Fault Investigation and Analysis for

Entergy's Sullivan Substation

May 20th and June 18th Voltage Depressions

New Orleans, LA

July 2026

EXECUTIVE SUMMARY

Between May 20th and June 18th, four separate "act of nature" events occurred on Entergy's transmission system serving Sullivan Substation. These events caused short-duration (1/12th of a second) voltage sags at Sullivan Substation. Each event resulted in a short circuit which was cleared by Entergy's automated high speed protective equipment. Entergy's equipment operated consistent with applicable industry requirements for maintaining power quality. Although the delivered power met industry requirements, the Sewerage & Water Board of New Orleans' system operation was disrupted. A properly designed system should have been able to continue running uninterrupted for the experienced voltage sag.

Table of Contents

I. Introduction to Analysis

To better understand the contents of this report, this section has been included to better explain how the analysis on each event was conducted.

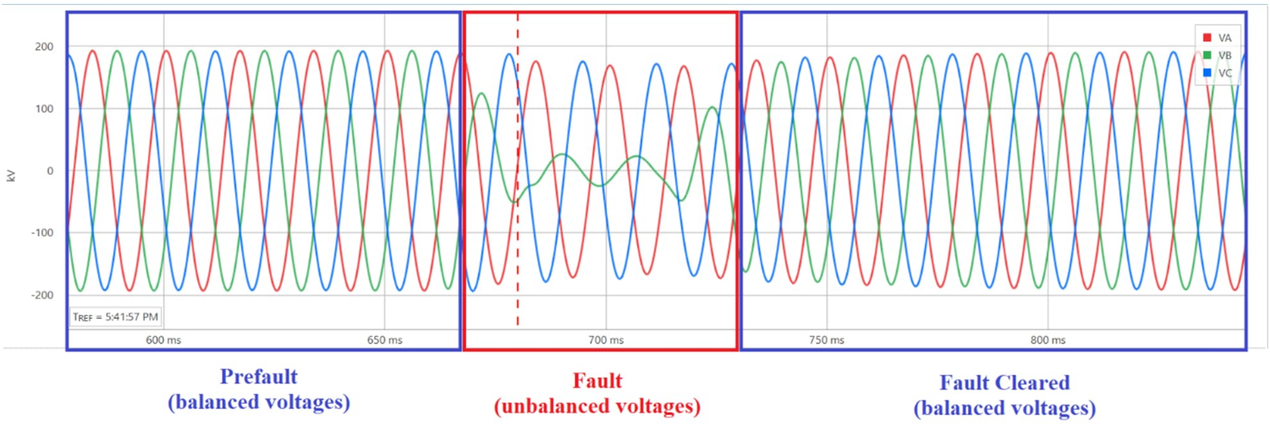
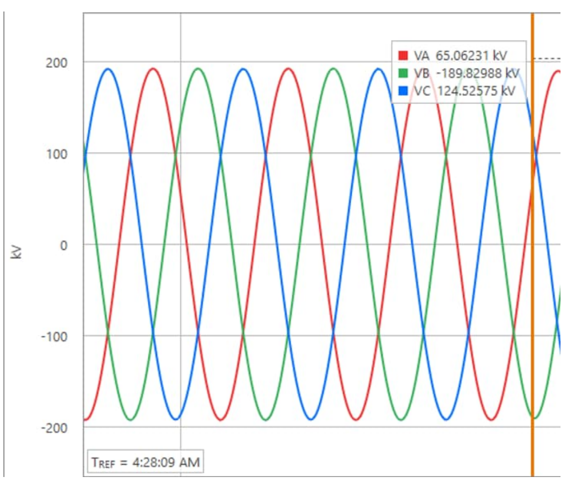
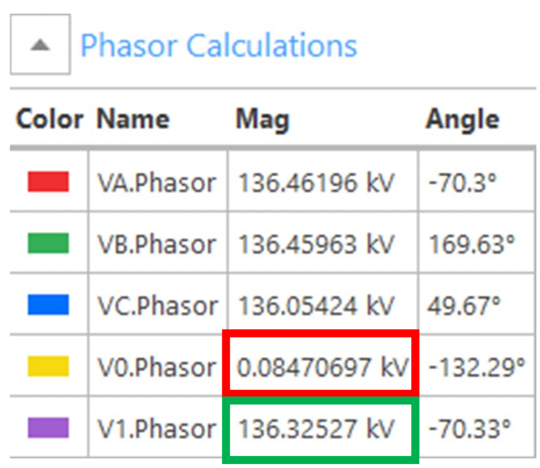


Figure 1.1

Figure 1.1 shows the propagation of a power system ground fault with the prefault, faulted, and post-fault conditions identified.

Zero-Sequence Voltage, denoted as $\mathbf{V_0}$, is the summation of all three phase voltages in a three-phase electrical system. When a system is balanced, as shown in Figure 1.2 below, zero-sequence voltage is effectively zero (boxed in red). This is a normal operating condition.



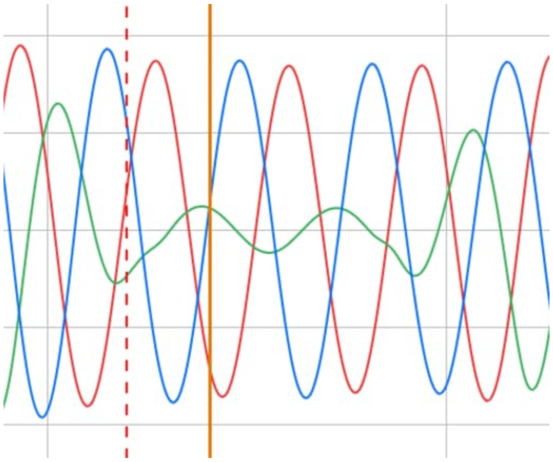


Phasor Calculations

Color	Name	Mag	Angle
	VA.Phasor	136.46196 kV	-70.3°
	VB.Phasor	136.45963 kV	169.63°
	VC.Phasor	136.05424 kV	49.67°
	V0.Phasor	0.08470697 kV	-132.29°
	V1.Phasor	136.32527 kV	-70.33°

Figure 1.2

During a ground fault condition, such as Figure 1.3 below, unbalanced voltage conditions lead to zero-sequence voltage increasing (boxed in red).



Phasor Calculations

Color	Name	Mag	Angle
	VA.Phasor	121.26503 kV	148.21°
	VB.Phasor	17.181782 kV	22.32°
	VC.Phasor	125.52505 kV	-79.33°
	V0.Phasor	27.670097 kV	-140.37°
	V1.Phasor	87.38315 kV	153.75°

Figure 1.3

In a ground fault situation, zero-sequence voltage is the quantity that describes the severity of the fault in relation to unfaulted conditions. The larger the zero-sequence voltage, the more severe the ground fault condition is.

Under normal operating conditions (an unfaulted system), the three phase system voltages are equal in magnitude. **Positive-Sequence Voltage**, denoted as $\mathbf{V_1}$, describes these three voltages as a single magnitude.

In Figure 1.2, the magnitude of positive-sequence voltage (boxed in green) is equivalent to the magnitude of any single, balanced phase voltage. In Figure 1.3, the magnitude of the positive-sequence voltage (boxed in green) is reduced because of the ground fault condition. Deviation in positive-sequence voltage is relevant for this study because it represents a voltage depression below normal levels and subsequent recovery that is measurable over time.

This document is an analysis of the event reports from protection relays in Sullivan substation provided by Entergy. These relays monitor the voltage waveforms of transmission lines carrying 230,000 volts (230 kilovolts). The point of delivery to the customer at Sullivan Substation, however, is 24 kilovolts (24 kV). It is critical to keep in mind that the voltage depressions as a percentage seen on the 230kV (high) side of Sullivan Substation happen simultaneously as the ones seen on the 24kV (low) side but are not equivalent in magnitude.

There are many reasons why this phenomenon may present itself, but the foremost reason in the case of Sullivan Substation is the transformers that transform the 230kV voltage to 24kV are arranged in a delta-wye configuration. This arrangement creates a balancing effect between the phases on the high side, reducing the magnitude of voltage drops on the low side of the transformer and thus providing better voltage stability to the connected customer. This effect will be shown in the event report analysis portion of this document.

In analyzing power system faults, it is also useful to understand the concept of cycles when referring to AC power. Figure 1.4 below shows a single electrical cycle between the two cursors. The standard frequency of AC power in the United States is 60Hz, or 60 cycles per second. This means that each electrical cycle is about 16.67 milliseconds in duration. It is useful to reference time in terms of cycles in the electrical power industry, since equipment operation time is most effectively measured in how many electrical cycles it takes to react.

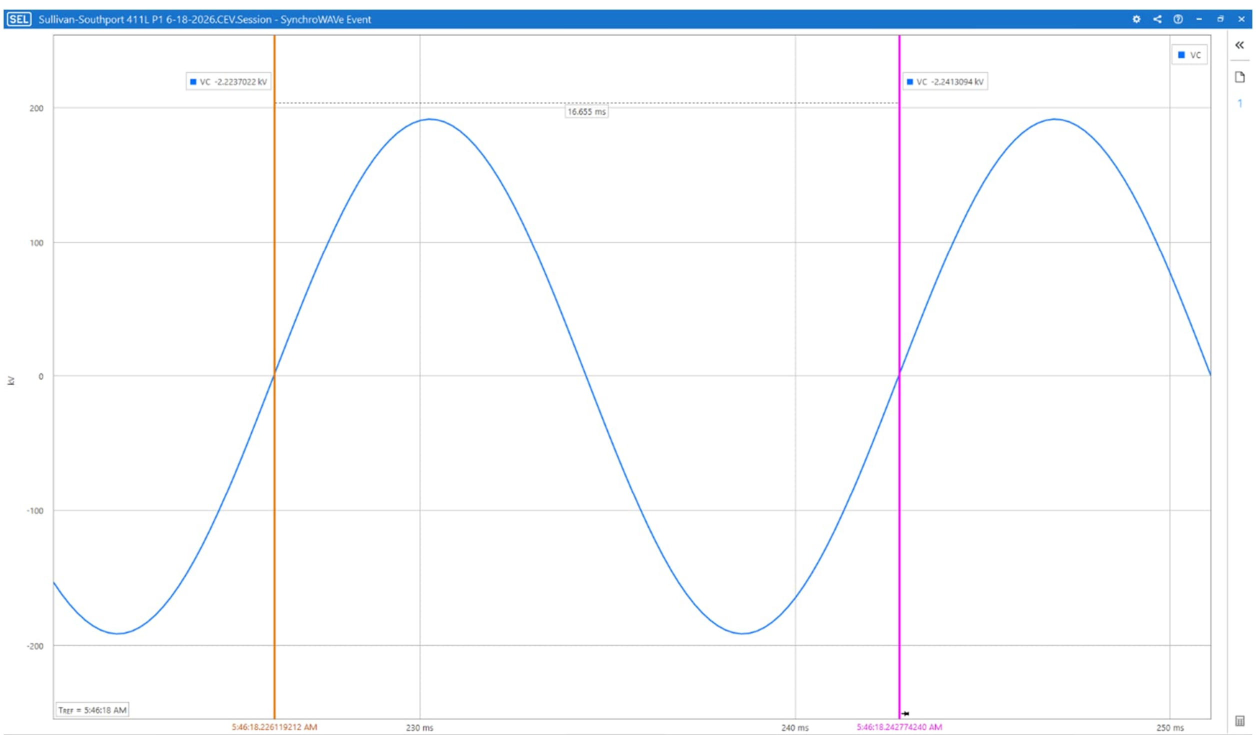


Figure 1.4

II. May 20th, 4:28AM Event Analysis:

Duration of voltage depression

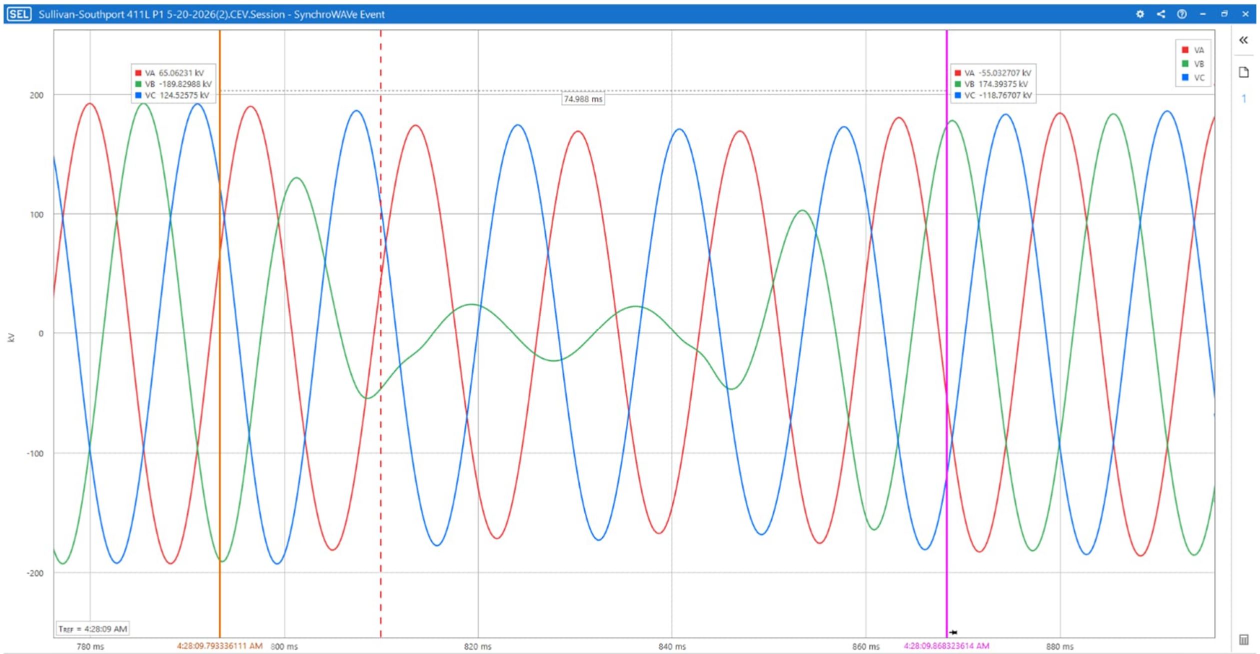


Figure 2.1

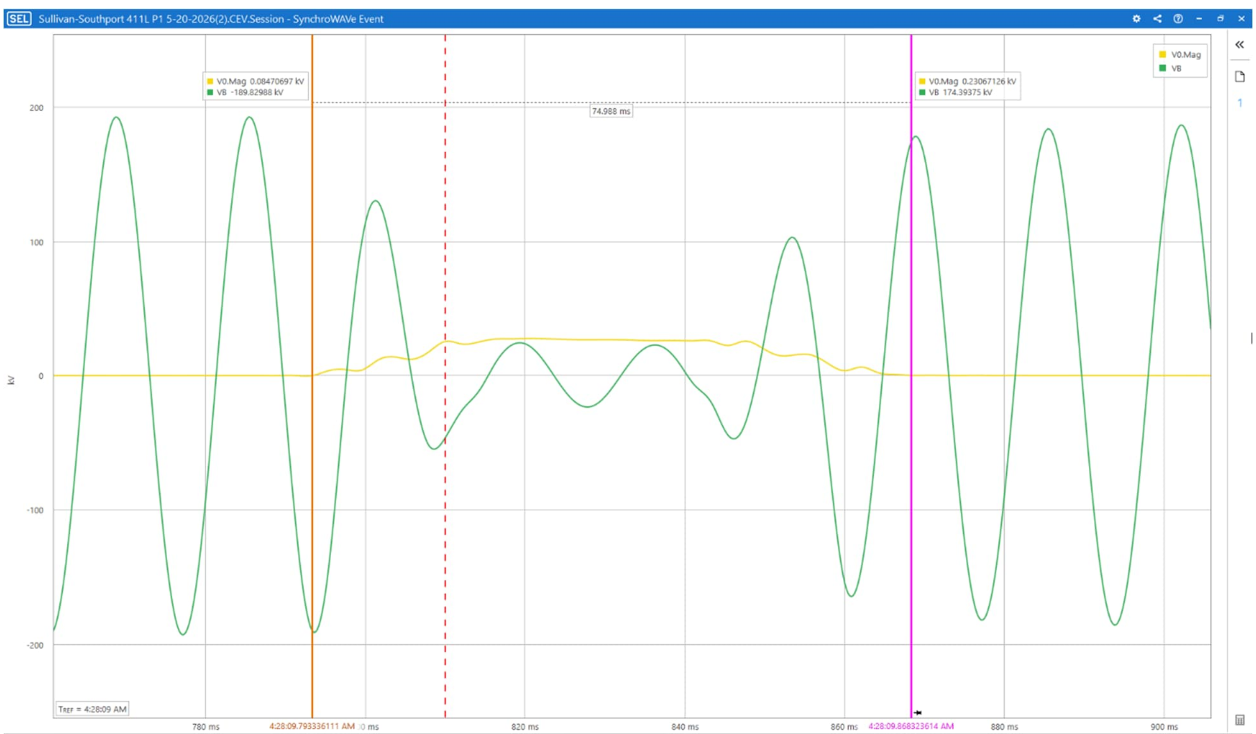


Figure 2.2

- o Figure 2.1 shows an oscillograph of the voltage depression seen at the time of the event.
- o Figure 2.2 shows an oscillograph with the faulted phase and zero-sequence voltage, V_0, plotted together.
- o Measuring the amount of time that V_0 was greater than "effectively zero" allows the duration of the event to be measured in its entirety.
  - ▪ The duration of the event was 74.988 milliseconds, 0.075 seconds, or 4.49 cycles.

Voltage phasor diagram and oscillograph

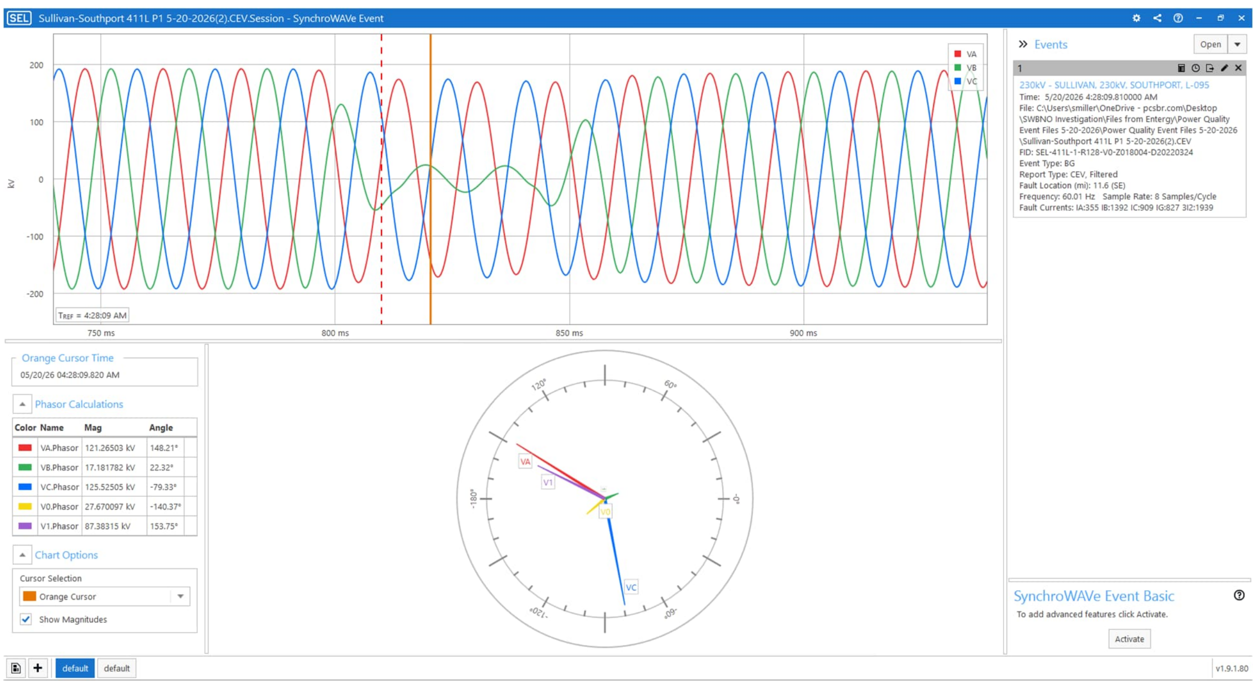


Figure 2.3

- o Figure 2.3 shows the point during the fault where zero-sequence voltage reached its maximum point and positive-sequence voltage reached its minimum.
- o The positive-sequence voltage minimum recorded was 35.89% below the prefault voltage, reflecting the reduction in magnitude of the faulted phase.

III. May 20th, 5:41PM Event Analysis:

Duration of Voltage Depression

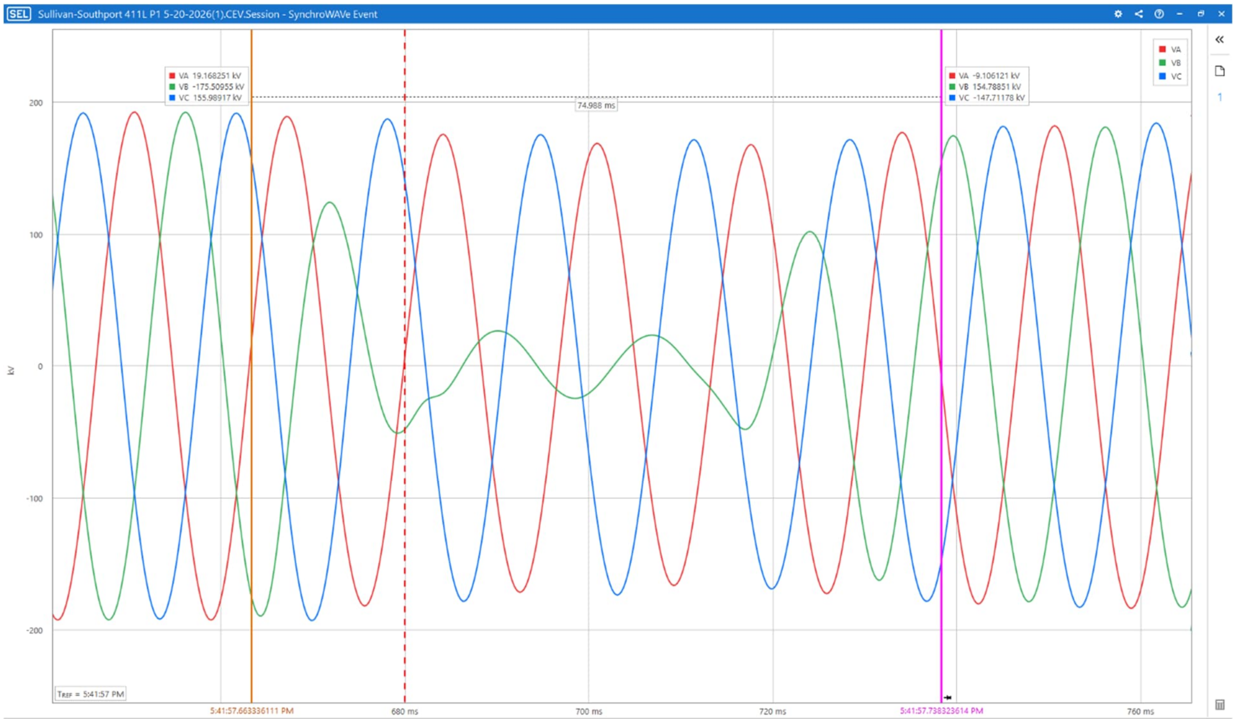


Figure 3.1

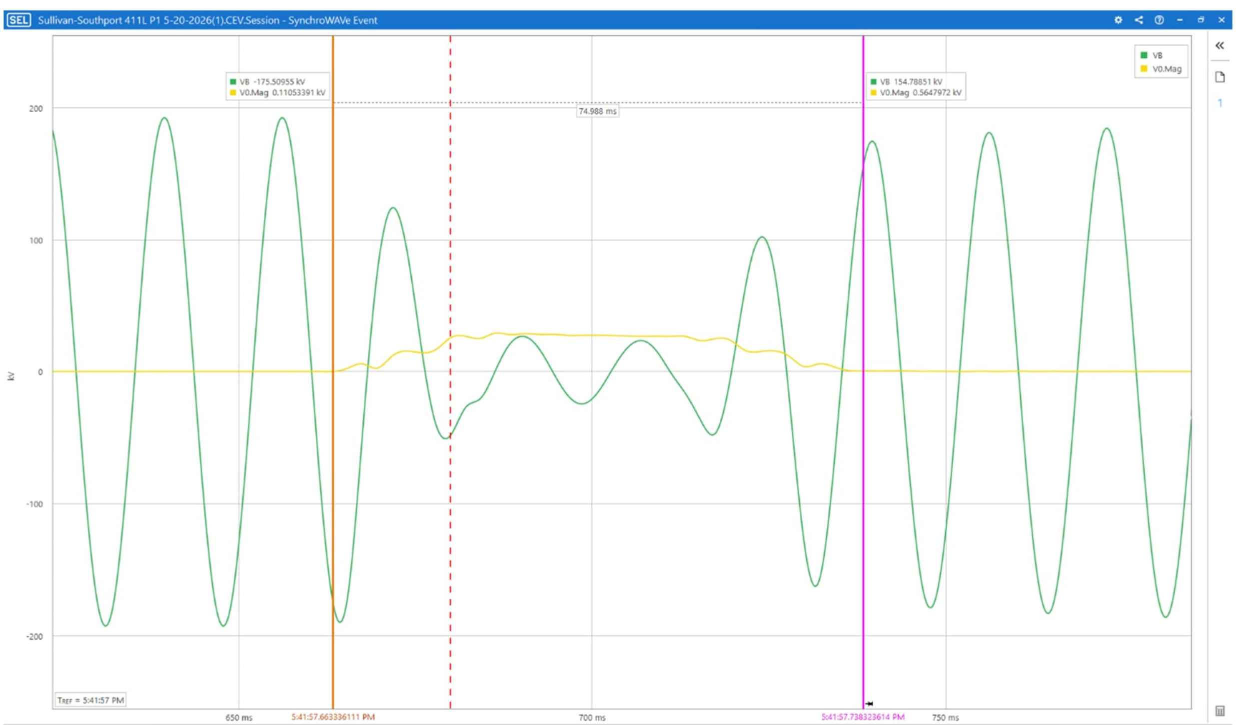


Figure 3.2

- Figure 3.1 shows an oscillograph of the voltage depression seen at the time of the event.
- Figure 3.2 shows an oscillograph with the faulted phase and zero-sequence voltage, V_0, plotted together.
- Measuring the amount of time that V_0 was greater than "effectively zero" allows the duration of the event to be measured in its entirety.
    - The duration of the event was 74.988 milliseconds, 0.075 seconds, or 4.49 cycles.

Phasor Diagram

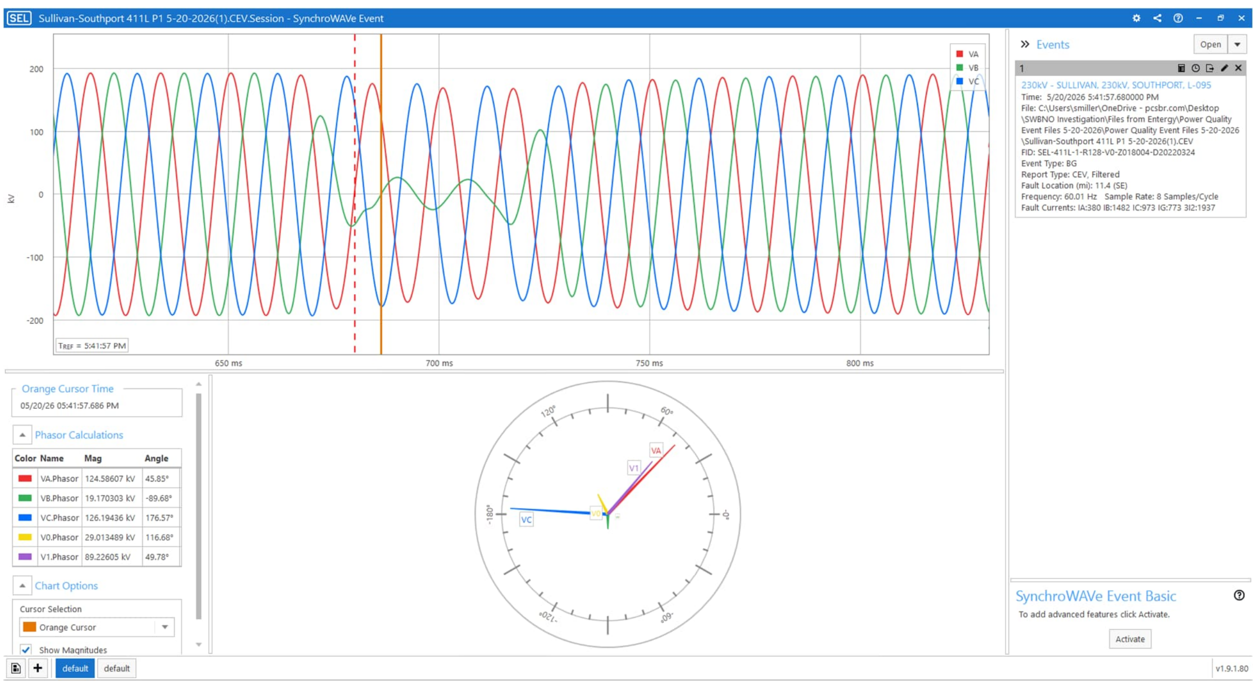


Figure 3.3

- Figure 3.3 shows the point during the fault where zero-sequence voltage reached its maximum point and positive-sequence voltage reached its minimum.
- The positive-sequence voltage minimum recorded was 34.42% below the prefault voltage, reflecting the reduction in magnitude of the faulted phase.

IV. May 20th, 5:46PM Event Analysis:

Duration of Voltage Depression

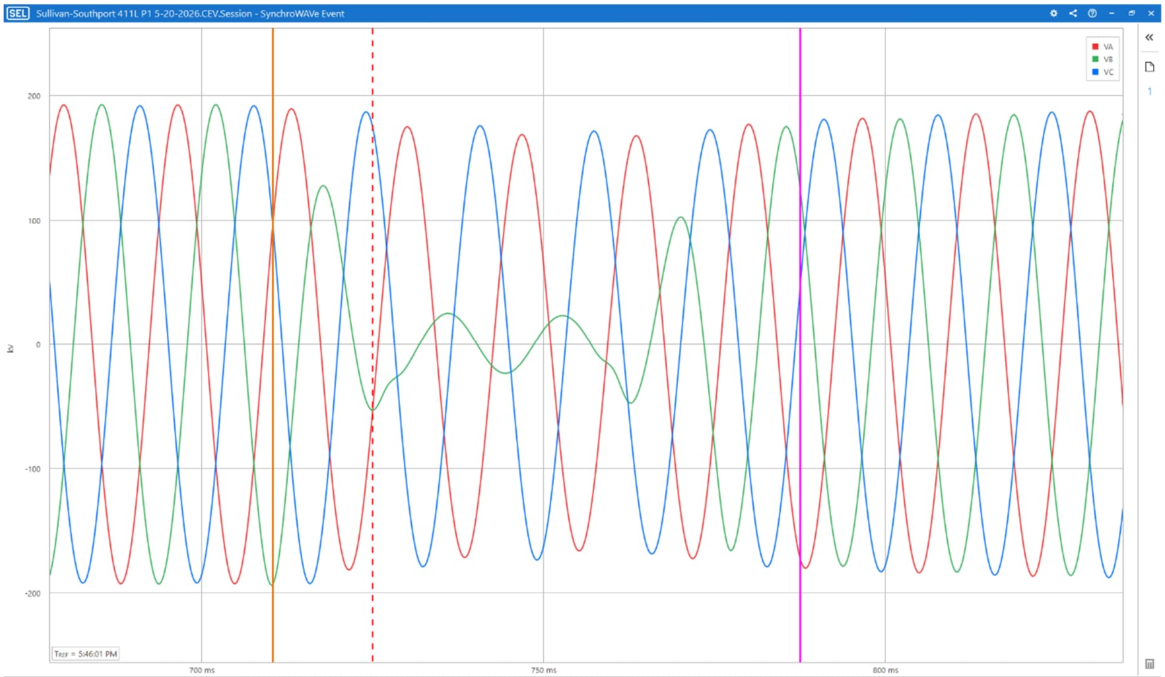


Figure 4.1

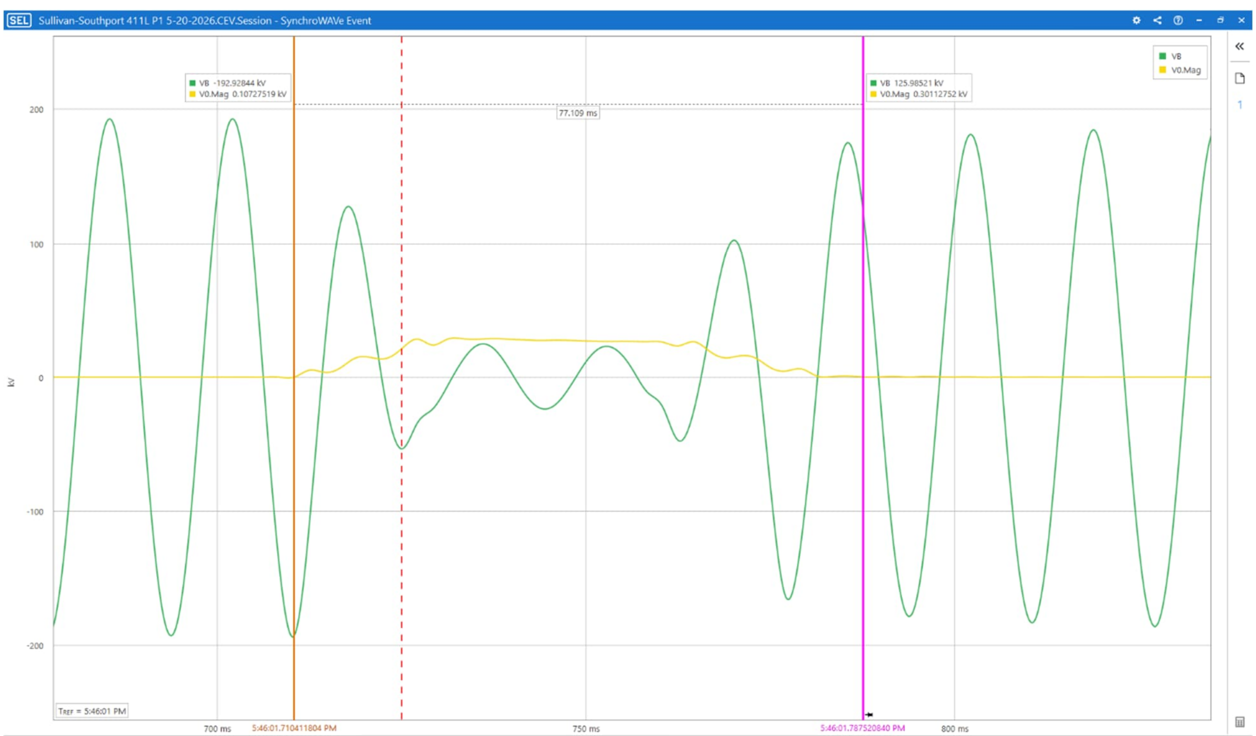


Figure 4.2

- Figure 4.1 shows an oscillograph of the voltage depression seen at the time of the event.
- Figure 4.2 shows an oscillograph with the faulted phase and zero-sequence voltage, V_0, plotted together.
- Measuring the amount of time that V_0 was greater than “effectively zero” allows the duration of the event to be measured in its entirety.
  - The duration of the event was 77.109 milliseconds, 0.077 seconds, or 4.63 cycles.

Phasor Diagram

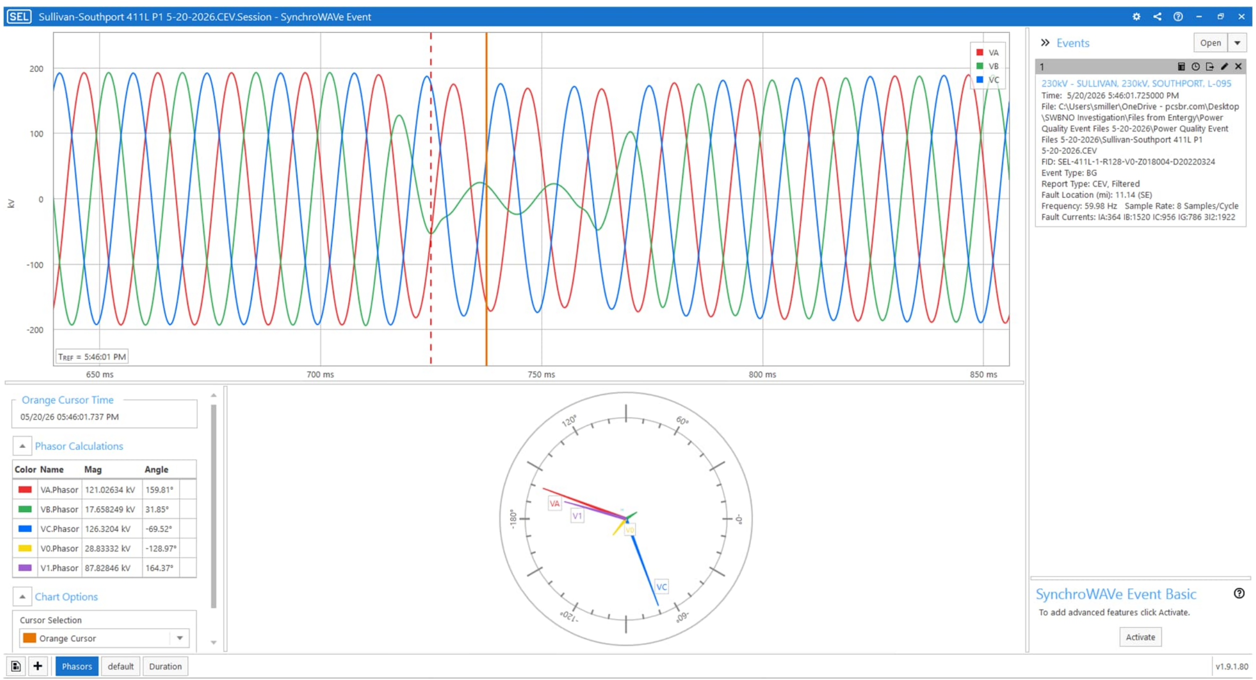


Figure 4.3

- Figure 4.3 shows the point during the fault where zero-sequence voltage reached its maximum point and positive-sequence voltage reached its minimum.
- The positive-sequence voltage minimum recorded was 35.54% below the prefault voltage, reflecting the reduction in magnitude of the faulted phase.

V. June 18th Event:

Duration of Voltage Depression

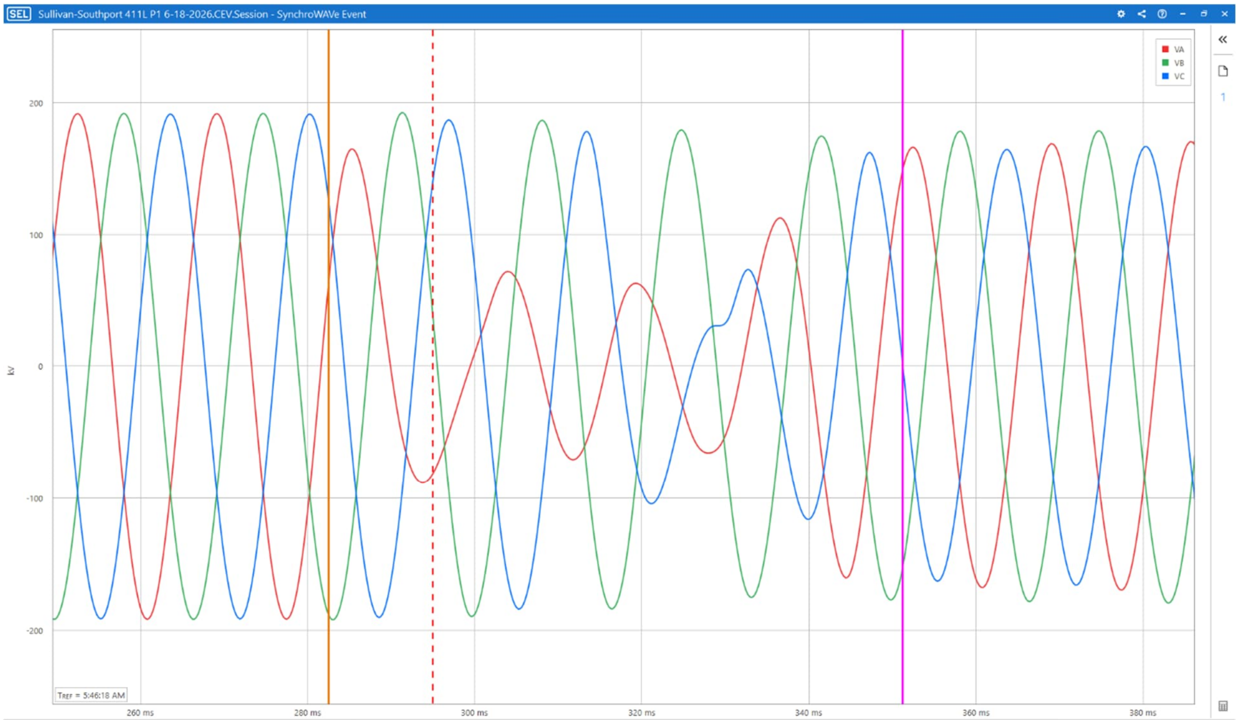


Figure 5.1

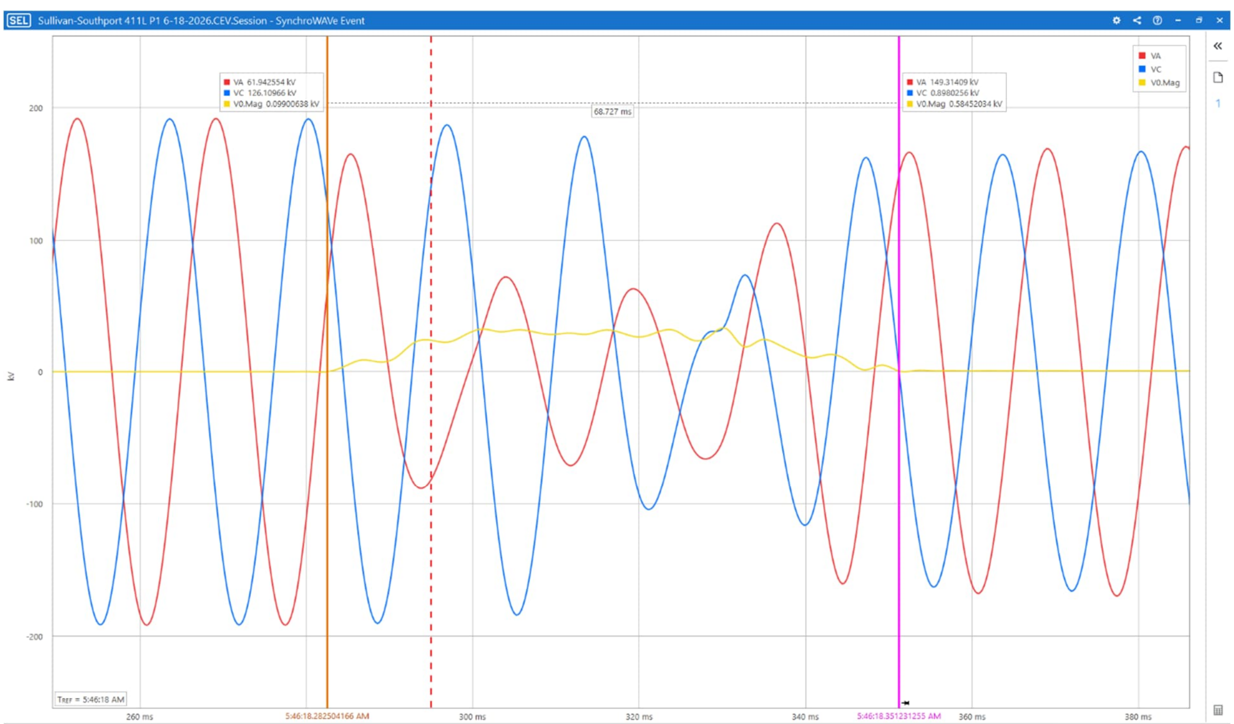


Figure 5.2

- Figure 5.1 shows an oscillograph of the voltage depression seen at the time of the event.
- Figure 5.2 shows an oscillograph with the faulted phases and zero-sequence voltage, V_0, plotted together.
- Measuring the amount of time that V_0 was greater than “effectively zero” allows the duration of the event to be measured in its entirety.
  - The duration of the event was 68.727 milliseconds, 0.069 seconds, or 4.12 cycles.

Phasor Diagram

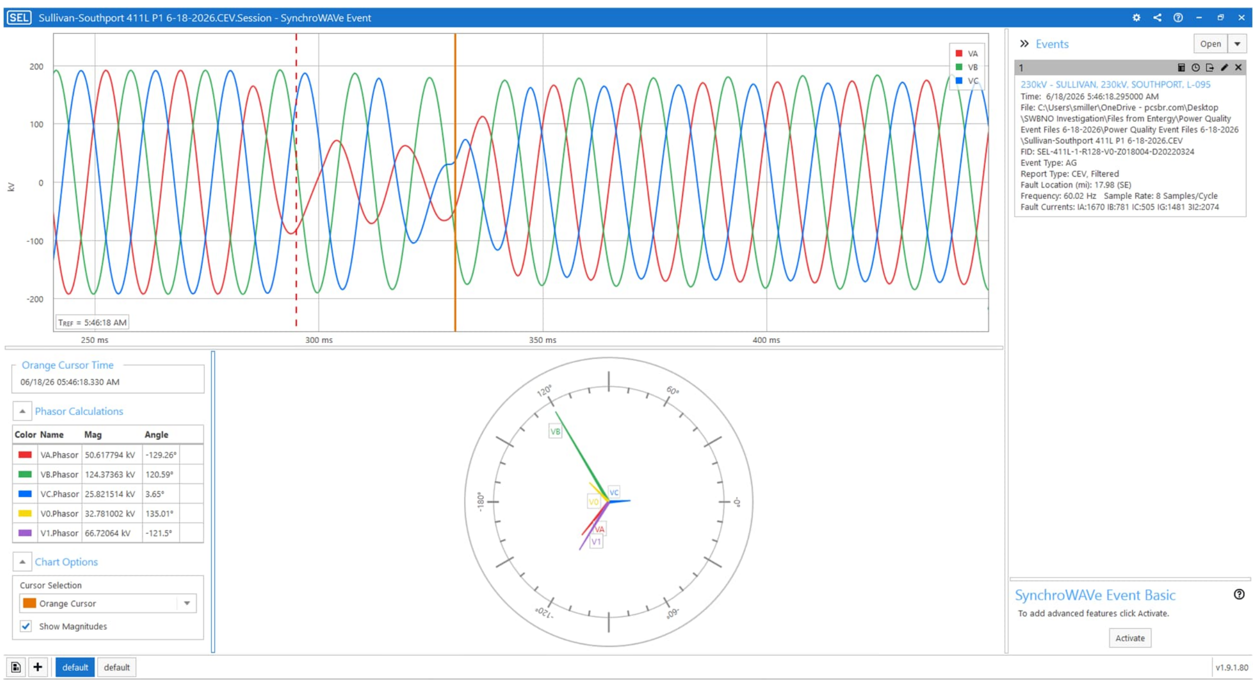


Figure 5.3

- Figure 5.3 shows the point during the fault where zero-sequence voltage reached its maximum point and positive-sequence voltage reached its minimum.
- The positive-sequence voltage minimum recorded was 51.82% below the prefault voltage, reflecting the reduction in magnitude of the faulted phase.

VI. Event Summary

Table 6.1, below, summarizes the recorded voltage drop events that occurred on May 20th and June 18th. Listed in the table is the time of each event, the length of the event, and the percentage drop of positive-sequence voltage associated with each event.

Date	Time	Event Length (ms)	Event Length (cycles)	Maximum %V_1 drop	Associated Figures
May 20th	4:28AM	74.988	4.49	36%	2.1 – 2.3
May 20th	5:41PM	74.988	4.49	34%	3.1 – 3.3
May 20th	5:46PM	77.109	4.63	36%	4.1 – 4.3
June 18th	5:46AM	68.727	4.12	52%	5.1 – 5.3

Table 6.1

It is important to note that the data presented in Table 6.1 is what was recorded on the transmission system. In the case of June 18th, a 52% reduction in positive-sequence voltage was experienced on the transmission line. As discussed in the first section of this document, a voltage drop on the transmission system will have its effects lessened by the equipment in the substation. That is to say the voltage drop at the point of delivery and connection to the customer will be of a smaller magnitude than what is observed on the transmission lines themselves. In the case of June 18th, the 52% reduction in positive-sequence voltage on the transmission system corresponded to only a 25% reduction in voltage measured by the connected customer. The two event reports are presented together (but not time-aligned) in Figure 6.1 on the following page.

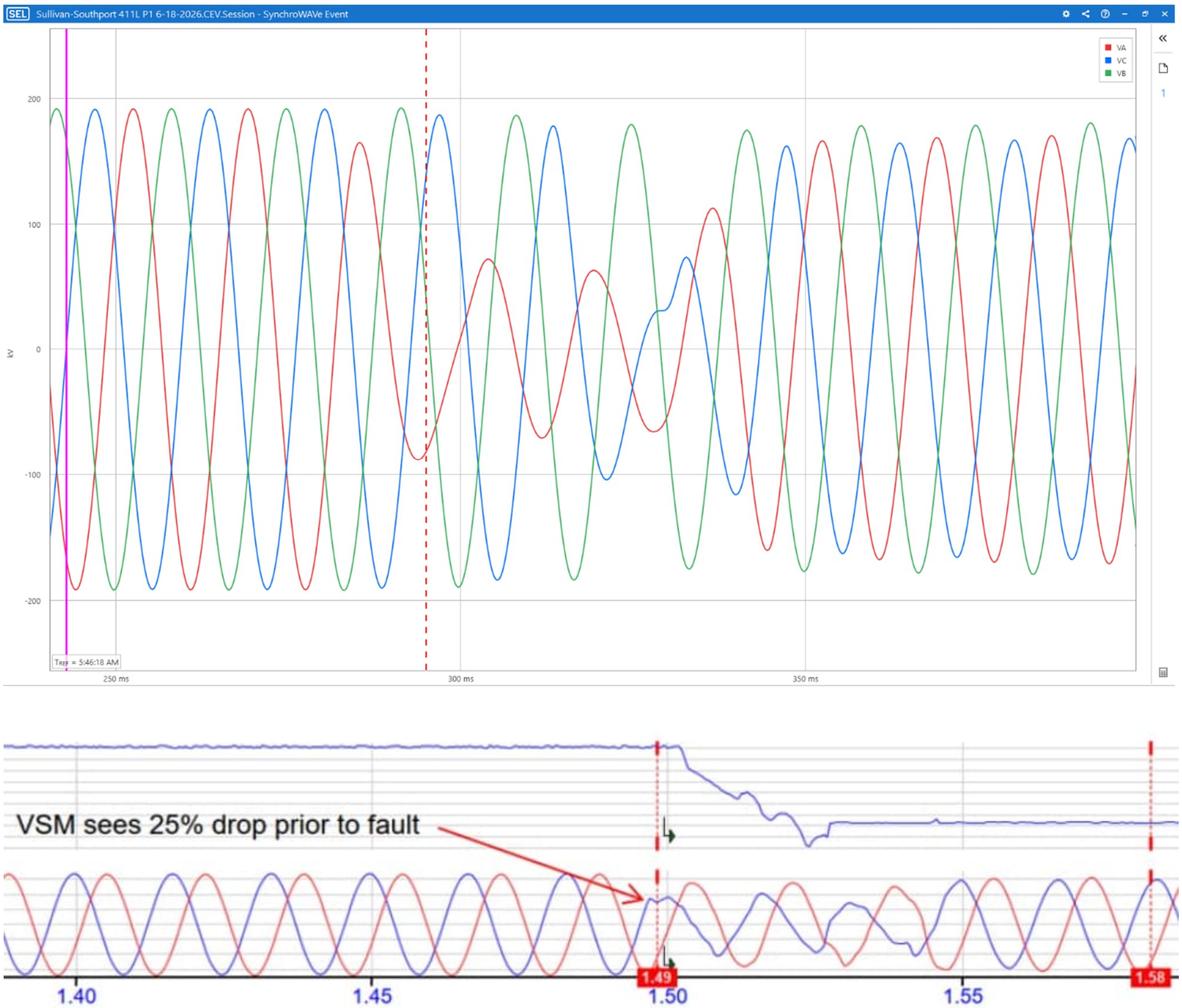


Figure 6.1 [1]

To clear a fault on a transmission line, a protective relay must first detect fault conditions on the line and then send a signal to a circuit breaker. The circuit breaker must then operate to open the transmission line and thus clear the fault. Acceptable times for the kind of fault investigated in this report are 1-1.5 cycles for the protective relay to detect the fault and 3-4 cycles for the breaker to operate after it has received the command to operate from the protective relay. This means that the expected, acceptable fault clearing time for the faults analyzed should be around 4-5.5 cycles. The faults investigated in this document led to voltage depressions that lasted between 4.1 and 4.6 cycles. Based on this, Entergy's Transmission System appears to be clearing faults timely and effectively.

Published on Entergy's website is a document titled "Power Quality Standard for Electric Service." Section 3.5 of this document, entitled "Voltage Sags," informs customers connected directly to the transmission system that "voltage sag[s] on the transmission system due to a fault will generally last from 5 to 12 cycles." [2]. It is the professional opinion of PCS that this number is accurate for generally all non-contingent (not multiple) faults that can be experienced by Sullivan substation. In this regard, for the cases investigated in this document, one can deduce that Entergy is providing the electrical service promised at the beginning of power delivery to the connected customer.

In all cases presented in this document, Sullivan substation operated effectively and in accordance with electrical standards required in the industry. In addition to its success in operation, Sullivan substation is designed such that every component in the substation is fully redundant. This means that any one component in the substation can fail and the connected customer will not experience a reduction in power quality worse than industry standards for clearing faults.

In most cases, faults like the ones discussed are attributed to strokes of lightning affecting the transmission lines. When considering that Louisiana sits in a high-probability area for strokes of lightning, faults like the ones experienced at Sullivan substation should be expected. Faults of the same nature and magnitude have been prevalent since the inception of the electrical grid and will continue to be on all above-ground power systems. They are referred to as "acts of nature" in the power industry.

The faults analyzed in this report had durations of around 75 milliseconds, which is about half the time it takes for the average person to blink [3]. A residential customer may experience this disruption as the lights in their house dimming slightly and returning to normal, if they even notice a disruption. The electrical system at an industrial customer's facility, such as a production plant with many connected motors, would be set up to "ride through" disruptions such as these. In most cases and for most customers, the voltage depressions recorded in Sullivan substation would have very little to no effect on their equipment and perception of power quality being delivered to them.

However, the connected customer at Sullivan substation, the Sewerage and Water Board of New Orleans, has proved to be negatively affected by the voltage depressions investigated in this report. When a voltage depression occurs at Sullivan substation, the Sewerage and Water Board's static frequency converters (SFCs) trip offline. This is the result of an "undervoltage trip" programmed into the controllers of said SFCs. These undervoltage trips are intended to react to voltage depressions and are detecting these conditions properly. The problem with the implementation of the undervoltage trips on the SFCs is that they are set up to trip instantaneously, which is uncommon when utilizing this kind of trip on this kind of equipment. The instantaneous nature of this trip is significantly reducing the ability of the SFCs at the Sewerage and Water Board to be able to ride through voltage depressions that wouldn't affect other customers.

PCS has been informed by the Sewerage and Water Board that steps have been taken to adjust the undervoltage trip parameters on the SFCs. In particular, the previous setpoint that tripped the SFCs at a 20% voltage depression has been adjusted to 30%. While this adjustment would have allowed the SFCs to ride through the depression recorded on June 18th, this solution will likely not solve the reliability problems being experienced. In this case, the instantaneous nature of the undervoltage trip programmed into the SFCs is the bad actor and is the main factor reducing the ability of the SFCs to ride through voltage drops. The Sewerage and Water Board has explained that the controller for the SFCs, however, does not allow a delay to be set on the undervoltage protection element. PCS has also been told that the manufacturer of the SFCs has been contacted about adding a delay to this protection element, but the outcome of such request has not been realized yet.

When configuring an undervoltage trip, it is important to understand the limitations of the equipment being protected. These limitations govern the magnitude and duration of a voltage drop that the equipment can safely be operated within. So, in the matter of the SFCs at the Sewerage and Water Board, the limitations of the SFCs must first be studied before a delay on the undervoltage protection element can be configured. In addition to contacting the equipment manufacturer about adding a delay to the undervoltage protection element, PCS recommends the Sewerage and Water Board request information regarding the absolute limitations of the SFCs in regard to the voltage deviations that can be withstood during operation.

Works Cited

1. Lee, Jo Anna. *RE: S&WB Requested Documents*, 24 June 2026.
2. "Power Quality Standards for Electric Service." Entergy Louisiana, 1 Jan. 2024.
3. "What Is the Average Time It Takes to Blink?" *Lens.Com*, 2026, www.lens.com/questions-answered/what-is-the-average-time-it-takes-to-blink/.