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High Reliability Power System Design

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Redundant Power Trains for Increased Reliability

- The most basic driving element in increasing power system reliability is to have redundant or alternate power trains to power the end load device should a particular piece of the power system fail or be unavailable
- The unavailability of equipment can a simple failure, but also planned maintenance

Redundant Power Trains for Increased Reliability

- The most common method by far is designing a power system with two power trains, A and B
- Such an A and B system then requires a second source of power
- Could be a second utility source, or a standby diesel engine-generator or other source of power

Failure Analysis – Single Point of Failure

- Failure analysis is driven by the concept of "single points of failure"
- A single point of failure is a single point in the power system beyond which the power system is down from the failed piece of equipment
- Example is the single transformer, or MCC, etc. in the above example

Failure Analysis – Coincident Damage

- **A secondary failure analysis concept is "coincident damage"**
- **Coincident damage is where the failure of one piece of equipment damages a piece of the alternate equipment power train**
- **Example is a pull box with both A circuit and B circuit cables**
- **Should the A cables explode during fault conditions, the arc flash could easily damage the B cables in close proximity**

Limitations of Redundancy

- Easy to keep adding equipment to power system to increase reliability
- Also adding cost
- Degree of final power system redundancy depends on owner's available budget
- Simply adding more power trains results in diminishing returns on investment, or asymptotic curve

Limitations of Redundancy

- The driving factor for owner is what value is placed on continued operation
- Or can be how catastrophic an outage is to the plant and for how long
- If the plant can be down without great adverse impact, then adding costs to the power system for increased reliability is not necessary
- This is rarely the case

Limitations of Redundancy

- So, we have to find an acceptable common ground to establish design criteria
- A hospital is one obvious example where reliability requirements are very high
- Another example is a highway tunnel where the public could be at risk should the power system fail

Reliability Calculation for Power Systems

- **Reliability calculation can be performed on any power system**
- **Most useful when <u>comparing the reliability index between different systems</u>**

Reliability Calculation for Power Systems

- Gastonia wanted to improve reliability and safety of existing power system
- We originally identified about 20 alternatives
- Narrowed down to about 6 alternatives
- Added slight variations to 6 alternatives for a total of 16 options representing alternative paths
- Calculated reliability index for all 16 options
- Provided cost estimate for each option to assign “value” to reliability improvements

Reliability Calculation for Power Systems

- **Reliability Index = λ x r = (failure rate per year) x (hours of downtime per year)**
- **IEEE Standard 493 (*also known as the Gold Book*)**

IEEE Std 493-1997
(Revision of IEEE Std 493-1990)

IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems

Sponsor

Power Systems Reliabilty Subcommittee
of the
Power Systems Engineering Committee
of the
IEEE Industry Applications Society

Approved 16 December 1997

IEEE Standards Board

Reliability Calculation for Power Systems

- For reliability values for typical electrical equipment in a power system:
- Used IEEE 493, Table 7-1, page 105: Reliability Data of Industrial Plants, for transformers, breakers, cables, swgr, gens, etc.
- Data represents many years of compiling data by IEEE on failure types and failure rates
- Data is updated periodically
- For comparison purposes, important to be consistent in use of reliability data

Typical IEEE Reliability Data for Equipment

	EQUIPMENT	λ	r	Hrs/Yr
•	Breakers, 480 V	0.0027	4.0	0.0108
•	Breakers, 12.47 kV	0.0036	2.1	0.0076
•	Cables, LV	0.00141	10.5	0.0148
•	Cables, HV	0.00613	19.0	0.1165
•	Cable Terms, LV	0.0001	3.8	0.0004
•	Cable Terms, HV	0.0003	25.0	0.0075

Typical IEEE Reliability Data for Equipment

EQUIPMENT	λ	r	Hrs/Yr
Switches	0.0061	3.6	0.0220
Transformers	0.0030	130.0	0.3900
Switchgear Bus, LV	0.0024	24.0	0.0576
Switchgear Bus, HV	0.0102	26.8	0.2733
Relays	0.0002	5.0	0.0010
Standby Eng-Gens	0.1691	478.0	80.8298

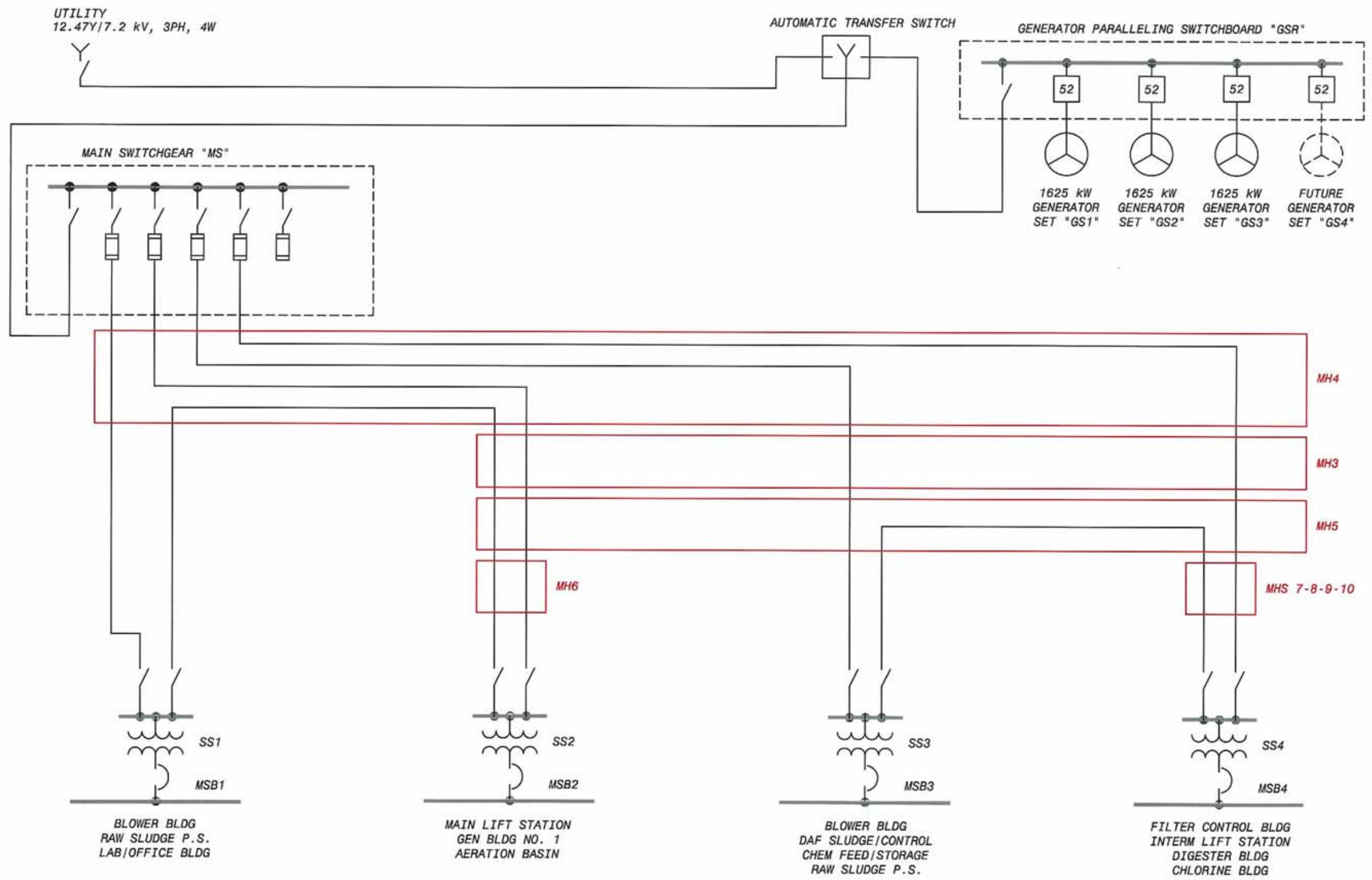
Reliability Calculation for Power Systems

- **For reliability values for utility circuits:**
- **Could use IEEE 493, Table 7-3, page 107: Reliability Data of Electric Utility Circuits to Industrial Plants**
- **Typical utility circuit options:**
- **Loss of Single Circuit = 2.582 hrs/yr**
- **Double Circuit, Loss of 1 Circuit: 0.2466 hrs/yr**
- **Loss of Double Circuit = 0.1622 hrs/yr**

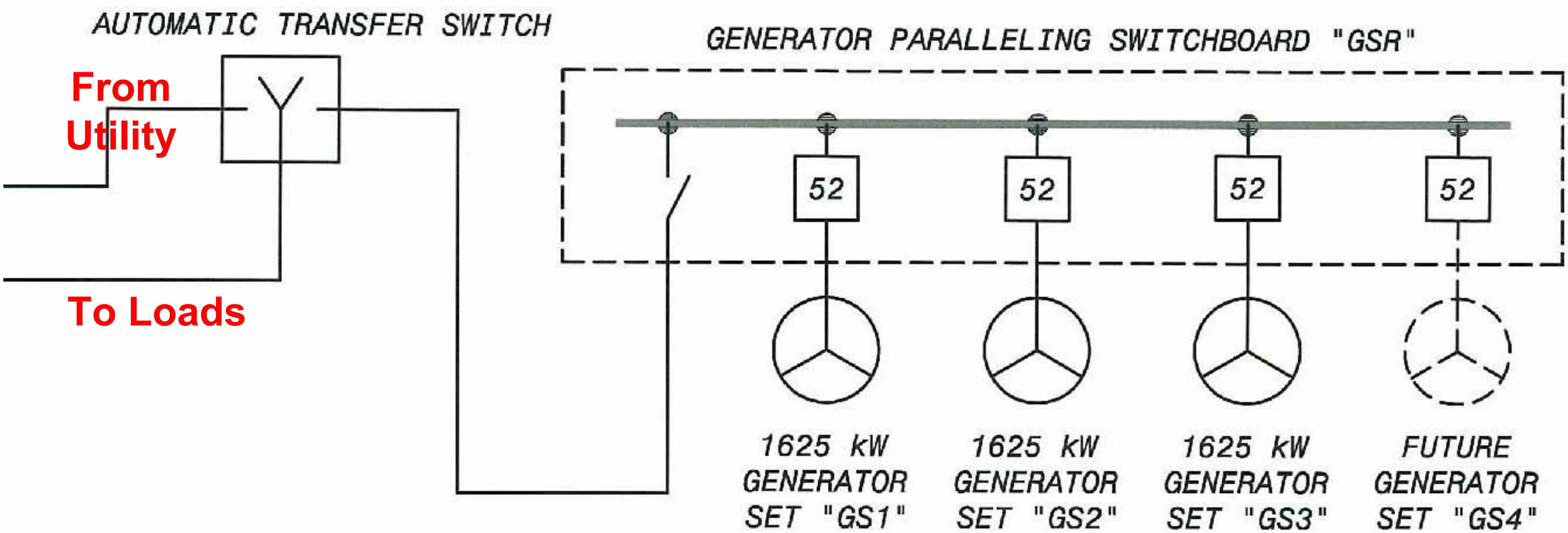
Reliability Calculation for Power Systems

- **Use <u>actual</u> historical outage data for Gastonia Electric (electric utility) Feeder No. 10-1 to Long Creek WWTP for past 5 years: 19.37144 minutes outage per year**
- **Gastonia Electric Feeder 10-1 to Long Creek WWTP = 0.0022 hrs/yr (19.37144 min/yr)**
- ***Better than IEEE data of 2.582 hrs/yr for single circuit!***

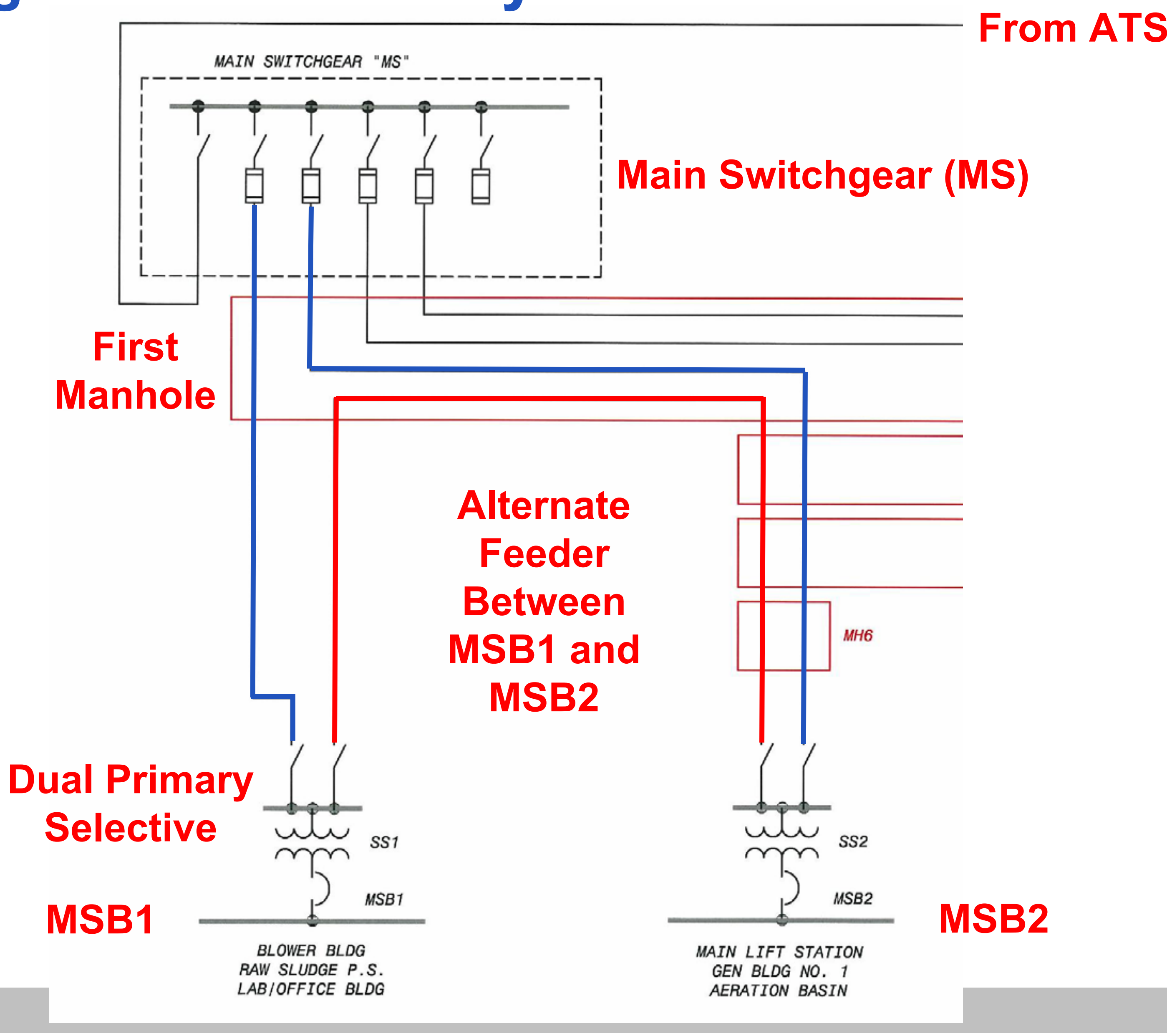
Existing WWTP Power System



Existing WWTP Power System



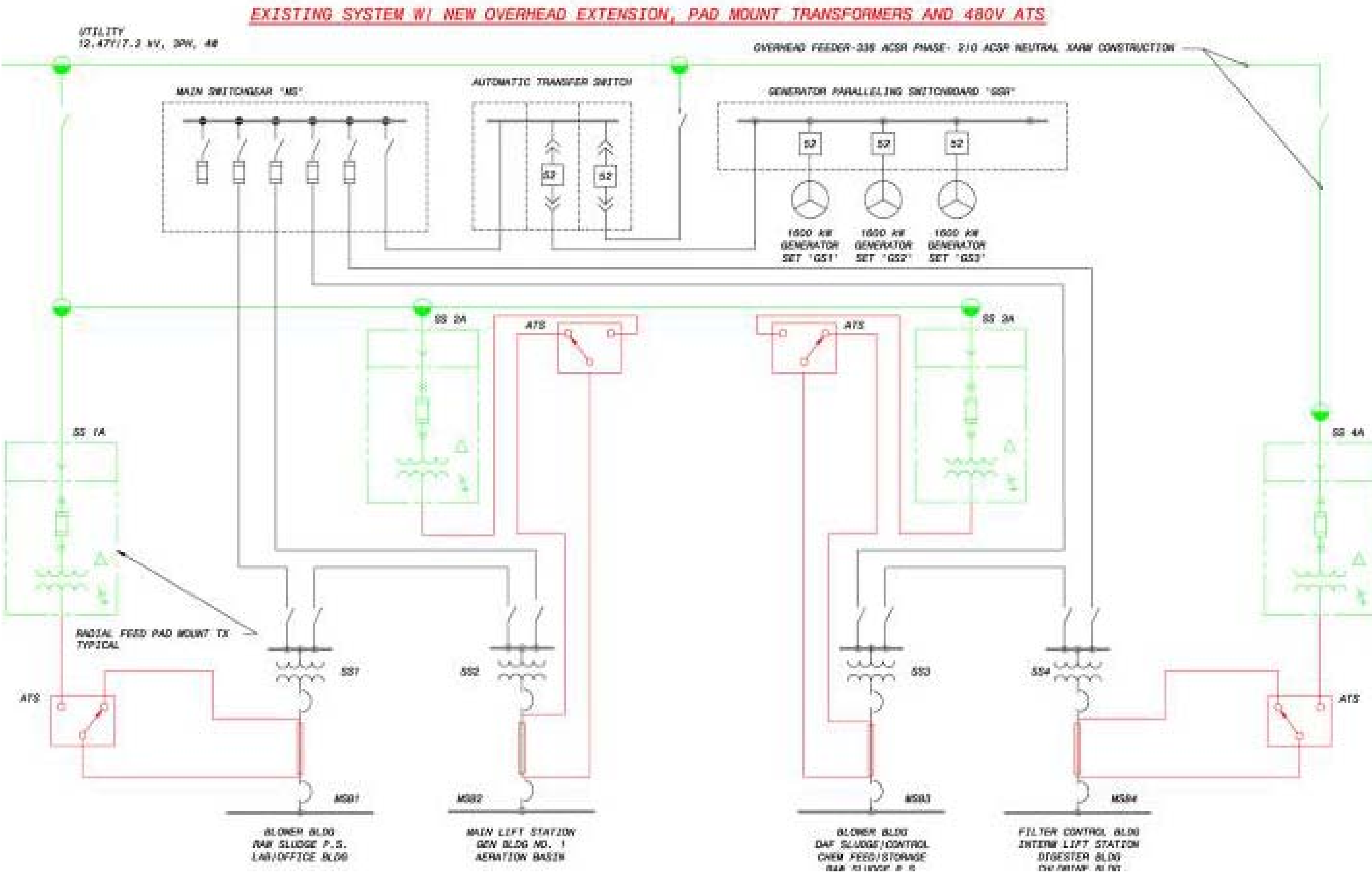
Existing WWTP Power System



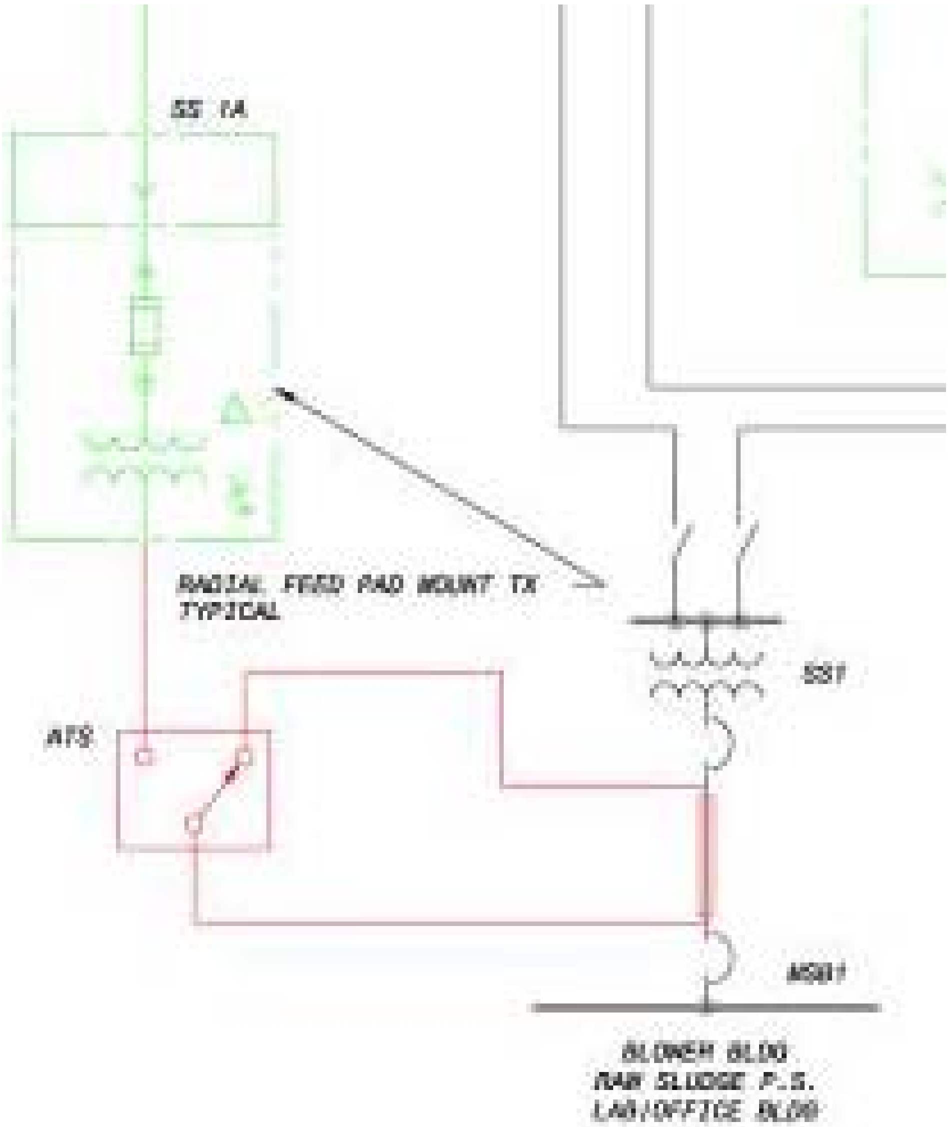
Reliability Calculations – Existing System

POWER TRAIN	INDEX
1A: Existing to MSB1	1.6355
1B: Existing to MSB1 via SS2	1.5583
1C: Existing to MSB3	1.6515
1D: Existing to MSB3 via SS4	1.5801

Alternative 2



Alternative 2



Reliability Calculations - Proposed System

Alternative 2: Pad Mounted Transformer with ATS

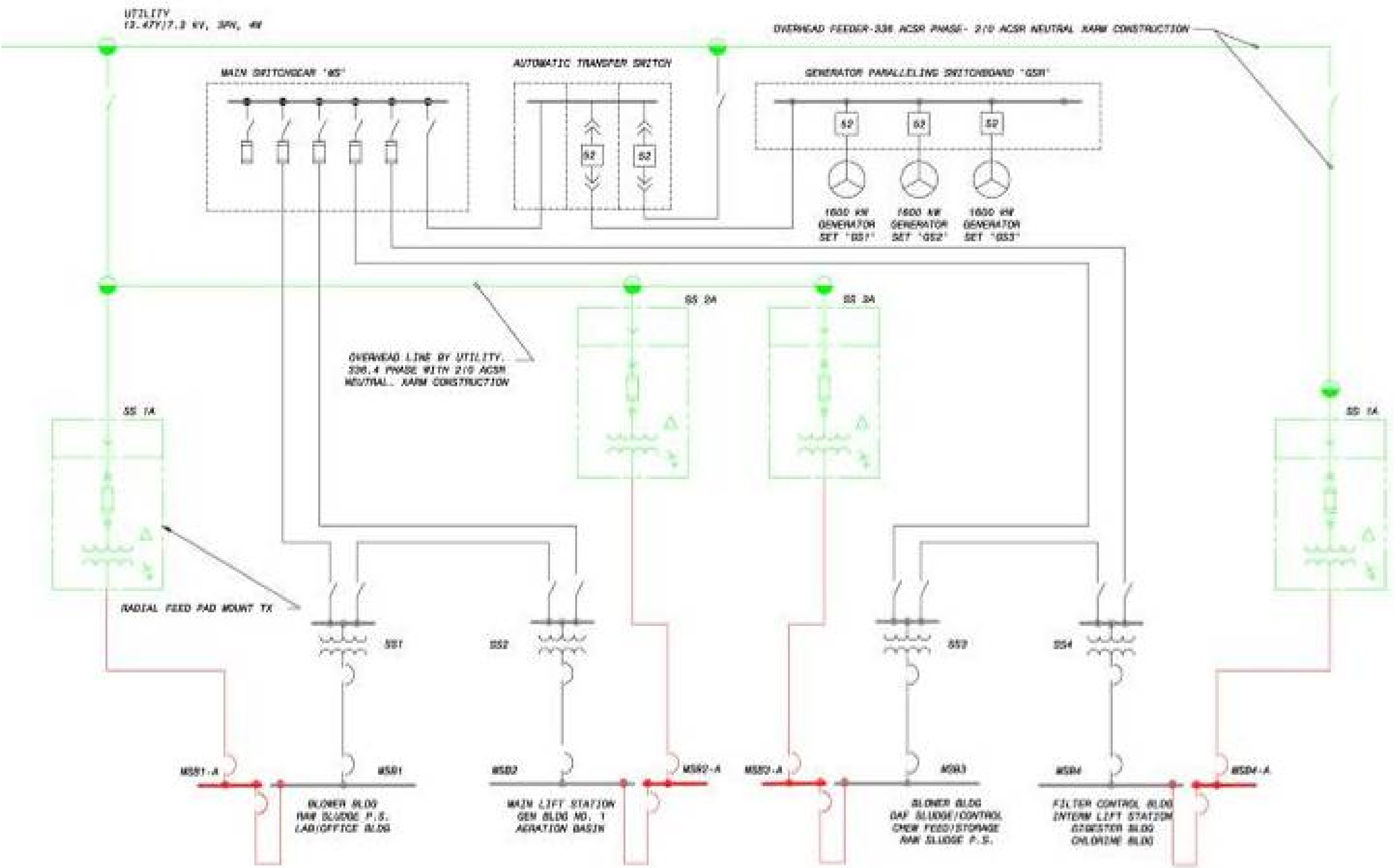
POWER TRAIN	INDEX
• 2A: New OH line w/ATS to MSB1	1.0307
• 2B: New OH line w/ATS MSB1 via SS2	0.8567
• Comparison to Existing:	
◦ 1A: Existing to MSB1	1.6355
◦ 1B: Existing to MSB1 via SS2	1.5583

Reliability Calculations - Proposed System

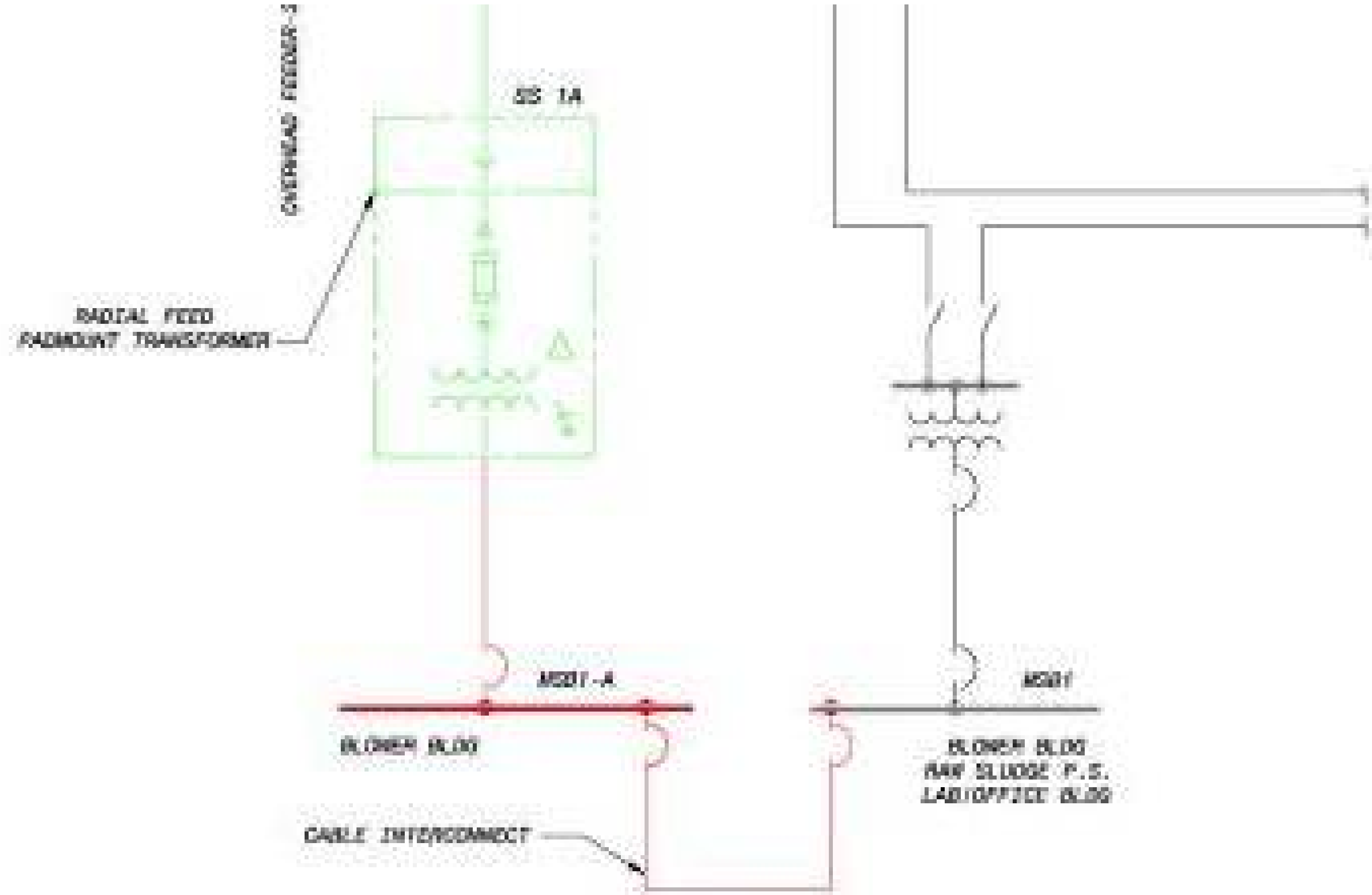
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches

$860,000

Alternative 3



Alternative 3



Reliability Calculations - Proposed System

Alternative 3: (4) Padmount Transformers with Redundant MSBs

POWER TRAIN	INDEX
• 3A: Transformer to M-T-M MSB1/1A	0.7306
• 3B: Transformer to M-T-M MSB1/1A via SS2	0.7165

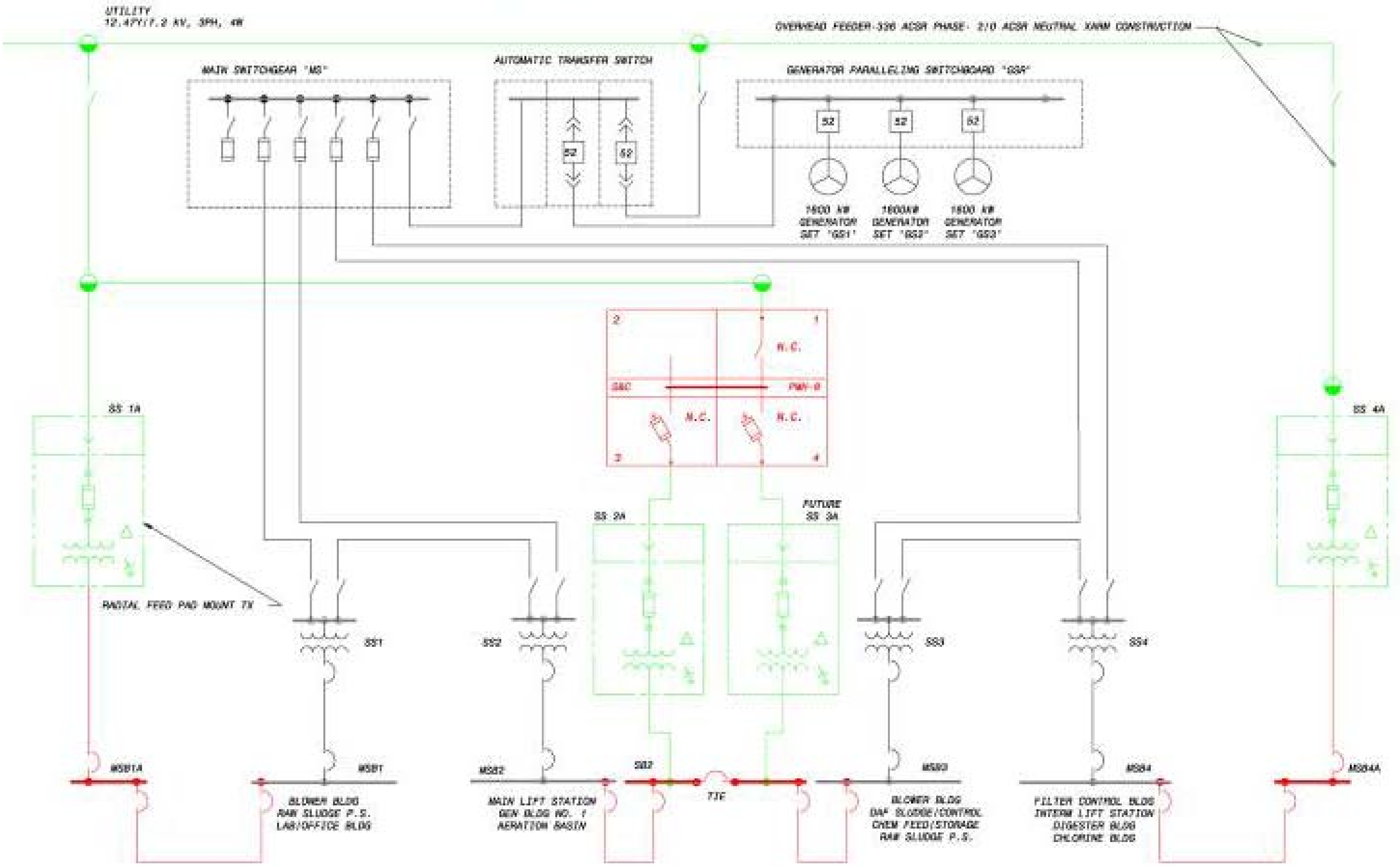
- Comparison to Existing:
  - 1A: Existing to MSB1 — 1.6355
  - 1B: Existing to MSB1 via SS2 — 1.5583

Reliability Calculations - Proposed System

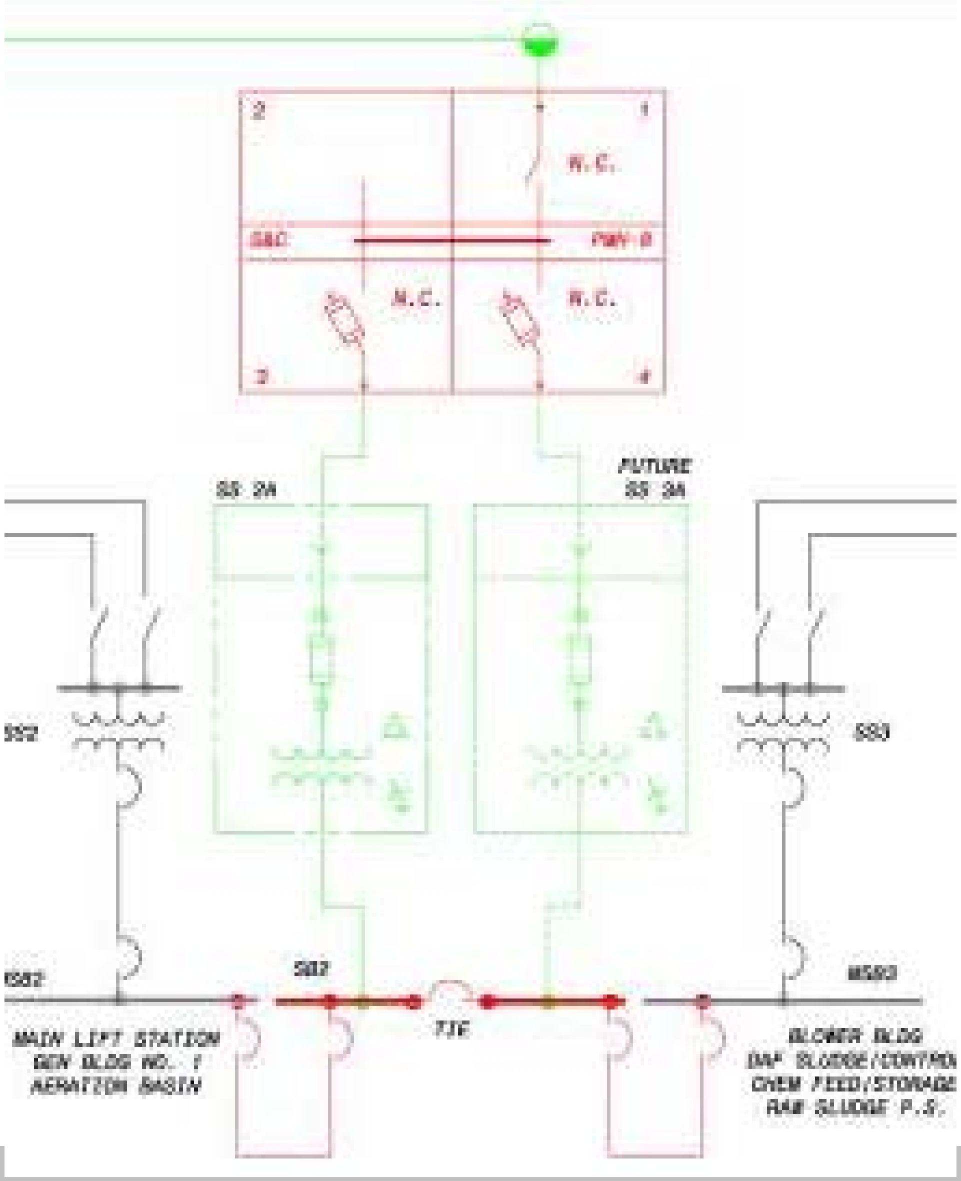
Alternative 3: (4) Padmount Transformers with Redundant MSBs

$1,100,000

Alternative 6



Alternative 6



Reliability Calculations - Proposed System

Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3

POWER TRAIN	INDEX
• 6A: Transformer to PMH to MSB-2/2A	0.8118
• 6B: Transformer to PMH to MSB-2A to MSB-3A	0.8496

- Comparison to Existing:
  - 1A: Existing to MSB1 — 1.6355
  - 1B: Existing to MSB1 via SS2 — 1.5583

Reliability Calculations - Proposed System

Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3

$1,160,000

Reliability Calculations - Proposed System

DESCRIPTION	APP. COST
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches	$860,000
Alternative 3: (4) Padmount Transformers with Redundant MSBs	$1,100,000
Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3	$1,160,000

Reliability Calculations - Proposed System

DESCRIPTION	APP. COST
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches	$860,000
Alternative 3: (4) Padmount Transformers with Redundant MSBs	$1,100,000
Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3	$1,160,000

Reliability Calculations - Proposed System

DESCRIPTION	Rel. Index
Existing System	1.6355
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches	1.0307
Alternative 3: (4) Padmount Transformers with Redundant MSBs	0.7306
Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3	0.8118

Reliability Calculations

SUMMARY OF RELIABILITY ANALYSIS	
DESCRIPTION	λr (forced hrs of downtime/year)
OPTION 1A: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1	
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
TOTAL OPTION 1A	**1.6355**
OPTION 1B: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1 & VIA SS2	
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From MS Swgr Feeder to SS2 Primary Switch to SS1 Primary Switch	0.6408
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
TOTAL OPTION 1B	**1.5583**

Reliability Calculations

OPTION 1C: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB3		
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Distribution System From SS3 Primary Switch to Transformer to MSB3	1.3189
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	TOTAL OPTION 1C	**1.6515**
OPTION 1D: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB3 & VIA SS4		
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Distribution System From MS Swgr Feeder to SS4 Primary Switch to SS3 Primary Switch	1.2159
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
	Distribution System From SS3 Primary Switch to Transformer to MSB3	1.3189
	Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
	TOTAL OPTION 1D	**1.5801**

Reliability Calculations

OPTION 2A: NEW OVERHEAD LINE TO TRANSFORMER TO 480 V ATS TO MSB1 MAIN BREAKER		
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
	Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
	Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
	Combine 12.47 kV Sources to ATS to MS Swgr to SS1 Primary Switch	1.4616
	Distribution System From SS1 Primary Switch to Transformer to 480 V ATS NP Lugs	1.3149
	Combine 12.47 kV Sources to ATS to MS Swgr to SS1 Primary Switch	1.4616
	Combine Option 1A with 2 Sources to ATS to MS to SS1 to 480 V ATS NP Lugs	2.7765
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
	Combine Source 3 with 12.47 kV Tap with Option 1A: ATS-MS-SS1-480 V ATS NP Lugs	0.8465
	Distribution System From 480 V ATS to MSB1 Main Breaker	0.1841
	Combine Source 3 with 12.47 kV Tap with Option 1A: ATS-MS-SS1-480 V ATS NP Lugs	0.8465
	TOTAL OPTION 2A	**1.0307**
OPTION 2B: NEW OVERHEAD LINE TO TRANSFORMER TO 480 V ATS TO MSB1 MAIN BREAKER VIA SS2		
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
	Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
	Distribution System From SS1 Switch to Transformer to 480 V ATS NP Lugs	1.3149
	Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
	Combine Option 1B with SS1 and SS1 via SS2 Switch to 480 V ATS NP Lugs	1.5021
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
	Combine Source 3 with 12.47 kV Tap with Option 1B: ATS-MS-SS1 and SS1 via SS2-480 V ATS NP Lugs	0.6726
	Distribution System From 480 V ATS to MSB1 Main Breaker	0.1841
	Combine Source 3 with 12.47 kV Tap with Option 1B: ATS-MS-SS1 and SS1 via SS2-480 V ATS NP Lugs	0.6726
	TOTAL OPTION 2B	**0.8567**

Reliability Calculations

OPTION 3A: NEW OVERHEAD LINE TO TRANSFORMER TO MSB1-A WITH MAIN-TIE-MAIN TO MSB1	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine Existing Distribution System to ATS-MS-SS1-Transformer-MSB1	1.6355
Bus-Tie Breaker from MSB1 to MSB1-A	0.0955
Combine Existing Distribution System to ATS-MS-SS1-Transformer-MSB1	1.6355
Combine Existing Distribution to MSB1 with Bus-Tie Breaker from MSB1 to MSB1-A	1.7310
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
TOTAL OPTION 3A	**0.7306**

Reliability Calculations

OPTION 3B: NEW OH LINE TO TRANSFORMER TO MSB1-A WITH MAIN-TIE-MAIN TO MSB1 VIA SS2	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From MS Swgr Feeder to SS2 Primary Switch to SS1 Primary Switch	0.6408
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Combine Existing System to SS1 Switch & Via SS2 Switch to MSB1	1.5583
Bus-Tie Breaker from MSB1 to MSB1-A	0.0955
Combine Existing System to SS1 Switch & Via SS2 Switch to MSB1	1.5583
Combine Existing System to MSB1-A with Bus-Tie Breaker from MSB1 to MSB1-A	1.6538
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
TOTAL OPTION 3B	**0.7165**

Reliability Calculations – Detailed Calculations

OPTION 6A: NEW OVERHEAD LINE TO PMH-8 TO TRANSFORMER TO MAIN-TIE-MAIN MSB2-A		
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB2-A	1.6310
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
	Distribution System From MS Swgr Feeder to SS2 Primary Switch	0.2644
	Distribution System From MS Swgr Feeder to SS1 Primary Switch to SS2 Primary Switch	0.5482
	Distribution System From MS Swgr Feeder to SS2 Primary Switch	0.2644
	Combine MS Feeder to SS2 Switch & MS Feeder to SS1 Switch to SS2 Switch	0.1784
	Distribution System From SS2 Primary Switch to Transformer to MSB2	1.3559
	Combine MS Feeder to SS2 Switch & MS Feeder to SS1 Switch to SS2 Switch	0.1784
	Combine Existing System to SS2 Switch & Via SS1 Switch to MSB2	1.5343
	Bus-Tie Breaker from MSB2 to MSB2-A	0.0821
	Combine Existing System to SS2 Switch & Via SS1 Switch to MSB2	1.5343
	Combine Existing System to MSB2-A with Bus-Tie Breaker from MSB2 to MSB2-A	1.6164
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB2-A	1.6310
	TOTAL OPTION 6A	**0.8118**

Reliability Calculations – Detailed Calculations

OPTION 6B: NEW OVERHEAD LINE TO PMH-8 TO TRANSFORMER TO MSB2-A TO MSB3-A		
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB3-A	1.6994
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Distribution System From MS Swgr Feeder to SS4 Primary Switch to SS3 Primary Switch	1.2159
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
	Distribution System From SS3 Primary Switch to Transformer to MSB3	1.3559
	Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
	Combine Existing System to SS3 Switch & Via SS4 Switch to MSB3	1.6171
	Bus-Tie Breaker from MSB3 to MSB3-A	0.0821
	Combine Existing System to SS3 Switch & Via SS4 Switch to MSB3	1.6171
	Combine Existing System to MSB3-A with Bus-Tie Breaker from MSB3 to MSB3-A	1.6992
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB3-A	1.6994
	TOTAL OPTION 6B	**0.8496**

Reliability Calculations – Detailed Calculations

COMPONENTS			λ (failures/year)	r (hrs of downtime/failure)	λr (forced hrs of downtime/year)
OPTION 1A: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1					
Source 1: 12.47 kV Single Circuit Electric Utility to ATS					
12.47 kV single utility circuit, Gastonia Electric 5-yr SAIDI=19.37144			---	---	0.0022
12.47 kV cable terminations (at riser pole)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV cables, underground, repair (riser to ATS)			0.0184	26.5	0.4873
	Cables in parallel =	2			
	Length of circuit (ft) =	500			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0184			
12.47 kV cable terminations (at ATS breaker)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV metal-clad breaker, replace (ATS incoming from utility)			0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 2 breakers (ATS)			0.0068	26.8	0.1822
12.47 kV relay (assumed for ATS controls)			0.0002	5	0.0010
Source 1: 12.47 kV Single Circuit Electric Utility to ATS					**0.7703**

Reliability Calculations – Detailed Calculations

Source 2: Plant Engine-Generators, 3-1600 kW, to ATS					
12.47 kV standby diesel engine-generator (G1/2/3)			0.1691	478	80.8298
12.47 kV metal-clad breaker, replace (G1/2/3 breaker)			0.0036	2.1	0.0076
12.47 kV cable terminations (at G1/2/3 breaker)			0.0009	25.0	0.0225
	Cables in parallel =	1			
	Number of terminations =	3			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0009			
12.47 kV cables, underground, repair (G1/2/3 breaker to gen swgr)			0.0005	26.5	0.0122
	Cables in parallel =	1			
	Length of circuit (ft) =	25			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0005			
12.47 kV cable terminations (at gen swgr breakers)			0.0009	25.0	0.0225
	Cables in parallel =	1			
	Number of terminations =	3			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0009			
12.47 kV metal-clad breaker, replace (gen swgr)			0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 3 breakers (gen swgr)			0.0102	26.8	0.2734
12.47 kV relay (gen swgr)			0.0002	5	0.0010
12.47 kV cable terminations (at gen swgr bus tap)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV cables, underground, repair (gen swgr to ATS breaker)			0.0029	26.5	0.0780
	Cables in parallel =	2			
	Length of circuit (ft) =	80			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0029			
12.47 kV cable terminations (at ATS breaker)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV metal-clad breaker, replace (ATS incoming from gens)			0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 2 breakers (ATS)			0.0068	26.8	0.1822
12.47 kV relay (assumed for ATS controls)			0.0002	5	0.0010
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS					**81.5352**

Reliability Calculations – Detailed Calculations

Failures/year, each =	0.0003			
Failures/year, total =	0.0018			
12.47 kV metal-clad breaker, replace (ATS incoming from gens)		0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 2 breakers (ATS)		0.0068	26.8	0.1822
12.47 kV relay (assumed for ATS controls)		0.0002	5	0.0010
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS				**81.5352**
Source 1: 12.47 kV Single Circuit Electric Utility to ATS				**0.7703**
Combine 12.47 kV Sources #1 & #2 to ATS				**0.7631**
Distribution System From ATS to MS Swgr Main Fused Switch				
12.47 kV cable terminations (at ATS bus)		0.0018	25.0	0.0450
Cables in parallel =	2			
Number of terminations =	6			
Failures/year, each =	0.0003			

Reliability Calculations – Detailed Calculations

Distribution System From ATS to MS Swgr Main Fused Switch					
12.47 kV cable terminations (at ATS bus)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV cables, underground, repair (ATS to MS main switch)			0.0018	26.5	0.0487
	Cables in parallel =	2			
	Length of circuit (ft) =	50			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0018			
12.47 kV cable terminations (at MS main switch)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV metal-enclosed switch, replace (MS main switch)			0.0061	3.6	0.0220
12.47 kV switchgear bus-insulated, 3+ switches (MS)			0.0102	26.8	0.2734
Distribution System From ATS to MS Swgr Main Fused Switch					**0.4341**
Combine 12.47 kV Sources #1 & #2 to ATS					**0.7631**
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch					**1.1972**

Reliability Calculations – Detailed Calculations

Distribution System From MS Swgr Feeder to SS1 Primary Switch				
12.47 kV metal-enclosed switch, replace (MS feeder to SS1)		0.0061	3.6	0.0220
12.47 kV cable terminations (at MS feeder to SS1)		0.0009	25.0	0.0225
Cables in parallel =	1			
Number of terminations =	3			
Failures/year, each =	0.0003			
Failures/year, total =	0.0009			
12.47 kV cables, underground, repair (MS feeder to SS1 switch)		0.0066	26.5	0.1754
Cables in parallel =	1			
Length of circuit (ft) =	360			
Failures/year per 1000 circuit feet =	0.00613			
Failures/year, total =	0.0066			
12.47 kV cable terminations (at SS1 primary selective switch)		0.0009	25.0	0.0225
Cables in parallel =	1			
Number of terminations =	3			
Failures/year, each =	0.0003			
Failures/year, total =	0.0009			
12.47 kV metal-enclosed switch, replace (SS1 primary selective)		0.0061	3.6	0.0220
Distribution System From MS Swgr Feeder to SS1 Primary Switch				**0.2644**

Reliability Calculations – Detailed Calculations

Distribution System From SS1 Primary Switch to Transformer to MSB1					
12.47 kV switchgear bus-insulated, 2 switches (SS1 primary)			0.0068	26.8	0.1822
Transformer, 12.47 kV-480 V, replace (SS1)			0.0030	342.0	1.0260
480 V transformer secondary breaker (SS1 secondary)			0.0027	4	0.0108
480 V cable terminations (at SS1 transformer secondary breaker)			0.0033	3.8	0.0125
	Cables in parallel =	11			
	Number of terminations =	33			
	Failures/year, each =	0.0001			
	Failures/year, total =	0.0033			
480 V cables, abovegrade, repair (SS1 secondary breaker to MSB1)			0.0056	10.5	0.0586
	Cables in parallel =	11			
	Length of circuit (ft) =	120			
	Failures/year per 1000 circuit feet =	0.00141			
	Failures/year, total =	0.0056			
480 V cable terminations (at MSB1 main breaker)			0.0033	3.8	0.0125
	Cables in parallel =	11			
	Number of terminations =	33			
	Failures/year, each =	0.0001			
	Failures/year, total =	0.0033			
480 V metalclad drawout breaker (MSB1 main breaker)			0.0027	4	0.0108
480 V switchgear bus-bare, 7 breakers (MSB1)			0.0024	24	0.0576
Distribution System From SS1 Primary Switch to Transformer to MSB1					**1.3711**
Distribution System From MS Swgr Feeder to SS1 Primary Switch					**0.2644**
OPTION 1A: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1					**1.6355**