Arc Hazard Analysis Report

For

Lake Worth Generation Plant

February, 2011

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Lake Worth Generation Plant

Lake Worth, Florida

Arc Hazard Analysis Report

I. ARC FLASH ASSESSMENT - SCOPE

UC Synergetic, Inc. (UCS) was contracted to perform an arc flash analysis of the Lake Worth Generation Plant for the City of Lake Worth (City), Florida, through our partnership with SET Solutions, LLC. This report summarizes the results of that analysis.

Based on UCS' site survey, along with available plant drawings, generator settings, and protective device settings provided by the City, a fault current and arc flash analysis was performed on the Generation Plant. The Generation Plant consists of nine generation units, as shown on the one-line diagrams in Appendix A. The generation units were modeled and analyzed using SKM™ software.

II. GENERATION SYSTEM ANALYSIS

The Lake Worth Generation Plant's generators can each run independently or in conjunction with the utility supply to the City. There are 480V, 2.4kV, 4.16kV, 13.2kV, 13.8kV, and 26.4kV buses within the Plant's system that provide connection between the utility supply, the City's 138kV Substation 20, the City's 26.4kV power distribution substation (Substation 10), the plant's generators, and main supplies to the lower voltage panelboards, switchgear, motor control centers (MCC), and motors located throughout the Plant's generation sites. These lower voltage facilities are operated at voltages such as 2.4kV, 480V, 120/208V, and 120/240V. The lower voltage facilities include loads such as boiler feed pumps, circulating water pumps, cooling tower fans, MCCs, and various other motors and distribution panels.

UCS modeled the medium and low voltage power supply facilities shown on the one-line diagrams. There are several 120/208V, 120/240V and 480V motors and loads that were not modeled and analyzed since they are individual loads that are understood to be de-energized by an upstream panel or MCC without affecting service to any other facilities. Examples of this include lighting panels, A/C units, battery chargers, heaters, air compressors, and other motors less than 50 HP.

Per IEEE-1584a Section 4.2, 208V panels fed from a transformer smaller than 125 kVA do not require evaluation for arc flash hazard. The Lake Worth Plant includes several 120/208V panels that are served from transformers smaller than 125 kVA and these panels were not modeled or evaluated for arc flash hazard.

UCS utilized SKM's ™ Power Tools to perform circuit modeling, short circuit, and arc flash analysis. Arc flash analysis was performed in accordance with IEEE 1584a for 13.8kV and below facilities. Modeling of the Plant's medium voltage facilities required modeling of the connections to the City's 26.4kV and 138kV electrical systems. UCS' basic assumption for these higher voltages facilities is that their protection system design includes a functioning instantaneous fault current detection scheme to rapidly clear fault conditions. UCS used a conservative 6 cycle fault clearing time for these higher voltage facility protective devices and assumes that instantaneous pickup would be active and reclosing disabled during any period when live line work is performed on high or medium voltage facilities inside and outside of Lake Worth's Generation Plant. Specific Plant buses impacted by this higher voltage protection scheme assumption are stated in Section B, Assumptions.

A. Inputs

1. Utility Source Impedance

Utility source impedance values were provided by the City in the form of a short circuit study calculation sheet from Aspen One-Liner. Fault currents for the 138kV system were provided for Substation 20's main bus and the 26.4kV system fault currents were provided for Substation 10's East and West bus locations. The Generation Plant's CGT-1 and CGT-2/S5 generation facilities are connected to the 138kV system and the Plant's M-Units (M Units 1 -5) and S-3 generation facilities are connected to the 26.4 kV system.

2. Conductors

Cable runs including run length, conductor size, and cable design were modeled based on plant record data provided by the City. Where plant records were not available, UCS used common design sizes that will carry the load being served coupled with conductor run lengths deemed reasonable for known facility locations.

3. Protective Devices and Settings

Protective devices modeled include fuses, molded case breakers, and medium and high voltage breakers and relays. Protective device parameter and setting information for most protective devices were either provided by the City or documented during the UCS site data collection effort. Where Plant device parameters and/or settings were not available or conflict with device setting configurations, UCS used reasonable assumptions based on similarly installed protective devices within the City's Plant. As noted above, where higher voltage protective device information was not available, UCS assumed the device protection scheme includes a functional instantaneous fault clearing device and no reclosing. Protective device settings were manually entered into SKM™ software which links the Arc Flash Analysis results to the protective device settings entered into the system.

4. Arc Gap

The IEEE 1584a standard arc gaps for respective equipment type and voltage ratings were used for arc flash calculations.

5. Working Distance

The IEEE 1584a standard working distances were used for all calculations. The working distance used for a specific bus calculation can be seen in the Arc Flash Analysis Results in Appendix B. These distances vary based upon the class of equipment being evaluated. The working distances listed in the IEEE 1584a standard are based on the distance of a persons face and body from a potential arcing source. Workers should be aware that a lesser distance from an arcing source will equate to a higher incident energy value.

6. Maximum Arc Fault Durations

Per IEEE 1584a Annex B, Section B.1.2, the maximum arc fault duration will be two seconds. This maximum arc fault duration can be realized if the fault current magnitude seen by a protective device is low enough to cause the protective device to operate slowly.

7. Bus Configurations

Relay protection schemes vary depending on the loads for each bus. The following general approaches were taken in regards to arc flash analysis of each bus:

- Switchgear bus main breakers are evaluated independently from the switchgear bus. This is necessary since the main breaker is protected by a different protective device than the switchgear bus.
- Motor Control Centers (MCCs) include a single independent analysis. This is possible since the MCC main breakers consists of a feeder breaker that resides remotely (i.e., the feeder breaker may not be located in one of the MCC cubicles).
- In keeping with IEEE 1584, this study takes into account all sources, including utilities, generators, and large motors, those 50 HP and larger, that contribute energy to short circuits. Large motors are modeled as actual motors, not shown as loads through a MCC or switchgear. Motors, 50HP and above modeled in this analysis include:

Motors 50HP and Larger

	CGT-2/S-5	S-3
Air Compressors	One at 50 HP	
Boiler Feed Pumps	Two at 150 HP	Two at 450 HP
Circulating Water Pumps	Two at 200 HP	Two at 200 HP
Cooling Tower Fans	One at 200 HP	Three at 60 HP
Condensate Pumps		Two at 75 HP
Forced Draft Fans		One at 100 HP One at 400 HP

This study was performed with all buses in their normal maximum permitted connectivity configuration. This means that the normal external source for the City of Lake Worth was connected in parallel with the Lake Worth Generation Plant but auxiliary connections between generation facilities were not closed. This configuration provides the greatest nominal available fault currents for the Plant.

B. Assumptions

UCS modeled the Plant's electrical system in as much detail as reasonably possible based on data availability and existing one-lines for the Plant's facilities. Comprehensive existing one-lines, relay, breaker, and line impedance data were not available for all facilities which resulted in modeling assumptions for various facilities and components of the Plant's system. The Plant's system modeling was shared with the City for review and information was made available to the extent possible for the benefit of this study prior to developing the final report. Appendix C is a comprehensive list of remaining assumptions made in the modeling of the City's Plant. The following is a list of general comments and/or specific assumptions that may have an impact on the results of the arc flash analysis and results.

1. All motors were modeled as induction type, 4 pole, 0.8 pf, and .93 efficiency.
2. All conductors were modeled as copper conductor unless specifically noted otherwise in plant records.
3. Wire sizes, not able to be determined, were modeled as common design sized to carry the load of the equipment being served.
4. Circuit distances not able to be determined were modeled as 100 feet unless it was reasonable to estimate greater lengths due to known facility locations.
5. The 480V tie between the secondary side of transformer TSS GT-1 and S-5 480V system is assumed normally open at CGT-1 ACB S5 Tie breaker.
6. GT-1 T-9 has an assumed impedance of 5.9% for the 3000kVA 13.2/2.4kV transformer.
7. The 150kVA 208V transformer in the CGT-1 model has an assumed impedance of 3.7%.
8. The 480V Alternate source from LS T10 Transformer (CGT-1 model) to MCC3C is assumed normally open at the CGT-1 MCC3C breaker.

9. The 112.5kVA GT2 SS Transformer in the CGT-2/S-5 model has an assumed impedance of 4.5%.

10. The 480V emergency tie between S1-G1 (S-3 model) is assumed to be normally open at the 480V breaker in the S-3 plant.

11. In general, low voltage breakers and relay settings that were not available were modeled with settings and characteristics of breaker or relay settings of a known device situated similarly to the unknown device. UCS used all information available but made assumptions to supplement the information requirements for the study.

12. UCS assumes that medium and high voltage protection system design includes a functioning instantaneous fault current detection scheme to rapidly clear fault conditions. UCS used a conservative instantaneous 6 cycle fault clearing time for relay and breaker sets when relay and breaker settings were not available for medium and high voltage facilities. UCS assumes instantaneous pickup would be active and reclosing disabled during any period when live line work is performed on high or medium voltage facilities inside and outside of Lake Worth's Generation Plant.

The following table identifies the breaker and relay settings unknown to UCS and notes the device that was used as its assumed modeling surrogate or assumptions made for the stated device:

Unknown Breaker and/or Relay	Equipment Protected	Assumed Breaker and/or Relay
CGT-1 Trans Source Relay and Transmission Source Breaker (CGT-1)	CGT-1 Production Transformer, CGT-1 Generator Bus, and 13.2kV Bus	Default to 6 cycle operating time.
Main Breaker GT-1 MCC (CGT-1)	GT-1 MCC 480V Bus	Molded case breaker with 800A trip and 6000A instantaneous settings.
200E Fuse (CGT-1) – Unknown fuse mfg. and style	HS T10 Basement Transformer and LS T10 Transformer (480V)	Assume S&C SM-4 200E fuse
138kV Relay and Breaker (CGT-2)	13.8kV Bus	Default to 6 cycle operating time.
S-5 Relay (CGT-2)	13.8kV Bus	Assume same device type and settings as CGT-2 Relay
ACB CGT2 Aux (CGT-2)	GT2 Aux Bus (480V)	Molded case breaker with 200A trip and 2000A instantaneous settings.
13S5 F1 and 13S5 F2 (CGT-2)	TSS5-1 and TSS5-2, respectively	Assume fuses are both S&C SM-5, 65E
ACB-GC 600A (CGT-2)	Water Plant Bus	Assume same device and settings as ACB-MCC1
ACB-Air Comp (CGT-2)	Air Compressor Bus	Assume 100A molded case breaker
Relay 26B1E06 (S-3)	HS ACB Gen 13.2kV	Default to 6 cycle operating time
Breaker ACB A2 (S-3)	LS S3/4 SST8 480V	Assume set exactly like ACB A1
Breaker for MCC3D 480V Panel (S-3)	LS 480V MCC3D Panel Bus	Assume set exactly like S3 480V Mezzanine
CT ratios for all 2.4kV motors (S-3)		Assume 200/5
Breakers for Condensate Pump 3A (S-3)	HS Cond Pump 3A	Assume same device type and settings as breakers for Condensate Pump 3B
Breakers settings for CTF A, CTF B, and CTF C (S-3)	Stated Cooling Tower Fans	Assume Sensor = 100, LTPU = 1.6, STPU = 4 and INST = 20.
Relay 26B1E02 (M Units)	Production Transformer TPMU and M Unit 4160V Bus	Default to 6 cycle operating time

C. Summary of Arc Flash Study Results

UCS utilized SKM™ to compute incident energy levels for the three phase bolted fault current at each bus noted in the study results, shown in "Appendix B: Arc Flash Analysis Results". The one-line diagrams show the buses at the high, medium, and low voltages of the system, as well as the protective devices utilized. Final results of the arc flash analysis for each Plant generation unit shows the incident energy results at the working distances for the respective pieces of equipment as well as the recommended safe boundary distance (in inches). This boundary distance ("Arc Flash Boundary") is the distance required to meet the recommended threshold value of 1.2 cal/cm^2, considered to be a "just curable burn." As the working distance increases, the incident energy value decreases. The one line diagrams modeled in SKM™ can be found in "Appendix A: One Line Diagrams".

Equipment that is confined or considered "in a box" may have limited working space and is therefore evaluated differently than open air equipment. Panelboards, MCCs, and switchgear, which are considered confined all have higher incident energy values because of the "arc in a box" factor. Arc flashes in a confined or tight space, have less room to dissipate and therefore have higher incident energy values. Equipment that has a protective device, i.e., breaker, fuse, etc., automatically has lower incident energy because of the faster clearing and operating time associated with each protective device. Incident energy levels can be reduced, if necessary, by installing faster operating devices.

Appendix B: Arc Flash Analysis Results provides a summary of the results of the arc flash calculations. The analysis also provides a way to compare results of similar classed equipment; for example, 480V MCCs. Listed below is a description of the information provided in the Arc Flash Analysis Results:

The "bus name" is derived from the Lake Worth Plant Drawings. The bus names apply to switchgear, MCCs, and all applicable power distribution panels.

The "Bus kV", "Bus Bolted Fault (kA)", and "Equip Type," display general bus classification information used within the arc flash calculations. Specifically, these values are used in the arc flash calculations.

The "Bus Bolted Fault (kA)" is the maximum, three-phase, fault current available at the bus.

While there is no column to specifically show the Arc Flash Duration, it can be calculated from the arc flash results. The duration is the sum of the “Trip/Delay Time (sec.)” and the “Breaker Opening Time (sec.)”. The trip/delay time is determined from the time current curve of the protective device and the available bolted fault current. As the bolted fault current decreases, the trip/delay time increases. However, the breaker opening time is a constant defined by IEEE 1584a intended to account for the time between the protective device instructing the breaker to open and the time the breaker actually clears the fault.

The “Arc Flash Boundary (inches)” is the distance from an arcing source that a person must stand, without personal protective equipment (PPE), where the incident energy level is below the “just curable burn” threshold of 1.2 cal/cm^2.

The “Incident energy (cal/cm^2)” is the calculated heat per unit area available at the bus being studied. This value represents the incident energy level at the specified working distance.

III. FINAL CONSIDERATIONS

When calculating incident energy levels, it is assumed that the devices are operating as designed and that the instantaneous trip devices, where used, are enabled and functional. It is imperative that when performing energized line work to ensure that instantaneous trips are enabled, where available. Furthermore, a regular maintenance program is essential to ensure devices are operating as designed. Incident energy levels during arc flash events are dependent on the fault clearing time and could be significantly higher if an instantaneous device is disabled, non-operational, or altered for any reason.

The results are based on UCS’ site survey, data provided by the Lake Worth Generation Plant at the time of assessment, and assumptions stated in this report. The energy levels and arc flash boundaries were calculated using SKM™ software using the fault current levels and device clearing times computed from the model, using the method stated.

This study should be considered a guide in determining appropriate engineering controls, work practices, and personal protective equipment (PPE) to be utilized by qualified personnel performing energized work. It is offered as a starting point, not a substitute for, a comprehensive and ongoing safety and training program in the practices and procedures associated with working on energized electrical facilities. Furthermore, it is absolutely essential that following any alterations to the system such as an adjustment to the relay settings or protection scheme, reconductoring, re-configuring or switching of the system, or a change to the generators or the utility source, that a re-evaluation of the assessment be undertaken.

Additional Concerns:

This report is based on several protective devices with assumed settings or maximum fault duration clearing times, which could impact the results of this study regarding minimum PPE requirements for working on energized equipment within the City's generation plant. UCS recommends re-calculating incident energy levels if the stated relay and breaker settings are confirmed to be different than assumed for the purpose of this study.

The study revealed some issues with protective device sizes and settings. The following are specific situations that warrant further review:

CGT-1's GT-1 MCC 480V Bus is protected by Main Breaker GT-1 MCC. This breaker is a molded case breaker with an assumed instantaneous setting of 6000A. This is just high enough that the breaker operates under its thermal curve, thereby introducing a significant delay into clearing a fault at the MCC bus. This delay results in a Dangerous arc flash category. An instantaneous setting of 3000A for this breaker will result in Category 0 PPE requirements for the MCC bus. However, UCS suggests checking to see if the lower instantaneous setting is possible to ensure quick clearing of a fault for this bus and to perform a protection coordination analysis to ensure breaker selection and settings can be achieved to work with upstream and downstream devices.

CGT-1's LS T10 Transformer is protected by a 200E fuse on the primary side of transformer T10. The impedance of the transformer sets up a situation where the fuse acts so slowly that a fault on the low side of the transformer creates a high incident energy arc flash. There may be an operational advantage to installing a breaker between the secondary side of transformer T10 and the 480V bus titled LS T10 Transformer under this study. A breaker installed in this location would result in significantly reduced incident energy associated with an arc flash at the 480V bus.

CGT-2/S-5's 13.8kV bus' calculated PPE Category is 4. The PPE category for this bus can be lowered to a Category 3 if the time dial setting on CGT-2 Relay can be lowered from a setting of 8 to a setting of 3. UCS recommends performing a protection coordination analysis to investigate whether the lower time dial setting is possible to achieve protection coordination with downstream devices.

CGT-2/S-5's ACB MCC1 and ACB MCC2 are the protective devices that clear faults for the large motors (boiler feed pumps, circulating water pumps, and cooling tower fans) in the CGT-2/S-5 plant. Each of these large motors has a calculated Category 4 or Dangerous PPE Category. The ACB MCC1 and ACB MCC2 settings currently have the lowest Short Time Pick Up (STPU) settings available for these devices and cannot be reduced further to lower the PPE categories or to reduce fault clearing time below 2 seconds. Changing the instantaneous settings for these devices does not aid in speeding up the fault clearing time for the large motor buses. This may not be an issue for the Plant if the standard operating procedure is to de-energize the large motor circuits at the MCCs when working on the facilities associated with the large motors.

CGT-2/S-5's ACB-A 1600A and ACB-B 1600A breakers have instantaneous settings that are higher than available fault currents for faults on downstream buses, thereby resulting in delays to clear faults on the downstream buses. Lowering the instantaneous settings from 8 to 4 for these breakers would trigger much quicker fault clearing times, lower incident energy values, and reduced PPE category requirements from Category 3 to Category 1 for LS of ACB-B 480V Bus and HS of ACB-GC and from Category 3 to Category 2 for HS of MCC1 ACB, HS of MCC2 ACB, and LS of ACB-A 480V Bus. UCS recommends performing a protection coordination analysis to investigate whether the lower instantaneous settings are possible for these breakers that will also coordinate with upstream and downstream devices.

As noted in the Assumption section of this report, S-3's breaker ACB A2 has assumed the same device type and settings as S-3's ACB A1 breaker. Assuming these breakers do not have instantaneous capability, faults occurring downstream of these breakers rely upon time current curves of the breakers to clear faults. The duration of fault clearing for buses LS S3SST7 and LS S3/4 SST8 480V buses is so long that the incident energy levels for these buses is high, resulting in Category 3 PPE requirements for both locations. There may be operational advantages to replacing ACB A1 and ACB A2 with protective devices with instantaneous capability to limit fault duration on their downstream buses. UCS recommends performing a protection coordination analysis to ensure changes in breakers and including instantaneous settings is a practical solution to lowering the FR clothing requirements for these buses and to ensure protective device coordination with upstream and downstream devices.

Relay data provided by the City for M Unit 5 generator breaker is CTR = 2000/5, Tap = 6, and time Dial = 3. The relay data provided to UCS included the statement that Unit 5 is set like Units 1-4. UCS used the stated settings for each of the M Unit generator breaker relays. The arc flash analysis results using these settings yield Category 3 FR clothing with notice that the default 2 second maximum clearing time was reached for each of the M Unit generator relays. UCS determined that the settings noted are high relative to the fault current availability from the generating units and will not trip for overcurrent protection in a timely manner. The following overcurrent relay settings yield results with fault current contribution duration less than 2 seconds. UCS is not recommending changes to the relay settings noted below without a protection coordination study and/or verification that the relay settings do not compromise or conflict with acceptable limits for the relays and protected circuits.

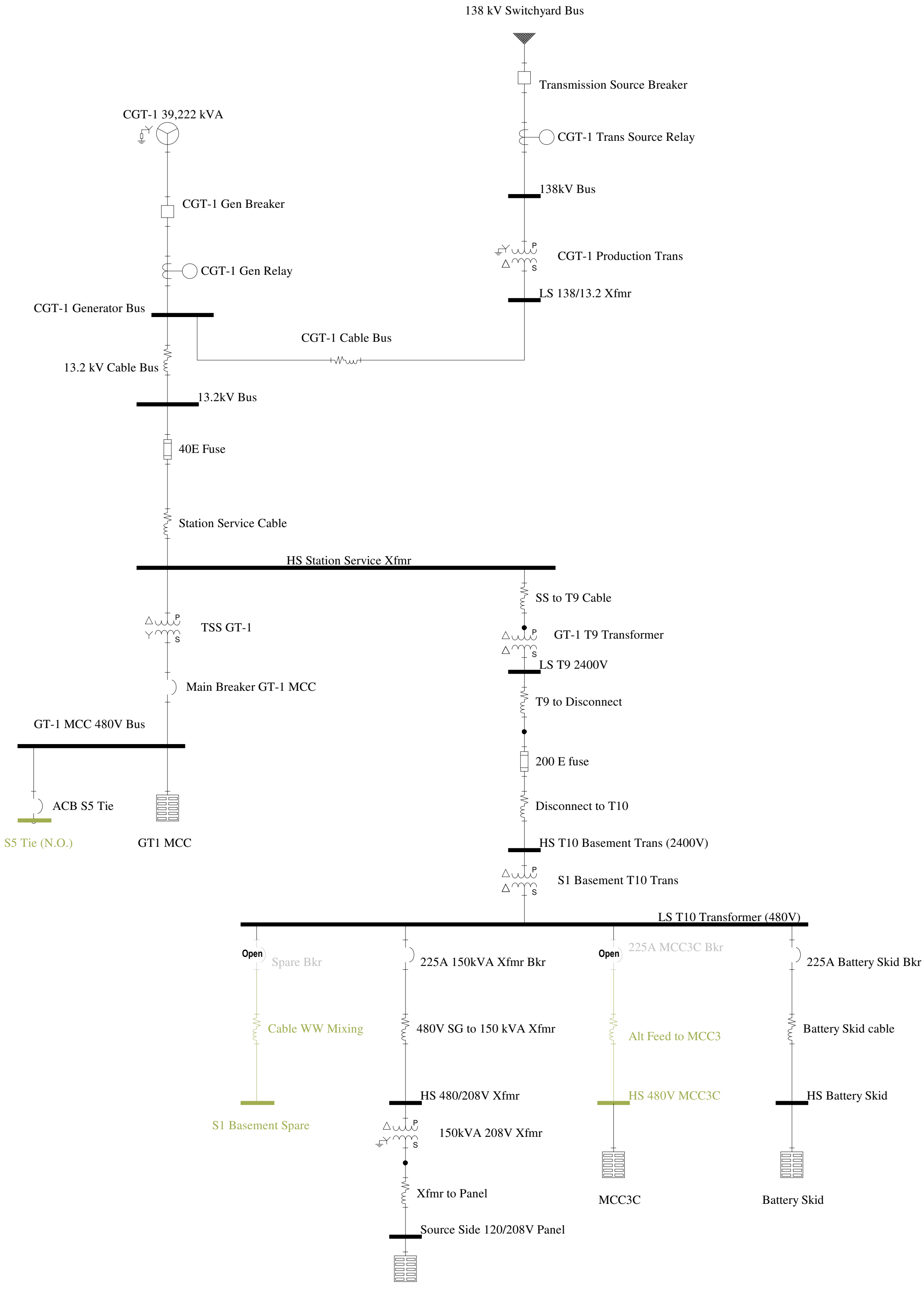
Tap = 2, Time Dial = 2 results in Cat 3 with fault current contribution duration = 1.648 seconds

Tap = 2.5, Time Dial = 0.5 results in Cat 2 with fault current contribution duration = 0.656 seconds

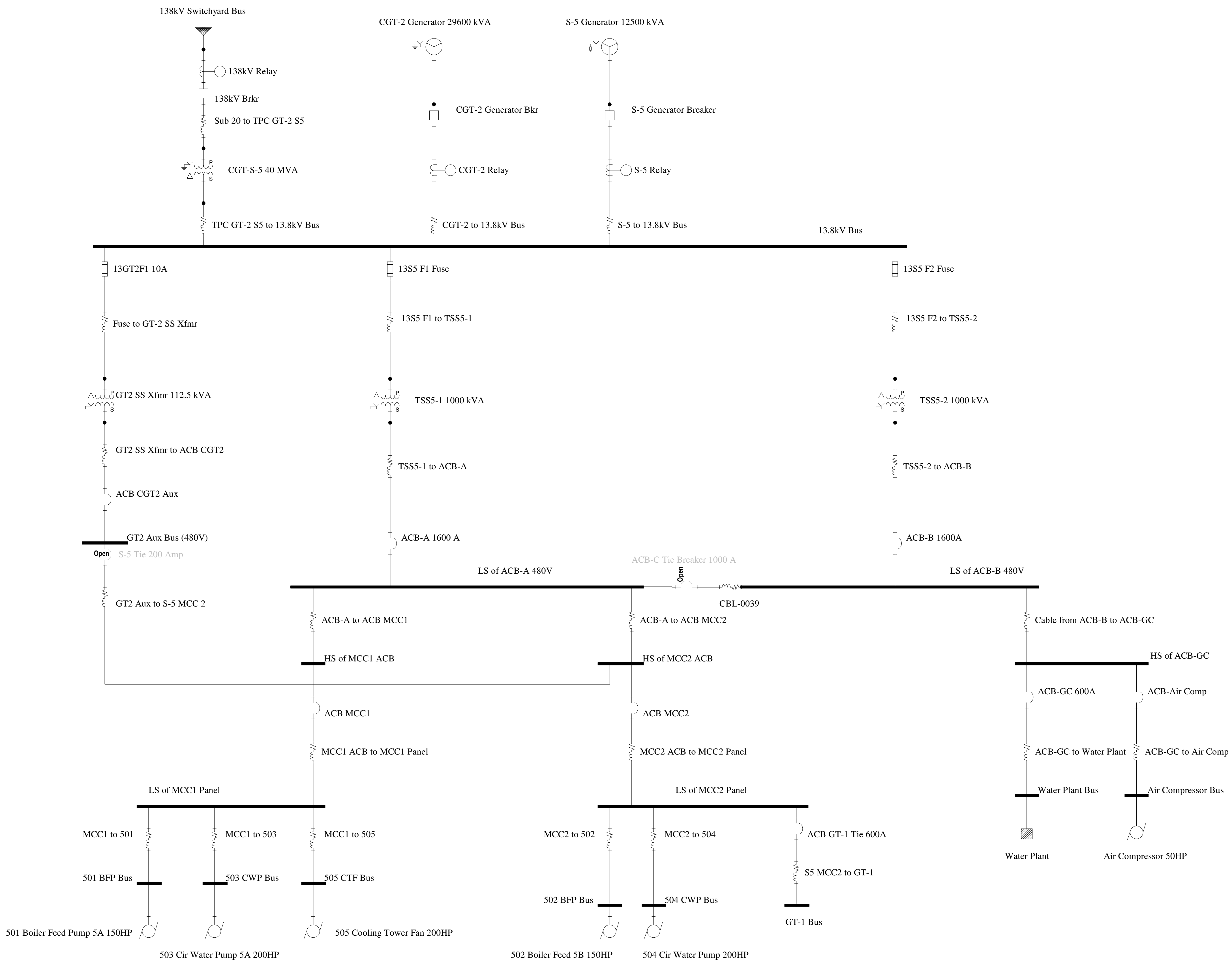
Tap = 2.5, Time Dial = 1 results in Cat 3 with fault current contribution duration = 1.121 seconds

APPENDIX A: ONE LINE DIAGRAMS

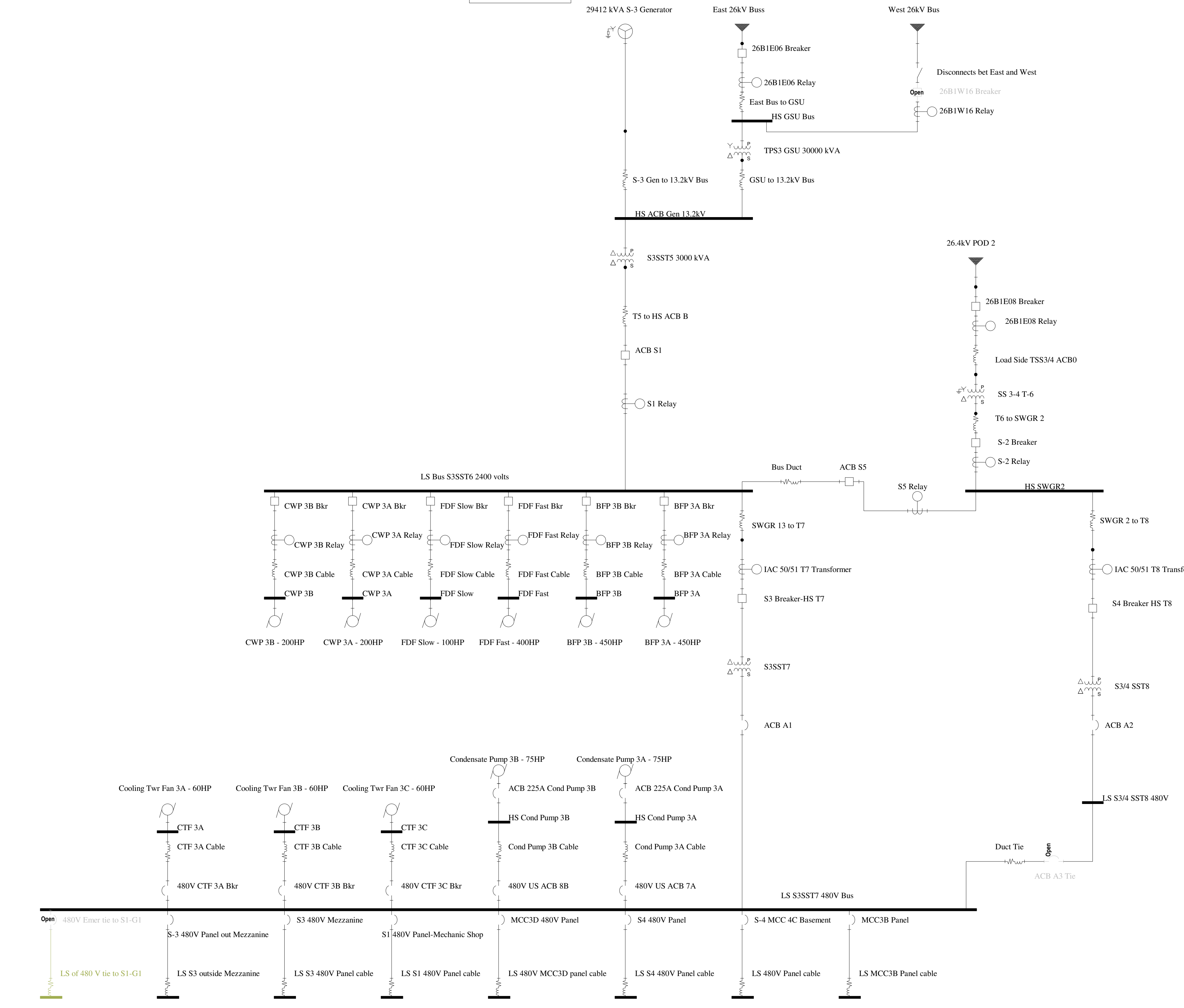
Lake Worth
CGT-1 Unit Drawing
February 4, 2011



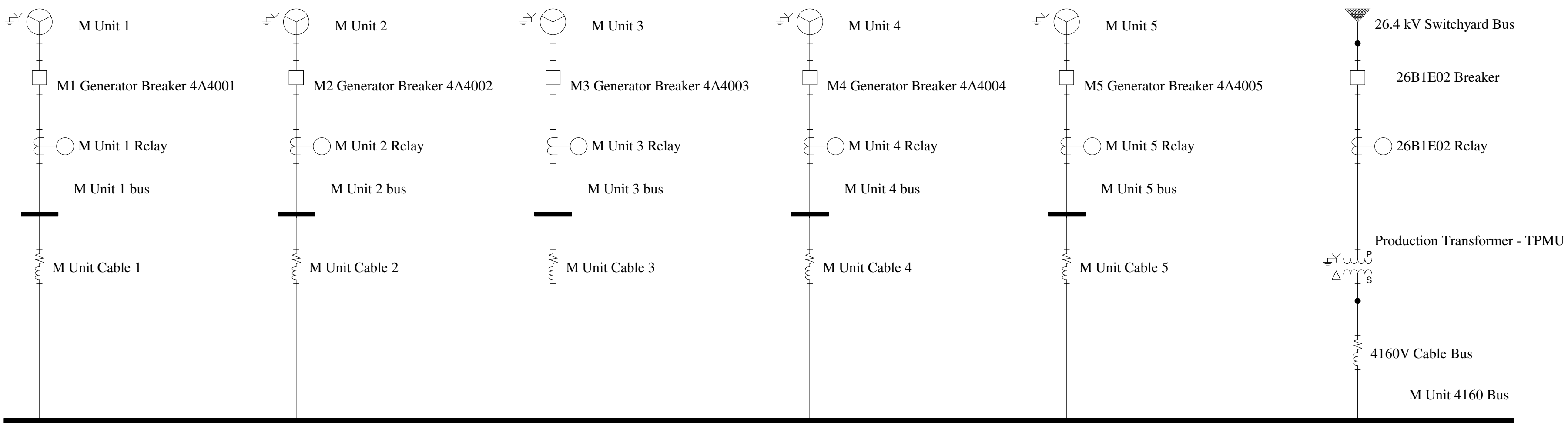
Lake Worth
CGT-2/S-5 Unit Drawing
February 4, 2011



Lake Worth
S-3 Unit Drawing
February 4, 2011



Lake Worth
M - Units Drawing
February 4, 2011



APPENDIX B: ARC FLASH ANALYSIS RESULTS

The following notes for Required Protective FR Clothing Categories are applicable to the arc flash analysis results tables:

Category 0: Nonmelting, Flammable Materials with Weight >= 4.5 oz/sq yd	0.0-1.2 cal/cm^2
Category 1: Arc-rated FR Shirt & Pants	1.2-4.0 cal/cm^2
Category 2: Arc-rated FR Shirt & Pants	4.0-8.0 cal/cm^2
Category 3: Arc-rated FR Shirt & Pants & Arc Flash Suit	8.0-25.0 cal/cm^2
Category 4: Arc-rated FR Shirt & Pants & Arc Flash Suit	25.0-40.0 cal/cm^2
Category Dangerous!: No FR Category Found	40.0-999.0 cal/cm^2

(*N2) – < 80% Cleared Fault Threshold

(*N3) – Arcing Current Low Tolerances Used

(*N9) – Max Arcing Duration Reached

Arc Flash Analysis Results - Unit CGT-1

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category	Cable Length From Trip Device (ft)
13.2kV Bus	CGT-1 Trans Source Relay	13.20	23.08	22.09	12.70	12.15	0.016	0.084	Yes	SWG	153	74	36	3.0	Category 1	125.00
CGT-1 Generator Bus	CGT-1 Trans Source Relay	13.20	23.25	22.25	12.79	12.24	0.016	0.084	Yes	SWG	153	74	36	3.0	Category 1	80.00
GT-1 MCC 480V Bus	Main Breaker GT-1 MCC	0.480	11.54	6.30	11.54	6.30	2	0.000	No	PNL	25	180	18	52	Dangerous! (*N3) (*N9)	
HS 480/208V Xfmr	225A 150kVA Xfmr Bkr	0.480	11.74	7.52	11.74	7.52	0.031	0.000	No	PNL	25	16	18	0.98	Category 0	25.00
HS Battery Skid	225A Battery Skid Bkr	0.480	10.26	6.70	10.26	6.70	0.034	0.000	No	PNL	25	16	18	0.94	Category 0	75.00
HS Station Service Xfmr	40E Fuse	13.20	22.93	21.94	22.93	21.94	0.016	0.000	Yes	SWG	153	11	36	0.48	Category 0	50.00
HS T10 Basement Trans (2400V)	200 E fuse	2.40	10.73	10.40	10.73	10.40	0.028	0.000	No	SWG	104	10	36	0.42	Category 0	20.00
LS 138/13.2 Xfmr	CGT-1 Trans Source Relay	13.20	23.28	22.28	12.88	12.33	0.016	0.084	Yes	SWG	153	74	36	3.0	Category 1	
LS T10 Transformer (480V)	200 E fuse	0.480	12.36	6.68	12.36	6.68	0.594	0.000	No	PNL	25	89	18	17	Category 3 (*N3)	20.00
LS T9 2400V	40E Fuse	2.40	11.14	10.80	11.14	10.80	0.036	0.000	No	SWG	104	14	36	0.58	Category 0	90.00
Source Side 120/208V Panel	225A 150kVA Xfmr Bkr	0.208	7.64	3.60	7.64	3.60	2	0.000	Yes	PNL	25	106	18	22	Category 3 (*N9)	35.00

Arc Flash Analysis Results - Units CGT-2/S-5

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category	Cable Length From Trip Device (ft)
13.8kV Bus	138kV Relay	13.80	26.33	25.14	11.54	11.01	0.016	0.084	Yes	SWG	153	833	36	25	Category 4	500.00
501 BFP Bus	ACB MCC1	0.480	10.37	6.76	8.30	5.41	1.95	0.050	Yes	PNL	25	144	18	36	Category 4 (*N9)	300.00
502 BFP Bus	ACB MCC2	0.480	10.21	6.67	8.75	5.72	1.95	0.050	Yes	PNL	25	144	18	36	Category 4 (*N9)	300.00
503 CWP Bus	ACB MCC1	0.480	11.90	7.61	9.45	6.04	1.95	0.050	Yes	PNL	25	153	18	40	Dangerous! (*N9)	300.00
504 CWP Bus	ACB MCC2	0.480	11.71	7.50	9.96	6.38	1.95	0.050	Yes	PNL	25	153	18	40	Dangerous! (*N9)	300.00
505 CTF Bus	ACB MCC1	0.480	11.90	7.61	9.45	6.04	1.95	0.050	Yes	PNL	25	153	18	40	Dangerous! (*N9)	300.00
Air Compressor Bus	ACB-Air Comp	0.480	8.17	5.52	7.94	5.36	0.016	0.000	Yes	PNL	25	7	18	0.28	Category 0	100.00
GT-1 Bus	ACB GT-1 Tie 600A	0.480	16.72	10.17	16.72	10.17	0.05	0.050	Yes	PNL	25	33	18	3.3	Category 1	100.00
GT2 Aux Bus (480V)	ACB CGT2 Aux	0.480	2.72	2.16	2.72	2.16	1.95	0.050	Yes	PNL	25	76	18	13	Category 3 (*N9)	
HS of ACB-GC	ACB-B 1600A	0.480	15.17	9.36	14.85	9.16	0.33	0.050	Yes	PNL	25	72	18	12	Category 3	100.00
HS of MCC1 ACB	ACB-A 1600 A	0.480	21.80	12.76	16.48	9.64	0.33	0.050	Yes	PNL	25	79	18	14	Category 3	100.00
HS of MCC2 ACB	ACB-A 1600 A	0.480	21.50	12.61	16.37	9.60	0.33	0.050	Yes	PNL	25	79	18	14	Category 3	100.00
LS of ACB-A 480V	ACB-A 1600 A	0.480	24.09	13.90	18.58	10.72	0.33	0.050	Yes	PNL	25	84	18	15	Category 3	
LS of ACB-B 480V	ACB-B 1600A	0.480	18.51	11.10	18.18	10.90	0.33	0.050	Yes	PNL	25	80	18	14	Category 3	
LS of MCC1 Panel	ACB MCC1	0.480	19.88	11.79	16.49	9.78	0.18	0.050	Yes	PNL	25	57	18	7.8	Category 2	100.00
LS of MCC2 Panel	ACB MCC2	0.480	19.37	11.54	17.22	10.25	0.18	0.050	Yes	PNL	25	56	18	7.7	Category 2	100.00
Water Plant Bus	ACB-GC 600A	0.480	13.74	8.60	13.74	8.60	0.18	0.000	Yes	PNL	25	43	18	5.0	Category 2	100.00

Arc Flash Analysis Results - Unit S-3

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category	Cable Length From Trip Device (ft)
BFP 3A	BFP 3A Relay	2.40	22.15	21.21	21.53	20.61	0.016	0.083	No	SWG	104	79	36	3.2	Category 1	110.00
BFP 3B	BFP 3B Relay	2.40	22.38	21.42	21.75	20.82	0.016	0.083	No	SWG	104	80	36	3.3	Category 1	100.00
CTF 3A	480V CTF 3A Bkr	0.480	5.83	4.14	5.56	3.95	0.03	0.083	No	PNL	25	23	18	1.8	Category 1	300.00
CTF 3B	480V CTF 3B Bkr	0.480	5.37	3.85	5.11	3.67	0.031	0.083	No	PNL	25	22	18	1.7	Category 1	335.00
CTF 3C	480V CTF 3C Bkr	0.480	4.97	3.61	4.72	3.42	0.031	0.083	No	PNL	25	21	18	1.6	Category 1	370.00
CWP 3A	CWP 3A Relay	2.40	18.79	18.04	18.52	17.79	0.016	0.083	No	SWG	104	66	36	2.7	Category 1	260.00
CWP 3B	CWP 3B Relay	2.40	18.79	18.04	18.52	17.79	0.016	0.083	No	SWG	104	66	36	2.7	Category 1	260.00
FDF Fast	FDF Fast Relay	2.40	20.59	19.74	20.04	19.21	0.016	0.083	No	SWG	104	73	36	3.0	Category 1	180.00
FDF Slow	FDF Slow Relay	2.40	20.23	19.40	20.10	19.27	0.016	0.083	No	SWG	104	72	36	2.9	Category 1	190.00
HS ACB Gen 13.2kV	26B1E06 Relay	13.20	15.33	14.77	6.30	6.07	0.016	0.084	Yes	SWG	153	163	36	5.2	Category 2 (*N2) (*N9)	
HS Cond Pump 3A	480V US ACB 7A	0.480	10.28	6.71	9.85	6.43	0.03	0.083	No	PNL	25	32	18	3.1	Category 1	120.00
HS Cond Pump 3B	480V US ACB 8B	0.480	10.09	6.61	9.66	6.32	0.03	0.083	No	PNL	25	32	18	3.0	Category 1	125.00
HS SWGR2	S5 Relay	2.40	24.50	23.42	13.78	13.17	0.016	0.080	No	SWG	104	87	36	3.5	Category 1	
LS 480V MCC3D Panel Bus	MCC3D 480V Panel	0.480	15.18	9.37	15.18	9.37	0.117	0.050	No	PNL	25	49	18	6.2	Category 2	95.00
LS 480V Panel Bus	S-4 MCC 4C Basement	0.480	14.70	9.11	14.70	9.11	0.03	0.050	No	PNL	25	32	18	3.1	Category 1	100.00
LS Bus S3SST6 2400 volts	S1 Relay	2.40	24.56	23.48	10.98	10.49	0.016	0.080	No	SWG	104	86	36	3.5	Category 1	20.00
LS MCC3B Panel Bus	MCC3B Panel	0.480	14.70	9.11	14.70	9.11	0.03	0.050	No	PNL	25	32	18	3.1	Category 1	100.00
LS S1 480V Panel Bus	S1 480V Panel-Mechanic Shop	0.480	15.12	9.34	15.12	9.34	0.03	0.050	No	PNL	25	33	18	3.2	Category 1	100.00
LS S3 480V Panel Bus	S3 480V Mezzanine	0.480	15.12	9.34	15.12	9.34	0.117	0.050	No	PNL	25	49	18	6.2	Category 2	100.00
LS S3/4 SST8 480V	ACB A2	0.480	13.97	8.73	13.97	8.73	0.436	0.050	No	PNL	25	94	18	18	Category 3	
LS S3SST7 480V Bus	ACB A1	0.480	16.34	9.98	14.05	8.57	0.443	0.050	No	PNL	25	96	18	19	Category 3	
LS S4 480V Panel Bus	S4 480V Panel	0.480	14.70	9.11	14.70	9.11	0.031	0.050	No	PNL	25	32	18	3.1	Category 1	100.00
S-3 480V Panel Outside Mezzanine	S-3 480V Panel out Mezzanine	0.480	13.22	8.33	13.22	8.33	0.03	0.000	No	PNL	25	17	18	1.1	Category 0	90.00

Arc Flash Analysis Results - M Units

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category	Cable Length From Trip Device (ft)
M Unit 1 bus	26B1E02 Relay	4.16	22.37	21.42	14.64	14.01	0.016	0.084	Yes	SWG	104	601	36	18	Category 3 (*N9)	200.00
M Unit 2 bus	26B1E02 Relay	4.16	22.37	21.42	14.64	14.01	0.016	0.084	Yes	SWG	104	601	36	18	Category 3 (*N9)	200.00
M Unit 3 bus	26B1E02 Relay	4.16	22.37	21.42	14.64	14.01	0.016	0.084	Yes	SWG	104	601	36	18	Category 3 (*N9)	
M Unit 4 bus	26B1E02 Relay	4.16	22.37	21.42	14.64	14.01	0.016	0.084	Yes	SWG	104	601	36	18	Category 3 (*N9)	200.00
M Unit 4160 Bus	26B1E02 Relay	4.16	23.17	22.17	15.20	14.54	0.016	0.084	Yes	SWG	104	621	36	19	Category 3 (*N9)	100.00
M Unit 5 bus	26B1E02 Relay	4.16	22.37	21.42	14.64	14.01	0.016	0.084	Yes	SWG	104	601	36	18	Category 3 (*N9)	200.00

APPENDIX C: ASSUMPTIONS

General Assumptions:

- All motors were modeled as 4 pole, 0.8 pf, and .93 efficiency.
- All conductors were modeled as copper conductor unless specifically noted otherwise in plant records.
- Wire sizes, not able to be determined, were modeled as common design sized to carry the load of the equipment being served.
- Distances not able to be determined were modeled as 100 feet unless it was reasonable to estimate greater lengths due to known facility locations.

GT1:

- CGT-1 Trans Source Relay and Transmission Source Breaker settings and parameters are not known. UCS used a conservative 6 cycle fault clearing time for these devices.
- Generator GT-1 Impedances: Used typical SKM provided impedance (synchronous, transient, and sub-transient) data for the generator's size and rated voltage.
- CGT-1 Cable Bus Size – Cable length (80') and type (XLP) between GT-1 turbine terminals and 40MVA GSU transformer is known but cable size is not known – assumed 4000 kcmil solid bus.
- 13.2kV Cable Bus Size - Cable length (45') and type (XLP) between GT-1 turbine terminals and 13.2 kV Bus is known but cable size is not known – assumed 4000 kcmil solid bus.
- GT-1 Production Transformer (138/13.2kV) – Assumed X/R ratio = 50
- TSS GT-1 transformer (13.8kV/480V) – Assumed X/R ratio = 4.7
- The 480V Tie between the secondary side of transformer TSS GT-1 and S-5 480V system is assumed normally open at CGT-1 ACB S5 Tie breaker.
- Main Breaker GT-1 MCC – Assumed 6000A Instantaneous setting.
- GT-1 T-9 Transformer (13.2/2.4kV) – No information available other than 3000kVA, 13.2kV/2.4kV delta/delta. Assumed transformer impedance = 5.9% with X/R = 10.8
- 200E Fuse (between T9 and T10) – Fuse size unknown – Assumed S&C SM-4 200E fuse.
- T10 Basement Transformer (2400/480V) – Assumed X/R = 5.2
- 480/120/208V Transformer – Impedance unknown – Assumed 3.7% with X/R = 3.6.
- The 480V Alternate Source from LS T10 Transformer (CGT-1 model) to MCC3C is assumed normally open at the CGT-1 MCC3C breaker.
- The 480V Spare Breaker in basement switchgear is assumed normally open.

GT2/S5:

- 138kV Breaker and Relay settings and parameters are not known. UCS used a conservative 6 cycle fault clearing time for these devices.
- 138kV circuit conductors from Sub 20 to the Generator Step Up Transformer (TPC GT-2 S5) is not known. Assumed 200' run of 3-1/C with ground using 1000 kcmil copper conductor, XLPE insulation.
- 13.8kV circuit conductors from the Generator Step Up Transformer (TPC GT-2 S5) to the 13.8kV Bus is not known. Assumed two parallel runs of 500' 3-1/C 500 kcmil copper conductor, XLPE insulation in conduit.
- S-5's breaker and relay settings are not known. Protective device size and settings for CGT-2 were assumed for this breaker and relay set.
- CGT-2's ACB-GC 600A breaker information is not known. Protective device size and settings for ACB-MCC1 were assumed for this breaker.

- 13.8kV circuit conductors from the generator GT-2 to the 13.8kV Bus is not known. Assumed 500' of 3-1/C 500 kcmil copper conductor, XLPE insulation in conduit.
- 13.8kV circuit conductors from the generator S-5 to the 13.8kV Bus is not known. Assumed 500' of 3-1/C 500 kcmil copper conductor, XLPE insulation in conduit.
- 13.8kV circuit conductors from the Fuse 13GT2F1 to the high side of transformer GT-2 SS 112.5 kVA Xfmr is not known. Assumed two parallel runs of 100' 3-1/C 3/0 kcmil copper conductor, XLPE insulation in conduit.
- Transformer GT2 SS Xfmr 112.5 kVA impedance is not known – Used SKM typical impedance of 4.5% for a transformer with this voltage ratio and winding types.
- 480V circuit conductors from the low side of transformer GT-2 SS 112.5 kVA Xfmr to the ACB CGT2 is not known. Assumed three parallel runs of 100' 3-1/C 3/0 kcmil copper conductor, XLPE insulation in conduit.
- Device settings for ACB CGT2 Aux molded case breaker are assumed to be 200A trip with 10x Instantaneous.
- Molded case breaker S-5 Tie 200A is assumed to be normally open.
- 480V cable length from GT2 Aux to S-5 MCC 2 is assumed to be 200'.
- Fuses 13S5 F1 and 13S5 F2 are assumed to be S&C SM-5 65E fuses.
- 13.8kV cable length from the 13.8kV Bus to TSS5-1 is assumed to be 100'.
- TSS5-1 Transformer (13800/277/480V) – Assumed X/R = 5.7
- 480V cable length from TSS5-1 to ACB-A is assumed to be 100'.
- 13.8kV cable length from the 13.8kV Bus to TSS5-2 is assumed to be 100'.
- TSS5-2 Transformer (13800/277/480V) – Assumed X/R = 5.7
- 480V cable length from TSS5-2 to ACB-B is assumed to be 100'.
- 480V cable length from ACB-A to HS MCC1 ACB is assumed to be 100'
- 480V cable from ACB MCC1 and LS of MCC1 Panel has assumed 3 parallel runs of 3-1/c 4/0 for 100'.
- 480V cable from ACB MCC2 and LS of MCC2 Panel has assumed 3 parallel runs of 3-1/c 4/0 for 100'.
- 480V cable from ACB-B to ACB-GC has assumed 1-3/c 750 kcmil for 100'.
- 480V cable length from ACB-GC to Water Plant is assumed to be 100'.
- Breaker ACB-Air Comp device information is not known. Assumed 100A molded case breaker.
- 480V cable length from MCC2 to 502 Boiler Feed Pump is assumed to be 200'.
- 480V cable length from MCC2 to 504 Circulating Water Pump is assumed to be 200'.
- 480V cable length from MCC1 to 501 Boiler Feed Pump is assumed to be 200'.
- 480V cable length from MCC1 to 503 Circulating Water Pump is assumed to be 200'.
- 480V cable length from MCC1 to 505 Cooling Tower Fan is assumed to be 200'.
- 480V cable length from MCC2 to GT-1 (emergency tie) is assumed to be 100'. This cable section is assumed to be open at the GT-1 end of the circuit.
- Breaker ACB GT-1 Tie 600A device information and settings are unknown. Assumed Westinghouse DS AMPTCT IA with settings:
  - Sensor = 600
  - LTPU = 1
  - LTD = 4
  - LTPU = 4
  - STD = 0.18
  - INST = 4

S-3:

- Generator S-3 Impedances: Used typical SKM provided impedance (synchronous, transient, and sub-transient) data for the generator's size and rated voltage.
- 26.4 kV breaker relay data for 26B1E06 and 26B1E08 relays are not known. UCS used a conservative 6 cycle fault clearing time for these devices.
- The 26.4kV circuit conductors from the S-3 Generator Step Up Transformer to the East 26kV Bus is not known. Assumed three parallel runs of 100' 3-1/C 350 kcmil copper conductor, XLPE insulation in conduit.
- Since the 26B1W16 breaker (between the GSU Bus and the West 26.4kV bus) is open and no information is available for the 26B1W16 Relay, modeling for the line section, relay and West Bus breaker are incomplete and unnecessary.
- TPS3 GSU Transformer (26.4/13.2kV) – Assumed X/R = 26
- S3SST5 Transformer (13.2/2.4kV) – Assumed X/R = 10.8
- The 26.4kV circuit conductors from Relay 26B1E08 to transformer SS 3-4 T6 is not known. Assumed three parallel runs of 100' 3-1/C 350 kcmil copper conductor, XLPE insulation in conduit.
- SS 3-4 T6 Transformer (26.4/2.4kV) – Assumed X/R = 10.5
- 2.4kV cable length of T6 to SWGR2 is assumed to be 100'.
- SS 3-4 T8 Transformer (2400/480V) – Assumed X/R = 5.2
- Breaker ACB A2 information is not available – Assumed set exactly like ACB A1.
- Duct Tie conductor between LS S3SST7 480V and LS S3/4 sst8 480V is not known. Since the tie breaker is normally open, the conductor was assumed to be very large (1600 kcmil bus duct).
- Duct Bus conductor between LS Bus S3SST6 2400V and HS SWGR 2 is not known. The breaker tying the stated buses together is assumed normally closed, the Bus Duct was assumed to be very short (20') and very large (2000 kcmil bus duct).
- MCC3D 480V Panel breaker information is not available – Assumed set exactly like S3 480V Mezzanine.
- Relay CT ratios for the following are assumed to be 200/5 and the motors associated with these locations assume 0.8 pf and 0.93 efficiency:
  - CWP 3B
  - CWP 3A
  - FDF Slow
  - FDF Fast
  - BFP 3A
  - BFP 3B
- S3SS T7 Transformer (2400/480V) – Assumed X/R = 5.2
- Breaker settings for Condensate Pump 3A assumed identical settings as Compensate Pump 3B.
- Breaker settings for CTF A, CTF B, and CTF C were assumed to be:
  - Sensor = 100
  - LTPU = 1.6
  - STPU = 4
  - INST = 20
- 480V emergency tie to S1-G1 is assumed normally open at the 480V breaker in the S-3 plant. The tie conductor is assumed to be three parallel runs of 1/0 copper for 100'.
- 480V cable section between S3 480V Mezzanine breaker and LS S3 480V Panel is assumed to be three parallel runs of 250 kcmil copper for 100'.
- 480V cable section between S1 480V Panel – Mechanic Shop breaker and LS S1 480V Panel is assumed to be three parallel runs of 250 kcmil copper for 100'.
- 480V cable section between MCC3D 480V Panel breaker and LS 480V MCC3D Panel Bus is assumed to be three parallel runs of 250 kcmil copper for 95'.

- 480V cable section between S4 480V Panel breaker and LS S4 480V Panel Bus is assumed to be three parallel runs of 2/0 kcmil copper for 100’.
- 480V cable section between S4 MCC 4C Basement breaker and LS 480V Panel Bus is assumed to be three parallel runs of 2/0 kcmil copper for 100’.
- 480V cable section between MCC3B Panel breaker and LS MCC3B Panel Bus is assumed to be three parallel runs of 2/0 kcmil copper for 100’.

M Units:

- Generator Impedances for Units 1 - 5: Used typical SKM provided impedance (synchronous, transient, and sub-transient) data for the generator’s size and rated voltage.
- 26.4 kV breaker relay data for 26B1E02 Relay is not known. UCS used a conservative 6 cycle fault clearing time for this device.
- The 26.4kV circuit conductors from the M Units Production Transformer to Substation 10 East Bus are not known. UCS assumed four parallel runs of 100’ 3-1/C 500 kcmil copper conductor, XLPE insulation in conduit.
- Production Transformer TPMU (26.4/4.16kV) – Assumed X/R ratio = 16.7
- The 1200A breaker and settings were provided for M-5 generator unit. The settings for this breaker conflicted with settings for M Units 1-4, which are reported to have the same breakers and settings. UCS used the M-5 Unit breaker and settings for M Units 1-4.