitigating the sources of precursor activity helps prevent faults on transmission lines. Reference [1] provides examples of precursory TW activity in a transmission line.

Previous work introduced TW-based monitoring to detect and locate precursors on power transmission lines [2]. These precursors are typically caused by conditions such as dirty insulator disks, missing insulator disks, or encroaching vegetation. The line-monitoring function uses arrival times associated with TW signals generated by precursor events. The locations of these low-energy events are calculated using the line length, TW line propagation time, and wave arrival times captured at both terminals of the transmission line. This line-monitoring function has provided utility personnel with a new resource to support the transition toward condition-based maintenance.

The utility has implemented and analyzed the results of the line-monitoring function to locate the sources of precursor activity, and utility patrol teams have identified missing insulator disks and bird nests at those reported locations. The utility subsequently corrected the identified conditions when the transmission lines became available for maintenance.

This paper provides a brief overview of the line-monitoring function and describes its capability to detect and locate precursor activity. This paper further examines the performance of the fault-locating device for transmission line faults and precursor events. We discuss precursor events detected in the field and show how this information is supporting the utility's transition to condition-based maintenance for transmission lines. The paper is organized as follows:

- Section II presents the utility system information and the motivation for proactive line monitoring.
- Section III presents the TW-based fault-locating principle, line-monitoring challenges, and line-monitoring logic to detect precursors in transmission lines.
- Section IV discusses installation and commissioning.
- Section V presents reporting methods and field-event analysis.
- Section VI explains how line-monitoring data are used to improve line maintenance.

The primary contributions of this paper are:

- Field validation of TW-based precursor monitoring on ENDE-T transmission lines.
- Verification of supervisory logic by using real-world events.
- Correlation of monitored locations with confirmed line defects.

- Integration of line-monitoring data into condition-based maintenance workflows.

II. SYSTEM INFORMATION

ENDE-T enables the transport of electricity from generation plants to distribution networks and nonregulated consumers across multiple regions of the country. The utility operates the power system across geographically diverse regions, ranging from the Amazon lowlands to the Andean highlands. The transmission network comprises 106 lines covering eight of the nine regions of Bolivia. The network operates at five nominal voltage levels: 500 kV, 230 kV, and 115 kV for interregional transmission, 69 kV for subtransmission lines, and 132 kV for an international link. Fig. 1 summarizes the percentage of transmission lines at each nominal voltage level.

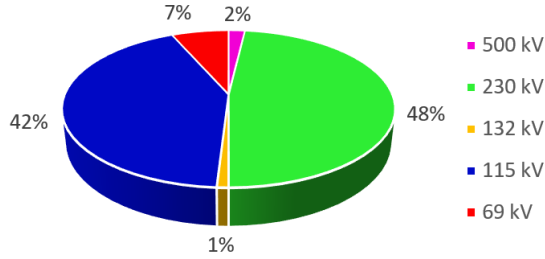


Fig. 1. Percentage of utility transmission lines by nominal voltage level.

A. Fault-Location Challenges

Fault-location capability in the utility network has evolved in parallel with successive generations of protective relay technology.

Numerical relays introduced impedance-based fault-locating algorithms, which reduced search areas significantly. However, these algorithms are inherently sensitive to line-impedance parameters and system conditions. To address this limitation, relay algorithms evolved to incorporate negative-sequence current, improving accuracy under conditions of zero-sequence mutual coupling in double-circuit lines [3], as well as algorithms that use voltages and currents from both line terminals, which are suitable for lines connected to inverter-based resources [4].

Because the installed relay fleet uses multiple impedance-based algorithms, reported fault locations can differ for the same fault event.

The most recent step in this technological progression has been the incorporation of TW-based fault locating in a subset of the utility relay fleet. This addition represents a step change relative to impedance-based methods and has been validated on lines in geographically diverse regions of the network.

B. Motivation for TW-Based Locating

The deployment of TW-based fault-locating devices on the utility network established an infrastructure capable of detecting and time-stamping high-frequency current transients with submicrosecond precision. While the initial driver for this deployment was fault-location accuracy, this infrastructure has revealed a broader operational potential: the continuous detection of low-energy TW events that may represent precursor activity associated with abnormal line conditions.

This capability, not achievable with impedance-based fault-locating methods, constitutes the natural next step in the evolution of fault-locating technology within the network.

In this context, the utility has extended the application of its TW infrastructure to a set of lines with challenging fault-location conditions operating at 230 kV and 500 kV.

C. Driver for Proactive Monitoring

To improve transmission line availability, reduce restoration times, and lower the costs associated with locating faults, the utility has deployed dedicated fault-locating devices, which use TW-based methods to achieve high-accuracy fault location. In addition, the devices provide line-monitoring functionality by using the same double-ended method that enables the detection and localization of precursor activity and generates alarms when multiple precursor events originate from the same location.

The line-monitoring approach adopted by the utility is based on the detection of multiple precursor events at a specific line section. When three or more precursor events are recorded at the same location, a user-configured threshold condition is met and a targeted field inspection is subsequently scheduled for that specific section. This threshold-based criterion balances detection sensitivity against the risk of false line patrol dispatch.

From a maintenance standpoint, this approach supports a gradual transition from predominantly scheduled and corrective practices toward location-directed, condition-based maintenance. Conventional maintenance programs rely on fixed, cyclical inspection schedules applied uniformly across the entire network, regardless of the actual condition of individual line sections. While effective at managing general risk, this approach is resource-intensive and fails to prioritize areas of elevated concern. Condition-based maintenance, by contrast, directs inspection resources to specific locations where empirical evidence indicates an elevated probability of incipient failures.

III. TW-BASED FAULT LOCATING AND LINE MONITORING

TWs are sharp step changes in current and voltage signals that are launched by the step change in voltage at the location of the power system disturbance. Power system disturbances include faults such as phase-to-ground and phase-to-phase as well as low-energy events that are transient in nature, caused by conditions such as insulator contamination, temporary faults due to conductor galloping, and lightning strikes.

A. Fault Locating

TW-based multi-ended fault locating uses the line length, the TW line propagation time, and the first-wave arrival time stamps measured at each end of a given transmission line (e.g., Terminal S and Terminal R) to estimate the fault location M (1).

$$M = \frac{LL}{2} \left(1 + \frac{t_S - t_R}{TWLPT} \right) \quad (1)$$

where:

LL is the total line length.

t_S is the first TW arrival time at Terminal S.

t_R is the first TW arrival time at Terminal R.

TWLPT is the TW line propagation time.

This principle can be expanded to multiterminal and hybrid lines, where the TWLPT may vary between conductor types (e.g., overhead vs. underground lines) [5]. Reference [6] provides accuracy analysis for TW-based fault-locating methods. Line-protection devices that include TW-based fault locating trigger fault-location calculation when the protection elements in the device indicate an internal fault on the monitored line. In standalone fault-locating devices (without line-protection elements), this trigger is provided to the device by the line-protection system.

B. Line Monitoring

The line monitoring leverages the multi-ended TW-based fault-locating results to tabulate and log precursor and fault events. During faults, TWs have substantial amounts of energy, making it relatively easy to detect and locate the disturbances associated with the monitored line. Detecting and locating precursor events, however, can be more challenging. Fig. 2 shows the phase voltages and TW phase currents for a B-phase-to-ground fault on Guarayos–Paraíso Line 1, recorded at the Guarayos terminal (refer to Fig. 11 for additional details of the Guarayos–Paraíso interconnection). Fig. 3 shows the phase voltages and TW phase currents for a precursor event, not associated with a fault, on the same line. Comparatively, precursor events are often more challenging to detect due to their wave patterns and lower magnitudes.

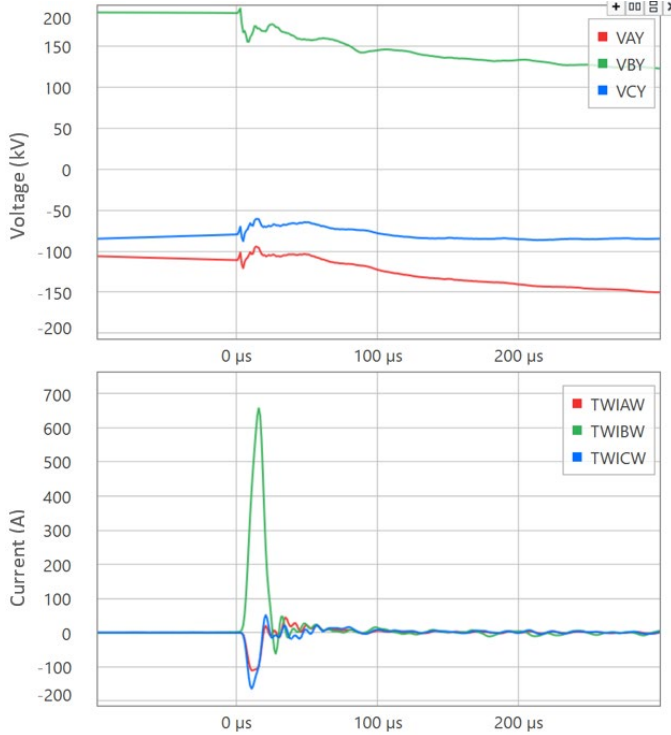


Fig. 2. Line fault example: the TW phase current associated with the faulted phase is 648 A primary.

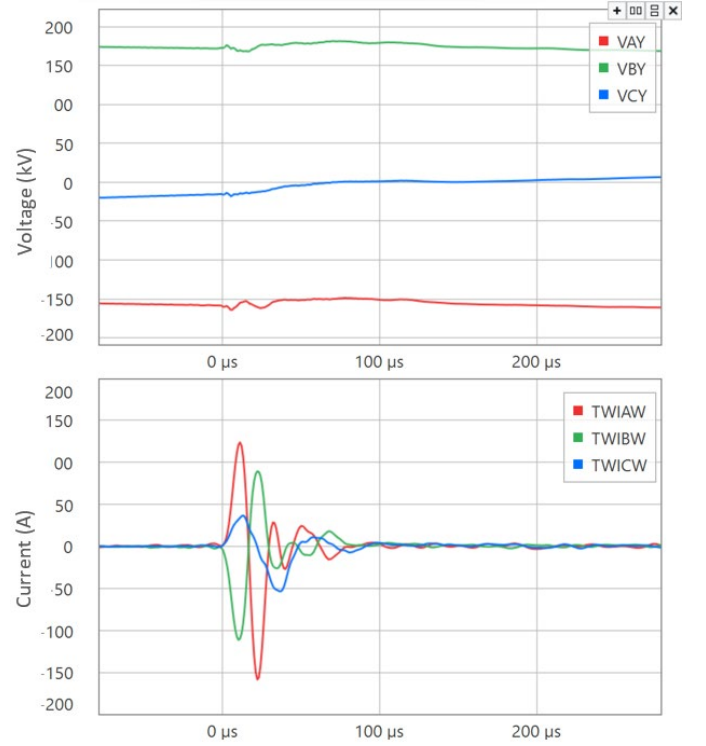


Fig. 3. Line precursor example: the TW phase current associated with the phase with the greatest magnitude is 158 A primary.

In lines that share the same tower, TWs generated by faults on one line couple into the adjacent healthy line. Reference [7] discusses TW coupling in parallel lines. The device monitoring the unfaulted line measures the superposition of the incident, the reflected wave of the coupled signals, and part of the transmitted waves from the faulted line. Fig. 4 shows the alpha current TWs captured on the faulted (L1) and healthy (L2) lines from both terminals. Note that the local and remote current TWs on both lines have the same polarities. However, for disturbances on the faulted line, the current TW polarity is the same as the pre-event voltage polarity.

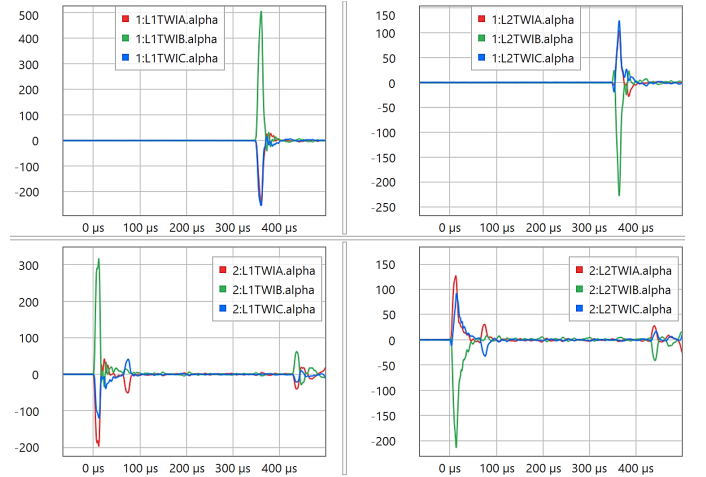


Fig. 4. Local and remote alpha current TWs recorded on both the faulted and healthy lines have the same polarities.

Fig. 5 shows the voltage and alpha current TWs recorded at the Guarayos terminal on both lines. The faulted line shows that the pre-event voltage and current TW polarities are the same.

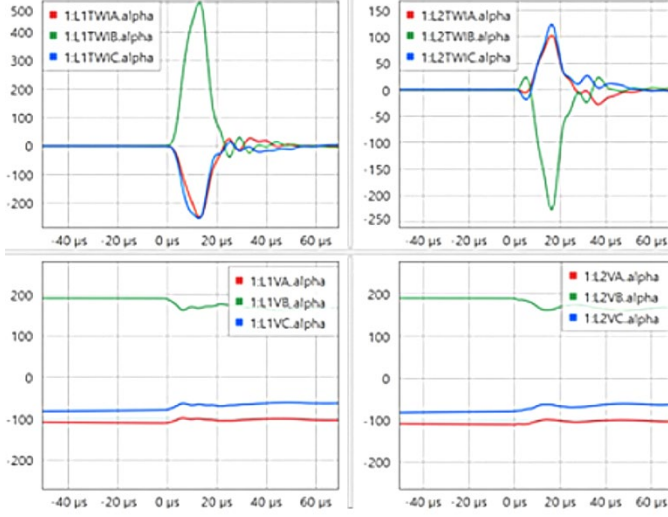


Fig. 5. The pre-event voltage and alpha current TW polarities recorded on the faulted line (L1) are the same.

The line-monitoring logic employs several supervisory conditions to ensure that precursor and fault events are associated only with internal disturbances.

C. Line-Monitoring Logic

This subsection describes the operating principles of the line-monitoring functionality and illustrates its application to two-terminal transmission lines [2]. Fig. 7 shows the basic signal-processing and local-supervision logic implemented in the line-monitoring device.

The line-monitoring logic identifies a TW event only when it is armed (LMARM = 1). Arming requires that all of the following conditions be satisfied:

- All phase-to-ground voltage magnitudes exceed 80 percent of their nominal values.
- No open-pole conditions exist.
- No loss-of-potential conditions exist.
- The device correctly estimates system frequency.

1) Phase Voltage and Current Signals

The rising edge of the current TW disturbance detector (TWIDD) serves as the event reference to capture the pre-event phase voltages, V_ϕ , and event phase currents, I_ϕ , used for local supervision, as shown in Fig. 6, where $\phi = A, B, \text{ and } C$.

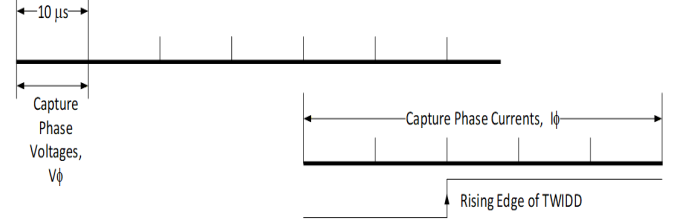


Fig. 6. Pre-event phase voltages and event phase currents for local supervision.

2) Phase TW Signals

The device obtains the phase TW signals, TWIA, TWIB, and TWIC, by using the differentiator-smoother (DS) filter whose window size is determined by TWDSW; a typical value of TWDSW is 10 μs . Section VIII.A shows the output of the DS filter in response to a step signal that emulates a sudden change in a current or voltage signal.

3) Mode TW Signals

From the phase TW signals, the device calculates the alpha-mode quantities, TWIAM, TWIBM, and TWICM, and the ground-mode (zero-sequence) quantity TWIG. The ground mode is obtained from the average of the three-phase TW signals. Comparison of these mode signals helps to identify lightning events external to the line.

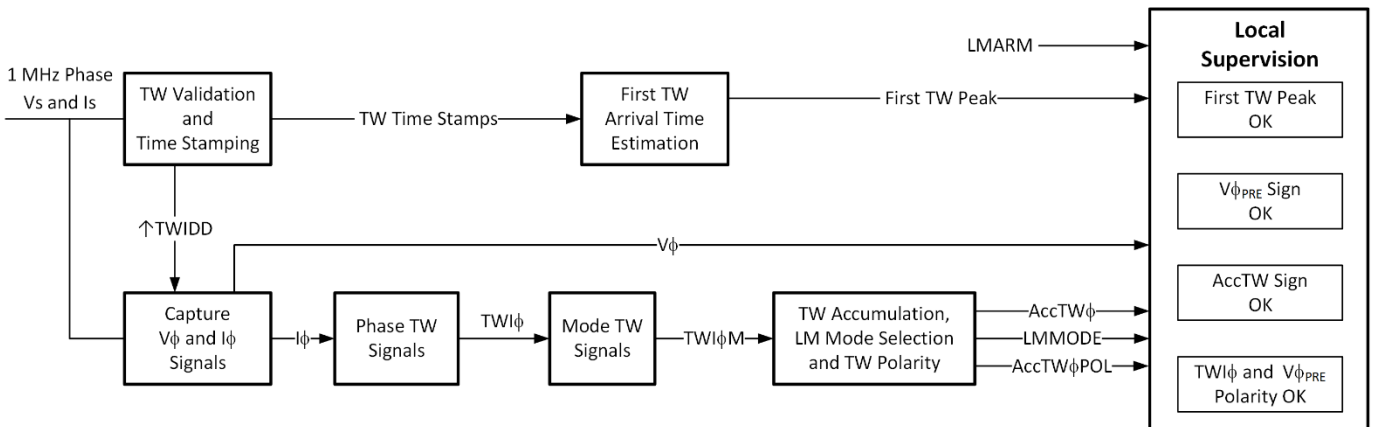


Fig. 7. Line-monitoring signal processing and local supervision.

4) Accumulated Mode TW Signals

The alpha- and ground-mode TW quantities are processed through a summation filter to produce the accumulated TW signals AccTWA, AccTWB, AccTWC, and AccTWG. The line-monitoring logic uses these accumulated quantities to determine mode selection, polarity, and supervision decisions. Section V describes field events that demonstrate the benefits of using accumulated currents. Section VIII.A shows the output of the summation filter (i.e., accumulated signal) after the original signal has passed through the DS filter.

5) Line-Monitoring Mode (LMMODE) Selection

Following the detection of a TW event, the device evaluates the accumulated values of the three alpha modes at a fixed time after the TWIDD assertion. The device then selects the mode with the largest absolute accumulated value as the LMMODE. Consequently, the LMMODE identifies the dominant alpha mode associated with the event.

6) Accumulated Mode TW Polarities

The algorithm determines the polarity of each alpha mode from the sign of its corresponding accumulated value. The corresponding polarity bits, AccTWAPOL, AccTWBPOL, and AccTWCPOLE, are transmitted to the remote terminal for local-remote polarity verification.

7) Local Supervision (LMGO)

In addition to the arming conditions described above, the local-supervision logic verifies four conditions:

- The first TW peak arrives within the expected time window.
- The pre-event voltage maintains a consistent sign.
- The accumulated TW signal maintains a consistent sign.
- The pre-event voltage sign is consistent with the accumulated TW sign.

All four conditions must be satisfied before LMGO asserts.

a) First TW Peak Arrival Time Verification

The first TW peak, FIRST_TW_PK, must occur within the first TW peak arrival window, which begins at the rising edge of TWIDD and typically spans three TWDSW intervals, as shown in Fig. 8. This requirement helps ensure that the observed signal corresponds to a valid TW event.

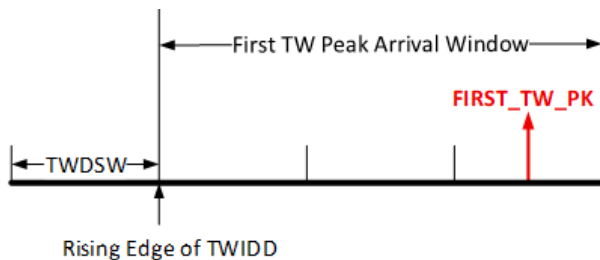


Fig. 8. First TW peak arrival within the first TW peak arrival window.

b) Pre-Event Voltage Sign Verification

Based on the selected LMMODE, the device examines the ten captured pre-event voltage samples from the corresponding

phase. For example, if the Phase A alpha mode is the dominant mode, the device selects the Phase A voltage samples. If all samples have the same sign, the pre-event voltage sign verification is successful, and the VPRESIGNOK indication is asserted.

c) Accumulated Mode TW Sign Verification

The device selects the accumulated TW signal associated with the dominant alpha mode and evaluates the polarities of the samples within an observation window defined by the starting sample, LMWT, and the window length, LMWD, as Fig. 42 in Section VIII.A illustrates. If all samples within the observation window have the same sign, the AccTWSIGNOK indication asserts.

d) Pre-Event Voltage and Accumulated TW Polarity Verification

When the pre-event voltage sign verification is successful, the device calculates a representative pre-event voltage from the ten captured samples after removing the maximum and minimum values. The polarity of this representative voltage is then compared with the polarity of the accumulated TW signal associated with the selected mode, LMMODE. If the polarities match, the VPRETWPOLOK indication asserts.

e) Final Local-Supervision Decision

The LMGO signal asserts only when all preceding verification checks shown in Fig. 9 are successful. The local terminal then transmits LMGO together with the alpha-mode polarity information, AccTWAPOL, AccTWBPOL, and AccTWCPOLE, to the remote terminal for additional verification.

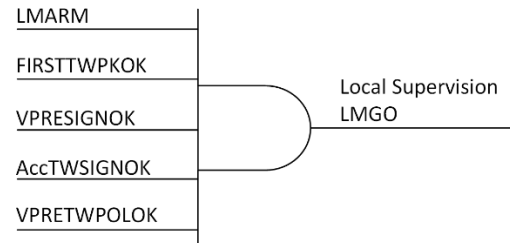


Fig. 9. Local supervision LMGO signal asserts when all of these verifications are successful.

8) Line-Monitoring Event (LMEVE)

The device declares an LMEVE event when a transient event occurs, and all of the following conditions are satisfied:

- Local supervision is asserted.
- Remote supervision is received.
- The local and remote accumulated TW signals of the locally selected mode have matching polarities.
- A valid multi-ended TW fault-location result (METWFL) is available.

The device uses these criteria to classify the transient as either a fault event or a low-energy event, as shown in Fig. 10.

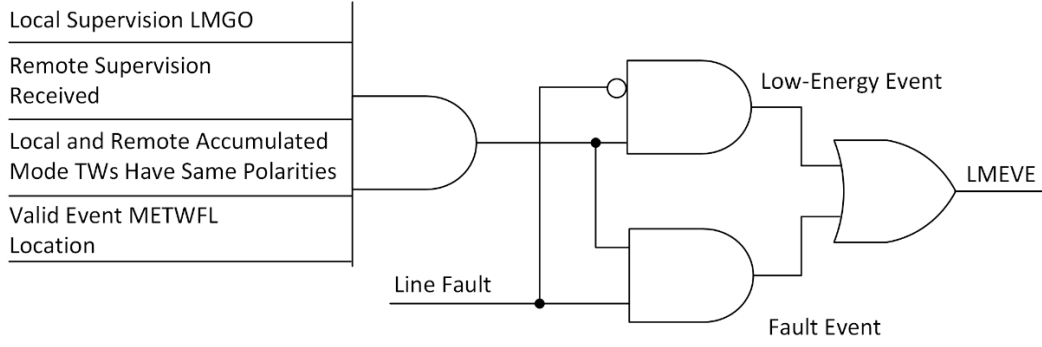


Fig. 10. The line-monitoring logic classifies transient events as low-energy or fault events. The line-fault input asserts when a line-protection element operates.

9) Dominant Ground-Mode Identification

Comparing the magnitudes of the alpha and ground modes can help identify nearby lightning activity external to the monitored line. The line-monitoring logic determines the maximum values of the accumulated alpha-mode and ground-mode signals. If the largest ground-mode magnitude equals or exceeds the largest alpha-mode magnitude multiplied by a specified comparison factor, the ground mode is considered dominant, and the TWI0 ground-mode indication is set to H; otherwise, it is set to L. For overhead transmission lines, the comparison factor is 1. Cable applications require higher values.

IV. INSTALLATION AND COMMISSIONING

The implementation of the TW-based fault-locating and line-monitoring system required coordination between protection maintenance, telecommunications, and operations teams. The utility deployed TW-based devices on transmission corridors where achieving fault-location accuracy was challenging. The utility installed these devices on the following transmission lines:

- 231 km, 230 kV Guarayos–Paraíso Lines 1 and 2
- 142 km, 230 kV Guarayos–Troncos Lines 1 and 2
- 236 km, 500 kV Carrasco–Santivañez line
- 75 km, 230 kV Carrasco–Yapacaní line

The deployment strategy considered both operational importance and historical maintenance challenges associated with these lines. The monitored transmission corridors traverse geographically diverse regions, including tropical lowlands and mountainous terrain, where access to fault locations may be difficult and restoration activities can require significant time and resources.

The utility installed the TW-based devices at selected substations and integrated them into the existing protection and communications infrastructure. An important advantage of the selected architecture is that a single TW-based device can simultaneously monitor two transmission lines, as Fig. 11 illustrates. This capability for the double-circuit lines was particularly beneficial, allowing the utility to optimize equipment deployment while maintaining complete monitoring coverage. The commissioning process included verifying current and voltage signals, confirming proper event capture, testing communications, and validating time synchronization via the IRIG-B protocol. Particular attention was given to precise-time alignment because of the accuracy requirements of TW-based fault-locating methods.

Utility protection personnel set the TW-based devices, supported by factory personnel. The team determined the corresponding TWLPT for each transmission line by performing several line energization tests from one terminal while the remote terminal remained open.

The TW-based devices were additionally integrated into the substation control systems by using DNP3 communication protocols. DNP3 signal mapping included TW peak time stamps, as well as line-monitoring alarm indications and associated distance calculations for precursor-event activity detection along the transmission lines.

To improve maintenance response and engineering analysis, the integrated DNP3 signals enabled automatic email notifications to maintenance protection personnel whenever line-monitoring alarms were triggered. This functionality allowed utility personnel to rapidly analyze location information provided by the line-monitoring system and coordinate field inspections with line personnel.

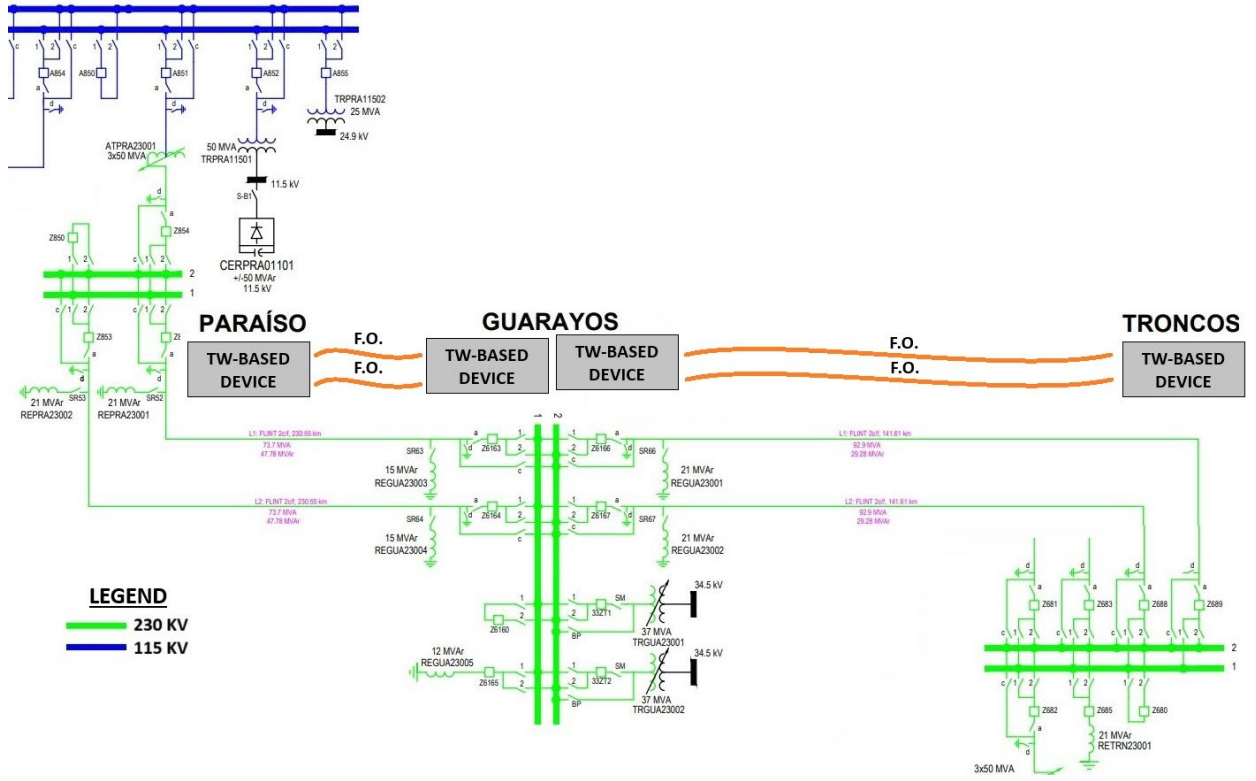


Fig. 11. TW-based devices installed on 230 kV double-circuit transmission lines: Guarayos–Paraiso and Guarayos–Troncos.

The installation phase also represented an important knowledge transfer opportunity between the manufacturer and utility personnel. The operational experience obtained during commissioning contributed to establishing internal procedures for event analysis, alarm interpretation, and maintenance response prioritization. Fig. 12 shows the installation of the TW device at the Paraiso substation.



Fig. 12. TW-based device installed on a protection and control cabinet at the Paraiso substation.

V. FIELD DATA, ANALYSIS, AND PERFORMANCE

This section presents precursor events recorded on different lines equipped with line-monitoring devices. Reliable identification of precursor events requires supervisory

conditions to distinguish between internal and external events. This section presents different field events to illustrate the performance of line-monitoring supervisory conditions and line-monitoring functionality.

A. Reporting and Alarming

The line-monitoring-reporting functionality includes two important data sets. The first data set is the tabulated bin locations and respective counts contained in text file format (.TXT). Reference [2] provides a detailed explanation of the bin locations along the line. The second data set includes a summary of each line-monitoring event, available in text and comma-separated value (.CSV) formats. Line-monitoring event data include the following information:

- The corresponding event record number containing the TWs associated with the line-monitoring event, if available.
- The date and time at which the TW disturbance was detected, along with the first TW arrival time stamps for local and remote devices.
- The multi-ended TW-based fault-location result.
- The updated event count for the bin associated with the location.
- The user-configurable blocking region or regions that contain the event location.
- The event type (low-energy event or fault).
- The phase or phases involved in the event.
- The dominant ground-mode indicator result.

In addition to the downloadable .TXT and .CSV line-monitoring logs, the LIMO ASCII command is available for

viewing the total number of events on the monitored line and the locations of active alarms. Fig. 13 depicts an example of a LIMO command used to display information from the line-monitoring alarm on Guarayos–Paraíso Line 2, located 43.5 km from the Guarayos terminal.

```
=>LIMO

PARAISO I Y II          Date: 2026/01/08 Time: 15:39:36.639
GUARAYOS 230kV         Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129 Serial Number: 1250103373

Line 1: GUARAYOS - PARAISO 1
No line monitoring alarms.

Line 2: GUARAYOS - PARAISO 2
Line Monitoring Alarm
Total number of events:    24

Alarm at location: 43.50 km
Location [km]  Event Count
43.25         0
43.50         3
43.75         0
```

Fig. 13. LIMO command output showing a line-monitoring alarm at the 43.50 km bin on the Guarayos–Paraíso Line 2.

Fig. 15 shows an example of the line-monitoring event data on the Guarayos–Paraíso Line 2, with the line-monitoring alarm threshold configured for three events. Note the locations and bin counts around the 43.5 km bin. Upon observing the third event at this location, the line-monitoring alarm asserted, and an event record was captured.

Based on the alarmed location, field inspection identified missing insulator disks on Phase B at Towers T-98 and T-99 of the Guarayos–Paraíso Line 2, as shown in Fig. 14.

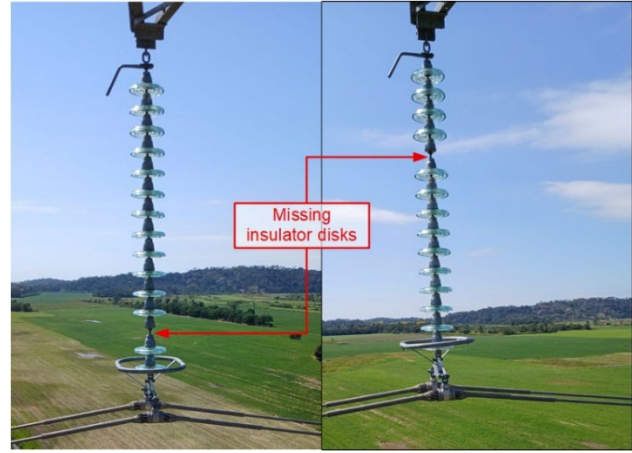


Fig. 14. Missing insulator disks on Phase B at Towers T-98 (left) and T-99 (right), Guarayos–Paraíso Line 2.

B. Event 1: Precursor Event Rejected by TW Arrival Window Supervisory Condition

TW-based devices on the Guarayos–Troncos double-circuit lines recorded an external event on November 26, 2025. Fig. 16 shows the current TWs measured on Line 2 at both stations. The first TWs detected at the Guarayos and Troncos stations were separated by 482.46 μ s, while the TWLPT for this line is 479.71 μ s. The detected TWs exhibit opposite polarities at the two stations, confirming the event was external.

At the Guarayos station, the TWIDD element asserted at the orange cursor, and the supervisory condition then waited three TWDSW intervals for a TW to be detected (the waiting period ended at the magenta cursor). Due to the small magnitude of the TW, the device did not detect a wave during this interval; instead, a TW was detected 330 μ s later. This case demonstrates that the first TW peak arrival window verification enhances security and prevents false-positive diagnostics.

Line Monitoring Event Data										
ER	DATE	TIME	LOCATION	EVENT_COUNT	BLK_REGION	F/E	PHASE	TW_TIME_LOCAL	TW_TIME_P2	TWI0
NA	2026/01/08	06:01:30.7912	102.073	1		E	AB	30.791204583	30.791295501	L
NA	2026/01/08	05:56:38.8744	100.367	2		E	AB	38.874372209	38.874474622	L
NA	2026/01/08	05:56:38.3919	100.329	1		E	AB	38.391930491	38.392033161	L
NA	2026/01/08	01:22:41.4095	23.797	1		E	CA	41.409488712	41.410106928	L
NA	2026/01/08	01:21:37.6578	22.760	1		E	CA	37.657766447	37.658391650	L
NA	2026/01/08	01:11:43.9881	29.289	1		E	CA	43.988149399	43.988730620	L
NA	2026/01/08	01:10:23.2667	31.316	1		E	CA	23.266736087	23.267303652	L
10044	2026/01/08	01:09:13.4781	43.524	3		E	CA	13.478081909	13.478567237	L
NA	2026/01/08	01:08:57.2514	43.584	2		E	CA	57.251362553	57.251847475	L
NA	2026/01/08	01:07:33.0768	43.412	1		E	CA	33.076833620	33.077319704	L

Fig. 15. Event log showing three events assigned to the 43.50 km bin on the Guarayos–Paraíso Line 2.

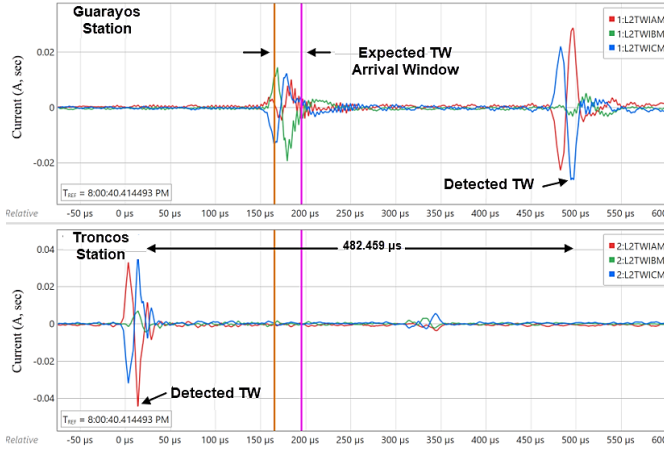


Fig. 16. TW peak arrives outside the expected window.

C. Event 2: Event Classification Using Accumulated Current TWs

An internal event was recorded on Guarayos–Troncos Line 1 on January 4, 2026. Fig. 17 shows the currents and voltages measured at the Guarayos station. A TW was detected in the current TW signal (L1TWIAM), as shown in Fig. 18. The detected peak was associated with a later positive peak of the waveform rather than the initial negative peak. The polarity of the detected TW was opposite that of the pre-event Phase A voltage polarity (see Fig. 18 at the time of the disturbance), which would indicate an external event. However, because the Phase C accumulated current TW signal (L1ACCTWC) was identified as having the greatest magnitude and its polarity matched the Phase C pre-event voltage polarity (see Fig. 18 at the time of the disturbance), the event was identified as an internal event. This case illustrates how accumulated TW quantities can provide a reliable reference when comparing the current TW polarity with its corresponding pre-event voltage polarity.

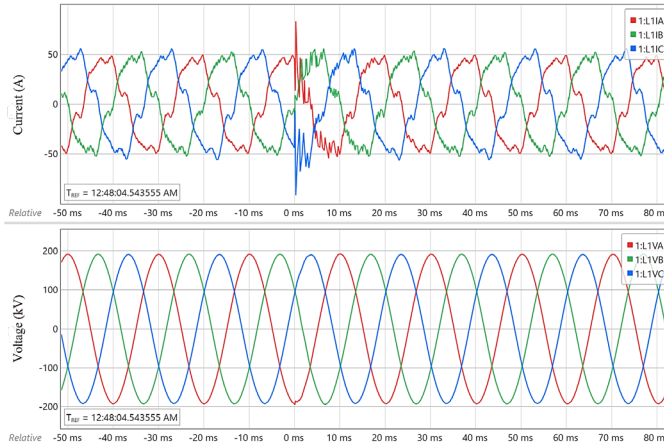


Fig. 17. Currents and voltages at the Guarayos station on January 4, 2026.

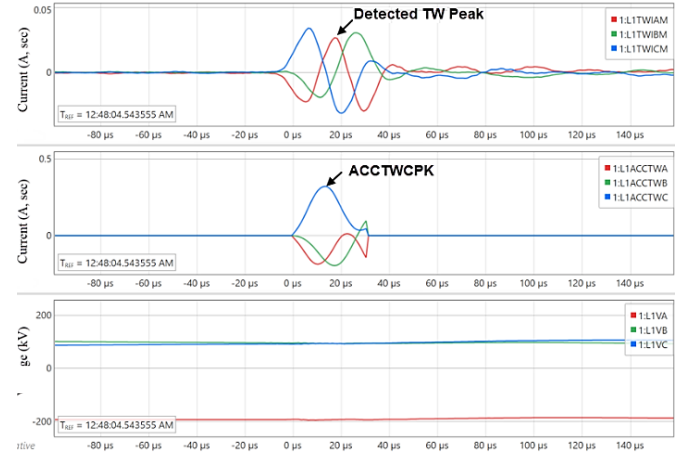


Fig. 18. Current TWs, associated accumulated TWs, and pre-event voltages at the Guarayos station.

D. Event 3: Accumulated TW Polarity Consistency Check for Security

Fig. 19 shows the currents and voltages recorded on Guarayos–Troncos Line 1 on October 13, 2025. In this event, Phase C was identified as the disturbed phase, based on the maximum magnitude of its accumulated current TW. The current TWs measured at the two stations were separated by 479.157 μ s, approximately equal to the line TWLPT of 479.62 μ s, indicating an external event propagating from Guarayos toward Troncos, as shown in Fig. 20. At the Guarayos station, the accumulated Phase C current TW (L1ACCTWC) underwent a polarity reversal within the observation window (see Fig. 21), thereby classifying the event as invalid. A polarity consistency assessment of accumulated TWs ensured robust polarity identification before comparison with other quantities.

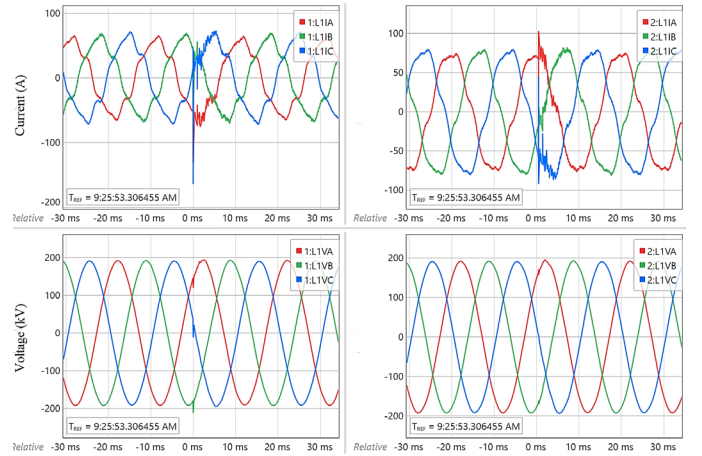


Fig. 19. Currents and voltages at the Guarayos station (Event Record 1; left two subplots) and Troncos station (Event Record 2; right two subplots) on October 13, 2025.

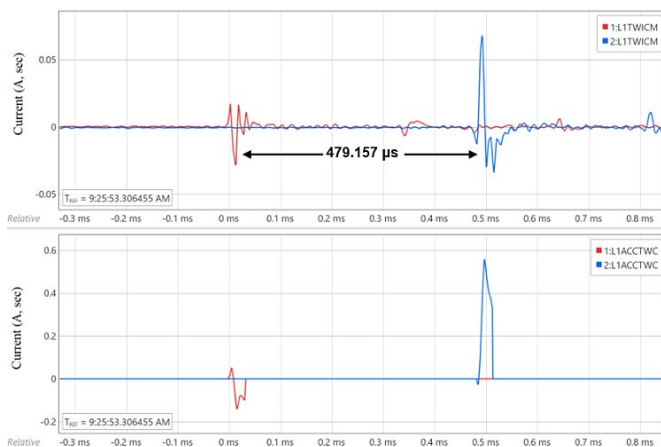


Fig. 20. Phase C alpha-mode current TWs at the Guarayos station (red trace) and Troncos station (blue trace).

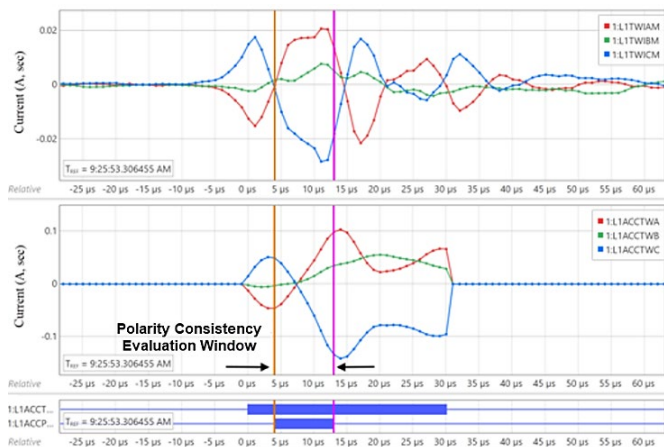


Fig. 21. Accumulated TW changes sign during the evaluation window (LMWD).

E. Event 4: Accumulated TW Polarity Comparison Between the Line Terminals

For the same external disturbance analyzed in Event 3, Fig. 22 shows the currents recorded on the adjacent parallel line, Guarayos–Troncos Line 2. Phase C was identified as the disturbed phase. The difference in TW peak arrival times is 481.645 μ s, which is close to the line TWLPT of 479.71 μ s. As Fig. 23 illustrates, the accumulated Phase C current TWs (L2ACCTWC) at the two stations exhibit opposite polarities, which indicates that the TW propagated from Guarayos to Troncos and confirms the event was external.

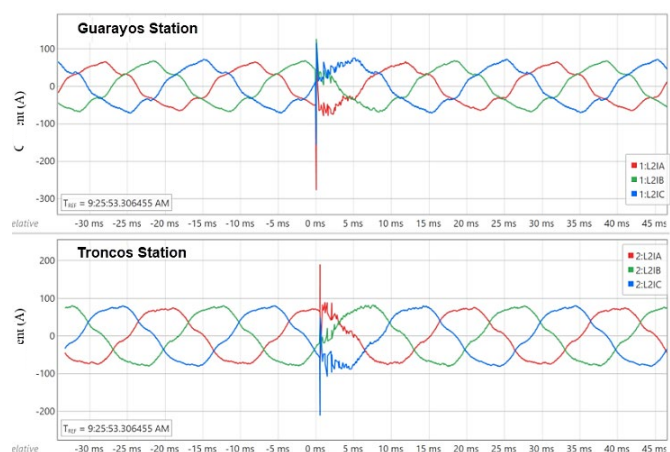


Fig. 22. Currents at Guarayos and Troncos stations.

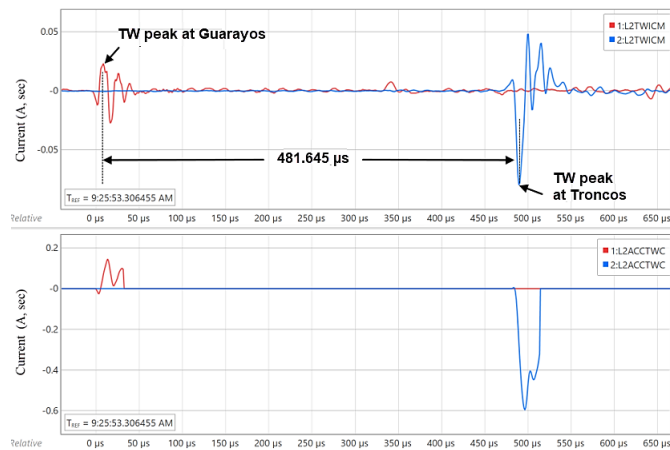


Fig. 23. Current TWs and the associated accumulated TWs at the Guarayos station (red trace) and Troncos station (blue trace).

F. Event 5: Missing Insulator Disk

Fig. 24 and Fig. 25 show an event recorded on Guarayos–Paraíso Line 1 (see Fig. 43 in Section VIII.B) on March 9, 2026. The event was detected by the line-monitoring logic at both the Guarayos and Paraíso stations. As shown in Fig. 26, the polarities of the accumulated Phase A alpha-mode current TWs (L1ACCTWA) remain consistent throughout the observation window at both stations. The polarities are identical at the two stations and consistent with the pre-event Phase A polarity. The device estimated the event to be 167.524 km from the Guarayos station, near Tower T-142 on Line 1. Fig. 27 shows the missing insulator disk on Phase A of this tower.

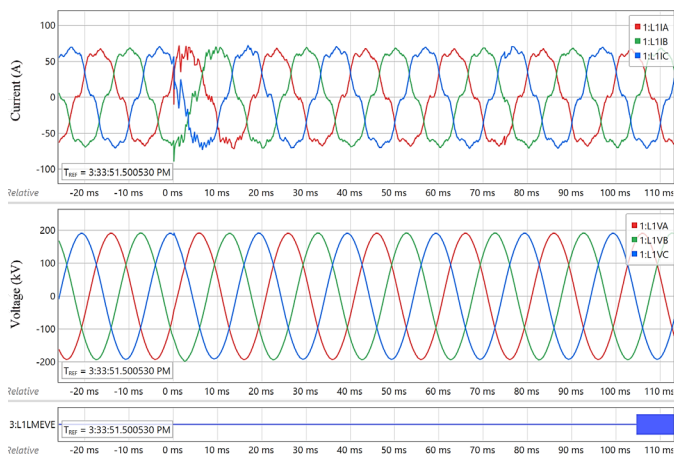


Fig. 24. Currents and voltages at Guarayos station on March 9, 2026.

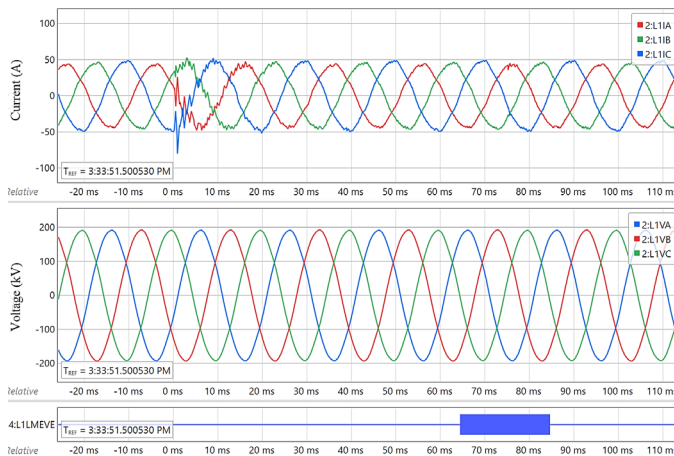


Fig. 25. Currents and voltages at Paraíso station on March 9, 2026.

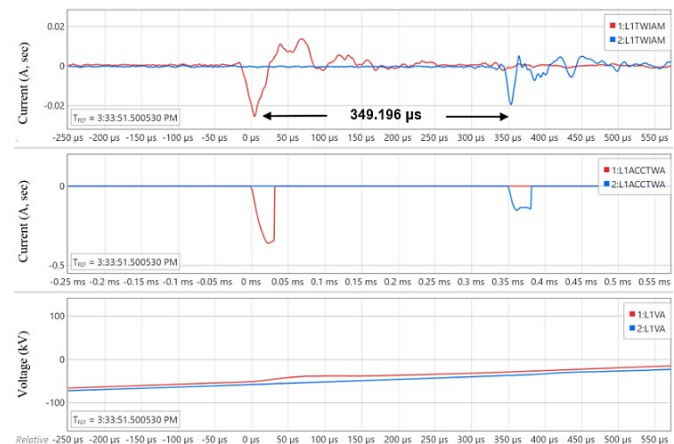


Fig. 26. Phase A alpha-mode TW, accumulated TW, and pre-event voltage at the Guarayos station (red trace) and the Paraíso station (blue trace).

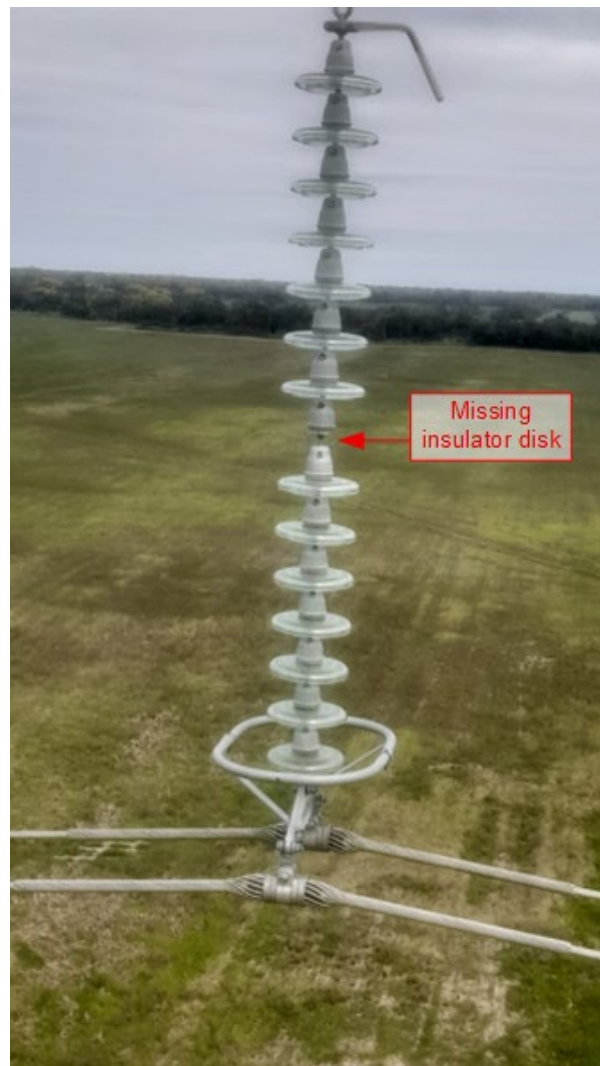


Fig. 27. Missing insulator disk on Phase A at Tower T-142 of Guarayos–Paraíso Line 1.

G. Event 6: Avian Contamination

Fig. 28 and Fig. 29 show an event record containing four line-monitoring events detected on Guarayos–Paraíso Line 1 on April 5, 2026. The line length is 231.14 km, with a TWLPT of 778.51 μ s. The TW-based devices estimated the event locations as 205.127 km, 203.470 km, 203.466 km, and 203.343 km from the Guarayos station, respectively. The line-monitoring alarm (L1LMA) asserted at both line terminals following the third line-monitoring event (L1LMEVE) binned at the 203.50 km location from the Guarayos station.

Fig. 30 presents the first line-monitoring event in the record. As shown, the accumulated Phase C alpha-mode current TWs exhibited the same polarity at both stations and were consistent with the pre-event Phase C voltage polarities measured at each station. Fig. 31 shows the current TWs recorded at both stations for the remaining three events clustered around the 203.50 km location.

Consistent with the alarmed location, field inspection identified evidence of bird droppings on Phase C at Tower T-424 along Guarayos–Paraíso Line 1, as shown in Fig. 32. Furthermore, line personnel reported the presence of

lagoons, which serve as feeding areas for birds, beneath the adjacent towers that may have contributed to the observed activity.

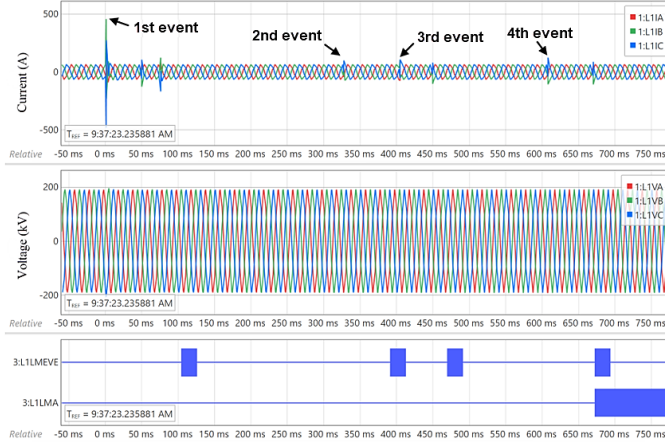


Fig. 28. Currents and voltages at the Guarayos station on April 5, 2026.

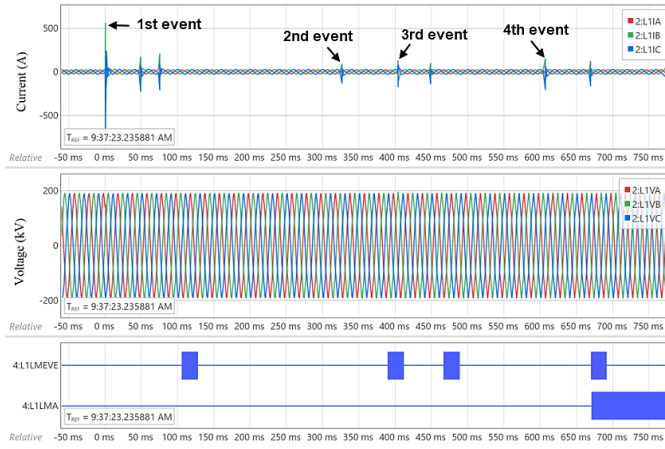


Fig. 29. Currents and voltages at the Paraíso station on April 5, 2026.

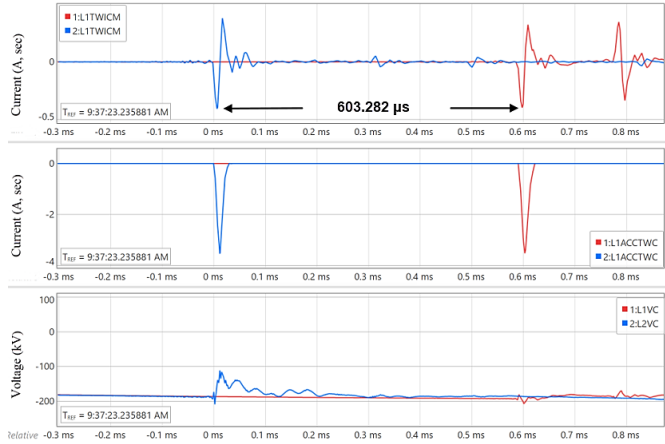


Fig. 30. Phase C alpha-mode TW, accumulated TW, and pre-event voltage for the first event at the Guarayos station (red trace) and the Paraíso station (blue trace).

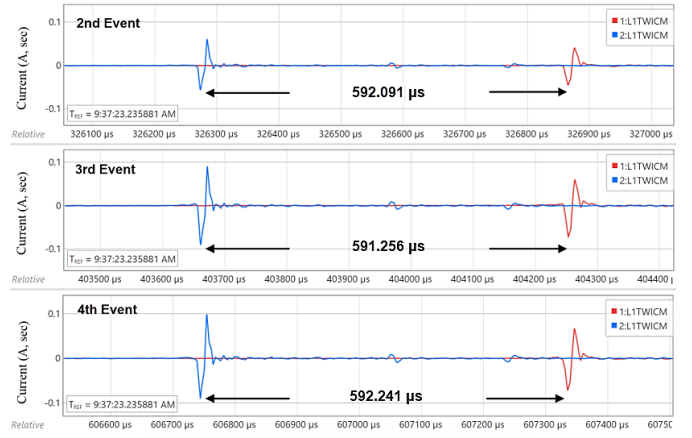


Fig. 31. Phase C alpha-mode TW for three events binned at 203.50 km from the Guarayos station, recorded at the Guarayos station (red trace) and the Paraíso station (blue trace).



Fig. 32. Bird contamination observed on Phase C at Tower T-424 of Guarayos-Paraíso Line 1.

H. Event 7: Lightning Event

Fig. 33 depicts a lightning strike event on the Carrasco–Yapacaní transmission line on December 22, 2025.

Fig. 34 shows that the first TW was detected in the Phase A alpha-mode TW at the Carrasco station and in the Phase C alpha-mode TW at the Yapacaní station. Both TWs were detected within their expected first TW peak arrival windows,

and the event was calculated to be 9.912 km from the Carrasco station based on the arrival times of the two TW peaks.

Fig. 35 shows that the Phase B alpha mode was selected as the disturbed phase at the Carrasco station based on the maximum magnitude of its accumulated current TW, as the orange cursor shows. After receiving the polarities of all three accumulated mode TWs from the Yapacaní station (refer to the magenta cursor), the device compared the accumulated Phase B current TW polarities from both stations, as Phase B was the line-monitoring mode selected at the Carrasco station. The accumulated Phase B current TW remained consistent throughout the observation window (LMWD) at the Carrasco station, and its polarity matched that of the Phase B pre-event voltage. The Phase B accumulated current TW polarities at both stations were positive.

In contrast, Phase C was selected as the disturbed phase at the Yapacaní station, and its accumulated current TW remained consistent throughout the observation window (LMWD). Its polarity also matched that of the pre-event Phase C voltage. Likewise, because Phase C was the line-monitoring mode selected at the Yapacaní station, the device compared the accumulated Phase C current TW polarities from both terminals at the Yapacaní station. The accumulated Phase C current TW polarities at the two stations were also identical.

As shown in

Fig. 35, the peak of the accumulated ground-mode TW (LIACCTWG) was greater than the peaks of the accumulated TW components of the three-phase modes (LIACCTW ϕ , where $\phi = A, B$, and C). This characteristic indicates that the event was likely caused by a lightning strike, which typically generates a strong ground-mode component, to a transmission tower or shield wire. Based on the calculated event location, the field crew identified Tower T-27 as the lightning strike point, as shown in Fig. 36.

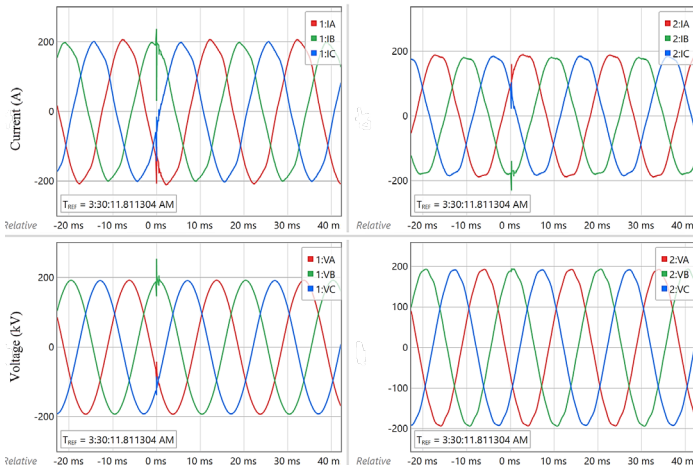


Fig. 33. Current and voltage waveforms at the Carrasco station (Event 1; left two subplots) and Yapacaní station (Event 2; right two subplots).

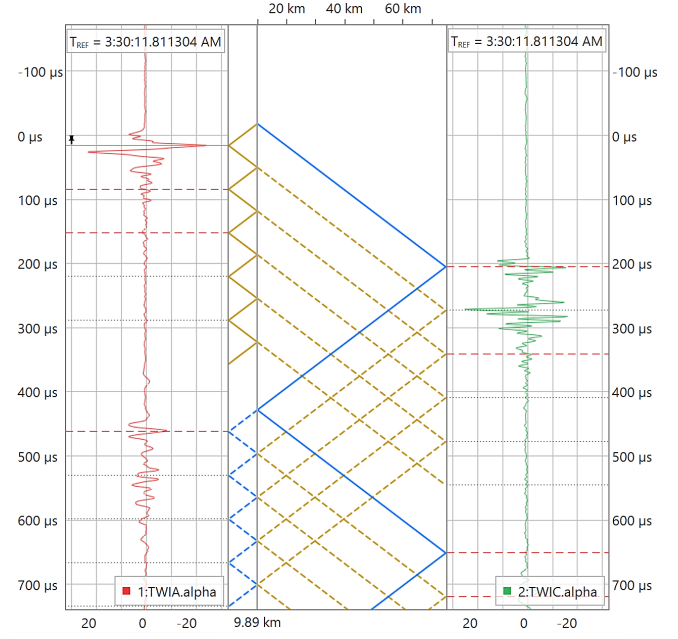


Fig. 34. Phase A alpha TW current at the Carrasco station (red trace) and Phase C alpha current at the Yapacaní station (green trace).

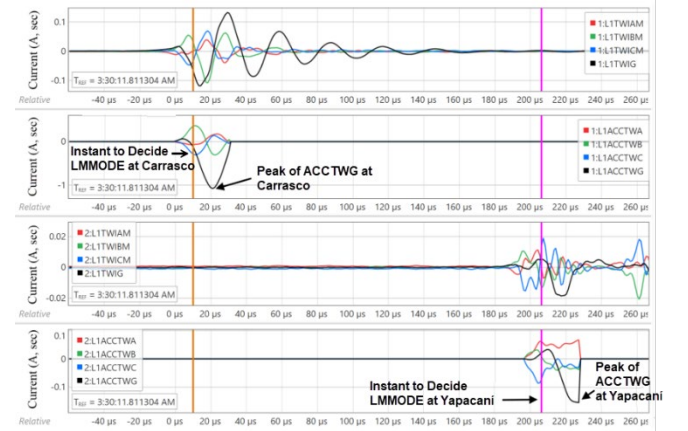


Fig. 35. Current TWs and associated accumulated TWs at the Carrasco station (two top subplots) and Yapacaní station (two bottom subplots).

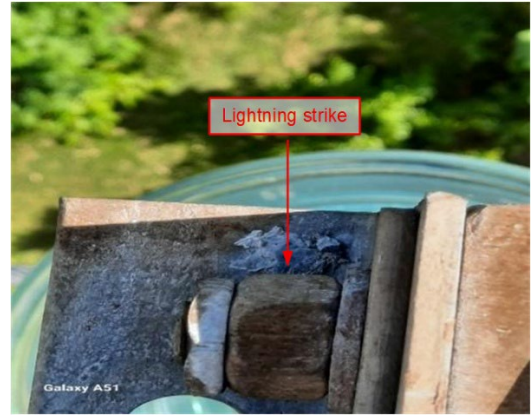


Fig. 36. Lightning strike spot at Tower T-27.

I. Summary of Field-Validated Events

Table I summarizes three representative field events detected by the line-monitoring system and subsequently validated through field inspections.

These cases demonstrate the capability of the TW-based monitoring system to identify and locate different types of transmission line disturbances, including insulation defects, avian contamination, and lightning-related activity. In each case, the TW-based location information guided targeted inspections that confirmed the underlying condition in the field, providing confidence in the event-classification logic and the location accuracy of the monitoring system. These findings demonstrate that the line-monitoring system provides actionable asset-condition information that can support condition-based maintenance and improve transmission line reliability.

TABLE I
FIELD VALIDATION OF TW-BASED FAULT-LOCATING AND LINE-MONITORING RESULTS

	Event 5: Missing Insulator Disk	Event 6: Avian Contamination	Event 7: Lightning Event
Date	March 9, 2026	April 5, 2026	December 22, 2025
Transmission Line	Guarayos–Paraíso Line 1	Guarayos–Paraíso Line 1	Carrasco–Yapacaní
Calculated TW Location	167.524 km from Guarayos	203.343–203.470 km from Guarayos	9.912 km from Carrasco
Confirmed Location	167.250 km from Guarayos	203.140 km from Guarayos	10.000 km from Carrasco
Location Error	+ 274 m (+0.12%)	+ 286 m (+0.12%), based on the average	- 88 m (-0.12%)
Field Inspection Location	Tower T-142	Tower T-424	Tower T-27
Field Finding	Missing Insulator Disk on Phase A	Bird Contamination on Phase C Insulation	Lightning Strike at Reported Location

VI. THE UTILITY MAINTENANCE PHILOSOPHY— USING LINE-MONITORING DATA

Prior to the implementation of the TW-based line-monitoring system, transmission line maintenance activities at the utility were primarily driven by scheduled inspections and corrective actions following line faults. Although routine patrols were effective for identifying visible defects, some incipient conditions remained undetected until they evolved into permanent outages.

The line-monitoring functionality introduced an additional resource for proactive condition-based assessment. Using the TW-based device monitoring capabilities, the utility engineering personnel were able to detect and locate precursor events associated with insulation deterioration, contamination, vegetation interaction, wildlife activity, and other abnormal conditions occurring along the transmission lines.

One of the most valuable aspects of the monitoring system was its capability to identify repetitive precursor activity originating from the same physical location. Recurrent precursor events provided a possible indication of developing problems that could eventually result in permanent faults if left unattended.

Utility engineers analyzed the events captured by the monitoring system and coordinated targeted field inspections at the reported locations. Following coordination meetings with transmission line maintenance personnel, additional technical information, including Keyhole Markup Language Zipped (KMZ) route files, transmission line transposition diagrams, and detailed line construction information, was incorporated into the analysis process. Utility engineers also correlated the TW-based records with lightning activity levels and seasonal weather conditions in the different geographic regions near the transmission lines.

This additional information improved the interpretation of the TW records because the engineering team could analyze the involved phase, transient current magnitude, and oscillographic characteristics associated with the detected events. The combined analysis of high-sampling rate TW records and transmission line physical information provided better visibility into the possible origins and behaviors of detected precursor activity.

To support the analysis process, utility engineering personnel developed transmission line spreadsheets organized by tower number, where the number of detected incidents associated with each section was recorded and tracked. The information collected from the line-monitoring function of the TW-based devices installed on the Santivañez–Carrasco, Carrasco–Yapacaní, Paraíso–Guarayos, and Guarayos–Troncos transmission lines was consolidated into these analysis tools. Fig. 37 shows the Paraíso–Guarayos Line 2 analysis spreadsheet. The orange counters indicate that more than five total precursor events were registered by both ends of the line, while the yellow counters indicate fewer than five events. Towers with orange counters are more likely to experience permanent incidents that require inspection. The spreadsheet provides maintenance personnel with information regarding oscillographic event records, field inspection photographs, weather conditions near the transmission lines, and actions taken during line patrol inspections.

The resulting reports were shared with the regional transmission line maintenance personnel to support targeted field inspections at the indicated locations. The feedback received from the regional maintenance teams became fundamental for correlating detected transient activity with actual field conditions, validating inspection results, and improving interpretation of the monitoring records. Fig. 38 shows Tower T-034 with moss growth on insulator disks and Fig. 39 shows the tower location.

Field investigations confirmed several conditions associated with detected precursor activity. Among the most relevant findings were missing insulator disks, moss growth on insulator disks, and bird nests located near energized equipment. These conditions created intermittent electrical activity that was successfully detected and localized by the monitoring system. After identifying the affected locations, maintenance teams performed corrective actions that included insulator disk replacement, cleaning, and bird nest removal.

A	B	C	D	E	F	G	H	I	J	K	L	M	N
FECHA ULTIMA ACTUALIZACION	FASE(S)	CONTADOR/DIST. FALLA	DESDE PARAISO	OSCILO	TORRE	OSCILO	DESDE GUARAYOS	CONTADOR/DIST. FALLA	FASE(S)	FECHA ULTIMA ACTUALIZACION	LLUVIAS SENAMHI	FOTO	DESCRIPCIÓN DE LO ENCONTRADO
			20.75	06112025_L2LMA			210.25						
			21.00		T-439		210.00						
			21.25				209.75	1	BC	6/1/2025	SECO		Sin observaciones
22/9/2025	BC	2	21.50		T-438		209.50	3	BC	22/9/2025	SECO		Sin observaciones
			21.75				209.25						
			22.00		T-437		209.00						
			22.25				208.75						
			22.50		T-436		208.50						
			22.75		T-435		208.25						
			23.00				208.00	2	BC	6/11/2025	LLUVIA LIGERA		
			23.25		T-434		207.75						Fase C con nido de ave en la ménsula
		1	23.5				207.50						
22/9/2025	BC	1	23.75		T-433		207.25	1	BC	22/9/2025	SECO	T2-433.jpeg	Nido de ave fase C
22/9/2025	BC	1	24				207.00	2	BC	22/9/2025	SECO		
		2	24.25		T-432		206.75					T2-432.jpg	Aislador roto fase B
			24.50				206.50						
22/9/2025	BC	2	24.75		T-431		206.25	2	BC	22/9/2025	SECO	T2-431.jpeg T2-431_1	Nido de ave fase CNido de ave
22/9/2025	BC	3	25.00				206.00	4	BC	16/9/2025	SECO		
16/9/2025	BC	3	25.25		T-430		205.75	1	BC	16/9/2025	SECO		Sin observaciones
			25.50		T-429		205.50						Sin observaciones
			25.75				205.25						
			26.00		T-428		205.00						
6/11/2025	BC	2	26.25				204.75						
			26.50		T-427		204.50						
			26.75				204.25						
			27.00		T-426		204.00						
			27.25				203.75						
			27.50		T-425		203.50						
	BC	2	27.75	05042026_L2LMA		050426_L2LMA	203.25	2	BC				
		1	28		T-424		203	1					

Fig. 37. Paraíso–Guarayos Line 2 analysis organized by tower number.

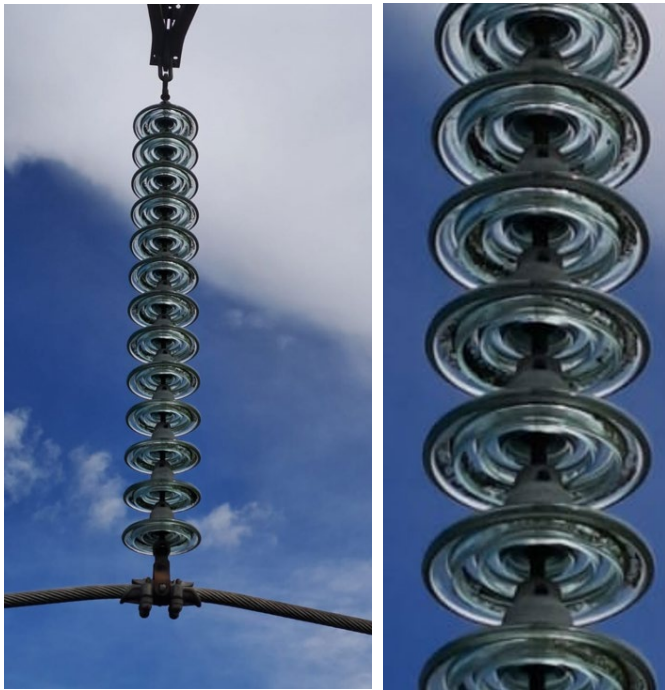


Fig. 38. Moss growth on insulator disks of Tower T-034 on 230 kV Carrasco–Yapacaní line.

The initial results obtained from the monitoring system are considered highly valuable, not only for future maintenance activities but for analysis of high-frequency transient phenomena that cannot be easily identified using conventional low-sampling rate event records. Utility transmission line maintenance personnel presently perform insulator condition assessment programs by using leakage current measurements, porcelain insulation testing, and other diagnostic techniques to optimize maintenance resources, inspection efforts, and spare-

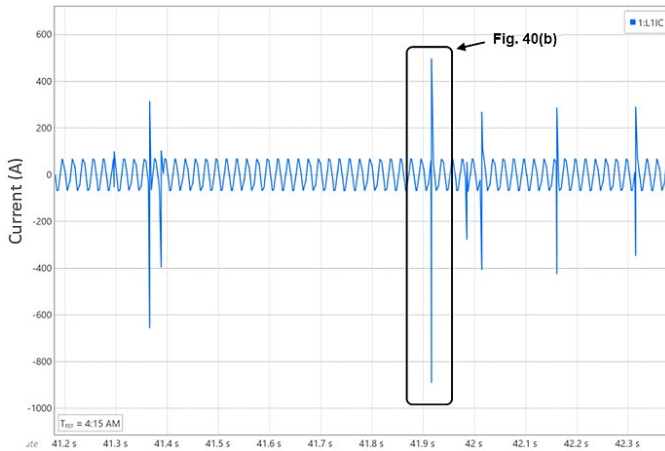
part management. The information provided by the TW-based monitoring devices complements these activities by identifying transmission line sections and potential insulator locations that may require more detailed inspection and testing.



Fig. 39. Location of Tower T-034 (utility KMZ route files).

The high-sampling rate TW records provide engineering personnel with enhanced visibility into transient phenomena occurring in the transmission system, including events that may not be observable through conventional protection records typically limited to lower-sampling rate oscillographic data.

Fig. 40 shows precursor activity from the 500 kV Carrasco–Santivañez transmission line recorded by the device at the Santivañez substation at 1 MHz sampling rate.



a) Precursor activity captured at 1 MHz sampling rate.



b) Expanded view of the precursor event highlighted in Fig. 40(a).

Fig. 40. Precursor activity from the 500 kV Carrasco–Santivañez transmission line.

This monitoring system provides maintenance personnel with additional information to prioritize field activities and focus resources on areas with detected abnormal transient activity. Additionally, the utility expects this capability to support future improvements in maintenance practices, particularly for long transmission corridors where access conditions can complicate inspection activities.

To further streamline field workflows and support this maintenance approach, the utility has developed a no-code mobile application integrated with a centralized cloud database for upcoming field deployment, as shown in Fig. 41. The no-code mobile application development environment enables personnel to adapt forms, workflows, and reporting functions without requiring software-development expertise. The application provides line patrol crews with tools to collect detailed information regarding field findings on TW-monitored transmission lines. It supports real-time geolocation of reported precursor events, photographic documentation of field conditions, and centralized data synchronization. These capabilities improve data collection and support maintenance planning, asset management, and field inspection activities.

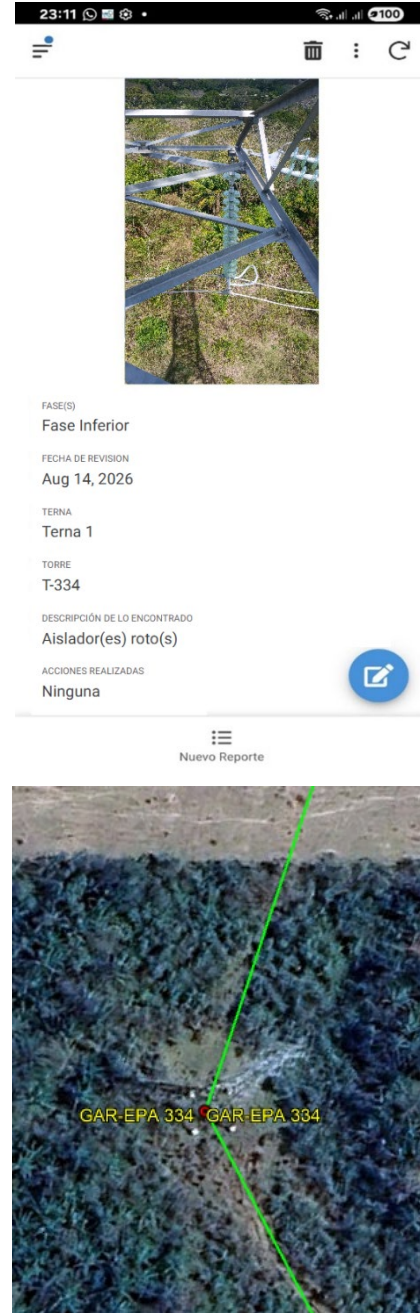


Fig. 41. No-code mobile application using GPS for collecting field findings on TW-monitored transmission lines.

The operational experience obtained during the initial deployment stage has demonstrated that precursor event monitoring provides important operational information beyond fault-location accuracy improvements alone. Although the maintenance philosophy has not yet formally changed, the monitoring data are already contributing to maintenance analysis and supporting the evolution of future condition-based maintenance strategies within the Bolivian transmission system.

VII. CONCLUSION

This paper has presented the deployment and operational experience of ENDE-T with TW-based fault locating and line monitoring on 230 kV and 500 kV transmission lines. The deployed system leverages double-ended TW measurements to detect and locate fault events and low-energy precursor events indicative of deteriorating transmission line conditions.

Field experience has demonstrated that reliable identification of precursor events requires supervisory conditions that distinguish internal disturbances from external events, lightning activity, and coupled TWs on adjacent circuits. The presented cases have demonstrated the value of TW arrival window verification, accumulated TW polarity assessment, polarity consistency checking, cross-terminal polarity validation, and pre-event voltage comparison in improving the security and dependability of line-monitoring applications.

Line-monitoring data have enabled utility personnel to identify and investigate locations experiencing repeated precursor activity. Additionally, field inspections have subsequently confirmed conditions such as missing insulator disks, moss growth on insulator disks, bird nests located near energized equipment, and lightning-related activity. The ability to localize these events has allowed maintenance personnel to prioritize inspections and corrective actions on specific transmission line sections rather than relying solely on routine patrol schedules. To further streamline this process across different corridors, the utility has developed a dedicated mobile application linked to a cloud-based repository, which is ready for upcoming deployment, to digitally track field findings.

The field results demonstrate that TW-based line monitoring complements traditional maintenance practices by providing accurately located information on low-energy events. The field-validated cases produced location errors of approximately 0.12 percent of line length and enabled utility personnel to direct inspections to specific towers where missing insulation, avian contamination, and lightning-related activity were confirmed. These capabilities provide actionable information for prioritizing inspections and corrective actions and support

the utility's continued evolution toward condition-based transmission line maintenance.

VIII. APPENDIX

A. Line-Monitoring Signal-Processing Principles

Fig. 42 illustrates the signal-processing principles used by the line-monitoring algorithm. The figure shows three waveforms: the original step signal, the output of the differentiator-smoother filter, and the output of the summation filter (accumulated signal). The step input emulates a sudden change in current or voltage associated with a TW event.

The figure also illustrates the accumulated TW sign observation window defined by LMWT and LMWD. These constants, which were established from field experience, correspond to portions of the accumulated signal where the polarity remains stable and representative of the TW event. In addition, the figure shows the maximum value of the accumulated signal, which is used to determine whether the ground-mode magnitude equals or exceeds the largest alpha-mode magnitude.

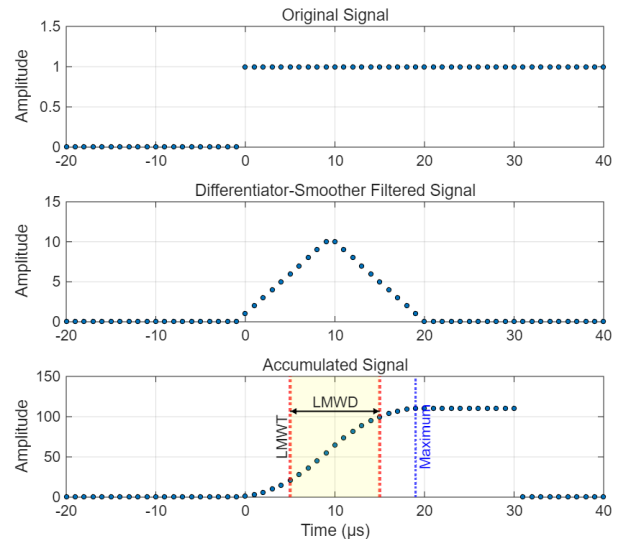


Fig. 42. Responses of the differentiator-smoother and summation filters to a step signal.

B. Guarayos–Paraíso Transmission Lines Tower Configuration

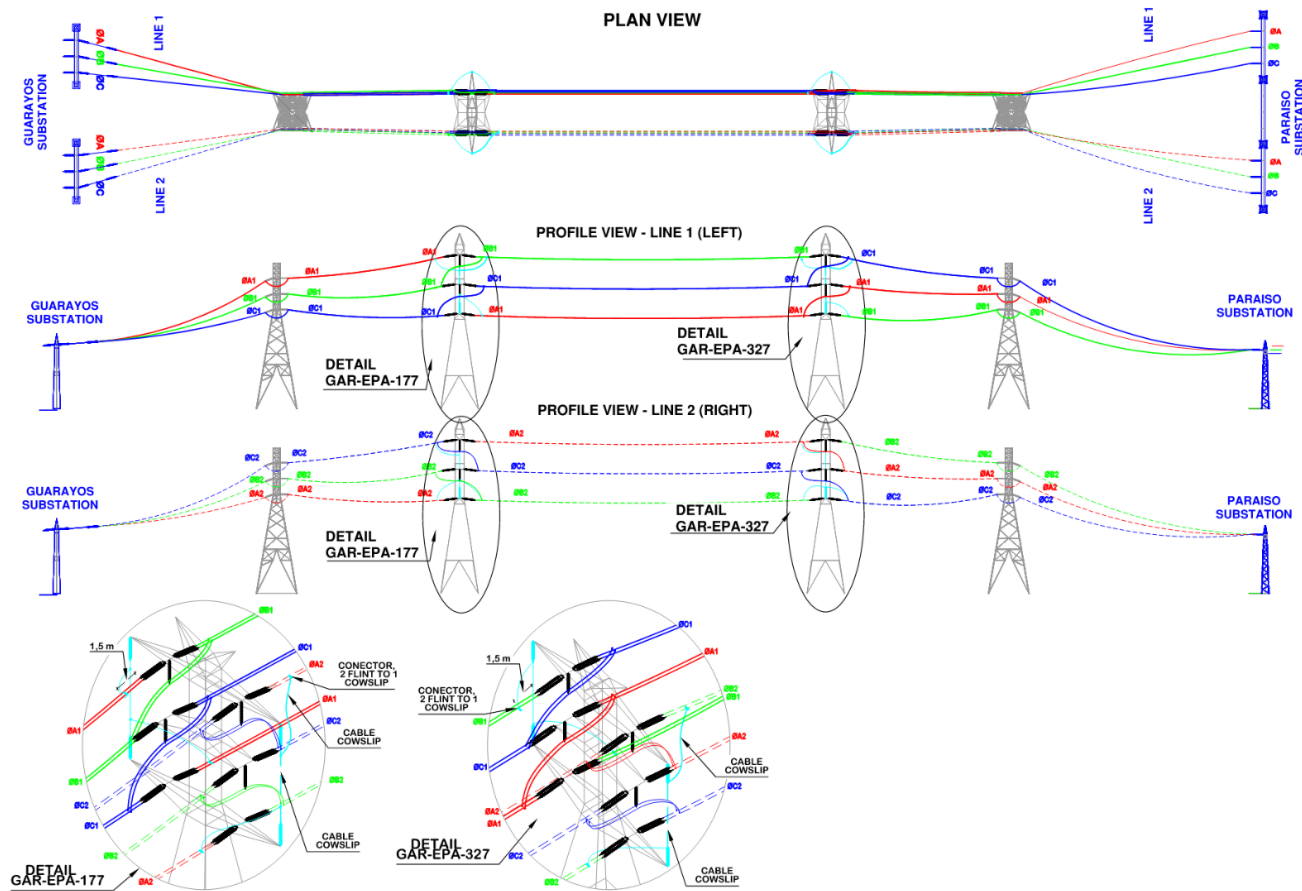


Fig. 43. Guarayos–Paraíso double-circuit 230 kV transmission lines.

IX. REFERENCES

- [1] E. O. Schweitzer, A. Guzmán, M. V. Mynam, V. Skendzic, B. Kasztenny, and S. Marx, "Locating Faults by the Traveling Waves They Launch," proceedings of the 67th Annual Conference for Protective Relay Engineers, College Station, TX, March 2014.
- [2] B. Kasztenny, M. V. Mynam, T. Joshi, and D. Holmbo, "Preventing Line Faults with Continuous Monitoring Based on Current Traveling Waves," proceedings of the 15th International Conference on Developments in Power System Protection, Liverpool, United Kingdom, March 2020.
- [3] E. O. Schweitzer III and Jeff Roberts, "Distance Relay Element Design," proceedings of the 19th Annual Western Protective Relay Conference, Spokane, WA, October 1992.
- [4] O. D. Naidu, S. Zubic, A. V. S. R. Sai, A. N. Praveen, P. Cost, and H. Eriksson, "Economical Setting-Free Double-Ended Fault Locator for Transmission Lines: Experiences From Recent Pilot Installations," *IEEE Access*, Vol. 10, September 2022, pp. 96805-96820, <https://doi.org/10.1109/ACCESS.2022.3205020>.
- [5] S. Sharma, A. Kathe, T. Joshi, and T. Kanagasabai, "Application of Ultra-High-Speed Protection and Traveling-Wave Fault Locating on a Hybrid Line," proceedings of the 46th Annual Western Protective Relay Conference, Spokane, WA, October 2019.
- [6] B. Kasztenny and M. V. Mynam, "Line Length and Fault Distance Considerations in Traveling-Wave Protection and Fault-Locating Applications," proceedings of the 75th Annual Georgia Tech Protective Relay Conference, Atlanta, GA, May 2022.
- [7] A. Guzmán, M. V. Mynam, V. Skendzic, J. L. Eternod, and R. Martínez Morales, "Directional Elements – How Fast Can They Be?" proceedings of the 44th Annual Western Protective Relay Conference, Spokane, WA, October 2017.

X. BIOGRAPHIES

Daniel Caballero M. received his BSEE with academic excellence (2016) and his MS in power systems (2024) from Universidad Mayor de San Simón (UMSS), Bolivia, where he also earned a postgraduate diploma in higher education (2017). He holds an additional postgraduate diploma in maintenance engineering (2021) from Universidad Católica Boliviana (UCB). In 2016, he joined ENDE Transmisión S.A., Bolivia, as a protection maintenance engineer and has served as Head of the Protection Maintenance Division since 2022. He is the secretary general of IEEE PES Bolivia and an undergraduate and postgraduate lecturer at several universities. Daniel has led major protection and control modernization and grid expansion projects in Bolivia. His technical expertise includes engineering design, operation and testing of protection systems, protection coordination, fault analysis, and IEC 61850 substations.

Jonathan A. Titichoca V. received his BSEE (2018) with honors from Universidad Mayor de San Simón (UMSS), Bolivia. He holds a postgraduate diploma in maintenance engineering (2021) from Universidad Católica Boliviana (UCB) and is an MS candidate in power systems. Throughout his career at ENDE Transmisión S.A., he has advanced from project engineering into his current role as protection maintenance engineer. His specialized field encompasses high-voltage protection systems, power network reliability, and disturbance analysis in transmission grids.

Armando Guzmán received his BSEE with honors from Guadalajara Autonomous University (UAG), Mexico. He also received a diploma in fiber-optics engineering from the Monterrey Institute of Technology and Advanced Studies (ITESM), Mexico, and his Master of Science and Ph.D. in electrical engineering and a Master of Engineering in computer engineering from the University of Idaho, USA. He served as Regional Supervisor of the Protection Department in the Western Transmission Region of the Federal Electricity Commission (the electrical utility company of Mexico) in Guadalajara, Mexico for 13 years. He has lectured at UAG and the University of Idaho in power system protection and power system stability. Since 1993, he has been with Schweitzer Engineering Laboratories, Inc. in Pullman, Washington, where he

is a Distinguished Engineer in R&D. He holds numerous patents and has published extensively in the areas of power system protection, fault location, and system monitoring. Armando is a senior member of IEEE and a member of CIGRE.

Michael West received his BSEE degree with a minor in mathematics from the University of Idaho in 2013 and his MSEE degree from the University of Idaho in 2016. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2015 and is a development lead engineer in the power systems group of Research and Development.

Hernan Flores received his BS 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 protection specialist for substations in 500 kV, 220 kV, and 138 kV. He is presently an application engineer at Schweitzer Engineering Laboratories Peru S.A.C. (SEL Peru). He is the leader in protection and control systems in the market of Peru and Bolivia. In 2021, he received the title of instructor from SEL University. He is interested in power system protection and new technologies, such as traveling-wave protection, fault location, and controlled switching.

Yajian Tong holds a master's degree in electrical and computer engineering. He is currently an electrical engineer in the research and development division at Schweitzer Engineering Laboratories, Inc. He is a licensed professional engineer in the state of Washington.

Mangapathirao (Venkat) Mynam received his MSEE from the University of Idaho in 2003 and his BE in electrical and electronics engineering from Andhra University College of Engineering in 2000. He joined Schweitzer Engineering Laboratories, Inc. (SEL) in 2003 as an associate protection engineer in the Engineering Services division. He is presently working as a senior engineering director in SEL Research and Development. He is a senior member of IEEE and holds patents in the areas of power system protection, control, and fault location. He was selected to participate in the National Academy of Engineering (NAE) 15th Annual U.S. Frontiers of Engineering Symposium.