SEL-421 PERFORMANCE AS BOTH A PROTECTIVE RELAY AND A PHASOR MEASUREMENT UNIT

WHITE PAPER

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INTRODUCTION

The SEL-421 has the unique ability to provide both line protection and Synchrophasor measurement. A frequent question is: how does this dual functionality affect relay performance? The testing performed for this paper demonstrates the performance of the SEL-421 as a protective relay and as a phasor measurement unit (PMU).

TEST SETUP

The test setup consists of a power system model in a Real-Time Digital Simulator (RTDS) and two SEL-421 relays connected in a closed loop fashion, as shown in Figure 1. The two relays are time synchronized to a GPS clock. The power system model includes two 230 kV sources, Source L and Source R, transferring power through parallel transmission lines, Line 1 and Line 2. The two SEL-421 relays protect Line 1 and measure synchrophasors.

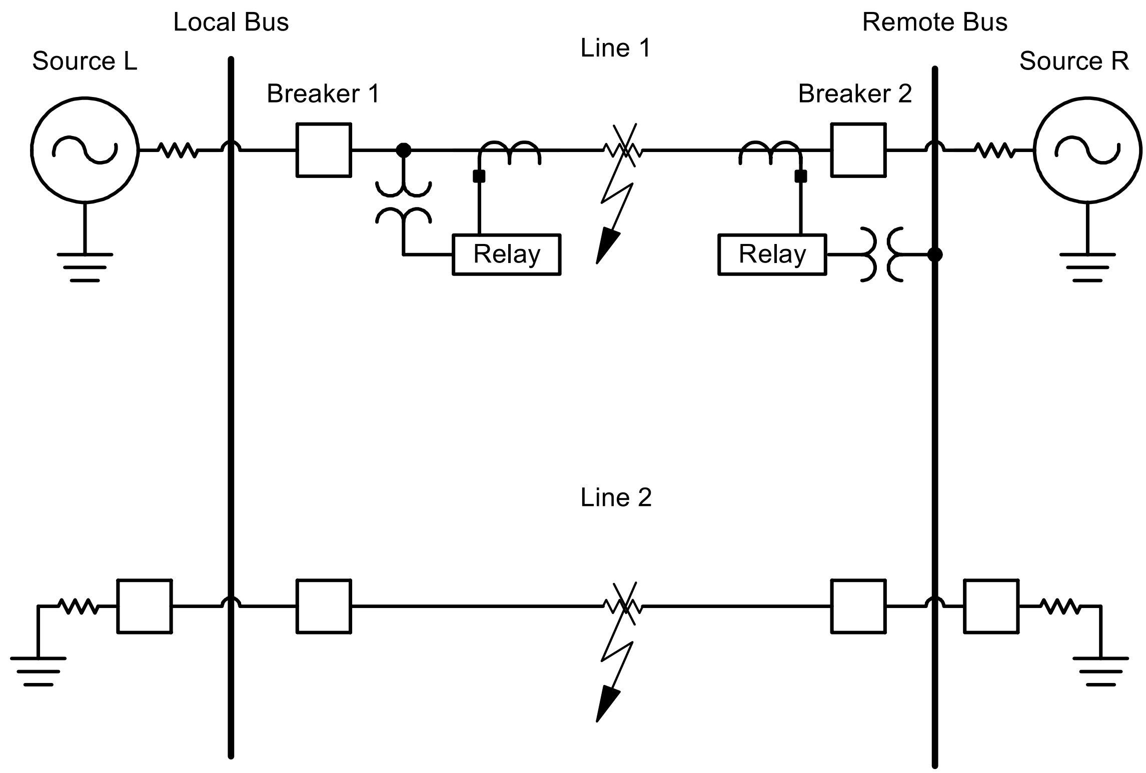

Figure 1 Test Setup

We set the relays to operate instantaneously for Zone 1 faults within 80 percent reach. We also used a POTT scheme to improve security. Table 1 shows the system data used for this paper.

Table 1 System Data

Parameter	Value
Positive-sequence line impedance	37.72 ∠87.18° Ω pri.
Zero-sequence line impedance	128 ∠73.58° Ω pri.
Source impedance ratio	0.13
PTR	2000
CTR	500
Phase rotation	ABC

TEST CASES

The purpose of testing SEL-421 performance as a protection device and a PMU was to answer the following questions:

1. Does the use of the Synchrophasor functionality in the SEL-421 adversely affect the protection capabilities of the relay?
2. When Synchrophasors are enabled on a SEL-421 and a fault occurs, does the operation of the protection algorithms interfere with the processing and communication of synchronized phasor-measurement quantities?

Trip Speed Comparison

Based on the first question, we considered six test cases with and without Synchrophasors enabled. Four test cases were within the protected zone (two instantaneous and two communications assisted) and two were outside the protected zone. We repeated each test case five times for four different faults (AG, AB, BCG, and ABC). We then evaluated an average of the tripping times as part of the conclusions. Table 2 lists the six test cases.

Table 2 List of Cases Considered for Testing

Case	Faulted Line	Fault Distance		Fault Type
		Local	Remote	
1	Line1	10	90	AG, AB, BCG, ABC
2	Line2	30	70	AG, AB, BCG, ABC
3	Line1	50	50	AG, AB, BCG, ABC
4	Line2	70	30	AG, AB, BCG, ABC
5	Line1	80	20	AG, AB, BCG, ABC
6	Line1	90	10	AG, AB, BCG, ABC

Results

Figure 2 and Figure 3 show the tripping times for local and remote relays with and without synchrophasors enabled (Global setting EPMU=N and EPMU=Y). Note that two cases (2 and 4 in Table 2) are not listed because they were out-of-section faults.

As can be seen in each of the following figures, there is virtually no difference in operation speed for the SEL-421 with or without the Synchrophasor function operating. Based on this data, the SEL-421 is still one of the fastest protection relays in the world, even when it operates simultaneously as a phasor-measurement unit.

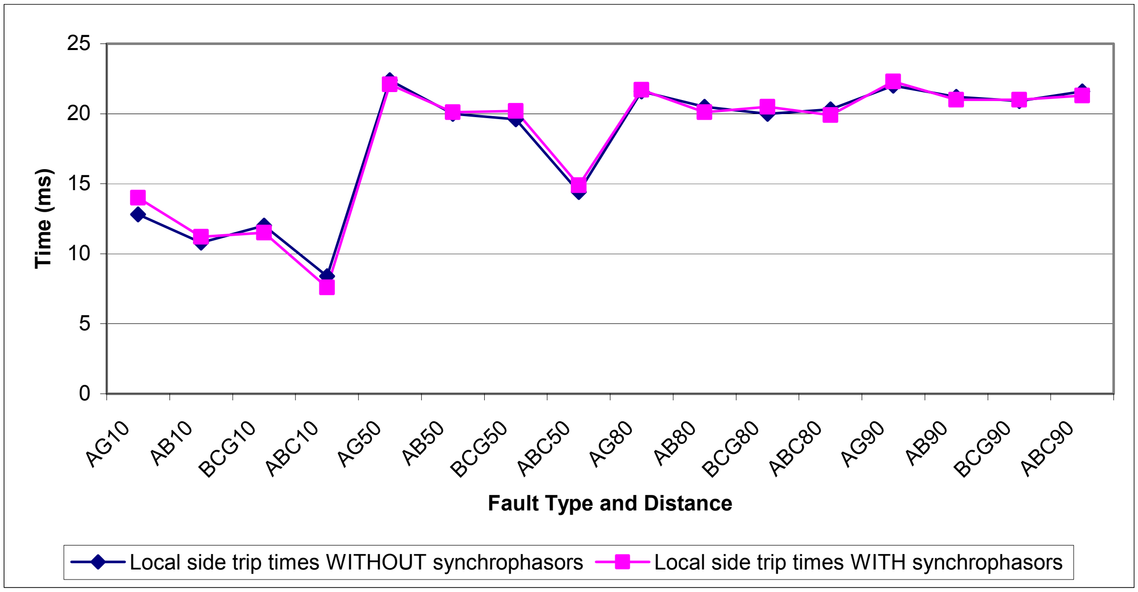

Figure 2 Local-Side Tripping Times With and Without Synchrophasors

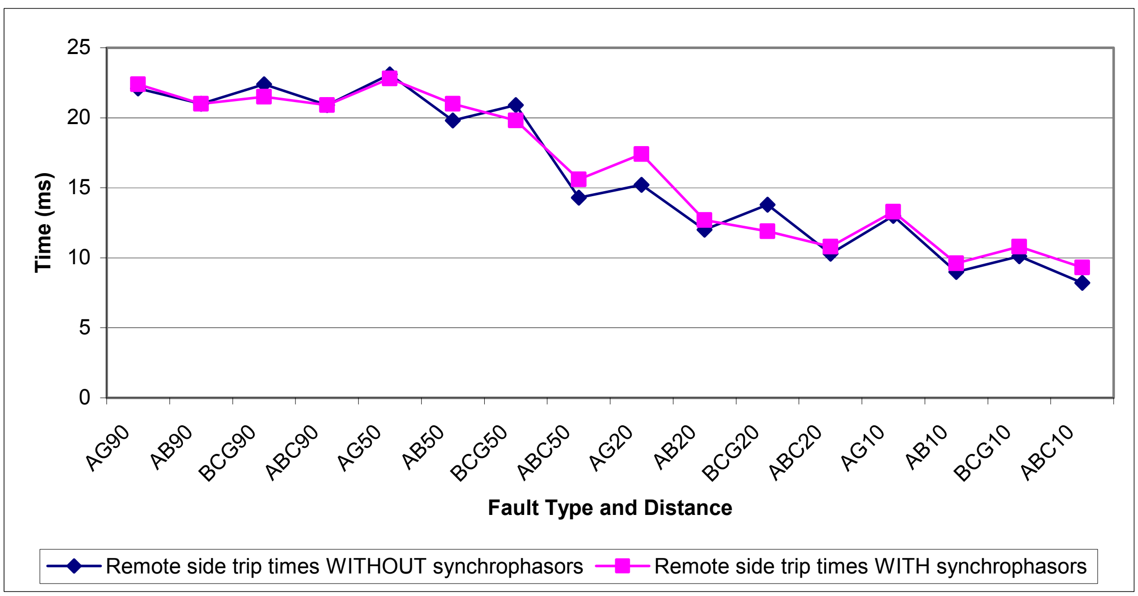

Figure 3 Remote-Side Tripping Times With and Without Synchrophasors

Phasor Data Processing and Communication

Based on the second question, we analyzed the synchrophasor data captured during the six test cases (with Synchrophasors enabled). We used a software program to collect synchrophasor data and a MathCAD program to correlate the data from both ends of the line, as well as to verify whether any data packets were lost during the disturbances.

Results

Table 3 correlates the tests performed with Figure 4 through Figure 25, which graph the SEL-421 relay's performance against expected communications response. These figures show either local- or remote-side measured, synchrophasor voltage magnitude for several faults. In addition, in four other graph plots (Figure 15, Figure 17, Figure 19, and Figure 21), we used the positive-sequence impedance analog quantity to validate the synchrophasor data. These quantities are per unit and are offset by two. If the time difference between two consecutive samples was greater than or less than one cycle, synchrophasor data check would have deasserted, indicating the loss of a data packet. However, synchrophasor data check never deasserted during our tests, which shows that no data packets were lost. Note that for these tests, the local PT was on the line side, and the remote PT was on the bus side (see Figure 1).

Table 3 List of Test Cases Applied

Faulted Line	Fault Distance	Relay	Fault Type	Figure Number
Line 1	10	Local	AG	4
Line 1	90	Remote	AG	5
Line 1	50	Local	AB	6
Line 1	50	Remote	AB	7
Line 1	90	Local	BCG	8
Line 1	10	Remote	BCG	9
Line 1	10	Local	ABC	10
Line 1	90	Remote	ABC	11
Line 2	30	Local	ABC	12
Line 2	70	Remote	ABC	13
Line 1	50	Local	ABC	14
Line 1	50	Local	ABC	15*
Line 1	50	Remote	ABC	16
Line 1	50	Remote	ABC	17*
Line 2	70	Local	ABC	18
Line 2	70	Local	ABC	19*
Line 2	30	Remote	ABC	20
Line 2	30	Remote	ABC	21*
Line 1	80	Local	ABC	22
Line 1	20	Remote	ABC	23
Line 1	90	Local	ABC	24
Line 1	10	Remote	ABC	25

* Figures that use positive-sequence impedance for data validation

Conclusion

As the data in the following figures show, the operation of the protection algorithms has no affect on the successful communication of phasor-measurement data. As mentioned earlier in this report, these data confirm that the SEL-421 provides world-leading power system protection and operates as well as any stand-alone phasor-measurement unit, all in one low-cost integrated package.

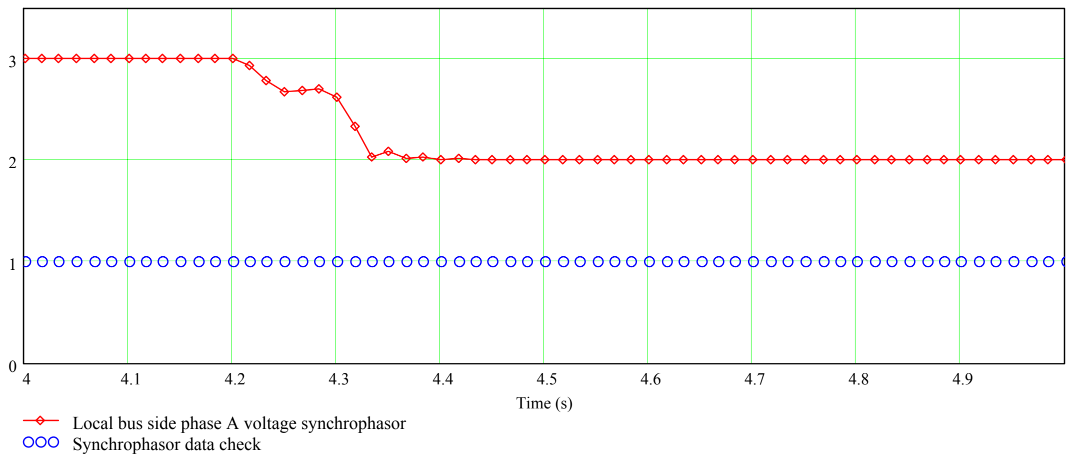

Figure 4 Synchrophasor Data for AG Fault at 10 Percent on Line 1 From Local End

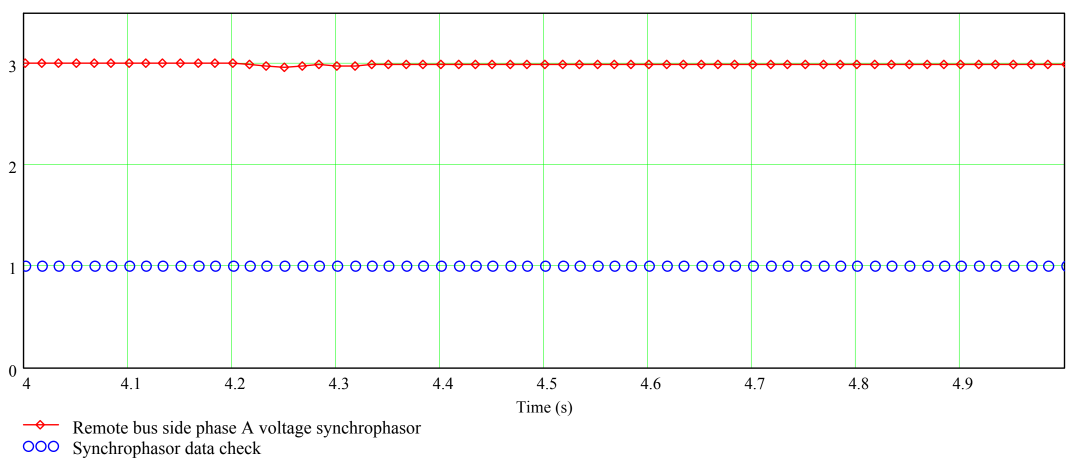

Figure 5 Synchrophasor Data for AG Fault at 90 Percent on Line 1 From Remote End

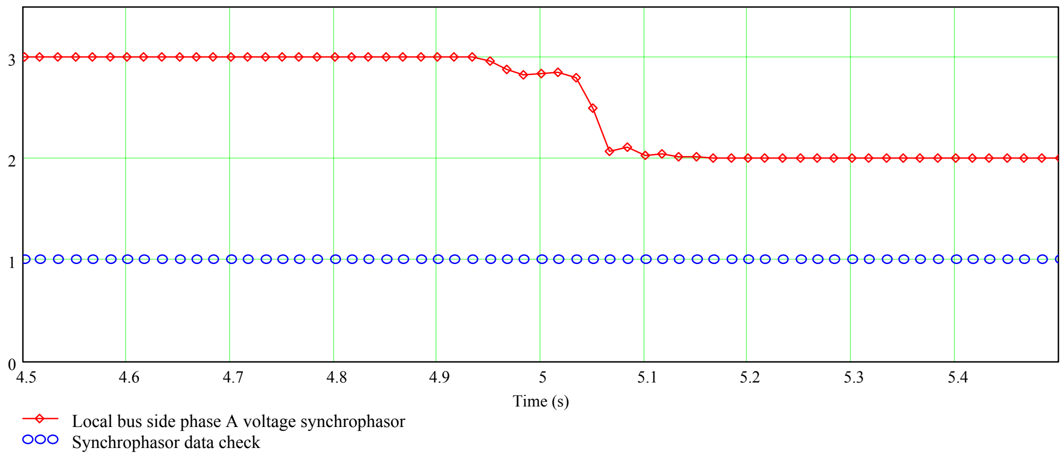

Figure 6 Synchrophasor Data for AB Fault at 50 Percent on Line 1 From Local End

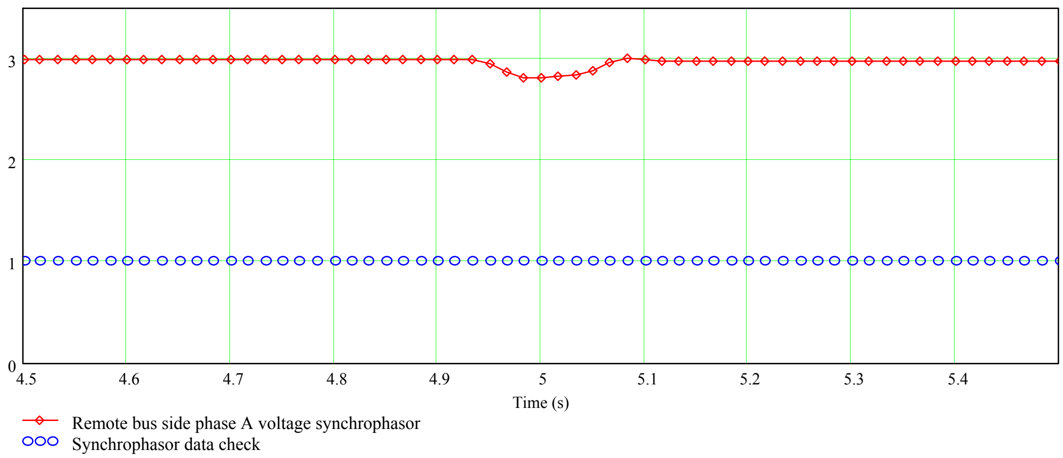

Figure 7 Synchrophasor Data for AB Fault at 50 Percent on Line 1 From Remote End

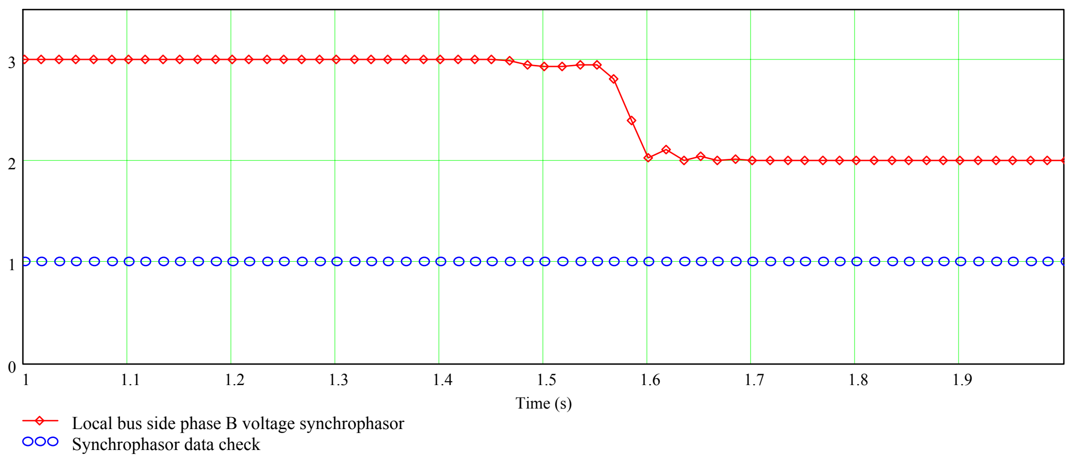

Figure 8 Synchrophasor Data for BCG Fault at 90 Percent on Line 1 From Local End

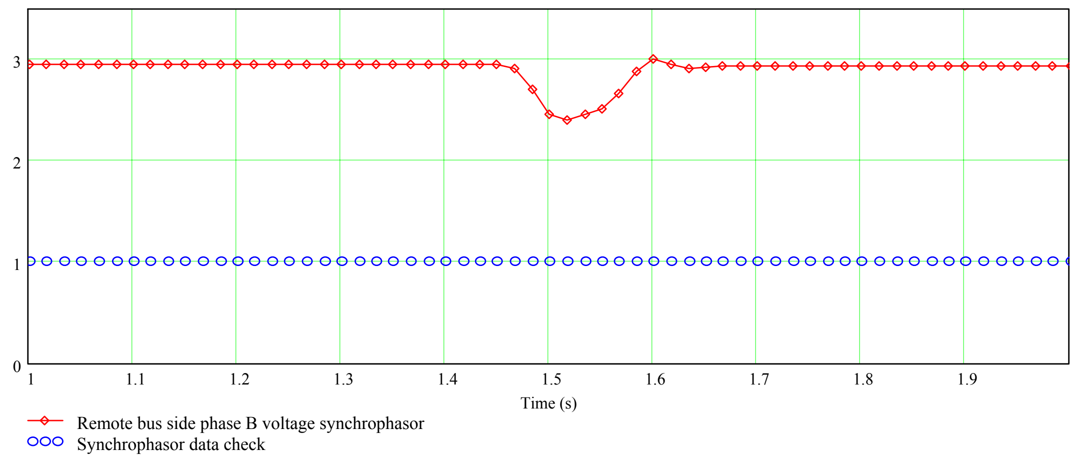

Figure 9 Synchrophasor Data for BCG Fault at 10 Percent on Line 1 From Remote End

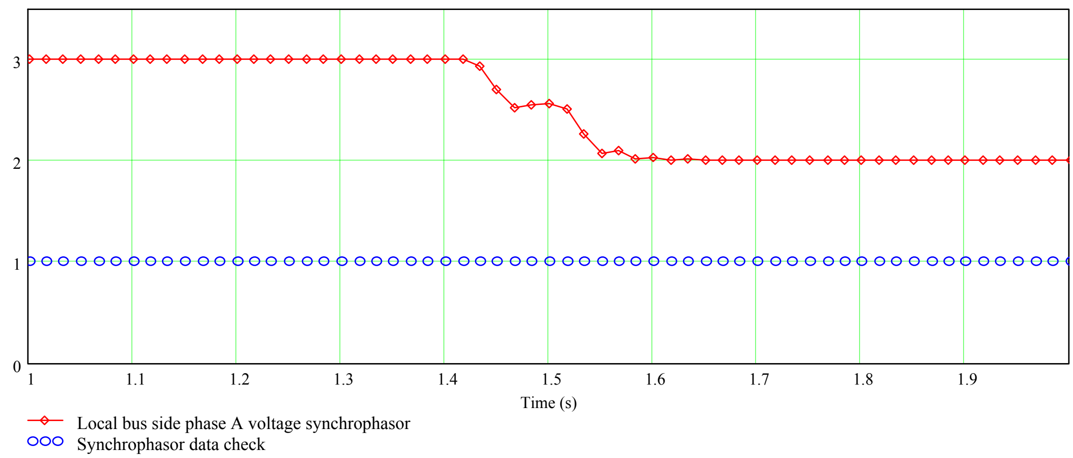

Figure 10 Synchrophasor Data for ABC Fault at 10 Percent on Line 1 From Local End

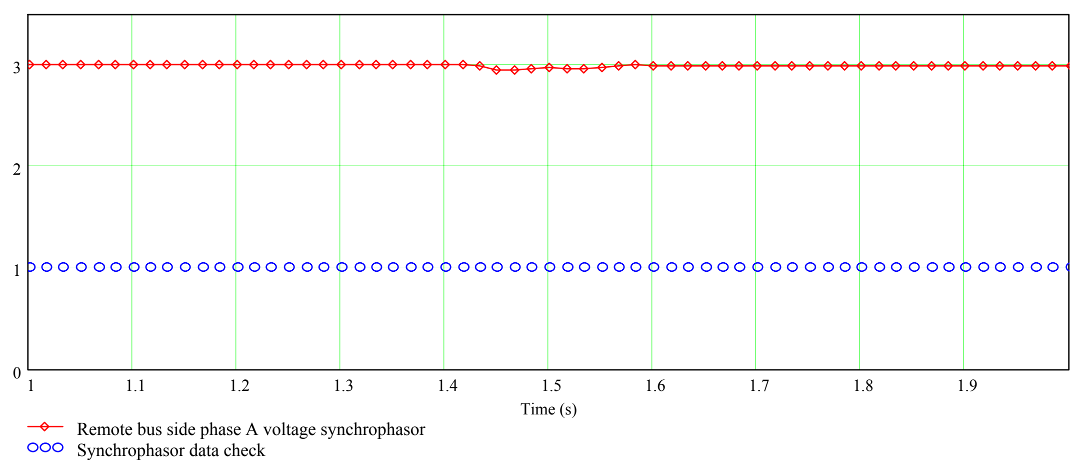

Figure 11 Synchrophasor Data for ABC Fault at 90 Percent on Line 1 From Remote End

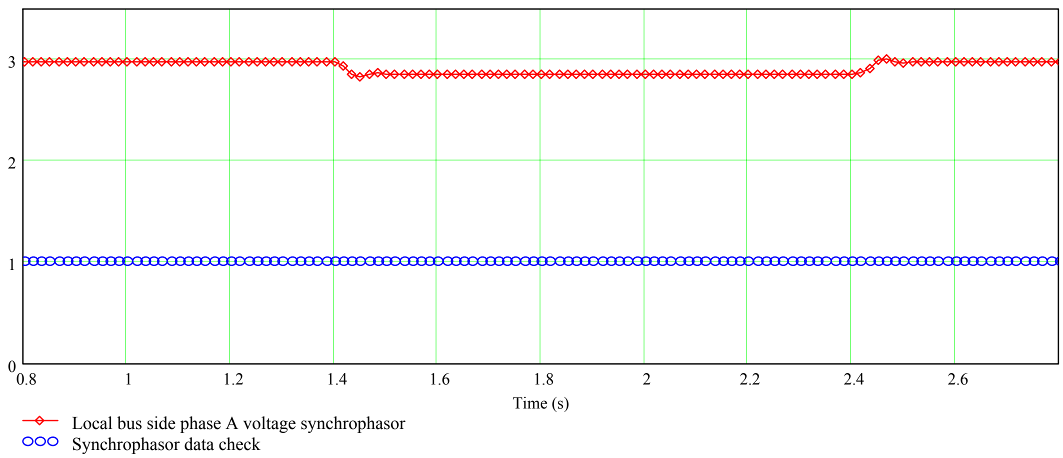

Figure 12 Synchrophasor Data for ABC Fault at 30 Percent on Line 2 From Local End

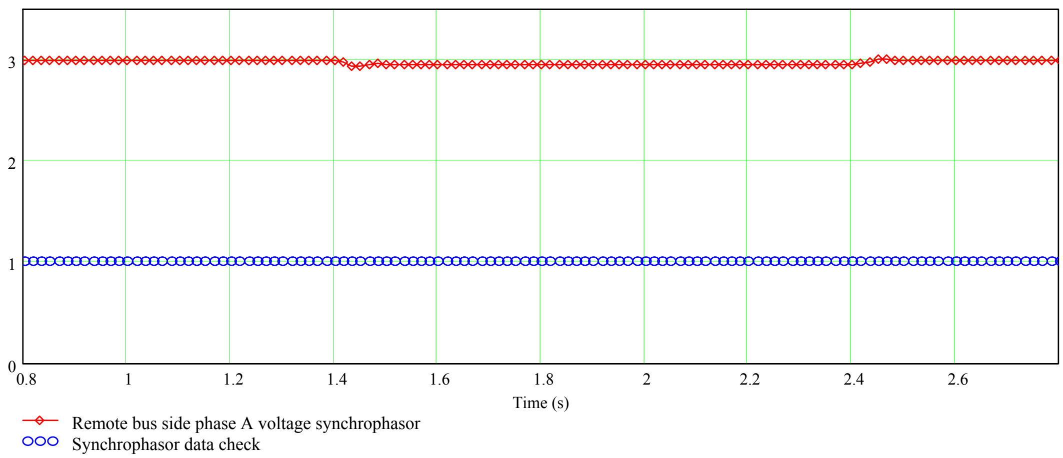

Figure 13 Synchrophasor Data for ABC Fault at 70 Percent on Line 2 From Remote End

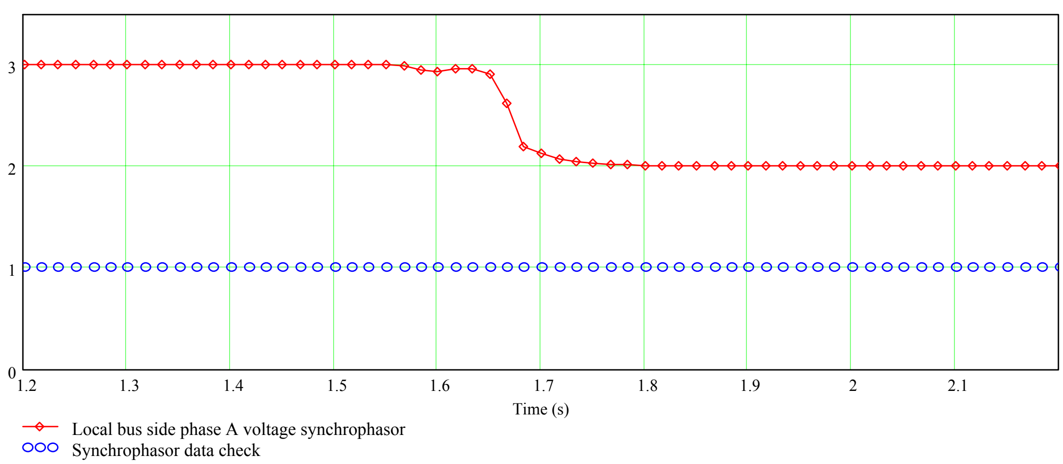

Figure 14 Synchrophasor Data for ABC Fault at 50 Percent on Line 1 From Local End

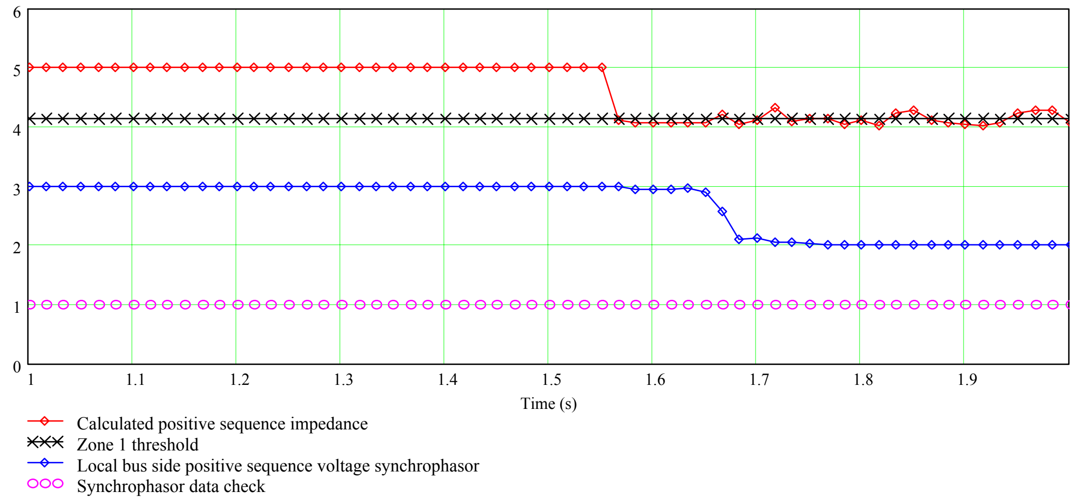

Figure 15 Analog Quantities in Synchrophasor Data for ABC Fault at 50 Percent on Line 1 From Local End

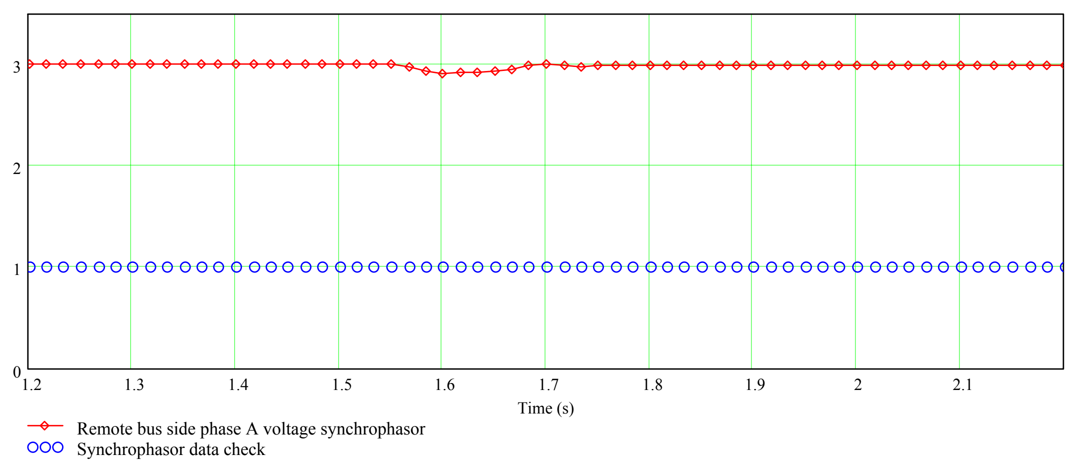

Figure 16 Synchrophasor Data for ABC Fault at 50 Percent on Line 1 From Remote End

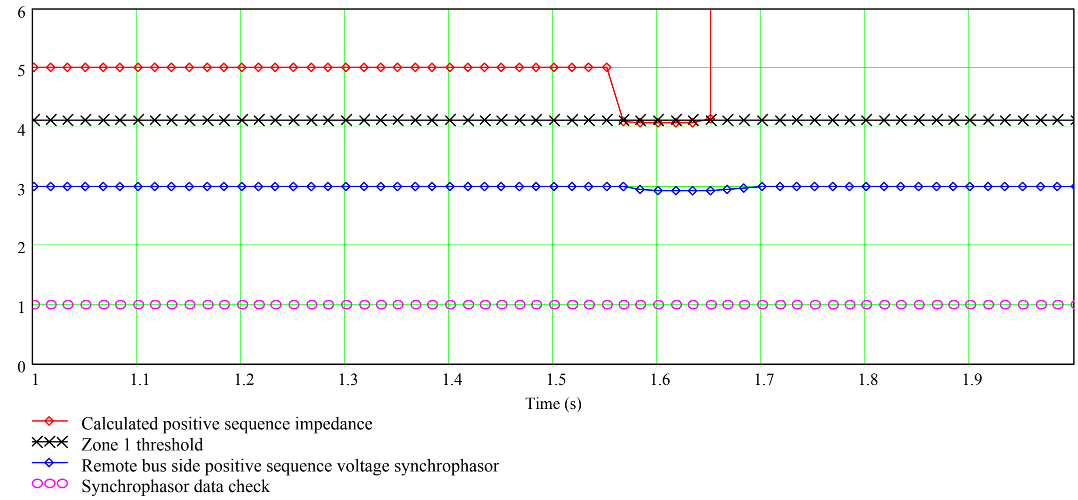

Figure 17 Analog Quantities in Synchrophasor Data for ABC Fault at 50 Percent on Line 1 From Remote End

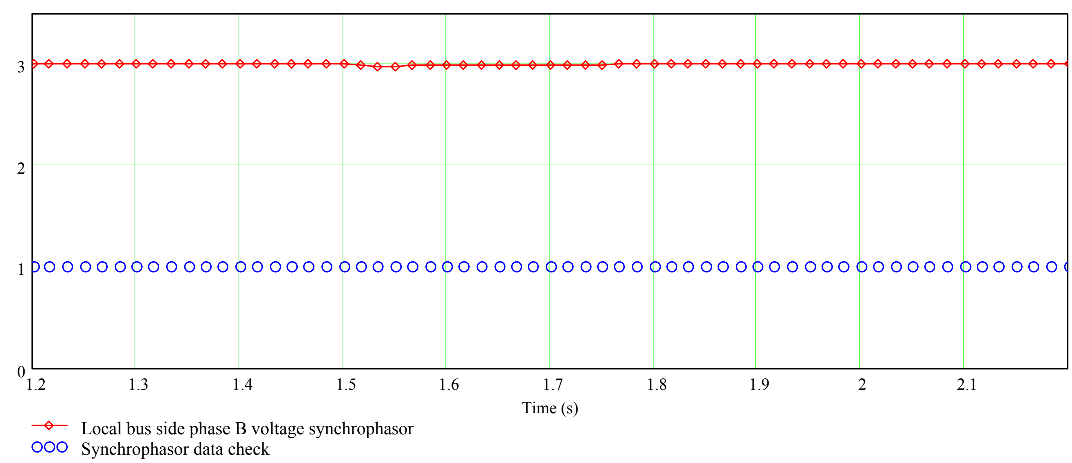

Figure 18 Synchrophasor Data for ABC Fault at 70 Percent on Line 2 From Local End

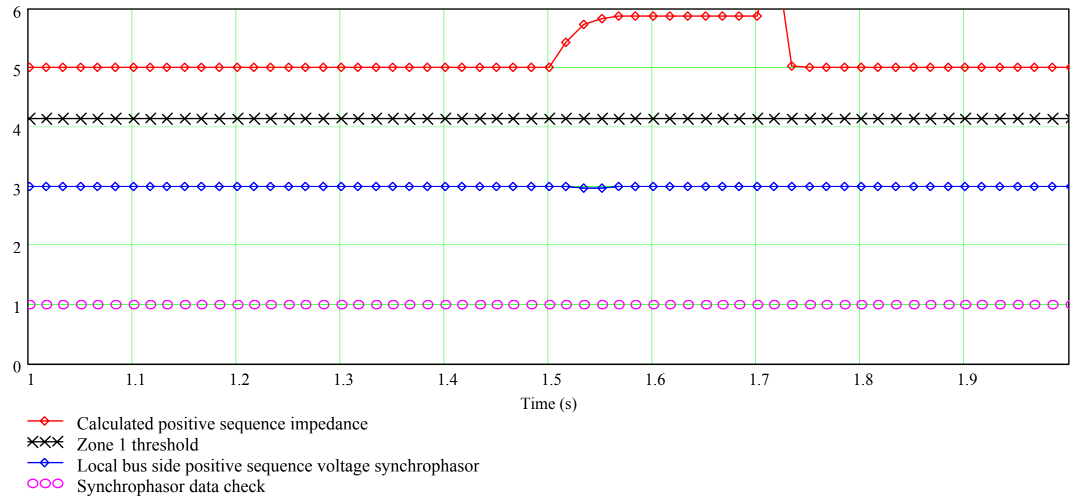

Figure 19 Analog Quantities in Synchrophasor Data for ABC Fault at 70 Percent on Line 2 From Local End

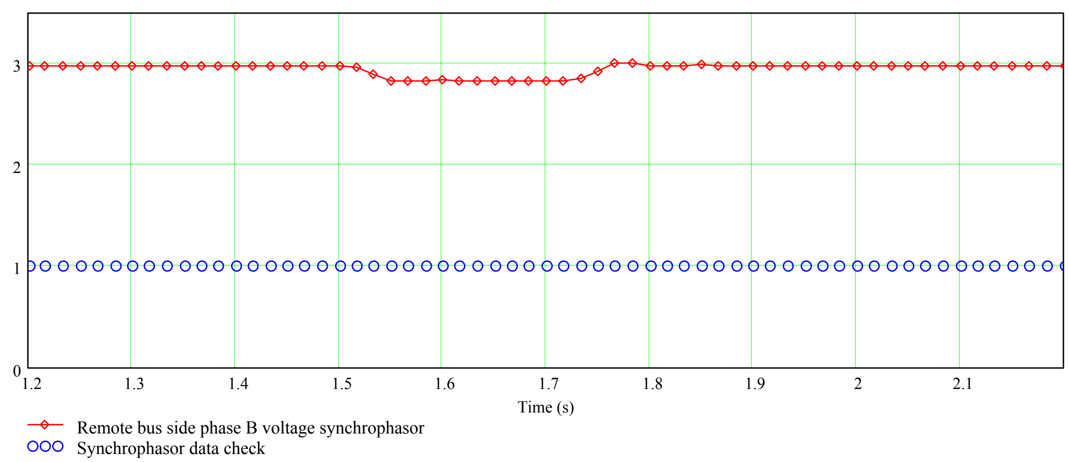

Figure 20 Synchrophasor Data for an ABC Fault at 30 Percent on Line 2 From Remote End

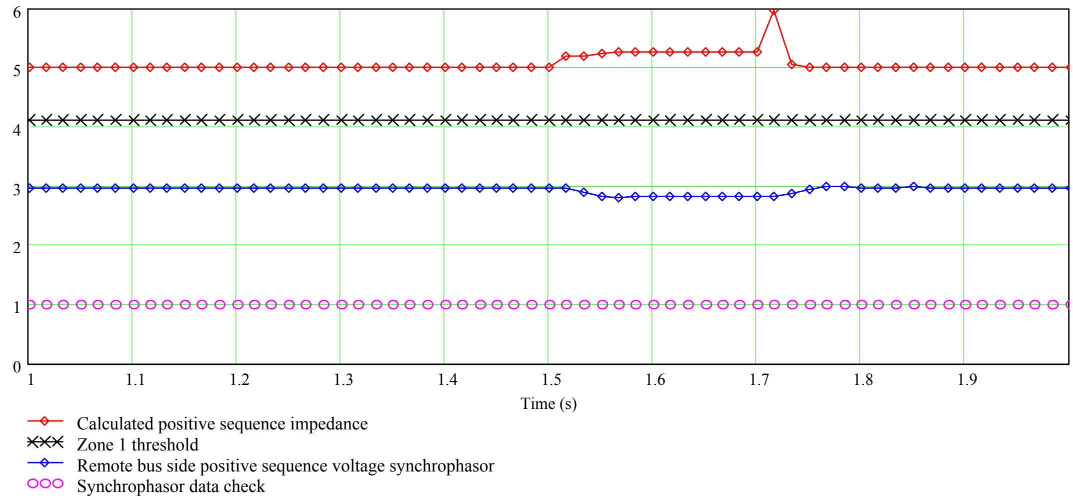

Figure 21 Analog Quantities in Synchrophasor Data for ABC Fault at 30 Percent on Line 2 From Remote End

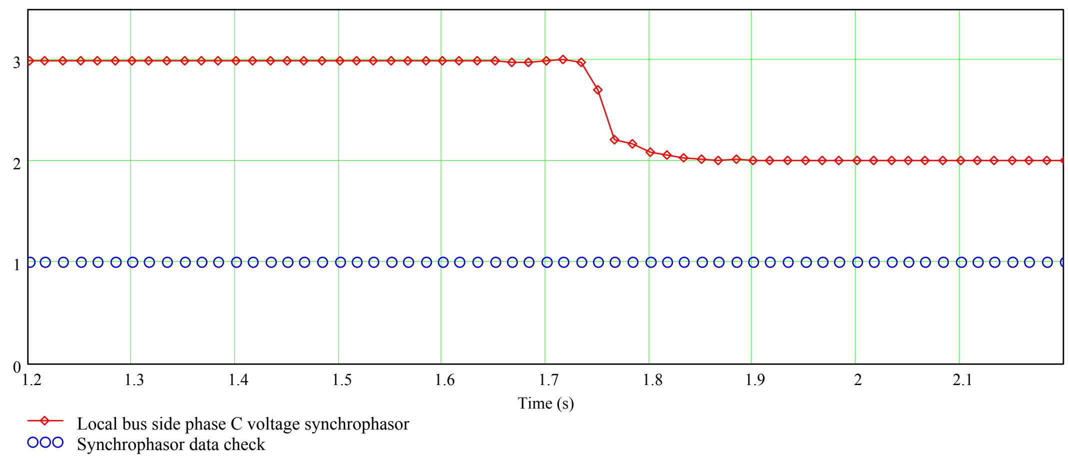

Figure 22 Synchrophasor Data for ABC Fault at 80 Percent on Line 1 From Local End

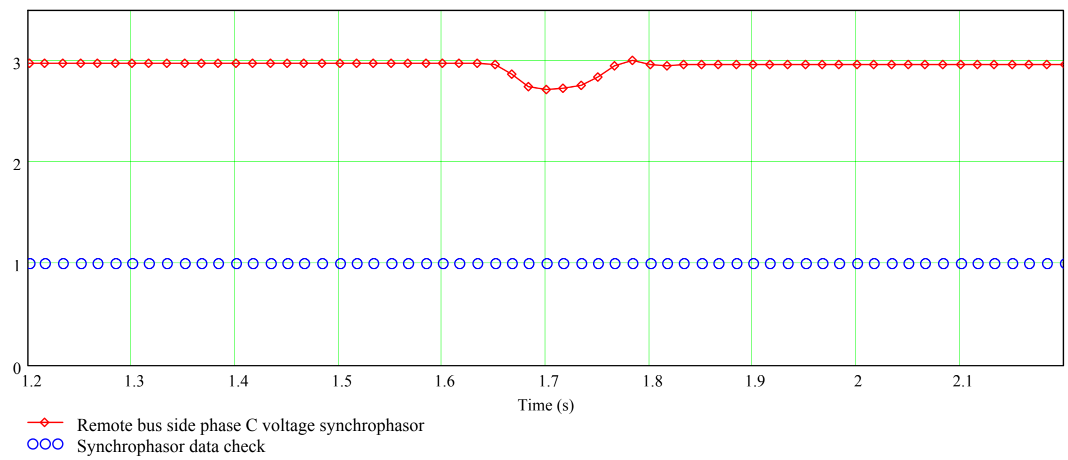

Figure 23 Synchrophasor Data for ABC Fault at 20 Percent on Line 1 From Remote End

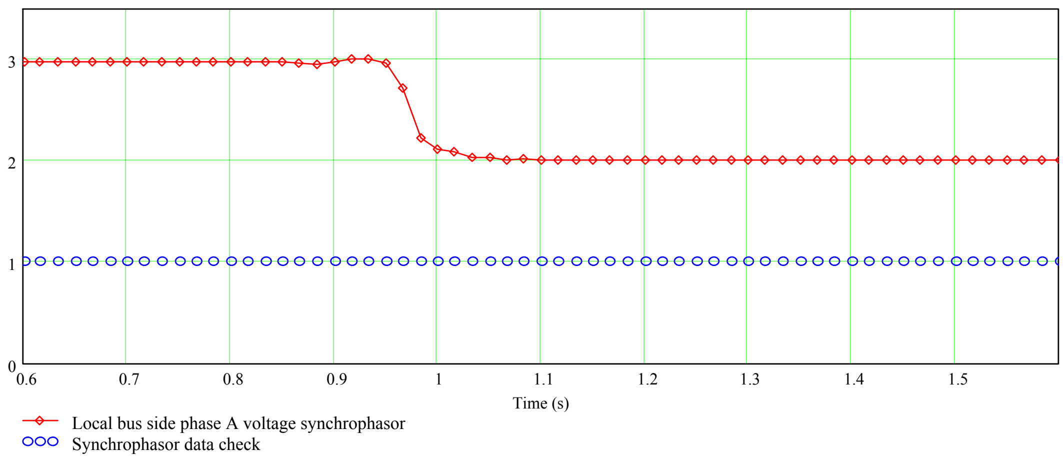

Figure 24 Synchrophasor Data for ABC Fault at 90 Percent on Line 1 From Local End

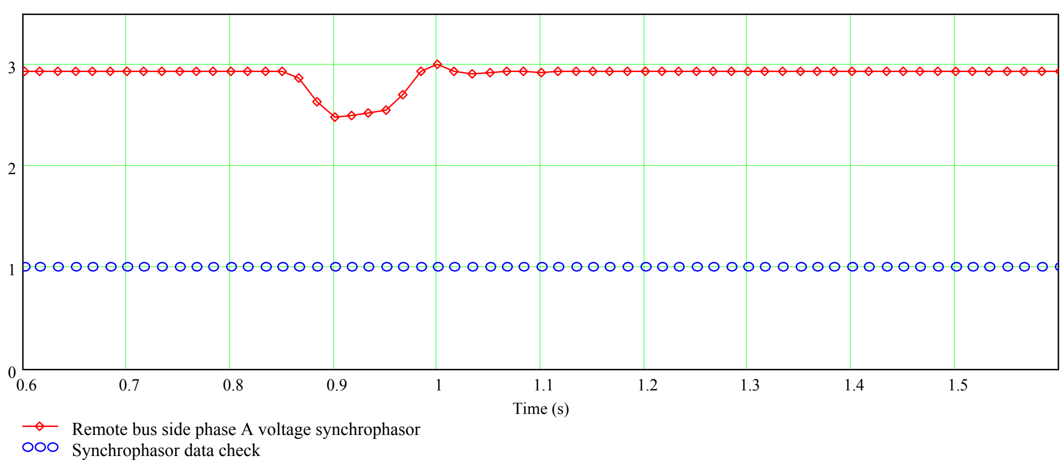

Figure 25 Synchrophasor Data for ABC Fault at 10 Percent on Line 1 From Remote End