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How OSHA's New Transient Overvoltage Requirements Affect Work Practices

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SUMMARY

This paper presents how the new Occupational Safety and Health Administration 29 CFR,§1910. 269 (OSHA 269) transient overvoltage (TOV) requirements affect a sample investor-owned utility (IOU) client's current safety approach distance to energized electrical equipment for transmission and distribution system. The new requirement could adversely impact many of the industry's current work practices as regulations go into effect January 31, 2016. It is anticipated that, if a utility solely utilizes the conservative TOV values supplied by OSHA without performing the appropriate an engineering analysis, then working distances will increase to values much greater than current working distances. The distances at high-voltage equipment may increase 50 percent or greater. Thus, prior to the deadline, utilities have the option of using the OSHA stipulation stating that, if the utility performs an engineering analysis using an electromagnetic transient program such as PSCAD or EMTP-RV, the amount of TOV could be reduced and consequently the MAD is decreased.

In 2014, OSHA updated its 29 CFR Parts 1910 and 1926, commonly referred to as the "269 Standard," which entails implementing new OSHA rules for electric power generation, transmission, and distribution, electrical protective equipment. Specifically, OSHA's update affects many electric utilities' MAD to energized equipment greater than 72.5 kV. As stated in OSHA 269 Paragraph (c)(1)(ii) of§1926.960, OSHA "requires the employer to determine the maximum anticipated per-unit TOV, phase-to-ground, through an engineering analysis or assume a maximum anticipated per-unit TOV, phase-to-ground, in accordance with OSHA Table V-8, which specifies the following maximums for AC systems."

Furthermore, if the TOV remains above OSHA's threshold, mitigation could be evaluated. A significant associated concern is that arc flash studies are dependent on TOV distances and consequently values will need to be recalculated to align with the TOV study. In other words, there is a resultant push-pull scenario between TOV and arc flash to help shape the future of safety distances to energized equipment. All substations over 69 kV will be needed to be analyzed for TOV and arc flash in order to be OSHA-compliant.

KEYWORDS

Minimum Safe Distance, Transient Overvoltage, OSHA-269, PSCAD, EMTP-RV

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1. Introduction

The new Occupational Safety and Health Administration 29 CFR,§1910. 269 (OSHA 269) transient overvoltage (TOV) requirements have prompted electric utilities to re-evaluate their present minimum approach distances (MAD) to energized electrical equipment for substations and transmission lines. The new requirement could adversely impact many of the industry's current work practices as regulations go into effect January 31, 2016. It is anticipated that, if a utility solely utilizes the conservative TOV values supplied by OSHA without utilizing an engineering analysis, then the MAD will increase to values much greater than present MAD. The distances at high-voltage equipment may increase 50 percent or greater. Thus, prior to the January 31 deadline, utilities have the option of using the OSHA stipulation stating that the revised provisions on MADs include a new requirement for the employer to determine maximum anticipated per-unit TOVs through an engineering analysis or, as an alternative, assume certain maximum anticipated per-unit TOVs (Paragraph c(1)(ii)). In other words, if the utility performs an engineering analysis using an electromagnetic transient program such as PSCAD or EMTP-RV, the amount of TOV could be reduced and consequently the MAD decreased. These software programs require careful consideration when modeling a utilities system. When simulating an event on the system, the amount of trapped charges on the studied line and time for the charges to dissipate directly affect the TOV calculations.

To demonstrate this point, the remainder of this paper discusses the tools to successfully meet the OSHA compliance requirement. This paper presents compliance considerations, TOV modeling, studies and assumptions, simulations, and mitigation of OSHA's 269 TOV requirements.

2. Compliance Considerations

In 2014, OSHA updated its 29 Code of Federal Regulations (CFR) Parts 1910 and 1926, commonly referred to as the "269 Standard," which entails implementing new OSHA rules for electric power generation, transmission, distribution, and electrical protective equipment. Specifically, OSHA's update affects many electric utilities' MADs to energized equipment greater than 72.5 kV. As stated in OSHA 269 Paragraph (c)(1)(ii) of§1926.960, OSHA "requires the employer to determine the maximum anticipated per-unit TOV, phase-to-ground, through an engineering analysis or assume a maximum anticipated per-unit TOV, phase-to-ground, in accordance with Table V-8, which specifies the following maximums for AC systems." Minimum approach distance can be defined as the distance, based on voltage involved, that an unprotected 269-qualified employee must maintain when exposed to energize parts.

As presented in Figure 1 below, the OSHA-recommended MAD values do not significantly differ from a MAD values for voltages less than 230 kV. Leidos investigated this issue for a mid-sized investor-owned utility (IOU) client. At high voltages, consideration on the impact of a utilities MAD would need to be evaluated to determine compliance.

Figure 1. Minimum Approach Distance Comparison

Voltage (kV)	Mid-Sized IOU MAD (ft)	OSHA Calculated Phase-to-Ground (ft)	OSHA Calculated Phase-to-Phase (ft)	OSHA TOV Recommendation (p.u.)
12	2.16	2.13	2.23	--
69	3.16	3.28	3.94	--
138	3.58	4.30	5.40	3.5
230	5.25	5.60	8.40	3.5
500	11.25	16.6	27.00	3.0
ft = feet p.u.= per unit				

As indicated in OSHA's Table 13 in Figure 2 below, the TOV (p.u.) values dictate the MAD distances. The greater the per-unit TOV, the greater the MAD that OSHA recommends for compliance. As such, in order to reduce the MAD to values close to industry standards, utilities would look for values between 2.3 and 2.4 at the 420.1 kV to 550.0 kV range.

Figure 2. OSHA Table 13 - AC Minimum Approach Distances 420.1 to 550.0 kV

T (p.u.)	Phase-to-Ground Exposure		Phase-to-Phase Exposure	
	m	ft	m	ft
1.5	2.0	6.4	3.5	11.4
1.6	2.1	6.9	3.7	12.2
1.7	2.3	7.5	4.0	13.2
1.8	2.5	8.0	4.3	14.1
1.9	2.6	8.6	4.6	15.1
2.0	2.8	9.2	4.9	16.1
2.1	3.0	9.8	5.3	17.2
2.2	3.2	10.5	5.6	18.2
2.3	3.4	11.2	5.9	19.2
2.4	3.6	11.9	6.2	20.3
2.5	3.8	12.6	6.5	21.3
2.6	4.1	13.4	6.8	22.4
2.7	4.3	14.1	7.2	23.6
2.8	4.6	15.0	7.5	24.7
2.9	4.8	15.8	7.9	25.9
3.0	5.1	16.6	8.2	27.0
m = meters T=TOV ft=feet				

An additional consideration to the MAD values is the determination of the distances to the arc for voltages greater than 46 kV. As shown in Figure 3(OSHA Figure 1), OSHA outlines the MAD distance between the worker and the energized equipment. Previously working distances associated to arc flash and MADs were independent of each other, but OSHA 269 recommends calculating the proper arc flash personal protective equipment in conjunction with MAD.

Figure 3. OSHA Minimum Approach Distance

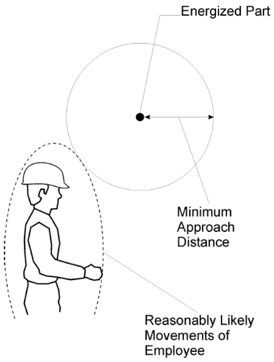


Figure 1—Maintaining the Minimum Approach Distance

As seen in Figure 4, the new arc flash working distance for 46 kV or greater is calculated by subtracting the arc length from the MAD. Therefore, to accurately calculate arc flash hazard levels, the MAD values must be taken into consideration. Figure 4 below represents OSHA's 269 Table 14, which recommends that the arc length be calculated, using the formula: (2 x kV/10). Essentially, if the MAD is reduced then the arc flash calculation will need to be re-checked.

Figure 4. OSHA Table 14 - Selecting a Reasonable Distance from the Employee to the Arc

Class of Equipment	Single-Phase Arc mm (inches)	Three-Phase Arc mm (inches)
Cable	NA*	455 (18)
Low voltage MCCs and panelboards	NA	455(18)
Low-voltage switchgear	NA	610(24)
5-kV switchgear	NA	910(36)
15-kV switchgear	NA	910(36)
Single conductors in air (up to 46 kilovolts), work with rubber insulating gloves	380(15)	NA
Single conductors in air, work with live-line tools and live-line barehand work	MAD-(2 x kV x 2.54) (MAD-2 x kV/10)✞	NA

*NA = not applicable
✞The terms in this equation are:
MAD = The applicable minimum approach distance, and
kV = The system voltage in kilovolts

3. Modeling for TOV Evaluation

Transient overvoltage in electrical transmission and distribution systems can be a result from faults and network switching operations. TOVs are of very short duration (microseconds to milliseconds) and can be of large magnitude. In order to study TOVs accurately, we must use an electromagnetic transient software program with a frequency-dependent model capability such as EMTP-RV or PSCAD. Figures 4 and 5, derived from PSCAD and EMTP-RV, respectively, represent the line transmission model in the software.

Figure 5. PSCAD Model of Transmission Line

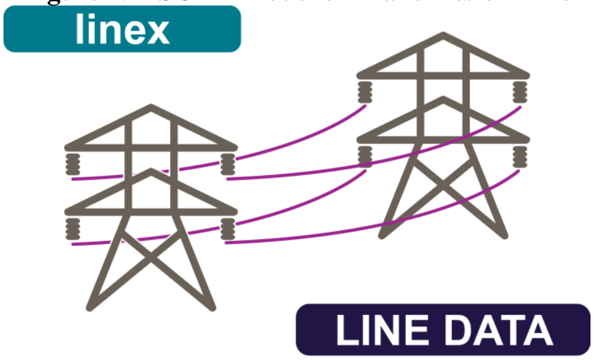
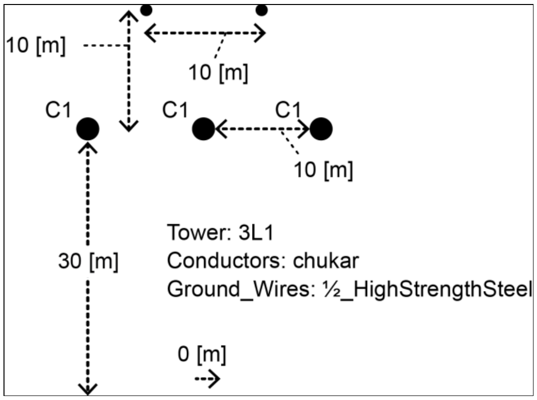


Figure 6. EMTP-RV Model of Transmission Line



Major considerations needed for building a TOV model are:

1. Line constant data
2. Network equivalents
3. Topology of the system.

Regardless of the software used, it is crucial to get the line-constant data. Typically, the user would be able to obtain the line-constant data from steady-state transmission software such as Electrocon's CAPE or Advanced System's ASPEN. It is also crucial to obtain the equivalent of the network, and such information could be obtained from a power flow program such as Siemens PTI's PSS□E and GE PSLF.

Once the above parameters are collected, the final consideration prior to modeling is to determine how many neighboring buses will need to be modelled. When studying TOV for a specific line in the system, neighboring transmission line capacitance is required to represent the system more accurately. Therefore, it is recommended to create a loop network around the studied line. Figures 7, 8, and 9 below were derived from modeling software to illustrate a typical network topology. The figures provide the user with an idea of the level of detail of the system would need to be modeled to perform TOV studies.

In order to accurately represent system current flows during fault and switching events a loop network is needed. A simplified partial model of the studied line, as represented in Figure 7, could produce unrealistic results. One of the issues would be to accurately simulate reclosing/energizing since the load side would have no energy supply under this radial representation. Another issue would be the loss of the entire system, which is not realistic for a network line.

Figure 7. Simple Model of Partial Line

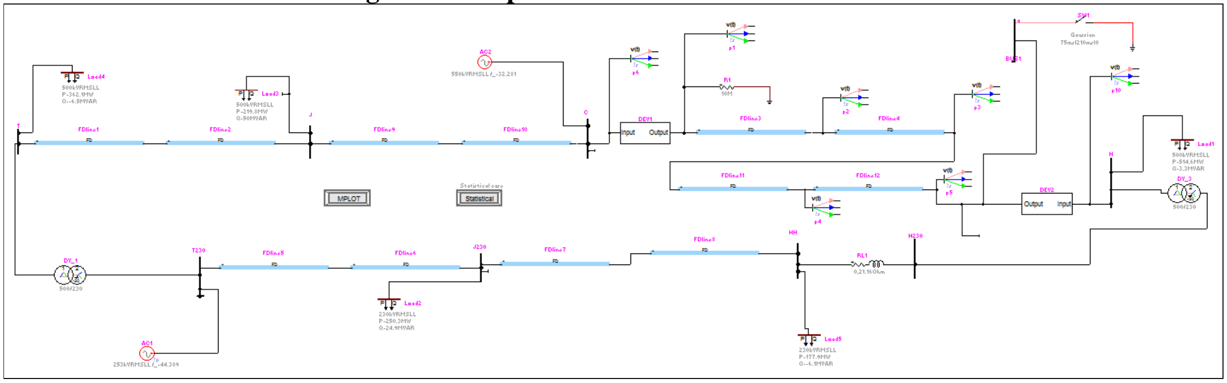
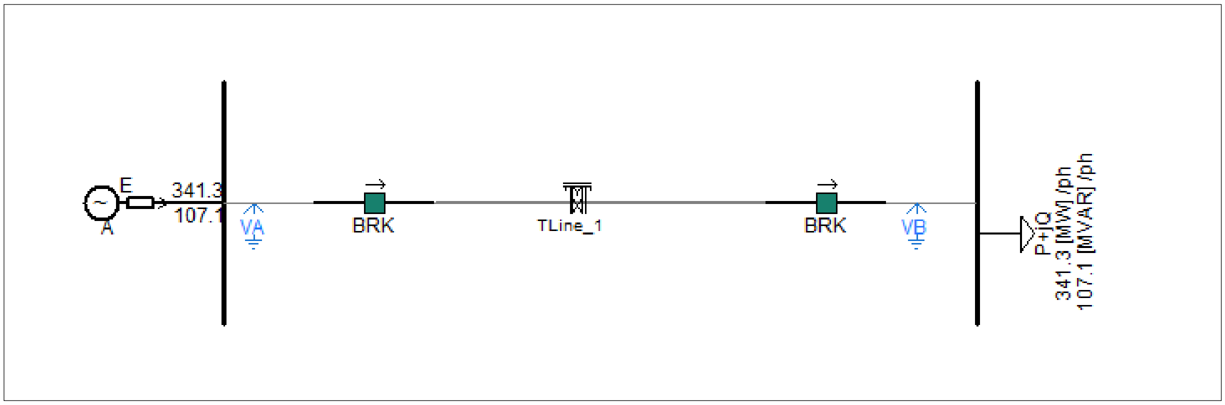


Figure 8. Detailed Model



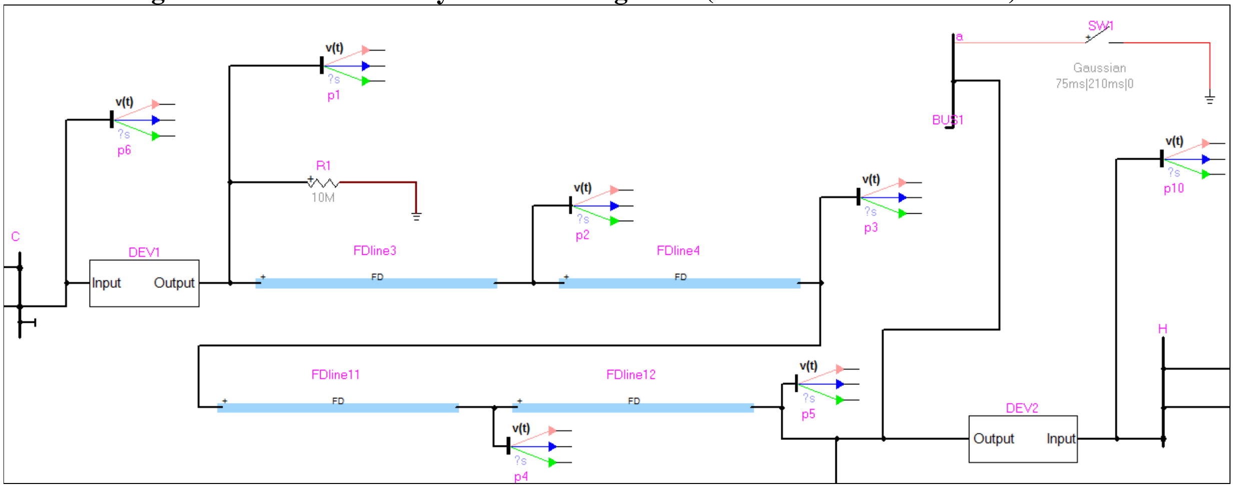
4. Studies and Assumptions

After creating and validating the model, it is important to determine the type of simulations and the location of the voltage measurements. It is recommended to split the study line into two to three segments at a minimum to effectively measure the TOV throughout the line into parts shown below:

- Local and remote substation (i.e., beginning and end)
- One-third
- Middle
- Two thirds

Figure 9 illustrates the four segments mentioned above. This approach helps identify the highest TOV captured at the line. Depending on the network and the location of the line, the worst TOV (i.e., the highest measurement) could be captured in different locations of the line. In other words, if only one measurement is taken, then we risk missing the worst TOV value.

Figure 9. Line Under Study Divided in Segments (Derived from EMTP-RV)



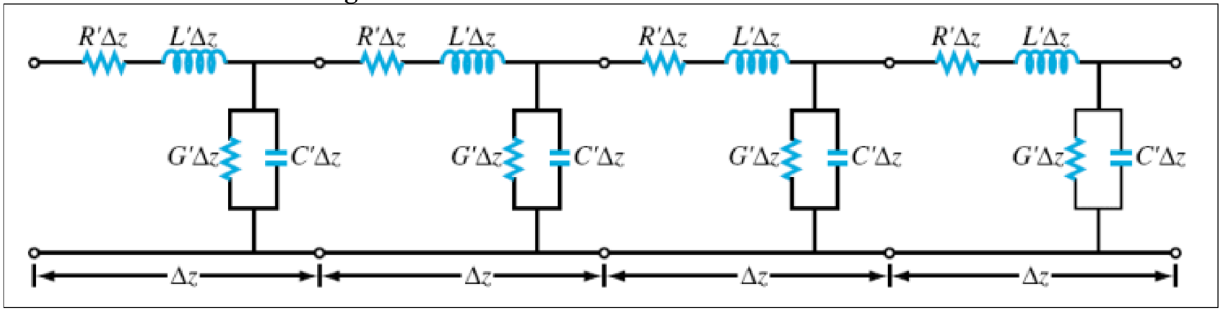
Different types of scenarios should be evaluated. The highest TOV could result from faults or de-energization. Therefore, it is recommended to perform the following simulations:

- Single-line-to-ground (SLG)
- Double-line-to-ground (DLG)
- Line de-energization

These three simulations should be performed under non-reclose and reclose scenarios. It is crucial to study high-speed reclose because the trapped charges on the line may not sufficiently dissipate which could lead to high TOV values.

A major consideration when performing TOV analysis is the shunt conductance value. Shunt conductance is a result of leakage current flowing across the insulators and air. Different software programs have different values that will yield significantly different TOV results. Therefore, it is important to investigate the most accurate value for the system under study. The value is complicated to calculate as it depends on many variables such as the type of insulator and the air quality. Utility-specific shunt conductance data is needed to accurately model the studied line.

Figure 10. Basic Transmission Line Model



Source: National University of Singapore, Department of Electrical & Computer Engineering.
https://www.ece.nus.edu.sg/stfpage/elehht/Teaching/EE2011%20Part%20B/Lecture%20Notes/Transmission%20Lines%20-%20Basic%20Theories.pdf

5. Simulation Results

The results of the simulation need to be compared with OSHA 269 table in order to accurately determine the MAD (Refer to OSHA Table 13 - AC Minimum Approach Distances 420.1 to 550.0 kV previously presented in Figure 2). This table is useful for utilities to determine mitigation if the distance is above the typical distance that the utility uses. An example of a double line to ground fault simulation is shown in Figure 11. In this example, the 2.42 p.u. TOV produced a MAD that was greater than a utility’s present distances. The TOV value prompts the need for further mitigation strategies.

A result for the 500 kV line in Figure 11 represents a DLG fault measured at the side of the bus, indicating the highest TOV is 2.42 p.u. If no mitigation is implemented based on OSHA 269 Table 13 for 500 kV line, the MAD would be 11.9 ft. If 11.9 ft is high and the utility needs a smaller distance, the utility could consider revisiting the studies and proposal mitigation measurement in order to reduce the MAD.

Another example is shown in Figure 12, which represents a 500 kV line after an SLG fault measure at the side of the bus with a 30-cycle high-speed reclose. The graph shows the TOV reaching 3.55 p.u.; the highest voltage was evident after the reclose of the line. As mentioned previously in section 3-Modeling of the TOV, this phenomenon is a result to the insufficient time for the trapped charges to dissipate prior to re-energization of the line.

Figure 11. DLG Fault – Measurement at Line Side (Voltage Reach 2.42 p.u.)

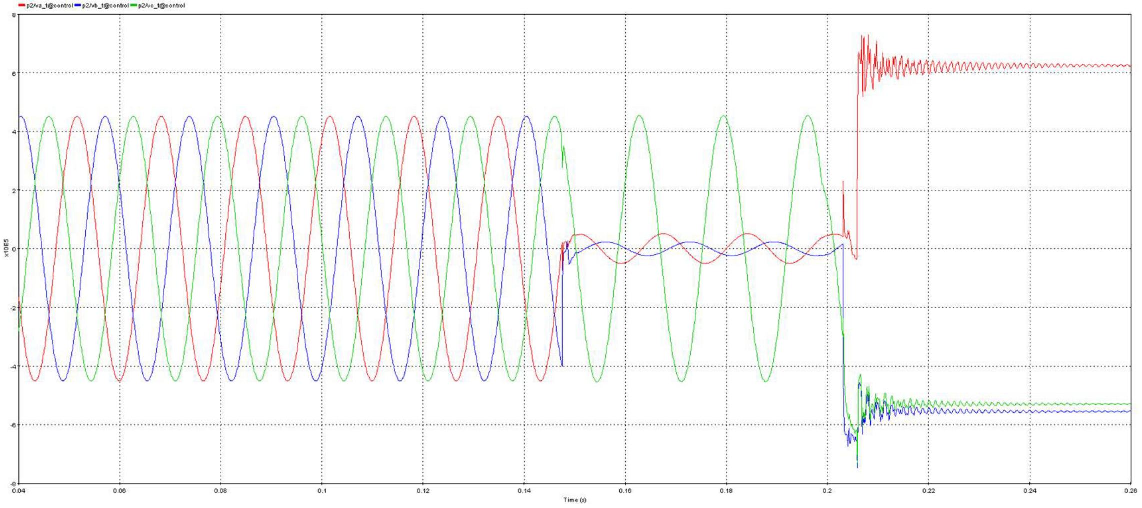
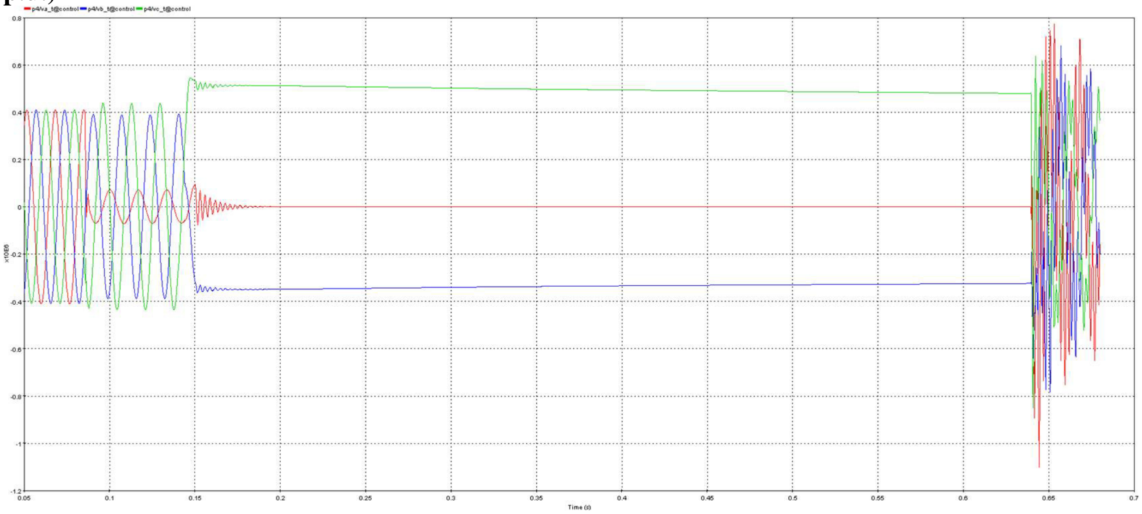


Figure 12. SLG Fault with 30 Cycles Reclose – Measurement at Line Side (Voltage Reach 3.55 p.u.)



6. Conclusion

OSHA 269 has added new considerations to determining a utilities MAD. The purpose of the engineering analysis is to ensure the present MAD distances are still within compliance. In the scenario that the TOV calculated forces a utility to possibly implement different mitigation strategies in order to maintain its present work practices.

There are a number of mitigation approaches that can be applied, depending on the severity of the TOV. For instance, TOV values above 3 per unit 500kV would translate into MAD distances greater than 16 feet and would therefore warrant a mitigation approach that would significantly reduce the TOV, such as pre-insertion resistors or transmission system upgrades. The range of TOVs will affect utility workers' ability to approach energized equipment. If the present MAD distances are increased marginally due to the studied TOV values, the utilities may consider for example installing surge arrestors. In some instances where the TOV values are so significant that the MAD prohibits work near energized equipment.

A final consideration to mitigation would the high TOV due to high-speed reclose schemes. In order to reduce the TOV disabling the high-speed reclose could be a solution. If the decision is to remove the high-speed reclose, it is strongly recommended to perform a dynamic stability study to make sure that it would not have an inadvertent impact to the system.

All of the mitigation approaches discussed are valid. However, before implementation, a technical study as described above should be performed on a case-by-case basis to determine the best method and validate the propose mitigation.