Utility Experience With an Ultra-High-Speed Line Protection Relay on a 230 kV Transmission Line

Ram Viswanathan, Andrew Jenkins, Monir Hossain, and Tu Nguyen
Entergy Corporation

Brennen Acosta and Jeremy Blair
Schweitzer Engineering Laboratories, Inc.

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

Utility Experience With an Ultra-High-Speed Line Protection Relay on a 230 kV Transmission Line

Ram Viswanathan, Andrew Jenkins, Monir Hossain, and Tu Nguyen, *Entergy Corporation*
Brennen Acosta and Jeremy Blair, *Schweitzer Engineering Laboratories, Inc.*

***Abstract*—As part of a pilot effort to learn more about time-domain relaying, fault locating, and ultra-high-speed protection, Entergy installed ultra-high-speed (UHS) line protection relays at both ends of a critical 230 kV transmission line that traverses a marshy area with limited access. While the pilot installation only monitored the transmission line and did not trip breakers, the fault records captured by the relays were analyzed and compared to fault records from in-service phasor-based relays. The comparative analysis focused on these key areas:**

- **Operational speed for each element**
- **Operational correctness for the elements expected for each faulted scenario**
- **Fault location accuracy**
- **Post-fault operator experience**

Over the course of the last three years, several faults have occurred on the transmission line due to a variety of causes, including fallen structures, failed insulators, and lightning. In the events analyzed, there were several examples of expected superior performance (e.g., submillisecond relay trips for line faults and fault location estimates within a span of the actual fault location). However, the utility operators were surprised to see the same benefits during a switch-onto-fault event, even though the time-domain elements were unavailable for that scenario.

While the comparative analysis was the focus, some unexpected results produced valuable lessons into the performance of the UHS relay as well as the settings and design considerations required to ensure successful implementation in future standard panel designs. This paper outlines these lessons using a case study of each operation.

I. Introduction

The ultra-high-speed (UHS) relay under study in this pilot uses time-domain protection elements in addition to phasor-based elements to trip very fast for internal faults while maintaining full dependability [1]. This paper focuses primarily on the performance of the UHS relay traveling-wave differential (TW87), incremental quantity distance (TD21), and incremental quantity directional (TD32) elements, though there were some operations in which the phasor-based elements were also evaluated. TW87 measures the wave of current that propagates down the line, which is initiated when a step change in voltage (such as during a fault) occurs. This is measured by both relays and time-stamped such that the relay can tell if the fault is internal or external. TD21 compares a measured change in voltage at the reach point to the pre-fault voltage at the reach point. If the change in voltage is higher, then the fault is within the reach and the element asserts. TD32 is based on the principle that the incremental voltage and incremental replica current have opposite polarity for forward faults and have the same polarity for reverse faults. Operating and restraining signals are developed in the time domain to utilize this relationship. Whereas phasor-based elements extract a small portion of the frequency content of the measured current and voltage signals to develop operate and restraint quantities for protection elements, time-domain elements use a much larger portion of the frequency content. Allowing more of the frequency component to pass into the element drastically improves speed. More on these three time-domain elements can be found at [2].

While the UHS relay highlighted in this paper also uses phasor-based elements, even these implement measures to improve speed more than the phasor-based elements found in the traditional relay [3]. Every relay element has its own balance between secure and dependable operation. Using a combination of time-domain and phasor-domain elements allows the UHS relay to be dependable and secure. It also means that we can compare the phasor-based element responses between the UHS and the traditional relays. With this in mind, each operation is analyzed to verify correct operations of the elements available for each faulted scenario considering system topology, operating conditions, and available protection system assets.

II. Information About the Pilot

Entergy utilities generate, transmit, distribute, and sell electric power in parts of Arkansas, Mississippi, Texas, and Louisiana. Their unique footprint along the Gulf Coast serves massive petrochemical complexes, liquid natural gas facilities, refineries, steel mills, and more. The utility has signed service agreements for tens of megawatts of load in 2025 and has more upcoming. Much of the upcoming load will be data center and heavy industrial load. These are often extremely sensitive loads with very low ride-through capabilities, requiring high-speed fault clearing.

At the time of the pilot, one of the utility's largest customers, with over 500 MW of load, was also located in the Gulf South and operated compression turbines set sensitively from the factory, which meant they could not tolerate 30 percent voltage dips during a traditional instantaneous fault-clearing time of 5 cycles. The protection settings for the compression turbines could not be modified while under warranty.

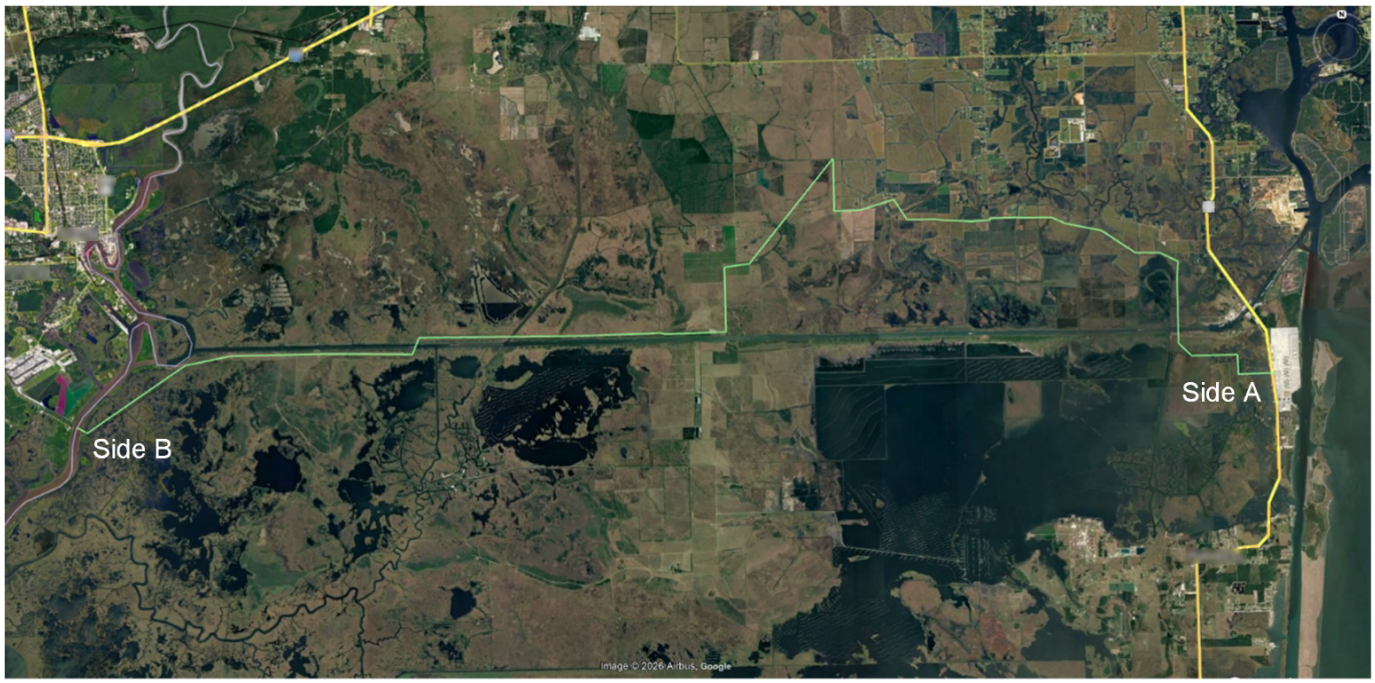

Fig. 1. Satellite Image of 40.64 mi Long Transmission Line

The terrain is mostly marshland (Fig. 1)—remote and almost completely inaccessible by road. The high-voltage lines feeding this customer extend 40 mi, most of which crosses marshland. Because access is limited, patrolling the line requires a combination of trucks, airboats, drones, and helicopters. Providing an accurate distance to fault was critical not only for customer operations but also for utility field crews determining the most efficient patrolling strategy. Helicopter patrols are very expensive. If the distance to fault can be narrowed to a few spans on the transmission line, drones can be deployed, offering exponentially better cost efficiency, greater safety, faster mobilization, and higher inspection detail.

This transmission line also crosses state boundaries, which means an accurate fault location helps determine which crew is responsible for responding. In the utility's experience, traditional impedance-based fault analysis tools can exhibit an error margin of up to 10 percent, which equates to about 4 mi on this line. Such an error margin makes it difficult to effectively use trucks, airboats, or drones because of the number of structures that must be inspected.

Given the location of this line, it is exposed to wildlife, such as birds, as well as severe weather conditions, including hurricanes, lightning, and galloping conductor events. These factors have led to frequent line operations.

Originally, only two lines served this customer. If one was lost due to a planned or unplanned outage, the customer would be fed from a single source, reducing reliability and increasing risk. Risk control strategies to reduce downtime and restore service therefore became extremely important. Time-delayed autoreclose was also enabled on the line under study; it had previously been disabled because it tied into a major generating station at the other end.

The utility has taken several steps over the years to improve reliability, such as installing lightning arresters in 2017, enabling autoreclose, and rebuilding a significant portion of the line following Hurricane Laura in 2020. This rebuild helped introduce fiber technology for protective relays and enabled the use of upgraded telecommunications infrastructure. Communications-assisted distance protection schemes were upgraded to differential protection. Traveling-wave fault locating was deployed to improve distance-to-fault accuracy. In 2021, a line current differential (87L) misoperation caused by channel asymmetry prompted protection engineers to explore improved protection options, initiating discussions for a pilot using UHS line protection as the newest technology available.

As part of this pilot, the utility commissioned UHS line protection relays at both ends of this critical 230 kV transmission line in December 2021 with settings mimicking the traditional line protection as closely as possible, incorporating TD21, a TD32-based permissive overreaching transfer trip (POTT) scheme, and TW87 as well as a phasor-based POTT scheme, step distance, and directional overcurrent. The UHS relays did not replace existing protection and were not wired to trip breakers. This allowed the utility to get experience with the new technology without incurring any risk of relay misoperation. A direct fiber pair was installed between the relays to support the TW87 and POTT schemes, a backup direct fiber pair was installed between the relays to support solely the POTT scheme, and a 1 Gbps fiber connection was provided to the substation network switch to enable remote engineering access from the remote terminal unit. Remote access to the UHS relay was important for fault data collection. Due to the high sampling rate of the UHS relay, the fault records are larger than in traditional relays and can be time-consuming to retrieve via a serial connection.

III. Case Studies

Over the course of the pilot, seven line faults occurred from which valuable lessons were learned about the technology itself as well as settings and design considerations to ensure successful implementation of the technology in standard line panel designs. This section outlines the findings from each operation.

A. Event 1

On January 24, 2023, the transmission line of interest tripped for a Phase-A-to-ground fault. This was the first event on the line after the UHS relay was installed. The differential protection on the traditional relay was unavailable at the time, but we can compare the performance of the UHS relay to that of the traditional relay's POTT scheme. The traditional relay on Side A issued a trip when it received permission from the other side of the line 19 ms after fault inception (Fig. 2). In this figure and all hereafter, the blue signal represents the UHS relay response and the magenta signal represents the traditional relay response. The fault was at 0.055 pu of the 40.64 mi line length from Side B, so the relay on Side B tripped on a Zone 1 mho element (Z1T) 9.5 ms after fault inception.

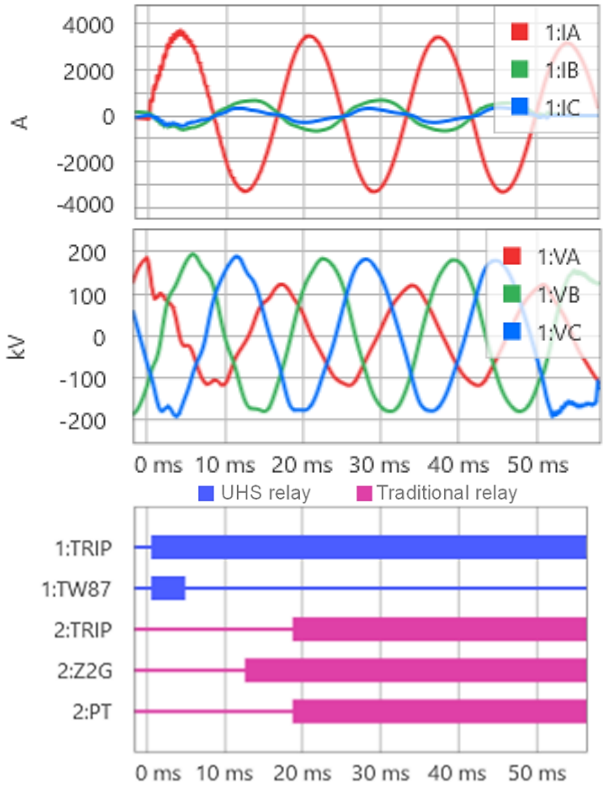

Fig. 2. Event 1 Side A Event Report

The UHS relay on Side A operated on TW87 in 0.8 ms. The UHS relay on Side B operated on the traveling wave-based differential element in 0.6 ms. Because the fault was so close to Side B, the assertion of the TD21 was expected, which we see 1.4 ms after fault inception. The slowest protection element in the UHS relay was almost seven times faster than the in-service phasor-based relay elements (Fig. 3).

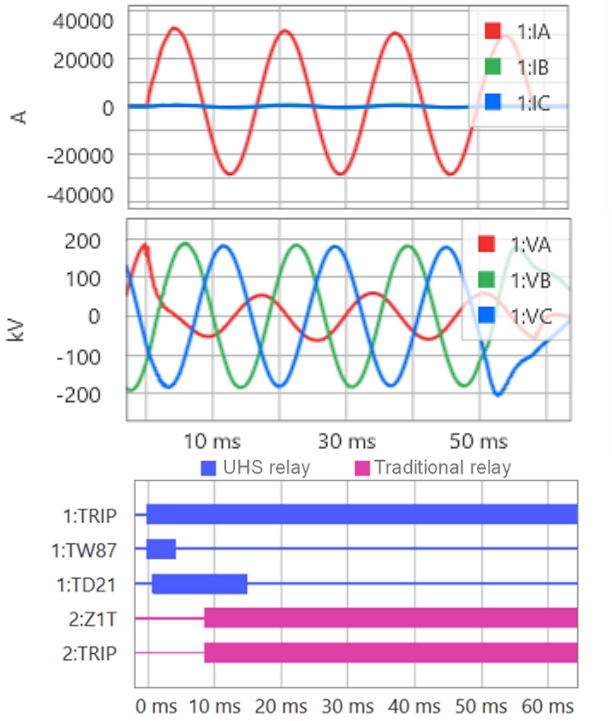

Fig. 3. Event 1 Side B Event Report

The double-ended impedance-based distance to fault from the traditional relay was estimated to be 2.02 mi from Side B, which would be between Structures 23 and 24 on the transmission line. The traveling-wave fault-locating method of the UHS relay gave a distance-to-fault value of 2.405 mi from Side B, which would be between Structures 25 and 26. The line was inspected, and on Structure 25, an insulator supporting the faulted phase was found loosely attached to the pole due to a bolt failure, allowing the faulted phase to move freely. Evidence of contact was not found, but the calculated 2.405 mi point on the line was 834 ft from Structure 25 and 361 ft from Structure 26.

With this physical evidence (Fig. 4), it is clear that all relays operated correctly. More importantly, it shows that the UHS relay gave a more accurate fault location than the impedance-based estimate from the phasor-based relay. It was within 900 ft of the actual fault, which is within one transmission line span.

Fig. 4. Picture of Failed Insulator Support

Immediate operator experience for this event was the same between the phasor-based relay and the UHS relay. Both relays operated and targeted correctly and reported a distance to fault, and retrieval of event data was similar. The higher accuracy of the UHS relay began building operator confidence in the new technology. Relay operation speed and fault location error for Event 1 are summarized in Table I.

TABLE I
RELAY COMPARISON FOR EVENT 1

Relay	Speed (ms)	Fault Location Error (ft)
UHS Side A	0.8	834
UHS Side B	0.6	834
Traditional Side A	19	1,198
Traditional Side B	9.5	1,198

B. Event 2

On April 15, 2023, the transmission line of interest tripped for a Phase-A-to-ground fault. The traditional line protection on Side A operated on a POTT scheme in 16 ms because differential protection was still not available at the time. The traditional relay on Side B operated on Zone 1 distance elements in 8 ms. The exact fault location was not found, but Side B estimated a fault location of 0.15 pu from that terminal so Zone 1 is the element expected to operate.

Operators initially suspected that neither of the UHS relays tripped because there was no event record showing the trip. However, in events that were captured shortly after the operation, they observed that front-panel targets were recorded displaying a POTT scheme trip. Upon investigation of the UHS relays, they found that the relays were repeatedly triggering events around the time of the fault such that the tripping event trigger in each relay could not be used to create a record. In a typical digital relay architecture, it takes longer to archive an event record in permanent memory than it does to take the initial recording so excessive event triggering poses a risk that more recordings may be requested than can be recorded and archived, as occurred in this instance. In any protection scheme, care should be taken to avoid event triggers that can chatter. The event trigger equation was found to be populated with a traveling-wave disturbance detector (TWDD) that was chattering when this fault took place. Unfortunately, without records of the trips themselves, we cannot say which elements drove the POTT scheme trip or what the operating speed was.

The TWDD bit was used during commissioning so the relay could trigger an event for a breaker closing to energize the line. It is not intended for use on an in-service line because it can be triggered by normal power system events, such as load fluctuations or switching at neighboring stations. It was observed that TWDD did not always chatter but exhibited more activity under lighter loading. As such, the inclusion of this word bit in the event trigger equation did not always prevent data collection, such as in the first event. The lesson learned from this event was that in the UHS relay, a final step in commissioning should be to remove TWDD from the event trigger equation for stable and reliable event triggering under any condition. While it did not affect this particular operation, the UHS relays had a chattering pole-open indication around the time of this event. The time-domain elements in these relays require that all poles be closed prior to a fault for the elements to operate. It was therefore recommended that the utility add the breaker status to the UHS relay. Without 52A, the relay uses only current to declare pole status to arm time-domain elements. When loading is light, the relay can declare pole open and disable the time-domain elements. Masking this bit with 52A would qualify the pole-closed condition even under light load.

The utility identified lightning activity near the location reported by the traditional relays using software and a sensor network specialized to this purpose. However, the exact location of the fault was never found. Relay operation speed and fault location error for Event 2 are summarized in Table II.

TABLE II
RELAY COMPARISON FOR EVENT 2

Relay	Speed (ms)	Fault Location Error
UHS Side A	Not Available	Not Available
UHS Side B	Not Available	Not Available
Traditional Side A	16	Not Determined
Traditional Side B	8	Not Determined

C. Event 3

The third event on the line took place on June 5, 2023. The traditional relays tripped the line with Phase-A-to-ground targets. Differential protection was not available in the traditional relays at the time. The traditional relays operated on Zone 1 mho elements from both sides, as the fault was close to the middle of the line. The relay on Side A operated in 16 ms (Fig. 5). Event reports from the relay on Side B were not available at the time of writing.

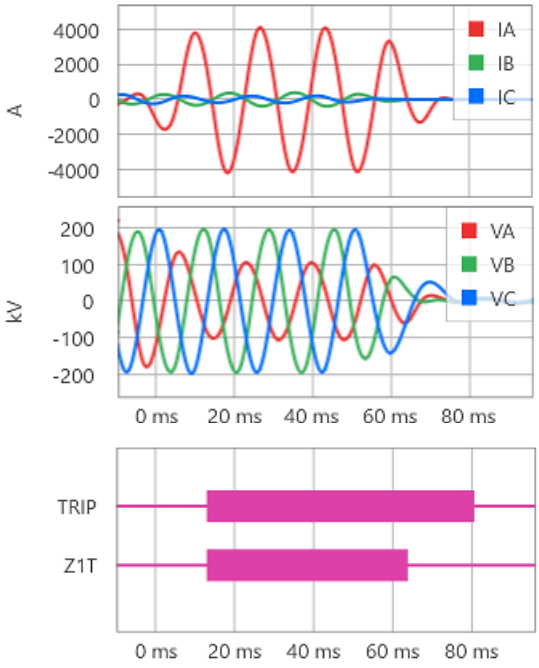

Fig. 5. Event 3 Side A Event Report (Traditional Relay)

The UHS relays on both sides tripped on a POTT scheme driven by TD32 in 1.5 ms. TW87 was enabled, but it did not operate for this fault, as not all of its supervisory conditions were met. The TD32 in this case provided additional dependability with the benefits of UHS relaying (Fig. 6).

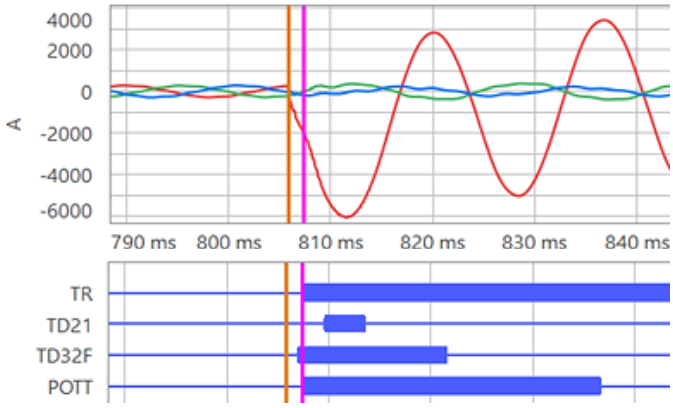

Fig. 6. Event 3 Side A Event Report (UHS Relay)

The traditional relay reported a distance to fault of 26.35 mi from Side A and 11.33 mi from Side B. The UHS relays reported a distance to fault of 27.51 mi from Side A and 13.31 mi from Side B. One very large lightning strike was detected very close to the line at a location 27.34 mi from Side A (Fig. 7). This is within one span of the location reported by the UHS relay, and the utility assumed it was the true location of the fault in this analysis. As such, it was also expected and confirmed that the TD21 elements at each end also operated just after the TD32-based POTT scheme issued a trip (Fig. 6). Relay operation speed and fault location error for Event 3 are summarized in Table III.

TABLE III
RELAY COMPARISON FOR EVENT 3

Relay	Speed (ms)	Fault Location Error (ft)
UHS Side A	1.5	898
UHS Side B	1.5	53
Traditional Side A	16	5,227
Traditional Side B	Not Available	10,400

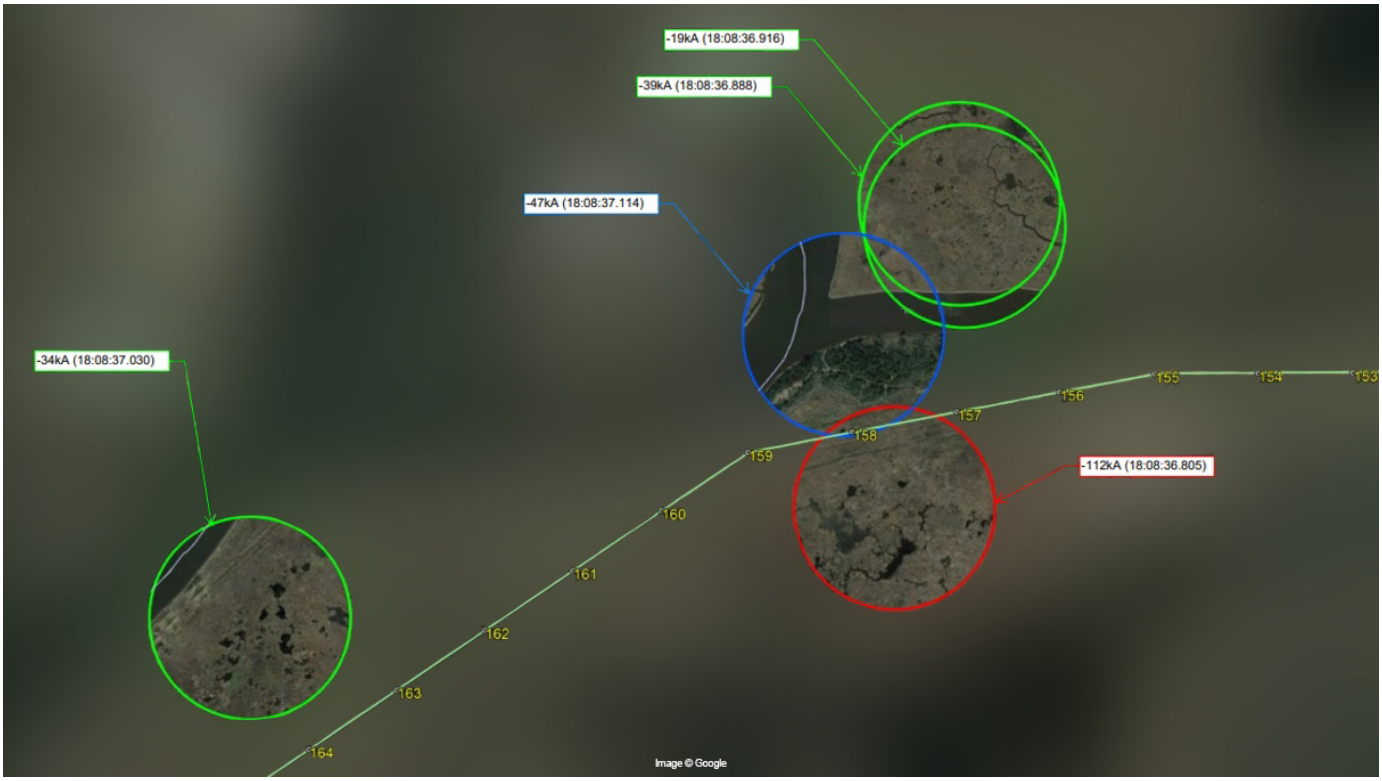

Fig. 7. Visualization of Lightning Activity for Event 3

D. Event 4

The fourth event on the line took place on December 16, 2023. Differential protection was not available in the traditional relays at the time of the event. The traditional relays tripped the line with Phase-A-to-ground targets. The relay on Side A tripped on Zone 1 mho elements in 23.2 ms (Fig. 8). The relay on Side B tripped on Zone 1 mho elements in 12.5 ms (Fig. 9).

The UHS relay on Side A tripped on a POTT scheme driven by phasor-based mho elements in 14.4 ms (Fig. 8). On Side B, the UHS relay tripped on the POTT scheme after receiving permission to trip in 14.9 ms but the phasor-based Zone 1 mho element asserted just after, at 15.2 ms. The TD21 elements did not operate on either end, even though the fault was found at 0.23 pu of the line length from Side B, which is within TD21 reach from both sides. Neither the TW87 or TD32 asserted either (Fig. 9). It was determined that the pre-fault load current was too low to arm time-domain elements in the absence of a 52A auxiliary contact to establish pole status. The risk of not using a 52A contact, as identified in Event 2, proved to be a valid concern in this event.

The traditional relays gave a fault location of 28.77 mi from Side A and 7.73 mi from Side B using a double-ended impedance-based distance-to-fault calculation. The UHS relay on Side A calculated a traveling-wave distance to fault of 31.11 mi, and the UHS relay on Side B calculated a traveling-wave distance to fault of 9.53 mi.

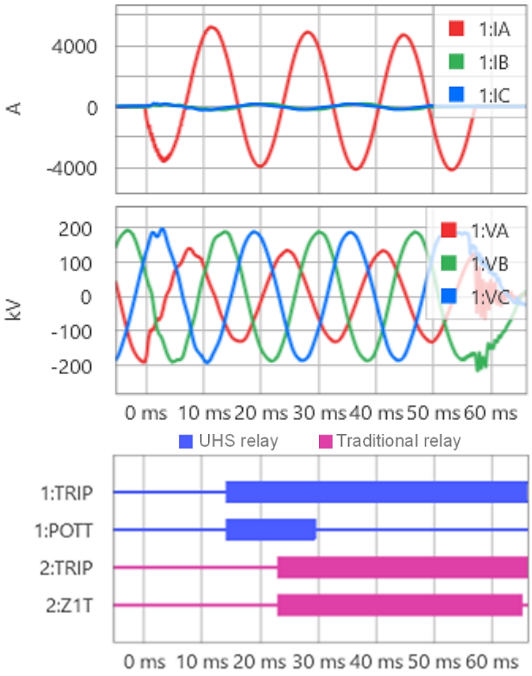

Fig. 8. Event 4 Side A Event Report

Transmission line inspection revealed a damaged suspension insulator 31.25 mi from Side A that appears to have allowed a conductor contact with the tower. A picture of the damaged insulator can be seen in Fig. 10. This event demonstrates the dependability offered in a UHS relay that also employs phasor-based elements, but it also underscores the importance of presenting the relay with the most complete power system information available by connecting a breaker status auxiliary. Relay operation speed and fault location error for Event 4 are summarized in Table IV.

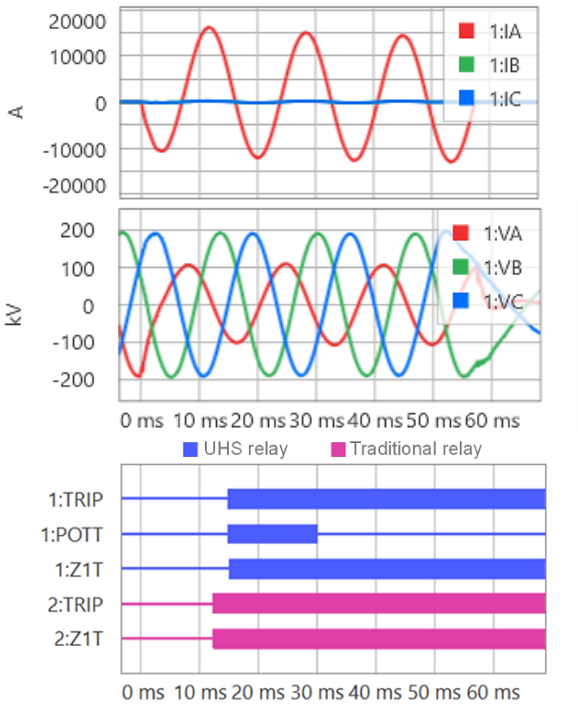

Fig. 9. Event 4 Side B Event Report

Fig. 10. Suspension Insulator Broken in Half

TABLE IV
RELAY COMPARISON FOR EVENT 4

Relay	Speed (ms)	Fault Location Error (ft)
UHS Side A	14.4	739
UHS Side B	14.9	739
Traditional Side A	23.2	13,094
Traditional Side B	12.5	8,770

E. Event 5

The fifth event took place on April 10, 2024. The traditional relays tripped the line with Phase-A-to-ground targets. Differential protection was still not available in the traditional relays. Oscillography shows that the fault evolved to include Phase B before it was cleared. The traditional relay on Side A operated on Zone 1 mho elements in 13.5 ms (Fig. 11). The traditional relay on Side B operated on Zone 1 mho elements in 21.5 ms.

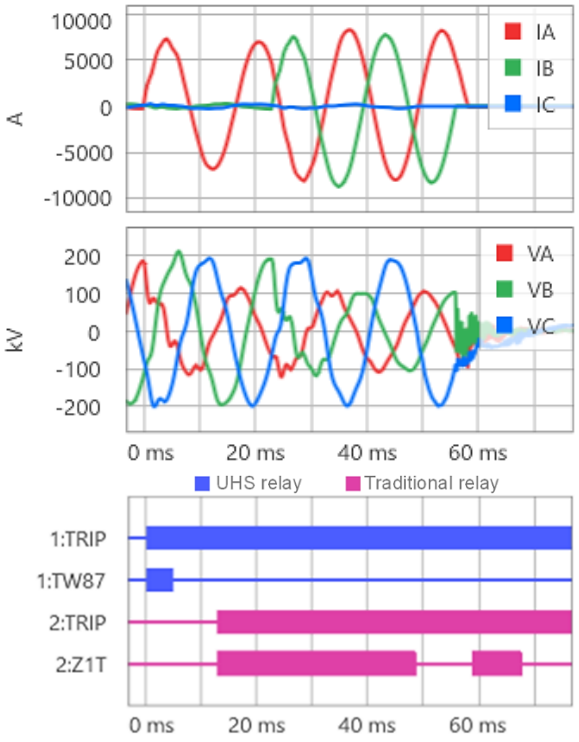

Fig. 11. Event 5 Side A Event Report

The UHS relays operated on TW87 as expected. The relay on Side A operated in 0.7 ms (Fig. 11). The relay on Side B did not record a tripping event because TWDD was still included in the event trigger equation. As such, the operate time from Side B is unknown.

The fault location from the traditional relay on Side A was 15.85 mi using a double-ended impedance-based distance-to-fault calculation. From Side B, the same calculation gave a distance to fault of 22.5 mi. The UHS relay on Side A gave a distance to fault of 15.976 mi. The actual fault location is not known, as line inspection did not reveal any damage. Numerous instances of lightning activity were detected along the entire length of the line around the time of the fault. Relay operation speed and fault location error for Event 5 are summarized in Table V.

TABLE V
RELAY COMPARISON FOR EVENT 5

Relay	Speed (ms)	Fault Location Error
UHS Side A	0.7	Not Determined
UHS Side B	Not Available	Not Determined
Traditional Side A	13.5	Not Determined
Traditional Side B	21.5	Not Determined

F. Event 6

The sixth event on this line took place on August 22, 2025. The traditional relays operated with Phase-A-to-ground targets. Differential protection in the traditional relays was enabled during this fault, and both sides operated in 13 ms. This event is unique in that we can compare the phasor-based differential to the TW87. Note that Fig. 12 shows Side A and Fig. 13 shows Side B.

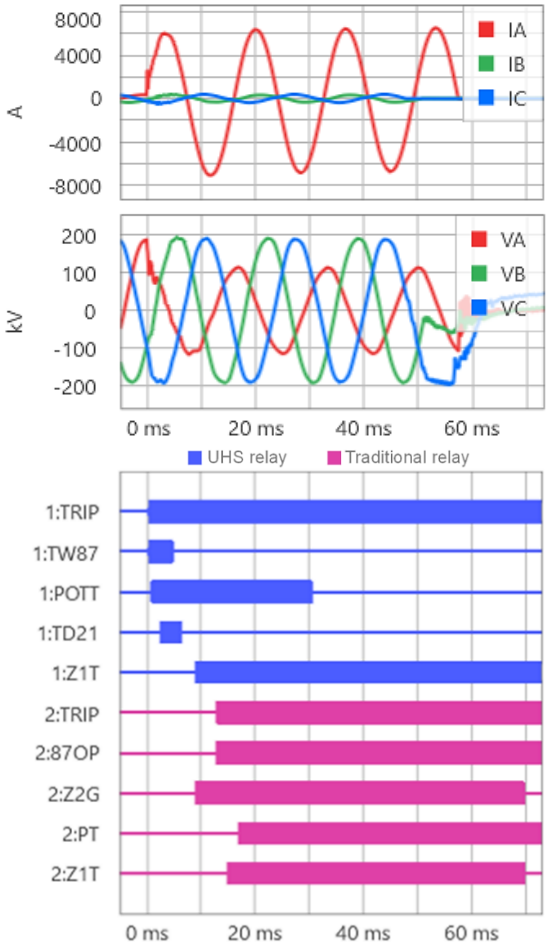

Fig. 12. Event 6 Side A Event Report

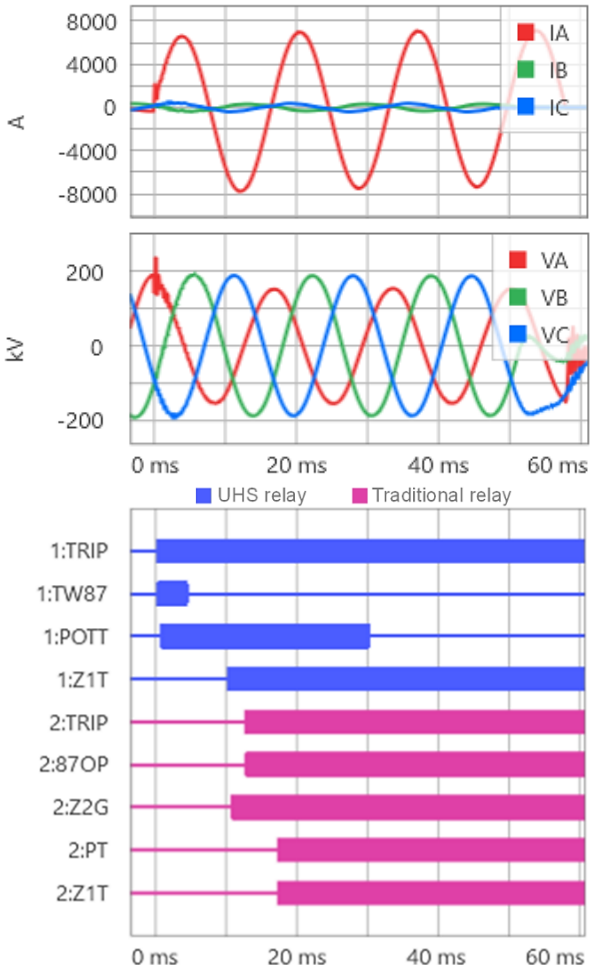

Fig. 13. Event 6 Side B Event Report

For the UHS relays, TW87 was available. Both sides of the line operated as expected in 0.7 ms. This is almost twenty times faster than the traditional differential relay.

We can compare the POTT scheme operation as well as the distance-based elements. The traditional relay on Side A would have operated on its Zone 1 mho element in 15.5 ms, with its POTT scheme operating shortly after, in 17.5 ms. The POTT scheme would have operated in 18 ms on Side B. In the UHS relay, the POTT scheme driven by TD32 would have operated in 1.2 ms on Side A and 1.6 ms on Side B.

Finally, we can compare what would have happened if there had been no communications on the line at all. For the traditional relays, Side A would have operated in 15.5 ms on a Zone 1 distance element. Side B would have operated in 18 ms on a Zone 1 distance element. For the UHS relays, TD21 on Side A operated in 2.8 ms. The relay on Side B did not pick up on TD21. TD21 is designed for speed and security and, as such, may not pick up for all faults within the set reach. The Side B UHS relay would have tripped on a Zone 1 mho distance element after 11 ms, still offering dependable protection faster than the same kind of element in the traditional relay. This difference is in part due to the UHS relay using an adaptive filter window. Whereas a traditional microprocessor relay uses a fixed filter window, the UHS relay can change the filter window size to include only fault information. This can allow for faster relay response times. More about this topic can be found in [3].

The traditional relays reported a distance to fault of 28.12 mi from Side A with traveling-wave fault locating. The relay on Side B reported 12.71 mi from that side via traveling-wave fault locating as well. The UHS relay reported a distance to fault of 28.001 mi from Side A and 12.632 mi from Side B. The actual fault location is not known, as line inspection did not reveal any damage. Relay operation speed and fault location error for Event 6 are summarized in Table VI.

TABLE VI
RELAY COMPARISON FOR EVENT 6

Relay	Speed (ms)	Fault Location Error
UHS Side A	0.7	Not Determined
UHS Side B	0.7	Not Determined
Traditional Side A	13	Not Determined
Traditional Side B	13	Not Determined

G. *Event 7*

The seventh event on this line occurred on February 2, 2026. This was another Phase-A-to-ground fault that evolved to include Phase B. Oscillography shows that the fault started to evolve on the initial trip. Operators manually reclosed the line from Side A 2 minutes after the trip and closed into a Phase-A-to-Phase-B-to-ground fault. The analysis for this event focuses on the relay performance at reclose.

The line was reclosed from Side A. The traditional relay operated on switch-onto-fault (SOTF) elements in 15.8 ms (Fig. 14). SOTF logic enables select relay elements to trip for a short time window after a breaker is closed. It is common practice to include an overreaching Zone 2 mho element in the SOTF scheme such that it can quickly trip the line if it is re-energized onto a fault. This is the element that picked up in this case.

The UHS relay has the same ability to define relay elements to trip for an SOTF condition. This pilot relay was set with the same philosophy as the traditional relay, including a phasor-based Zone 2 mho element, voltage-controlled overcurrent, and a high-set overcurrent element in the SOTF equation. But when the Side A breaker was reclosed, the UHS relay did not call for a trip until its phasor-based Zone 2 mho element tripped 33.2 ms after the close, which was longer than the utility expected for an SOTF operation. TW87, TD32, and TD21 are not expected to operate for an SOTF condition because they would not have been armed prior to breaker closure. The fault current was lower than the high-set overcurrent threshold, and the voltage depression was not low enough to permit the voltage-controlled overcurrent to operate.

We see a different response because of a difference in how the polarizing voltage is applied. The traditional relay uses positive-sequence memory voltage that is calculated by applying an infinite-impulse response filter to measure positive-sequence voltage. The resulting quantity creates an excellent polarizing quantity for mho elements when used with traditional sources. More on this topic can be found in [4]. The traditional relay is always calculating the positive-sequence

memory voltage and, as a result, makes use of it almost immediately after line energization, even when using line-side potential transformers (PTs). Conversely, the UHS relay uses a phase-locked loop (PLL) for polarization. This quantity is dynamically calculated based on system conditions. Before the relay can use any polarization, it must see steady-state conditions before locking a polarizing quantity. This leads to a stable memory-polarizing voltage for a wide variety of system dynamics and types of sources but also introduces some delay to elements dependent on it following line energization with line-side PTs.

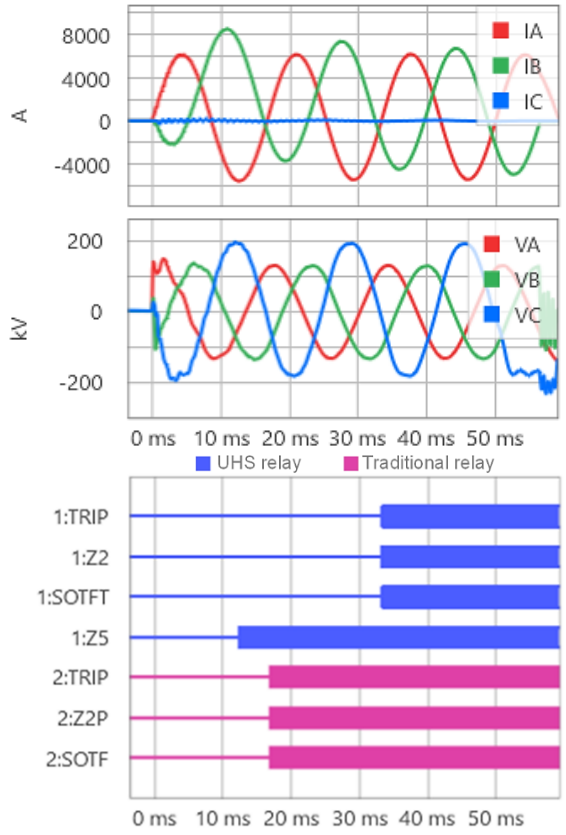

Fig. 14. Event 7 Side A Event Report

The solution to this in the UHS relay under study is to use a self-polarized mho element set to overreach the protected line instead of a memory-polarized mho element. In simpler terms, the measured voltage should be used instead of the output of the PLL as the polarizing quantity for the mho element. The Z5 element in this relay is self-polarized. The Z5 element was set for this relay, and Fig. 14 shows that it does operate much faster, even faster than the Z2 element in the traditional relay. The exact operate time of that element was 12.5 ms. More on relay element response to SOTF conditions can be found in [5].

The traditional relay reported a distance to fault of 30.35 mi for the initial trip, then reported 31.60 mi for the reclose. This is a discrepancy of 1 mi between the reported distances. The UHS relay reported 30.20 mi for the initial fault and then 30.25 mi for the reclose.

On the initial fault, the traditional relay used double-ended traveling-wave fault locating so the distance to fault was similar to that reported by the UHS relay. On the reclose, the line was single-ended so the traditional relay could not use double-ended traveling-wave fault locating and it did not support single-ended traveling-wave fault locating. Thus, the method used on the reclose was single-ended impedance, which is known to be less accurate. The UHS relay did support single-ended traveling-wave fault locating. The actual distance to fault was found to be 30.35 mi from Side A. The UHS relay can more accurately measure the distance to fault on a single-ended line. Table VII reflects the reclose.

TABLE VII
RELAY COMPARISON FOR EVENT 7

Relay	Speed (ms)	Fault Location Error (ft)
UHS Side A	33.2	528
Traditional Side A	15.8	6,600

IV. SUMMARY OF LESSONS LEARNED

Section III presented a comparative analysis of relay performance across seven fault scenarios evaluated over a three-year operational period. Progressive refinement of relay settings and logic elements, informed by operational events, has enhanced the extraction of actionable data from UHS protective relays.

A. Speed of Operation

UHS relays are incredibly fast. As noted in Section III, they were sometimes even 20 times faster than phasor-based relays. Submillisecond operations were observed in three instances. Speed of operation provides several advantages:

- Faster clearing times on a transmission line can allow more operational flexibility [6].
- Protection speed affects the safety of the public and utility personnel, equipment wear, and power quality [7].
- The reduction in fault-clearing time directly decreases voltage sag duration, addressing the stringent voltage ride-through requirements of sensitive industrial loads, as mentioned in Section II. UHS protection schemes facilitate market competitiveness, positioning utilities to capture growing segments of power quality-sensitive customers, like heavy industry, independent power production, and data centers.
- UHS relays can allow flexibility for utilities to purchase circuit breakers or execute projects. When critical clearing time is tight, utilities often pay a premium to purchase 2-cycle circuit breakers to satisfy stability requirements. However, lead time and cost of 2-cycle circuit breakers could be a risk or critical path for project execution. In these circumstances, utilities may be able to use UHS relaying with 3-cycle circuit breakers to meet the same critical clearing time requirements.

B. Correctness of Operation

The UHS relay elements behaved as expected for system conditions and topology but did demonstrate that time-domain elements are intentionally biased for speed and security instead

of perfect dependability. Therefore, a complete UHS relay requires dependable phasor-based protection elements operating in parallel with the time-domain elements. The utility also plans to move forward with this approach, working to standardize a panel employing a combination of traditional and UHS relays. This method results in excellent average operating times of the complete application and improved dependability.

C. Fault Location Accuracy

Actual fault location was identified for only four (1, 3, 4, and 7) of the seven faults. UHS relays using traveling-wave fault-locating methods provided more accurate locations than the impedance-based fault-locating methods used by the traditional relay. The UHS relay estimated the distance to fault to within a tower span in all cases, which helped the operations team in the field make more informed decisions on patrols (helicopter versus airboat versus drone), saving operations and maintenance costs. This also reduces restoration time and improves the customer experience. Impedance-based fault-locating methods exhibited an error margin of up to 13,000 ft in this case study. The distance-to-fault-location accuracy of the UHS relays was within 1,000 ft. Results from this pilot are so promising that the utility is considering using the UHS relays as the primary source of measuring the distance to fault. Even though the traditional relay offered traveling-wave fault location estimates, the UHS relay offered traveling-wave fault location estimates under more scenarios, including SOTF conditions.

D. Operator Experience

Any trip on this line is considered operationally critical because it leaves a large, critical customer fed radially from the transmission system. UHS relays gather event information at a higher sampling rate, helping engineers better understand relay operation, resolve issues more quickly, and restore the circuit with greater confidence. However, this requires enhanced network connectivity to relays. The ability to connect to relays remotely allows operators to take advantage of immediate access to data and event files. Additional information gathered by UHS relays helps when analyzing relay operations in greater detail, facilitating root-cause analysis and reducing the number of "unknown cause" codes for NERC PRC-005 analysis. This reduces possible compliance violations with better monitoring and data, resulting in an improved experience with customers and regulators.

V. Conclusion

This pilot provides further validation that UHS relays do offer a speed advantage over traditional relays. This is especially beneficial near generating stations and large industrial customers. Additionally, traveling-wave distance to fault from UHS relays was shown to be more accurate than the impedance-based distance to fault from the traditional relays. The utility considers this the preferred source of distance to fault.

The case studies highlighted that UHS relays must still include phasor elements to maximize dependability. Using a combination of UHS relays and traditional relays on a line panel provides diversity of hardware, diversity of principle, and maximized dependability for the overall protection of one asset.

The case studies also show some lessons learned on setting a UHS relay. SOTF performance should be included in the relay evaluation to determine the optimal elements to use. Engineers should understand how pole-open conditions affect dependability of current-based protection elements and determine if breaker status connected to the relay can improve dependability. Commissioning of traveling-wave technology benefits from event triggering during a line energization test using a sensitive disturbance detector, but this must be removed before putting the relay using this technology in service.

VI. Acknowledgments

The authors gratefully acknowledge the contributions of Dr. Milton Quinteros for his work on this pilot project, from its inception to the writing of this paper. Also thank you to Danny Myers and Brensen Stevens from Entergy who were among the first to respond when there was a fault on this line.

VII. References

[1] F. Shanyata, S. Sharma, D. Joubert, R. Kirby, and G. Smelich, "Field Experience With Ultra-High-Speed Protection, Traveling-Wave Fault Locating, and Circuit Breaker Reignition Detection on a 220 kV Line in the Kalahari Basin," proceedings of the PAC World Global Conference 2021, virtual format, August–September 2021.

[2] E. O. Schweitzer, III, B. Kasztenny, M. Mynam, A. Guzmán, and V. Skendzic, "New Time-Domain Line Protection Principles and Implementation," proceedings of the 13th International Conference on Developments in Power System Protection, Edinburgh, United Kingdom, March 2016.

[3] B. Kasztenny, M. V. Mynam, T. Joshi, and C. Daniels, "A New Digital Filter Using Window Resizing for Protective Relay Applications," proceedings of the 15th International Conference on Developments in Power System Protection, Liverpool, United Kingdom, March 2020.

[4] E. O. Schweitzer, III, "New Developments in Distance Relay Polarization and Fault Type Selection," proceedings of the 16th Annual Western Protective Relay Conference, Spokane, WA, October 1989.

[5] R. Poduval, R. McDaniel, and S. Dasgupta, "Switch Onto Fault: Maintaining Dependability, Security, and Speed," proceedings of the 47th Annual Western Protective Relay Conference, virtual format, October 2020.

[6] R. B. Eastvedt, "The Need for Ultra-Fast Fault Clearing," proceedings of the 3rd Annual Western Protective Relay Conference, Spokane, WA, October 1976.

[7] E. O. Schweitzer, III, B. Kasztenny, A. Guzmán, V. Skendzic, and M. V. Mynam, "Speed of Line Protection – Can We Break Free of Phasor Limitations?" proceedings of the 41st Annual Western Protective Relay Conference, Spokane, WA, October 2014.

VIII. Biographies

Ram Viswanathan has an MS degree in electrical engineering with a specialization in electric power and energy systems. He is an active member of IEEE and North American Transmission Forum (NATF). He has over 10 years of experience in relay protection working for Entergy Services, LLC in various engineering roles.

Andrew Jenkins joined Entergy Services, LLC as a protection and controls engineer in 2019. Andrew has specialized in protective relay settings development, supporting transmission systems and distribution networks through the analysis, configuration, and coordination of protective relays. Andrew's professional interests include power system protection, substation automation, IEC 61850 applications, and the continued modernization of the grid. Andrew earned his BSEE from LSU New Orleans, formerly known as University of New Orleans.

Monir Hossain joined Entergy Services, LLC as a relay settings engineer in 2019. He also worked for the Entergy transmission standards group, as well as the testing and commissioning group. Monir was involved in developing various protection standards and automating relay testing for Entergy. Currently, he is working as a senior staff engineer for large capital projects. Before joining Entergy, Monir was working in transmission planning, SCADA operation, and grid maintenance for other utilities. He earned his PhD in electrical engineering from LSU New Orleans, formerly known as University of New Orleans.

Tu Nguyen has a BSEE from LSU New Orleans, formerly known as University of New Orleans, and has over 35 years of experience with Louisiana Power & Light (LP&L) and Entergy as a commissioning engineer, relay design engineer, and protection application engineer. He has been an IEEE member since 1990.

Brennen Acosta joined Schweitzer Engineering Laboratories, Inc. (SEL) as an application engineer in 2023. He previously worked for Entergy Corporation as a relay field operations support engineer. He earned his BSEE degree from LSU New Orleans, formerly known as University of New Orleans.

Jeremy Blair, PE, joined Schweitzer Engineering Laboratories, Inc. (SEL) as an application engineer in 2013. He previously worked for Entergy Corporation as a distribution planning engineer with responsibilities in distribution system planning, protection, power quality, and automation in Baton Rouge, Louisiana. He also managed Entergy's Automatic Load Transfer and Sectionalization Program over its four-state territory. Jeremy earned his BSEE from Louisiana Tech University and his MSECE from Georgia Institute of Technology. He is a licensed professional engineer in the state of Louisiana.

© 2026 by Entergy Corporation and
Schweitzer Engineering Laboratories, Inc.
All rights reserved.
20260915 • TP7270-01