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Lessons Learned of AC Arc Flash Studies for Station Auxiliary Service Systems

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SUMMARY

Substation auxiliary service systems are important to supply continuous and momentary power to electrical equipment inside a substation, such as lighting, HVAC, transformer fans, circuit breaker motors, etc. [1]. As a result, station service equipment must be frequently operated or maintained. Either operation or maintenance could trigger an arc flash incident if a fault occurs simultaneously. In order to minimize potential arc flash hazards, AEP Transmission uses ASPEN to model station service systems and calculate incident energy at identified risk locations using an embedded arc flash hazard calculator based on IEEE-1584 [2]. This paper discusses various lessons learned from AEP studies with a focus on project processes and a sensitivity analysis of input data. Knowledge from these lessons learned allows arc flash studies to be more accurate, efficient, and less burdensome to station projects.

KEYWORDS

Station AC Service, Arc Flash, Incident Energy, Process, Sensitivity Analysis

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INTRODUCTION

Arc flash incidents from electrical faults on station AC service circuits (≤ 480 V) can result in the possible injury or death of station personnel. Typically, greater risk is associated with the low-side of AC station service (SS) transformers due to longer fault clearing times with greater exposure to the energized parts. The severity of an arc flash event depends on many factors including worker position relative to the electrical fault, fault duration, fault current magnitude, arcing gap width, and environmental conditions. As a result, an arc flash study is required, accounting for all possible variables, to quantify the severity of an arc flash incident (incident energy is the metric for this purpose). Furthermore, the arc flash study allows the development of mitigation strategies for high incident energy at identified risk locations. Common options for reducing the AC SS incident energy are adding a low-side fuse (required by AEP's current standard) and/or adjusting the fuse type/speed/amperage rating. In addition, consider reducing cable length and/or increasing the cable size downstream from the SS center cabinet.

Fig. 1 depicts a one-line diagram and the corresponding equipment photo of an example SS system including SS high-side fuses, SS transformers, safety-switch cabinet and SS center (transfer/throw-over switch) cabinet. Both the safety-switch and SS center cabinets are likely maintained or operated by personnel while the circuit is still energized. Therefore, calculating incident energy for those risk locations is necessary.

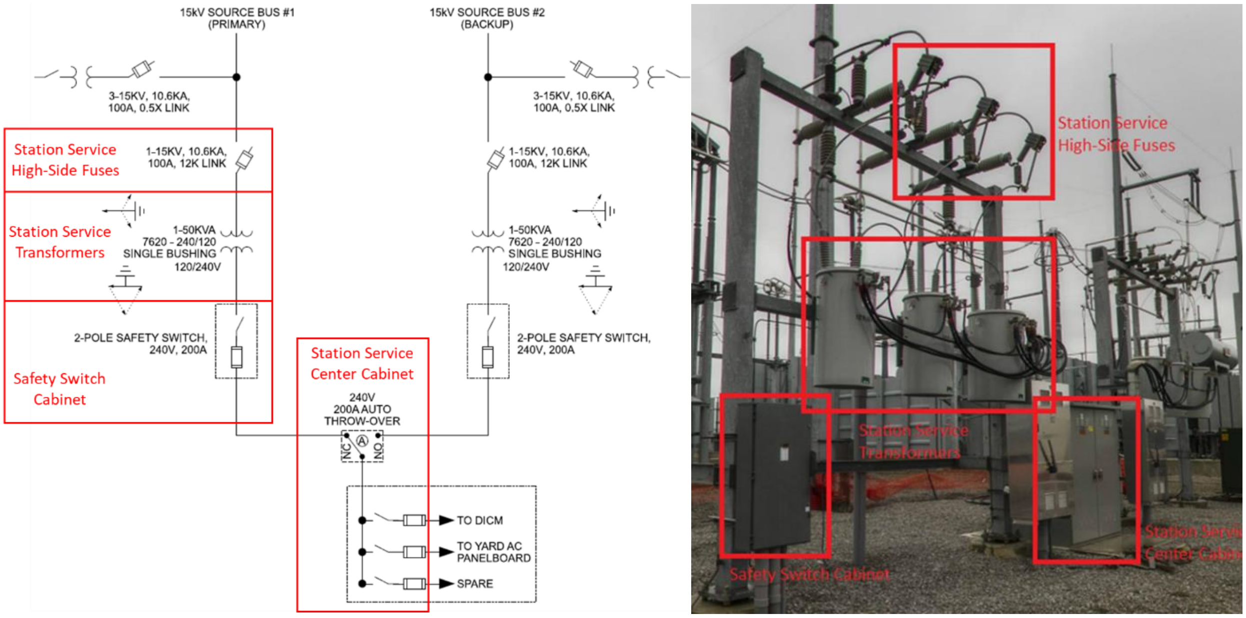


Figure 1: Station service one-line diagram and physical layout (examples)

As shown in Fig. 1, the SS center cabinet connects to a Drop-In Control Module (DICM) and yard AC panelboards/control cabinets downstream. These devices are commonly worked on by station personnel and should be treated as risk locations as well. Fig. 2 shows examples of a DICM (on the left) and circuit breaker control cabinets (highlighted on the right).

Figure 2: DICM and circuit breaker control cabinets (examples)

Above all, a study — which models all SS equipment and cables, and calculates incident energy at possible risk locations (as summarized above) — is strongly recommended. An ASPEN (fault and arc flash analysis software currently utilized by AEP) simulation example is shown in Fig. 3.

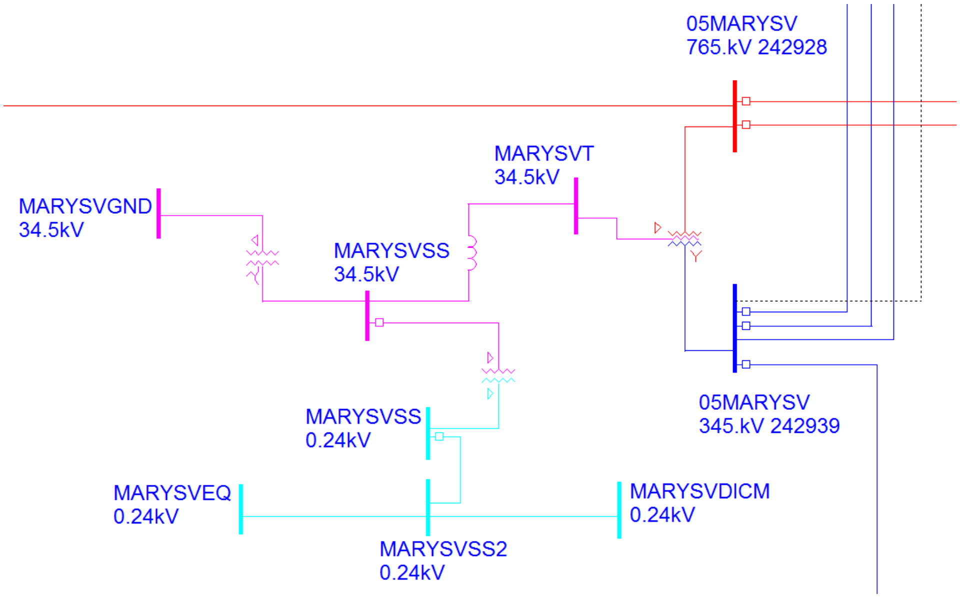


Figure 3: ASPEN simulation of an example arc flash study

Since an arc flash study needs to include information from multiple pieces of equipment, input data collection is one of the most important and time-consuming efforts. As a result, aligning the data gathering, calculations and mitigation with the project management process is significant to make a study more accurate and efficient. Additionally, an input data sensitivity analysis is beneficial to prioritize which variables require more attention while some others could be neglected or generically assumed. The following content of this paper focuses on a few lessons learned regarding the arc flash study process and sensitivity analysis.

AEP ARC FLASH STUDY PROCESS

AEP’S PROJECT PROCESS

1. The planning department determines needs in the power grid and proposes projects to address them. Each project begins as a high-level proposal, including mostly major equipment, such as circuit

breakers, transformers, and station bays. The project is vetted by various engineering and construction departments and then goes to the station engineering department where it is further developed.

2. The station engineering department develops the proposed project into a rough design, called a “scope.” A scope includes all major equipment and most minor equipment. It consists of a one-line diagram showing the electrical overview of the station, a station layout plan showing the location of the equipment, and a list of equipment to be installed. A scope receives an estimate and is then sent to a review board for full funding.
3. Once the project is funded, it can be fully designed and built. In this stage, most major studies are performed, such as grounding studies, lightning shielding studies, and SS design.
4. Lastly, the engineering department orders material, and the project is constructed.

INCORPORATING STUDY INTO PROJECT TIMELINE

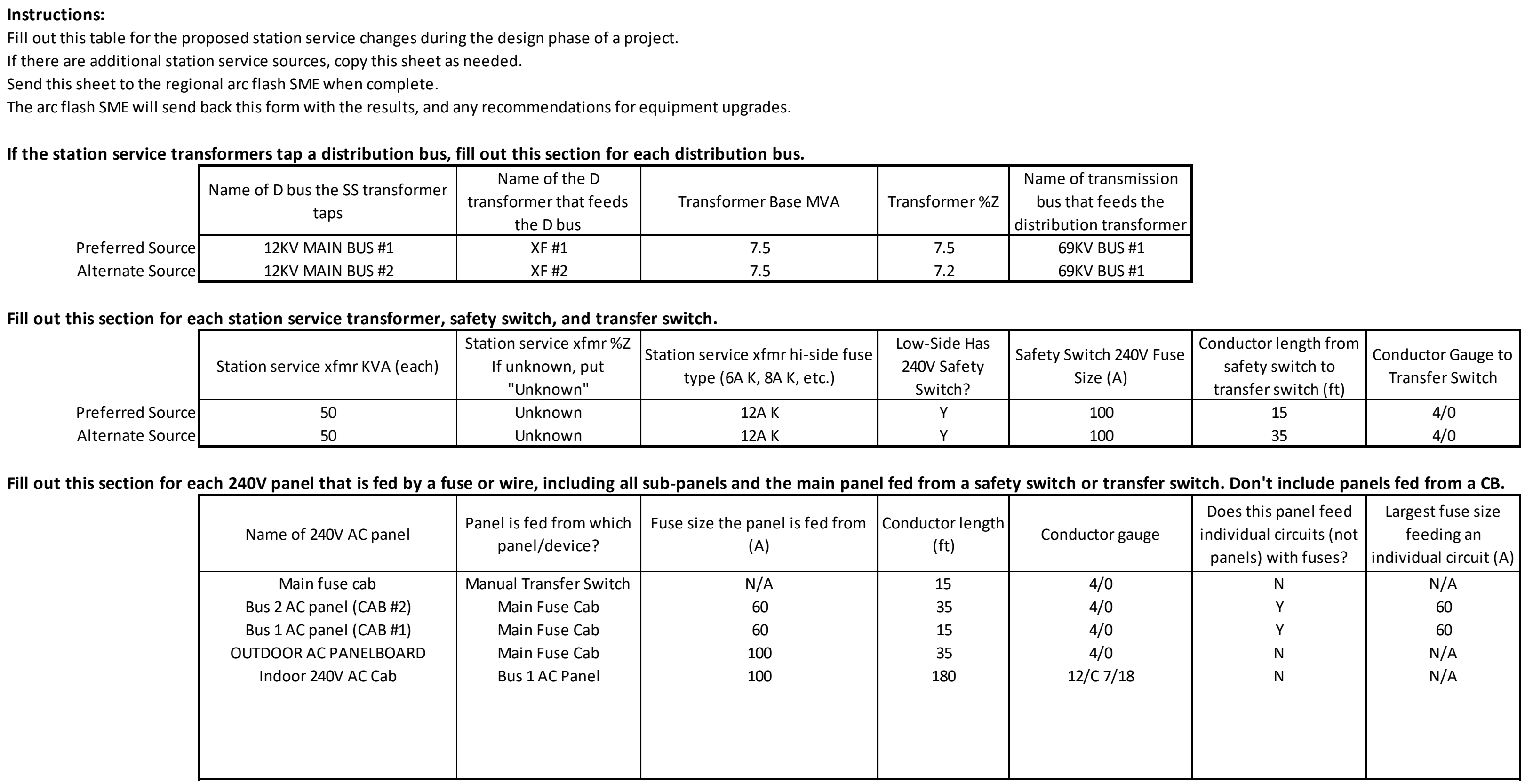
It is important that no significant cost is added after a scope is approved for full funding. A project is submitted to PJM (the regional transmission organization, or RTO) and various third-parties before approval. These organizations review the equipment to be installed, as well as the cost. These organizations can challenge a proposed project and request additional justification. After review, additional changes that increase a project’s cost may result in additional requests for justification. Furthermore, changes in cost adversely affect the project’s budget. Thus, AEP needs to ensure that an arc flash study will not trigger any significant costs after scoping.

The only significant cost that an arc flash study could trigger is the addition of a transformer high-side circuit switcher. A distribution voltage bus (12 kV) could exceed 8 cal/cm^2 at the minimum working distance of 36 inches if there was a fault that was not cleared quickly enough. This could happen if the clearing device is a distribution transformer high-side fuse. A faster fuse or a circuit switcher may be required to reduce the arc flash potential to a safer level. This part of the arc flash study would need to happen before the scope is approved. The solution is to check if there is a high-side fuse during scoping. If one is found, a distribution bus arc flash study is performed. Because it is rare on AEP’s system to find a distribution transformer protected by high-side fuses, this is usually not a concern.

For all other situations, the best time to do a study is during step 3, the detailed design phase. During this phase, the SS equipment is selected. The information required for this study is available at this point. If there are any arc flash issues with the equipment selected, it can easily be adjusted. There is also sufficient time for this in most project schedules.

STUDY WORKLOAD

Since arc flash studies are a new task, not everyone is trained to perform them yet. AEP has assigned one subject matter expert (SME) for each 10 engineers. We have developed a spreadsheet so that engineers can list their SS equipment on it and the SME can perform the study. The studies take anywhere from 30 minutes to four hours, depending on the complexity of the 240 V system. Fig. 4 and Fig. 5 depict an example of a completed worksheet and results table, respectively. Fig. 6 provides an example of an arc flash study in ASPEN.



Instructions:

Fill out this table for the proposed station service changes during the design phase of a project.
If there are additional station service sources, copy this sheet as needed.
Send this sheet to the regional arc flash SME when complete.
The arc flash SME will send back this form with the results, and any recommendations for equipment upgrades.

If the station service transformers tap a distribution bus, fill out this section for each distribution bus.

	Name of D bus the SS transformer taps	Name of the D transformer that feeds the D bus	Transformer Base MVA	Transformer %Z	Name of transmission bus that feeds the distribution transformer
Preferred Source	12KV MAIN BUS #1	XF #1	7.5	7.5	69KV BUS #1
Alternate Source	12KV MAIN BUS #2	XF #2	7.5	7.2	69KV BUS #1

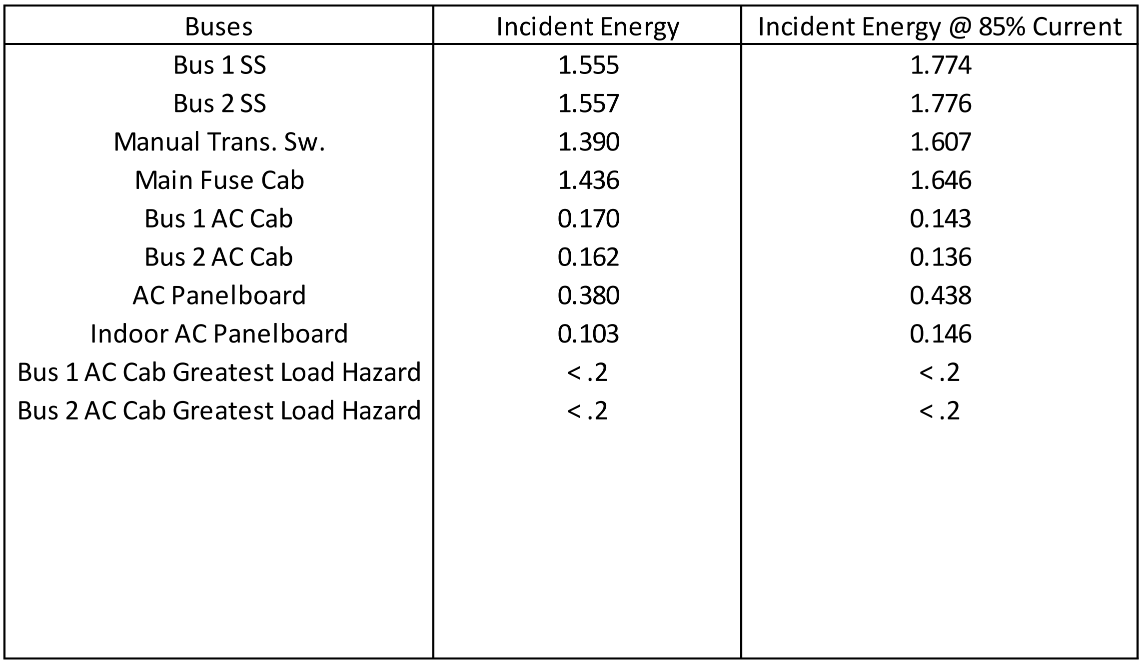
Fill out this section for each station service transformer, safety switch, and transfer switch.

	Station service xfmr KVA (each)	Station service xfmr %Z If unknown, put "Unknown"	Station service xfmr hi-side fuse type (6A K, 8A K, etc.)	Low-Side Has 240V Safety Switch?	Safety Switch 240V Fuse Size (A)	Conductor length from safety switch to transfer switch (ft)	Conductor Gauge to Transfer Switch
Preferred Source	50	Unknown	12A K	Y	100	15	4/0
Alternate Source	50	Unknown	12A K	Y	100	35	4/0

Fill out this section for each 240V panel that is fed by a fuse or wire, including all sub-panels and the main panel fed from a safety switch or transfer switch. Don't include panels fed from a CB.

Name of 240V AC panel	Panel is fed from which panel/device?	Fuse size the panel is fed from (A)	Conductor length (ft)	Conductor gauge	Does this panel feed individual circuits (not panels) with fuses?	Largest fuse size feeding an individual circuit (A)
Main fuse cab	Manual Transfer Switch	N/A	15	4/0	N	N/A
Bus 2 AC panel (CAB #2)	Main Fuse Cab	60	35	4/0	Y	60
Bus 1 AC panel (CAB #1)	Main Fuse Cab	60	15	4/0	Y	60
OUTDOOR AC PANELBOARD	Main Fuse Cab	100	35	4/0	N	N/A
Indoor 240V AC Cab	Bus 1 AC Panel	100	180	12/C 7/18	N	N/A

Figure 4: Example of a completed arc flash analysis form



Buses	Incident Energy	Incident Energy @ 85% Current
Bus 1 SS	1.555	1.774
Bus 2 SS	1.557	1.776
Manual Trans. Sw.	1.390	1.607
Main Fuse Cab	1.436	1.646
Bus 1 AC Cab	0.170	0.143
Bus 2 AC Cab	0.162	0.136
AC Panelboard	0.380	0.438
Indoor AC Panelboard	0.103	0.146
Bus 1 AC Cab Greatest Load Hazard	< .2	< .2
Bus 2 AC Cab Greatest Load Hazard	< .2	< .2

Figure 5: Screenshot of arc flash analysis results table

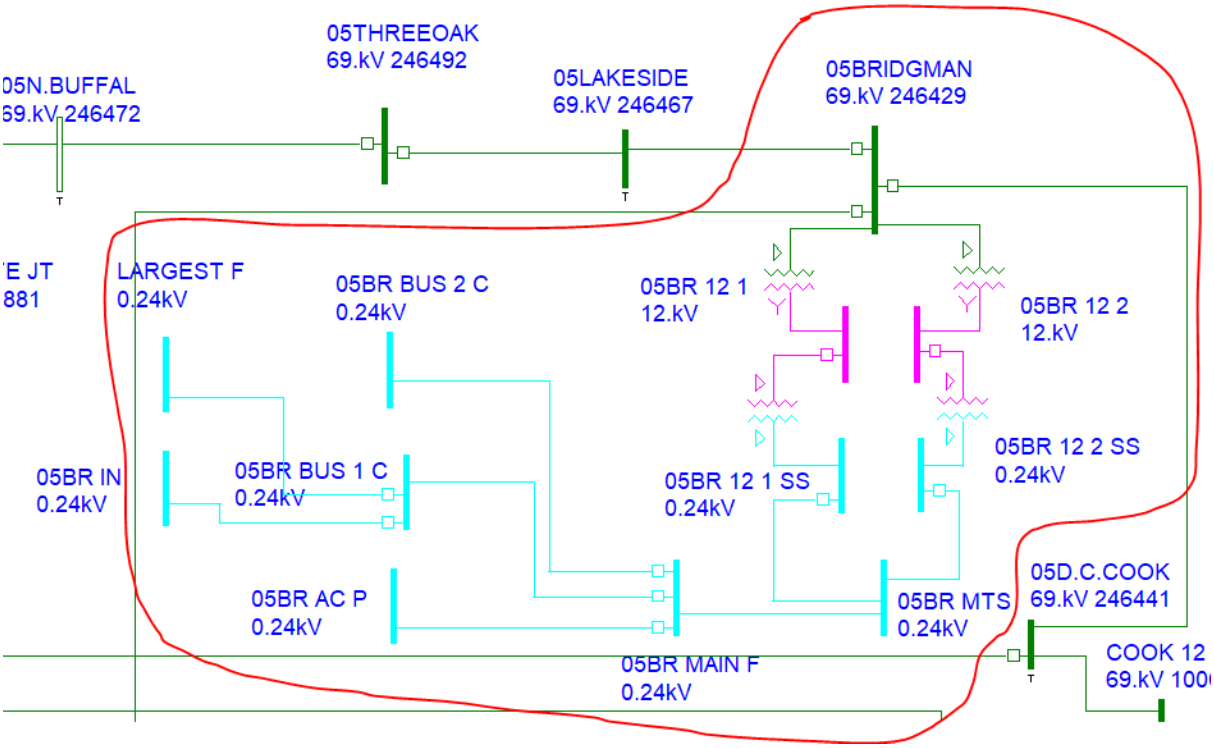


Figure 6: ASPEN arc flash study example

ARC FLASH STUDY SENSITIVITY ANALYSIS

Arc flash is a complex phenomenon with many factors that influence the amount of incident energy produced during an occurrence. Understanding how the design and location of a substation affects the severity of an arc flash incident can lead to better protection of workers. Thus, a sensitivity study was performed that includes various parameters pertaining to substations. The purpose of the study was to identify the design parameters that play the greatest role in determining the potential arc flash hazard within a station. Table 1 lists the various parameters used in this study with their associated range of values used. Test values stem from commonly encountered equipment and characteristics in AEP stations.

Table 1: Sensitivity Study Parameters

Parameter	Range			
High-Side Bus Three-Phase Fault Current (A)	1678	3158	4626	5750
SS Transformer Configuration	Y-Δ	Δ-Δ	---	---
SS Transformer Positive-Sequence Impedance (p.u.)	1.50%	2.00%	2.50%	---
SS Transformer Capacity (kVA)	10	25	50	---
High-Side Fuse	K-TIN-006K	K-TIN-008K	K-TIN-010K	K-TIN-012K
Safety-switch Fuse	KTN-R-100	NON-250-100	KTN-R-200	NON-250-200
SS Center Fuse	LPN-RK-100	LPN-RK-200	LPN-RK-400	LPN-RK-600
Cable Type between Safety-switch and SS Center Cabinets	1/0	2/0	4/0	---
Length of Cable between Safety-switch and SS Center Cabinets (ft)	5	10	15	---
Cable Type between SS Center and AC Panel Cabinets	#12	#10	#6	---
Length of Cable between SS Center and AC Panel Cabinets (ft)	25	50	75	---
Number of AC Panel Circuits	1	2	3	---

PROCEDURE

The general procedure of the sensitivity study was to begin by establishing a base case, which serves as the point of reference for all comparisons. A random 12 kV bus was selected to serve as the location of the base case. After determining the location, the various SS cabinets were populated. These cabinets include a safety-switch cabinet, the SS center cabinet, and an AC panel cabinet. The components and parameters selected during this population phase were set as the base parameters. Once all SS equipment was generated, the short circuit fault current on the low side bus was estimated by applying a three-phase fault. Following calculation of the three-phase fault current of the low-side bus, a series of arc flash hazard studies were performed; one for each of the SS cabinets. The arc current, clearing time, incident energy, and the fuse that cleared the fault were recorded. After completing the base case, the study proceeded to change a single variable while maintaining all others. Once all pertinent information was collected, the effect of each variable was determined by comparing each test case to the base case and calculating a percent difference. The percent differences were then classified based on the scheme outlined in Table 2. The classification system allows easy identification of parameters that had a significant effect.

Table 2: Classification System

Percent Difference	**Color**
Equal to -100%	🟩
Between -10% and -100%	🟦
-10 % to 10%	
Between 10% and 100%	🟨
Greater than or Equal to 100%	🟥

RESULTS AND DISCUSSION

High-Side Bus Three-Phase Fault Current

Table 3 displays the percent differences associated with adjusting the high-side three-phase fault current. To obtain the various fault currents, it was necessary to change the location of the study to different stations. The greatest increase is associated with a lower high-side bus three-phase fault current; however, this increase is relatively small with a percent difference of approximately 3%. Overall, greater fault current magnitudes on the high-side bus are associated with lower incident energies.

Table 3: High-Side Bus Three-Phase Fault Current Results

Case	**Base**	**1**	**2**	**3**
High-Side Bus Three-Phase Fault Current (A)	3158	4626	1678	5750
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	-0.798	2.927	-1.025
Incident Thermal Energy @ SS Center Cabinet (%)	---	-0.275	1.377	-0.413
Incident Thermal Energy @ AC Panel (%)	---	0.000	0.917	0.000
Arcing Current @ Safety-switch Cabinet (%)	---	0.418	-1.358	0.522
Arcing Current @ SS Center Cabinet (%)	---	0.367	-1.362	0.471
Arcing Current @ AC Panel (%)	---	0.155	-1.009	0.078
Clearing Time @ Safety-switch Cabinet (%)	---	-1.212	4.450	-1.560
Clearing Time @ SS Center Cabinet (%)	---	-0.823	2.778	-1.029
Clearing Time @ AC Panel (%)	---	-0.446	2.232	-0.446

SS Transformer Parameters

Configuration:

Table 4 summarizes results obtained when varying the winding configuration of the SS transformer. There appears to be no significant difference between transformer configurations with changes of less than 0.5% in the parameters of interest. In addition, changes in transformer configuration only affected the bus directly downstream of the transformer, which is the safety-switch cabinet.

Table 4: SS Transformer Configuration Results

Case	**Base**	**1**
Transformer Configuration	Y-Δ	Δ-Δ
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	-0.030
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.000
Incident Thermal Energy @ AC Panel (%)	---	0.000
Arcing Current @ Safety-switch Cabinet (%)	---	0.000
Arcing Current @ SS Center Cabinet (%)	---	0.000
Arcing Current @ AC Panel (%)	---	0.000
Clearing Time @ Safety-switch Cabinet (%)	---	-0.037
Clearing Time @ SS Center Cabinet (%)	---	0.000
Clearing Time @ AC Panel (%)	---	0.000

Positive-Sequence Impedance:

Positive-sequence impedance had a significant effect on the quantities of interest. Furthermore, changes in the positive-sequence impedance of the SS transformer affected all downstream buses with the magnitude of the effect decreasing as the distance from the transformer increased. Lastly, incident energy and positive-sequence impedance exhibit a positive correlation. Table 5 displays the results of these tests.

Table 5: SS Transformer Positive-Sequence Impedance Results

Case	**Base**	**1**	**2**
Positive-Sequence Impedance (p.u.)	2.0%	1.5%	2.5%
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	-31.62	45.54
Incident Thermal Energy @ SS Center Cabinet (%)	---	-17.22	12.12
Incident Thermal Energy @ AC Panel (%)	---	-5.50	8.26
Arcing Current @ Safety-switch Cabinet (%)	---	22.51	-14.57
Arcing Current @ SS Center Cabinet (%)	---	22.26	-14.56
Arcing Current @ AC Panel (%)	---	7.07	-6.75
Clearing Time @ Safety-switch Cabinet (%)	---	-45.07	72.63
Clearing Time @ SS Center Cabinet (%)	---	-33.44	32.92
Clearing Time @ AC Panel (%)	---	-12.50	16.07

Capacity:

Capacity, similar to positive-sequence impedance, significantly influenced results and affected all downstream buses. Reducing the SS transformer capacity from 25 to 10 kVA resulted in the incident energy at the safety-switch cabinet increasing over 4000%. Conversely, increasing transformer capacity from 25 to 50 kVA resulted in a decrease of approximately 50% in the incident energy at the safety-switch cabinet. Thus, incident energy exhibits a negative correlation with transformer capacity. In addition, the amount of incident energy appears to be more sensitive to decreases in capacity than to increases. Table 6 provides a summary of results regarding capacity tests.

Table 6: SS Transformer Capacity Results

Case	**Base**	**1**	**2**
Transformer Capacity (kVA)	25	50	10
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	-53.51	4298.64
Incident Thermal Energy @ SS Center Cabinet (%)	---	-39.39	73.55
Incident Thermal Energy @ AC Panel (%)	---	-10.09	110.09
Arcing Current @ Safety-switch Cabinet (%)	---	62.56	-47.89
Arcing Current @ SS Center Cabinet (%)	---	61.92	-47.77
Arcing Current @ AC Panel (%)	---	14.13	-31.68
Clearing Time @ Safety-switch Cabinet (%)	---	-72.50	8796.45
Clearing Time @ SS Center Cabinet (%)	---	-64.09	250.10
Clearing Time @ AC Panel (%)	---	-21.88	215.18

Fuse Parameters

Table 7, Table 8, and Table 9 provide test results for changing the high-side fuse, safety-switch fuse, and SS center fuse, respectively. There are some general trends among the different fuses. First, fuses typically affect only the bus immediately downstream of the fuse. An exception would be the KTN-R-100 fuse in Table 8. This fuse along with KTN-R-200 are fast-acting fuses. Thus, they are sensitive to current levels. The KTN-R-100 proved sensitive enough to trip for an arc flash incident at the AC panel cabinet before the SS center fuse, which is normally responsible for clearing a fault at the AC panel cabinet. A second trend is that larger fuses exhibit a positive correlation with incident energy. This is due to the longer clearing times. Table 9 exhibits a phenomenon where the results are the same for all three of the larger fuses. This phenomenon is due to the upstream safety-switch fuse clearing the fault before the larger SS center fuses. Therefore, there is a limit based on fuse coordination.

Table 7: High-Side Fuse Results

Case	**Base**	**1**	**2**	**3**
High-Side Fuse	K-TIN-008K	K-TIN-006K	K-TIN-010K	K-TIN-012K
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	-60.42	151.90	1442.84
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Incident Thermal Energy @ AC Panel (%)	---	0.00	0.00	0.00
Arcing Current @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Arcing Current @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Arcing Current @ AC Panel (%)	---	0.00	0.00	0.00
Clearing Time @ Safety-switch Cabinet (%)	---	-60.42	151.90	1442.81
Clearing Time @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Clearing Time @ AC Panel (%)	---	0.00	0.00	0.00

Table 8: Safety-Switch Fuse Results

Case	**Base**	**1**	**2**	**3**
Safety-switch Fuse	NON-250-100	KTN-R-100	KTN-R-200	NON-250-200
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Incident Thermal Energy @ SS Center Cabinet (%)	---	-89.81	-48.35	477.96
Incident Thermal Energy @ AC Panel (%)	---	-55.96	0.00	0.00
Arcing Current @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Arcing Current @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Arcing Current @ AC Panel (%)	---	0.00	0.00	0.00
Clearing Time @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Clearing Time @ SS Center Cabinet (%)	---	-89.81	-48.46	477.78
Clearing Time @ AC Panel (%)	---	-55.80	0.00	0.00

Table 9: SS Center Fuse Results

Case	**Base**	**1**	**2**	**3**
SS Center Fuse	LPN-RK-100	LPN-RK-200	LPN-RK-400	LPN-RK-600
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Incident Thermal Energy @ AC Panel (%)	---	809.17	809.17	809.17
Arcing Current @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Arcing Current @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Arcing Current @ AC Panel (%)	---	0.00	0.00	0.00
Clearing Time @ Safety-switch Cabinet (%)	---	0.00	0.00	0.00
Clearing Time @ SS Center Cabinet (%)	---	0.00	0.00	0.00
Clearing Time @ AC Panel (%)	---	805.80	805.80	805.80

Cable Parameters

Cable Type and Length between Safety-switch and SS Center Cabinets:

Table 10 contains results pertaining to the cable type tests and Table 11 contains results for the cable length tests performed between the safety-switch and SS center cabinets. Regarding cable types, 1/0 and 2/0 both exhibited higher incident energies compared to 4/0. This is likely due to 1/0 and 2/0 possessing higher impedances than 4/0 with 1/0 cable having the greatest impedance. Therefore, there is a positive trend between incident energy and cable impedance. As for cable length, there is a positive correlation between incident energy and length. This reiterates the role of cable impedance in determining final amounts of incident energy. Lastly, changes in cable type and length affected all downstream buses.

Table 10: Cable Type Results

Case	**Base**	**1**	**2**
Cable Type between Safety-switch and SS Center Cabinets	4/0	1/0	2/0
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0.000	0.000
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.138	0.138
Incident Thermal Energy @ AC Panel (%)	---	0.917	0.000
Arcing Current @ Safety-switch Cabinet (%)	---	0.000	0.000
Arcing Current @ SS Center Cabinet (%)	---	-0.105	-0.052
Arcing Current @ AC Panel (%)	---	-0.233	-0.155
Clearing Time @ Safety-switch Cabinet (%)	---	0.000	0.000
Clearing Time @ SS Center Cabinet (%)	---	0.103	0.103
Clearing Time @ AC Panel (%)	---	0.446	0.446

Table 11: Cable Length Results

Case	**Base**	**1**	**2**
Cable Length between Safety-switch and SS Center Cabinets (ft)	5	10	15
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0.000	0.000
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.413	0.689
Incident Thermal Energy @ AC Panel (%)	---	0.917	0.917
Arcing Current @ Safety-switch Cabinet (%)	---	0.000	0.000
Arcing Current @ SS Center Cabinet (%)	---	-0.367	-0.733
Arcing Current @ AC Panel (%)	---	-0.311	-0.699
Clearing Time @ Safety-switch Cabinet (%)	---	0.000	0.000
Clearing Time @ SS Center Cabinet (%)	---	0.720	1.440
Clearing Time @ AC Panel (%)	---	0.446	1.339

Cable Type and Length between SS Center and AC Panel Cabinets:

Similar to tests performed between the safety-switch and SS center cabinets, cable type and length tests between the SS center and AC panel cabinets emphasize the role of cable impedance in determining total amounts of incident energy. The main difference is that the cable type and length tests between the SS center and AC panel cabinets exhibit greater magnitudes of change. The most probable explanation for this difference is greater variation in impedance between the cable types and greater variation in cable lengths.

Table 12 and Table 13 depict results associated with cable type and length, respectively.

Table 12: Cable Type Results

Case	**Base**	**1**	**2**
Cable Type between SS Center and AC Panel Cabinets	#10	#12	#6
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0.00	0.00
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.00	0.00
Incident Thermal Energy @ AC Panel (%)	---	45.87	-16.51
Arcing Current @ Safety-switch Cabinet (%)	---	0.00	0.00
Arcing Current @ SS Center Cabinet (%)	---	0.00	0.00
Arcing Current @ AC Panel (%)	---	-22.28	28.42
Clearing Time @ Safety-switch Cabinet (%)	---	0.00	0.00
Clearing Time @ SS Center Cabinet (%)	---	0.00	0.00
Clearing Time @ AC Panel (%)	---	91.07	-36.16

Table 13: Cable Length Results

Case	**Base**	**1**	**2**
Cable Length between SS Center and AC Panel Cabinets (ft)	50	25	75
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0.00	0.00
Incident Thermal Energy @ SS Center Cabinet (%)	---	0.00	0.00
Incident Thermal Energy @ AC Panel (%)	---	-14.68	31.19
Arcing Current @ Safety-switch Cabinet (%)	---	0.00	0.00
Arcing Current @ SS Center Cabinet (%)	---	0.00	0.00
Arcing Current @ AC Panel (%)	---	25.39	-18.01
Clearing Time @ Safety-switch Cabinet (%)	---	0.00	0.00
Clearing Time @ SS Center Cabinet (%)	---	0.00	0.00
Clearing Time @ AC Panel (%)	---	-33.48	62.05

Number of AC Panel Circuits

Table 14 depicts the results collected for adjusting the number of AC panel circuits. The number of AC panel circuits connected to the SS Center cabinet has no effect on the incident energy, arcing current, or clearing time. Therefore, the number of AC panel circuits can be ignored when identifying high-risk arc flash situations. The only exception that may occur is if a source is connected to a panel that may supply additional energy to a fault.

Table 14: Number of AC Panel Circuits

Case	**Base**	**1**	**2**

Number of AC Panel Circuits	1	2	3
Incident Thermal Energy @ Safety-switch Cabinet (%)	---	0	0
Incident Thermal Energy @ SS Center Cabinet (%)	---	0	0
Incident Thermal Energy @ AC Panel (%)	---	0	0
Arcing Current @ Safety-switch Cabinet (%)	---	0	0
Arcing Current @ SS Center Cabinet (%)	---	0	0
Arcing Current @ AC Panel (%)	---	0	0
Clearing Time @ Safety-switch Cabinet (%)	---	0	0
Clearing Time @ SS Center Cabinet (%)	---	0	0
Clearing Time @ AC Panel (%)	---	0	0

SENSITIVITY STUDY CONCLUSIONS

It was found that parameters resulting in large changes to system impedance values greatly affect the total amount of incident energy emitted during arc flash events. Counterintuitively, increased impedance resulted in higher incident energy. This trend is due to the interaction between arcing current and clearing time. Increased system impedance reduces the amount of arcing current, which in turn, increases the amount of time required for the fault to be cleared and vice versa. Both arcing current and clearing time factor into incident energy calculations; however, clearing time has greater influence of incident energy amounts than arcing current. This emphasizes the importance of fuses in mitigating the harm posed by arc flash incidents, and properly tracking how system changes influence impedance for downstream components. As for the impact of the various parameters used in this study, Table 15 provides a breakdown of parameters and their effects on incident energy.

Table 15: Parameter Impact Summary

Parameter	Impact
High-Side Bus Three-Phase Fault Current	Low
SS Transformer Configuration	Negligible
SS Transformer Positive-Sequence Impedance	High
SS Transformer Capacity	High
High-Side Fuse Curve	Moderate
Safety-Switch Fuse Curve	Moderate
SS Center Fuse Curve	Moderate
Cable Type between Safety-switch and SS Center Cabinets	Low
Cable Length between Safety-switch and SS Center Cabinets	Low
Cable Type between SS Center and AC Panel Cabinets	Moderate
Cable Length between SS Center and AC Panel Cabinets	Moderate
Number of AC Panel Circuits	Negligible

CONCLUSION

An AC arc flash study for SS systems is preferably performed after scoping stage because the project funding impacts from the study results are typically not significant. A centralized SME team for arc flash studies is adopted by AEP, while each SME relies on corresponding project engineers to fill in a well-organized input data collection form. ASPEN is used by SMEs to model SS circuits and equipment based on the entered form and calculate incident energy at risk locations. Finally, mitigations are needed, such as changing to a faster fuse, or reporting high-incident-energy locations.

Based on the sensitivity analysis results (Table 15), emphasis should be placed on transformer characteristics when identifying high-risk arc flash locations, as changes in transformer values resulted in significant changes for all downstream buses. Afterwards, fuses should be investigated due to their role in determining the clearing time of the arc during an arc flash incident. Though changes in incident energy were significant when changing fuse types, the incident energy changes were generally localized with only the immediate bus downstream being affected. Afterwards, cable type and length should be checked to ascertain impedance values and possible effect. Lastly, there is no need to factor SS transformer configurations or number of AC panel circuits into the identification process as there was minimal to no effect associated with the parameters in ASPEN.

BIBLIOGRAPHY

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