THE EFFECTS OF NEUTRAL SHIFTS
ON PROTECTIVE RELAYS

Authors:

Joe Perez P.E., SynchroGrid, College Station, Texas 77845

Amir Makki Ph.D, Softstuf, Philadelphia, PA 19106

Shijia Zhao, Texas A&M University, College Station, Texas 77845

Presented before the
68th Annual
Texas A&M Protective Relay Conference
College Station, Texas
March 30th – April 4th, 2015

THE EFFECTS OF NEUTRAL SHIFTS ON PROTECTIVE RELAYS

Joe Perez P.E., SynchroGrid, College Station, Texas, jperez@synchrogrid.com
Amir Makki Ph.D., Softsuf, Philadelphia,Pa, amir@softstuf.com
Shijia Zhao, Ph.D Candidate, TAMU, College Station, Texas

I. Introduction

The power system is full of interesting phenomena that have challenged engineers since the very first AC grids were put in place. There are occasions during faults that the system behavior does not look quite right. One interesting case is when the neutral falls outside the power system triangle. This phenomenon is commonly known as a neutral shift or neutral inversion, and can cause protective relays to determine the location of the fault incorrectly. However, the neutral shift is not an easy term to grasp and is not easily recognized in fault waveforms. This paper presents the event analyst with the theory, causes, and field record waveforms behind neutral shifts and their effects on protective relays, which will aid the analyst in the analysis of neutral shifts.

The neutral shift phenomenon is studied in this paper and case studies are presented on the impact and effects in protective relays. Thus, this research is to investigate and show the impact of neutral shift on protective relay behaviors. This paper introduces the reader to the basics of neutral shifts, describes three cases of neutral shifts, and shows the impact of neutral shift on protection relays.

II. Basics of Neutral Shift

The definition of neutral shift or inversion is not new to the power system area and has been researched since the early beginnings of power systems. The transmission, sub-transmission, and distribution systems are mostly composed of delta or wye connected systems. The delta system, a common system employed by electrical utilities, defers from the wye system specially in not having a neutral point. A delta system is inherently ungrounded and it can have line to ground voltages through the line to ground capacitance, leakage reactance, and other impedances such as single-phase potential transformers used for metering or relaying. During single line to ground faults, the neutral point is shifted, but leaves the phase-to-phase voltage triangle intact.

A wye system can become ungrounded if the ground becomes isolated and it can also have line to ground voltages through the capacitance and leakage reactance. Since these impedances are connected to ground, the ground serves as the neutral point of this neutral isolated system. If the voltages and impedances are balanced, the line to ground voltages will be equal in magnitude with respect to the neutral point [1]. If a set of balanced voltages is connected to a set of unbalanced impedances, the neutral point is then shifted or inverted and the neutral point can be located outside the voltage triangle [2].

A delta or isolated neutral system with a set of balanced voltages and balanced impedances is shown in figure 1 below. Notice that the neutral point is inside the voltage triangle.

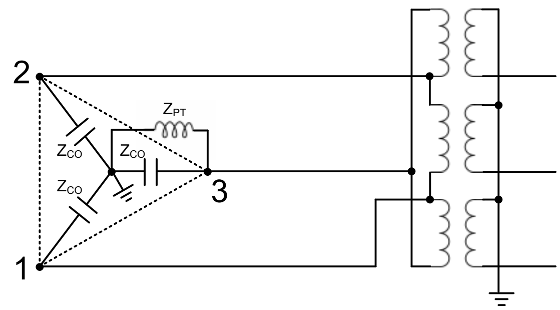

Fig. 1: No Neutral Shift

Figure 2 below shows a set of balanced voltages, but the impedance for one of the phases has been modified. As a result, we noticed that the neutral point shifted from its original point and is now located outside the voltage triangle.

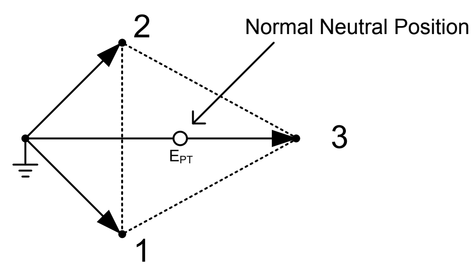

Fig. 2: Neutral Shift

Depending on the value of the connected impedance such as Z_{PT} in figure 1, the neutral point can either be shifted or totally inverted as shown in figure 3 below.

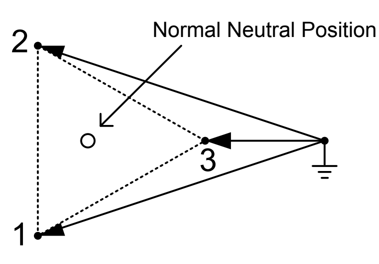

Fig. 3: Neutral Inversion

As shown above, the connected impedance has an effect on the location of the neutral point and can vary depending on its magnitude. For example, the capacitance to ground and leakage reactance magnitudes will be different depending on the system voltage. This impedance can also change depending on the characteristics of the potential transformers that are connected to ground. The mathematical explanation is given in reference 1 if the reader wants to dig deeper.

In summary, neutral shifts or inversion are common in delta or isolated neutral systems. The following section will look into case studies of real system operation on the transmission system where neutral shifts were observed.

III. Importance of Graphical Representation of Neutral Shift

Most of the digital fault display and analysis programs that are available on the market today do not naturally provide for graphical display of neutral shift. Neutral shift is best observed graphically from phasor diagrams. However, typical phasor diagrams display three phase quantities at one cycle in time. To observe neutral shift we need to compare the prefault quantities to the fault quantities thus requiring a display that can show two separate cycles in time.

For example, figure 4 shows prefault and fault voltages for case 1 displayed on two separate phasor diagrams. Clearly, it is difficult to measure neutral shift by looking at separate phasor diagrams.

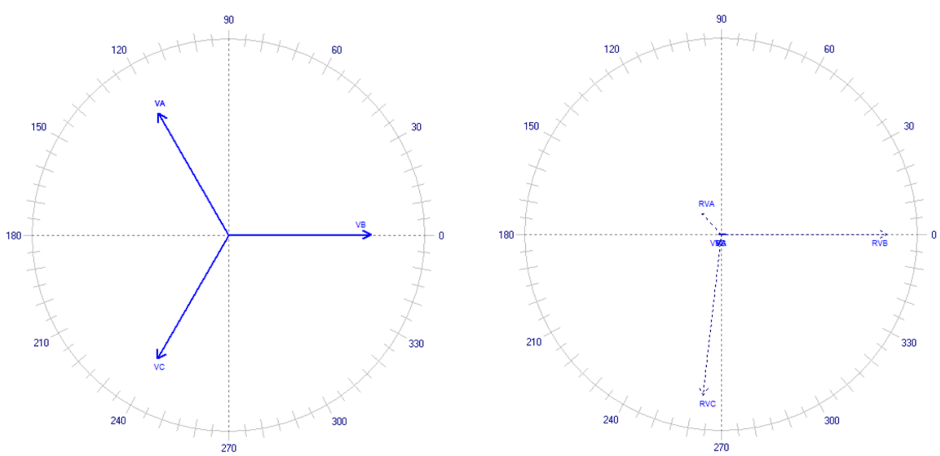

Fig. 4: Prefault Voltage Phasors (left) and Fault Phasors (right)

The best way to measure neutral shift is to graphically superimpose the phasor diagrams of figure 4 onto one diagram as shown in figure 5.

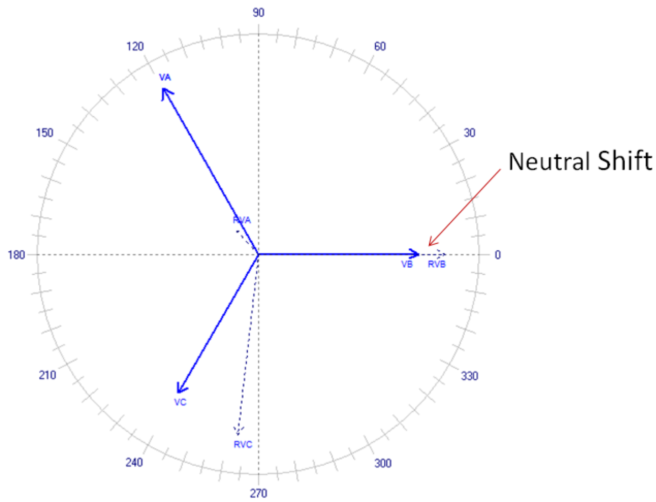

Fig. 5: Superimposed prefault and fault phasors

IV. Case Studies

For this section, we show cases where: no neutral shifts, neutral shifts and semi-neutral shifts are observed during a transmission fault.

Case 1: Solid Grounded System:

In the first case, a single phase A line to ground fault on a solid grounded system was seen in the transmission system. Taking unfaulted phase B as reference, we can see that the magnitudes before and after the fault are not affected and therefore no neutral shift occurs. As can be seen on the phasor diagram in figure 6, the neutral point has a negligible.

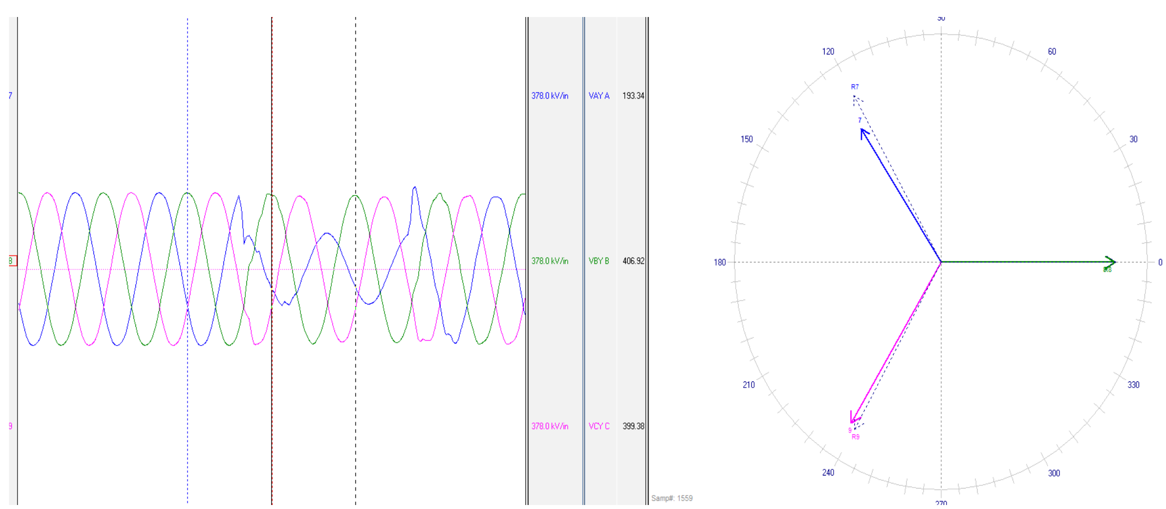

Fig. 6: Waveforma and Phasor Diagrm of Case 1

Case 2: Ungrounded System:

For the second case, a PSCAD simulation was performed on an ungrounded system to force a neutral shift. A single A phase to ground fault was performed. It can be observed that voltage magnitudes and angles of phases B and C have increased and changed due to the single phase A line to ground fault. The phasor diagram in figure 7 shows that such increase is due to the shift of the neutral point. It can also be seen that since the source is not grounded, the voltage triangle is kept intact.

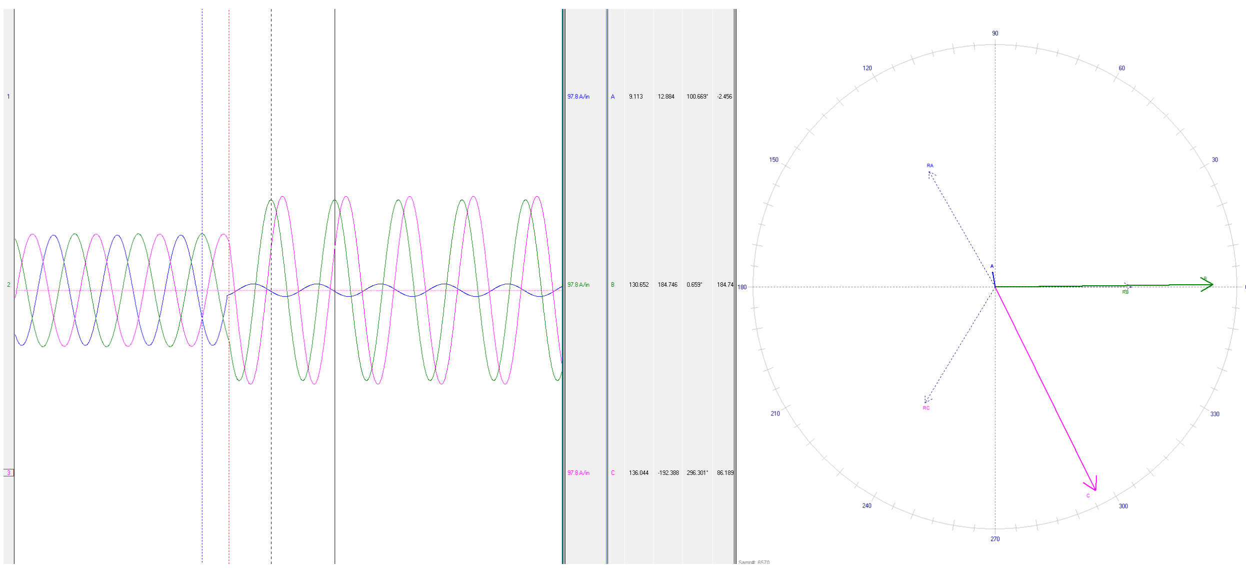

Fig. 7: Waveform and Phasor Diagram of Case 2

Case 3: Isolated Neutral:

The third case is also a line to ground fault in the transmission system but in this case the neutral point has shifted. Since most transmission systems are solid grounded, this phenomenon is not common. Taking unfaulted B phase as reference, it can be observed that before and after the fault B phase magnitude has increased substantially as compared to case 1 above. As a result, the neutral shift can be clearly seen. The phase-to-phase magnitudes of B&C remain the same before and after the fault indicating that the system voltage did not increase. As shown in figure 8 below, the voltage triangle is “half broken” after the fault as compared with case 2. This might be due to a partially isolated neutral on the system.

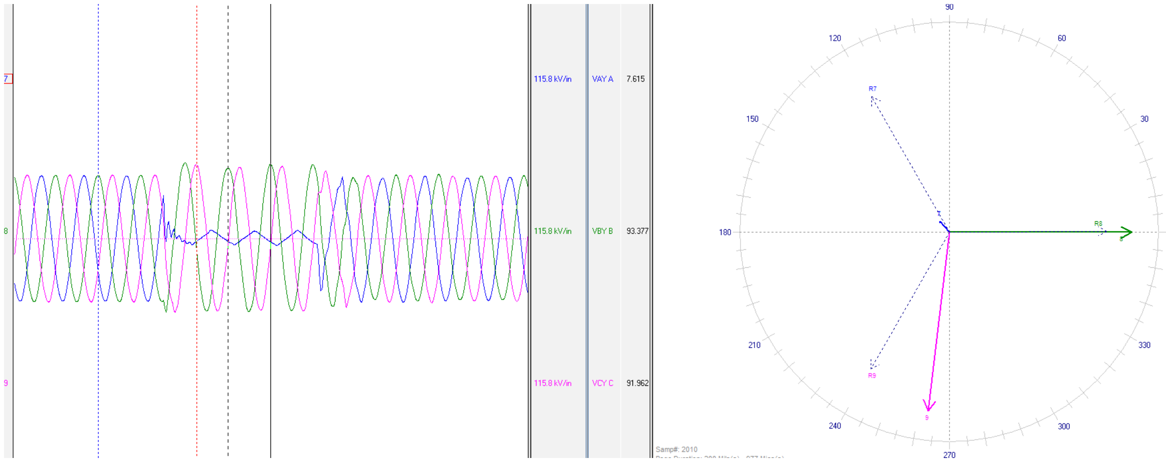

Fig. 8: Waveform and Phasor Diagram of Case 3

V. Impact on Protective Relay

In order to show the impact of neutral shift on a protective relay, two simulated cases were further studied from case two above. The goal of this simulation is to see the effect of the neutral shift on the faulted voltage measured by the protective relay.

The first simulation is taken from case 2 above which has an ungrounded system with balanced impedances. This simulation showed that a neutral shift is observed during the fault as shown in Figure 9.

The second simulation (case 2a) considered reducing the phase A impedance to determine the impact on the faulted phase voltage magnitude. The results of this simulation are shown in figure 9.

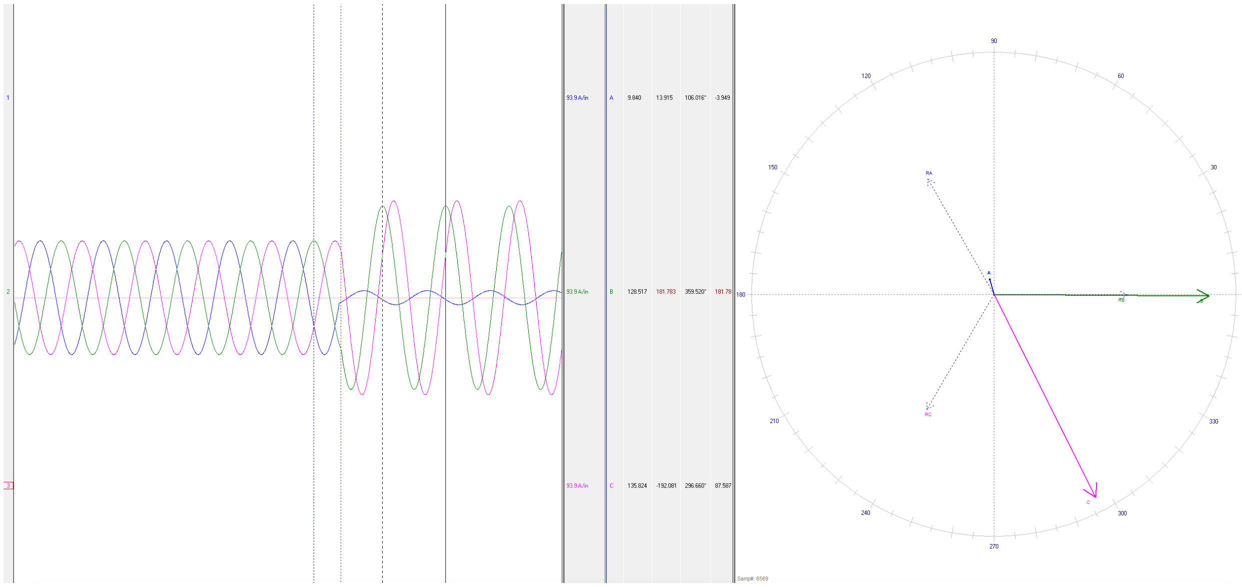

Fig.9: Wavform and Phasor Diagrams of Cases 2

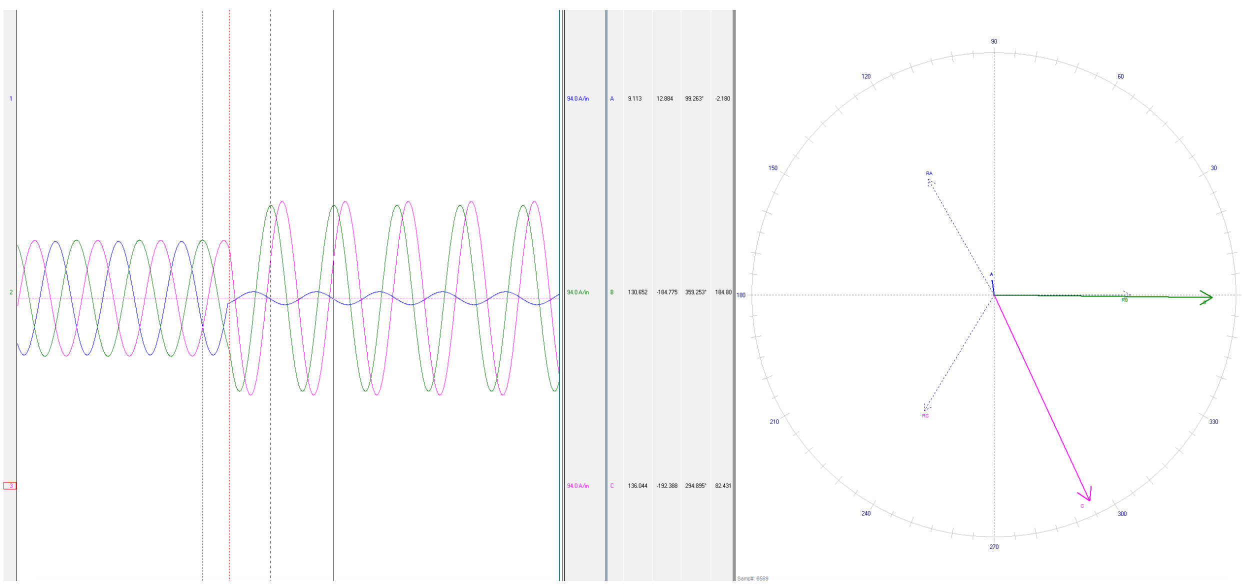

Fig. 10: Waveform and Phasor Diagram Case 2a

The numeric comparison of voltages before and during the fault is shown in Table 1.

Table 1 Comparison between case 2 and case 2a

	Case 2		Case 2a	
	Normal /kV	Fault /kV	Normal /kV	Fault /kV
A-B	138	137.26	138	138.23

A-C	138	144.07	138	144.07
B-C	138	138	140	142.12
Phase A	79.67	9.84	79.82	9.11
Neutral Shift	48.86		50.99	

It can be seen from Table 1, with decrease of phase A impedance, the neutral shift is manifested leading to a decrease of phase A fault voltage. When phase A impedance is reduced, neutral shift increased by 4.36%, phase A fault voltage decreased by 7.42%.

In summary, comparison between case 2 and case 2a proved that unequal impedance could lead to manifestation of neutral shift and then the decrease of phase A voltage, which could potentially cause protective relays to mis-operate if faults are within the Zone 1 margin of error.

It is possible that the effect shown above might have had an impact on the operation demonstrated in case 3.

VI. Summary and Conclusion

This paper has shown the benefits of viewing and determining neutrals shift by graphically showing it in the voltage triangle along with the phasor diagram. We have demonstrated how neutral shifts are observed on solid grounded, ungrounded and semi-ungrounded systems. Finally, it was determined that neutral shifts can have a direct impact on the fault phase voltage and therefore affecting protective relay performance.

VII. References

[1] L. L. Gleason, "Neutral Inversion of a Single Potential Transformer Connected Line-to-Ground on an Isolated Delta System," *American Institute of Electrical Engineers, Transactions of the,* vol. 70, pp. 103-111, 1951.

[2] J. L. Blackburn, *Symmetrical components for power systems engineering*: CRC Press, 1993.

[3] B. G. Gates, "Neutral inversion in power systems," *Electrical Engineers, Journal of the Institution of,* vol. 78, pp. 317-325, 1936.

VIII. Author Biographies

Joe Perez received his B.S. degree in Electrical Engineering from Texas A&M University in 2003. Joe is the author of many relay application notes and has presented technical papers at WPRC, Texas A&M and Georgia Tech Relay Conferences. Joe is the owner of SynchroGrid, a registered professional engineer in the state of Texas and a member of PSRC, IEEE, and PES. Joe resides in the Bryan/College Station area. He can be contacted at jperez@synchrogrid.com.

Amir Makki has worked at Softstuf since 1991. He has BS and MS degrees in Electrical Engineering from Tennessee Tech University and pursued his Ph.D. studies in Software

Engineering at Temple University. His main interest is automating fault and disturbance data analysis. He is extensively published and holds a number of U.S. patents and trademarks. Amir is a senior member of IEEE and is an active member of the Protection Systems Relay Committee where he chaired a number of working groups including COMTRADE, COMNAME, and the Cyber Security Task Force for Protection Related Data Files

Shijia Zhao received the B.S. degree in Electrical Engineering in 2012 from Huazhong University of Scienc and Technology (HUST), Wuhan, China. Now, he is pursuing the Ph.D. degree in the Department of Electrical and Computer Engineering at Texas A&M University, College Station. His main research interest is in the development and application of power system reliability techniques, as well as the efficient integration of renewable energy.