Black Start / System Restoration Studies using PSLF

Steven A. Barnes
GE Energy Management
Energy Consulting

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Motivation for Simulation of Black Start Plans

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NERC Standard: EOP-005-2

Against the backdrop of increasing regulatory scrutiny, electric utility companies are being required to verify the effectiveness of their black start restoration plans through testing, simulations or a combination of both.

EOP-005-2: **System Restoration from Blackstart Resources**
Enforcement Date 07/01/2013

R6. Each Transmission Operator shall verify through analysis of actual events, steady state and dynamic simulations, or testing that its restoration plan accomplishes its intended function. This shall be completed every five years at a minimum Such analysis, simulations or testing shall verify:

R6.1. The capability of Blackstart Resources to meet the Real and Reactive Power requirements of the Cranking Paths and the dynamic capability to supply initial Loads.

R6.2. The location and magnitude of Loads required to control voltages and frequency within acceptable operating limits.

R6.3. The capability of generating resources required to control voltages and frequency within acceptable operating limits.

What can the Transmission Operator Do?

1. Test the black start restoration plan.
2. Simulate the black start restoration plan.

Given existing transmission and generating unit constraints, testing may not be practical or economical.

Simulation of the restoration plan may be the only practical recourse.

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So What is a Black Start Plan?

- A black start restoration plan provides a logical sequence of events that transmission operators need to take for the safe isolation and restart of the TO's operating area following the occurrence of a massive power outage that includes the complete loss of generation, load and the transmission network serving the system load.
- A black start plan typically involves the following steps:
  1. Selection of generating units with self-starting capability.
     - Small combustion turbines or hydro turbines.
  2. Energizing the cranking path between the black start unit and the auxiliary motor load in the power plant to be black started.
     - Overhead transmission and/or underground cables.
     - Step-up and auxiliary transformers.
  3. Starting up of station service loads.
     - Induction motor load ranging from a few hundred to several thousand HP.
     - Plant lighting, small motor load, fire systems, electronics.
  4. Once the larger units are online (synchronized), the full restoration of the system load occurs.
     - Sequential restoration of transmission paths, distribution-fed substations, system load.
     - Shunt compensation?

Traditional Black Start Studies

- A traditional black start study of the past would typically only look at the procedure for a small combustion turbine in supplying power to a large steam turbine's station auxiliary load and its ability to start the largest motor.
- The typical black starting model includes the following:
  - The black start (combustion turbine) unit.
    - Generator electrical and mechanical model
    - Excitation model
    - Turbine-governor model
  - The black start (combustion turbine) unit's generator step-up transformer (GSU).
  - The cranking path (overhead transmission or underground cables).
  - The black started (large steam turbine) unit's generator step-up transformer (GSU).
  - The black started (large steam turbine) unit's auxiliary transformer(s).
  - The black started (large steam turbine) unit's auxiliary motor load, typically the largest motor.
    - Forced Draft (FD) or Induced Draft (ID) Fans
    - Boiler Feed-Water Pumps

Today's Black Start Studies

- Black start studies of today need to look beyond the typical motor starting study done in the past, but also verify that the plan to put the transmission system back together is feasible from a steady-state, dynamic and possibly transient perspective.

- The steady-state analysis of this isolated power system can include:
  - Voltage control and steady-state overvoltage (Ferranti effect) analysis.
  - Capability of the black starting units ability to absorb VARs produced by the transmission system connecting the plants.
  - Step-by-step simulation of the black start plan being tested to ensure its feasibility and compliance with required operational limits.
  - Verification of the robustness of the tested black start plan to ensure its ability to compensate for the unavailability of key components to be used in the plan.
  - Generation and load matching.

- The dynamic analysis of this isolated power system can include:
  - Load-frequency and voltage control.
  - Load rejection – voltage and frequency dynamics.
  - Self-excitation assessment.
  - Large induction motor starting.
  - Motor starting sequence assessment.
  - System stability.

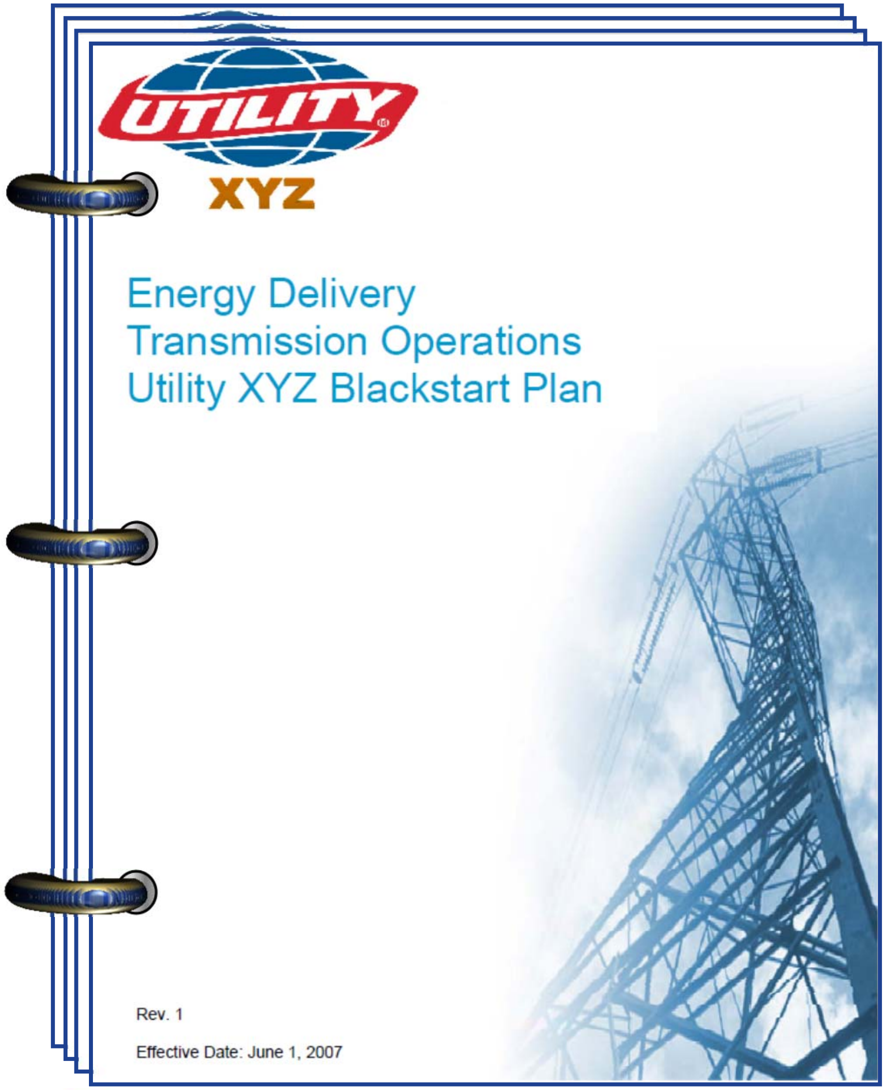
- The transient analysis of this isolated power system can include:
  - Transmission line switching (transient overvoltage) analysis.

Preparation and Research

What's Typically Needed

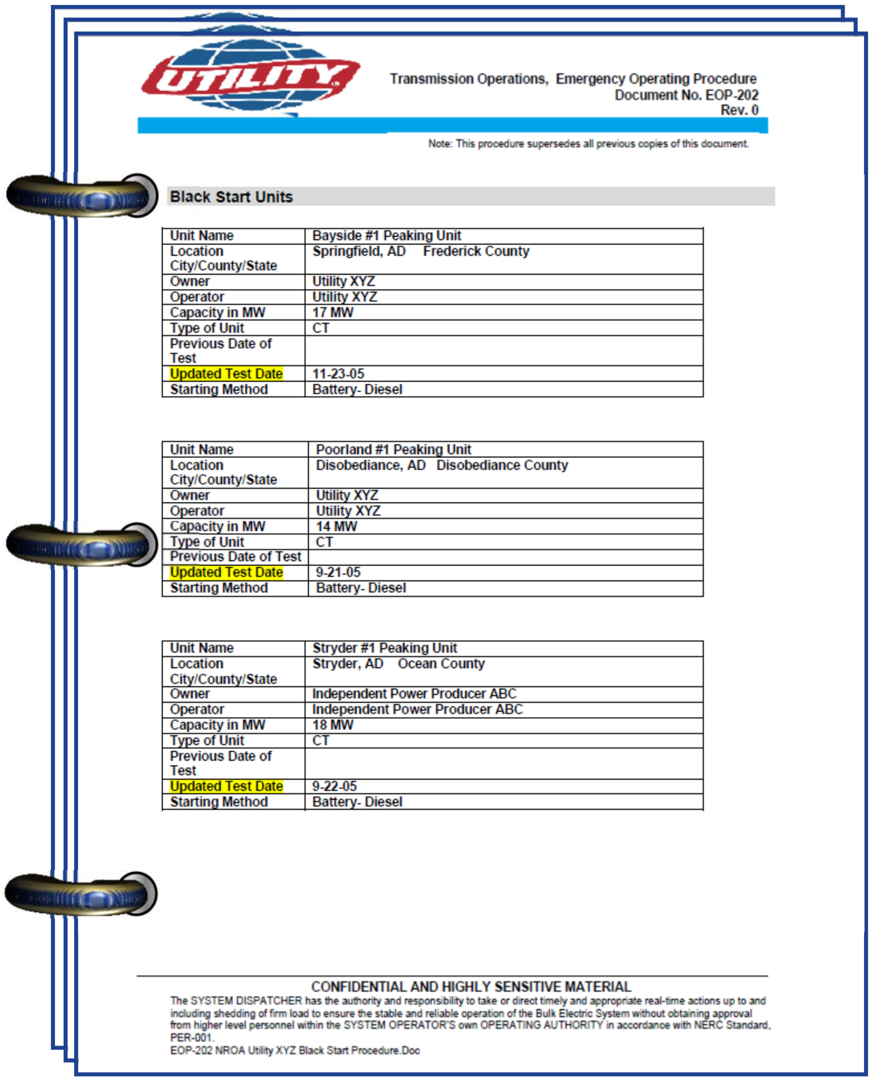
- Detailed Black Start Plan
- Standard Power Flow & Dynamics Databases
- Reliability Criteria
- Transmission System Breaker Diagrams
- Black Start Plant and Power Plant One-Line Diagrams
- Power Plant Auxiliary Load Information
- Detailed List of Transmission Fed Distribution Substations
- An Automated Software Program Tool
- Good Engineering Judgment and Knowledge!!!!

Detailed Black Start Plan



The Transmission Owner's detailed black start plan should provide the following information:

Detailed Black Start Plan



UTILITY

Transmission Operations, Emergency Operating Procedure
Document No. EOP-202
Rev. 0

Note: This procedure supersedes all previous copies of this document.

Black Start Units

Unit Name	Bayside #1 Peaking Unit
Location City/County/State	Springfield, AD Frederick County
Owner	Utility XYZ
Operator	Utility XYZ
Capacity in MW	17 MW
Type of Unit	CT
Previous Date of Test	
Updated Test Date	11-23-05
Starting Method	Battery- Diesel

Unit Name	Poorland #1 Peaking Unit
Location City/County/State	Disobediance, AD Disobediance County
Owner	Utility XYZ
Operator	Utility XYZ
Capacity in MW	14 MW
Type of Unit	CT
Previous Date of Test	
Updated Test Date	9-21-05
Starting Method	Battery- Diesel

Unit Name	Stryder #1 Peaking Unit
Location City/County/State	Stryder, AD Ocean County
Owner	Independent Power Producer ABC
Operator	Independent Power Producer ABC
Capacity in MW	18 MW
Type of Unit	CT
Previous Date of Test	
Updated Test Date	9-22-05
Starting Method	Battery- Diesel

CONFIDENTIAL AND HIGHLY SENSITIVE MATERIAL

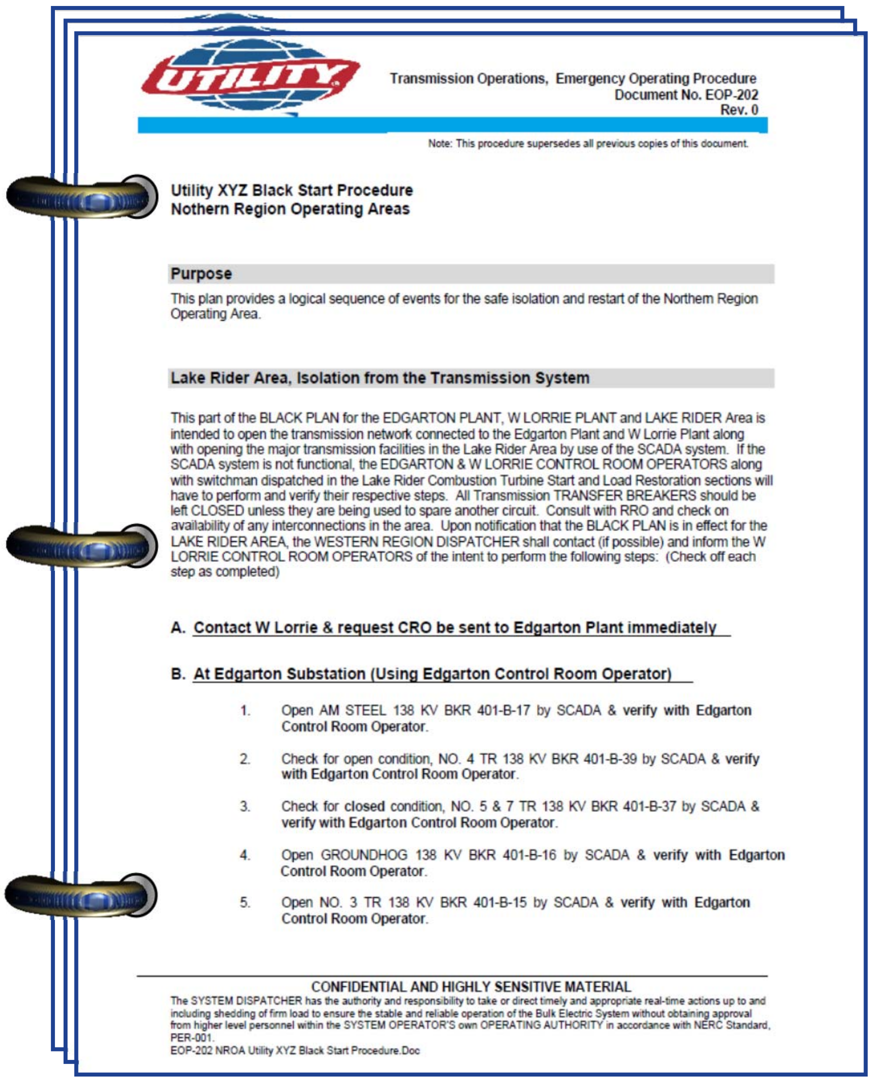
The SYSTEM DISPATCHER has the authority and responsibility to take or direct timely and appropriate real-time actions up to and including shedding of firm load to ensure the stable and reliable operation of the Bulk Electric System without obtaining approval from higher level personnel within the SYSTEM OPERATOR'S own OPERATING AUTHORITY in accordance with NERC Standard, PER-001.

EOP-202 NROA Utility XYZ Black Start Procedure.Doc

The Transmission Owner's detailed black start plan should provide the following information:

- Selection of generating units with self-starting capability (black start units).

Detailed Black Start Plan



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Utility XYZ Black Start Procedure
Nothern Region Operating Areas

Purpose

This plan provides a logical sequence of events for the safe isolation and restart of the Northern Region Operating Area.

Lake Rider Area, Isolation from the Transmission System

This part of the BLACK PLAN for the EDGARTON PLANT, W LORRIE PLANT and LAKE RIDER Area is intended to open the transmission network connected to the Edgarton Plant and W Lorrie Plant along with opening the major transmission facilities in the Lake Rider Area by use of the SCADA system. If the SCADA system is not functional, the EDGARTON & W LORRIE CONTROL ROOM OPERATORS along with switchman dispatched in the Lake Rider Combustion Turbine Start and Load Restoration sections will have to perform and verify their respective steps. All Transmission TRANSFER BREAKERS should be left CLOSED unless they are being used to spare another circuit. Consult with RRO and check on availability of any interconnections in the area. Upon notification that the BLACK PLAN is in effect for the LAKE RIDER AREA, the WESTERN REGION DISPATCHER shall contact (if possible) and inform the W LORRIE CONTROL ROOM OPERATORS of the intent to perform the following steps: (Check off each step as completed)

A. Contact W Lorrie & request CRO be sent to Edgarton Plant immediately

B. At Edgarton Substation (Using Edgarton Control Room Operator)

1. Open AM STEEL 138 KV BKR 401-B-17 by SCADA & verify with Edgarton Control Room Operator.
2. Check for open condition, NO. 4 TR 138 KV BKR 401-B-39 by SCADA & verify with Edgarton Control Room Operator.
3. Check for closed condition, NO. 5 & 7 TR 138 KV BKR 401-B-37 by SCADA & verify with Edgarton Control Room Operator.
4. Open GROUNDHOG 138 KV BKR 401-B-16 by SCADA & verify with Edgarton Control Room Operator.
5. Open NO. 3 TR 138 KV BKR 401-B-15 by SCADA & verify with Edgarton Control Room Operator.

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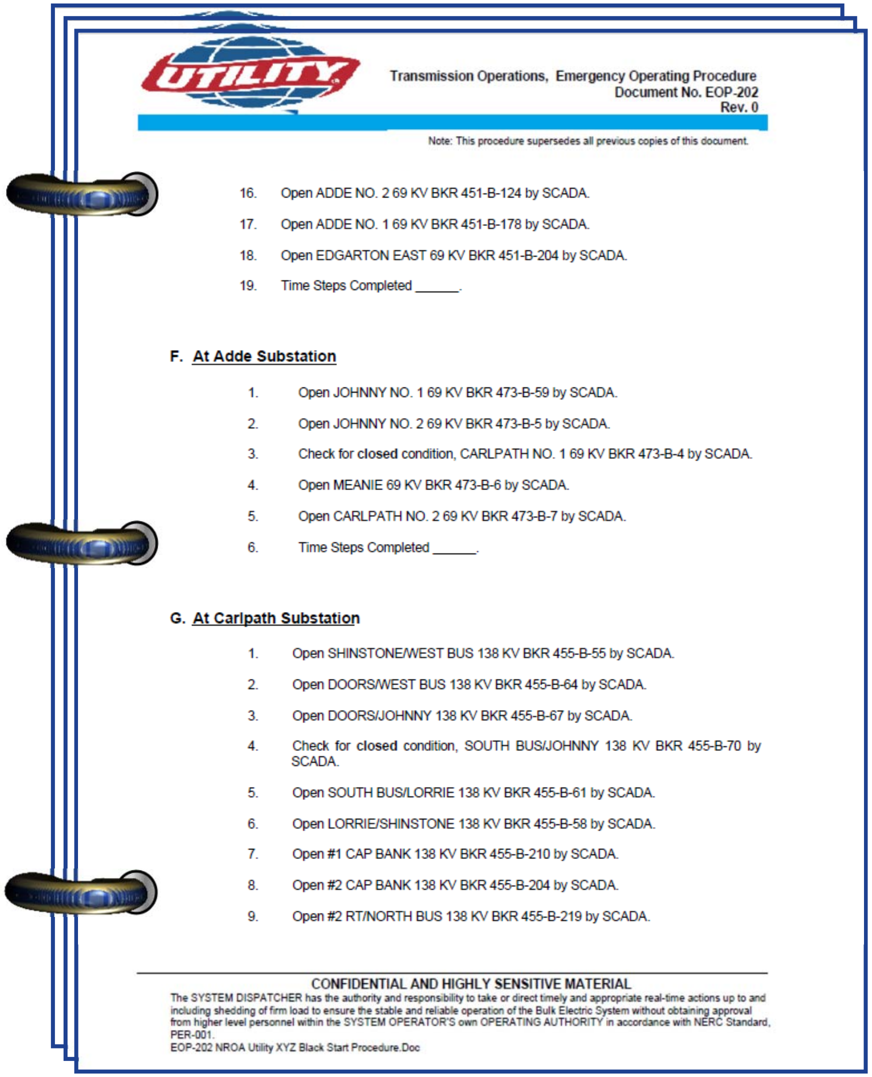
The Transmission Owner's detailed black start plan should provide the following information:

- Selection of generating units with self-starting capability (black start units).
- It is essential to establish the necessary cranking paths for plant restoration at appropriate Black Start plants.

Detailed Black Start Plan


UTILITY

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16. Open ADDE NO. 2 69 KV BKR 451-B-124 by SCADA.
17. Open ADDE NO. 1 69 KV BKR 451-B-178 by SCADA.
18. Open EDGARTON EAST 69 KV BKR 451-B-204 by SCADA.
19. Time Steps Completed ______.

F. At Adde Substation

1. Open JOHNNY NO. 1 69 KV BKR 473-B-59 by SCADA.
2. Open JOHNNY NO. 2 69 KV BKR 473-B-5 by SCADA.
3. Check for **closed** condition, CARLPATH NO. 1 69 KV BKR 473-B-4 by SCADA.
4. Open MEANIE 69 KV BKR 473-B-6 by SCADA.
5. Open CARLPATH NO. 2 69 KV BKR 473-B-7 by SCADA.
6. Time Steps Completed ______.

G. At Carlpath Substation

1. Open SHINSTONE/WEST BUS 138 KV BKR 455-B-55 by SCADA.
2. Open DOORS/WEST BUS 138 KV BKR 455-B-64 by SCADA.
3. Open DOORS/JOHNNY 138 KV BKR 455-B-67 by SCADA.
4. Check for **closed** condition, SOUTH BUS/JOHNNY 138 KV BKR 455-B-70 by SCADA.
5. Open SOUTH BUS/LORRIE 138 KV BKR 455-B-61 by SCADA.
6. Open LORRIE/SHINSTONE 138 KV BKR 455-B-58 by SCADA.
7. Open #1 CAP BANK 138 KV BKR 455-B-210 by SCADA.
8. Open #2 CAP BANK 138 KV BKR 455-B-204 by SCADA.
9. Open #2 RT/NORTH BUS 138 KV BKR 455-B-219 by SCADA.

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- The plan should provide a logical sequence of events for the safe isolation and restart of the Transmission Owner's Operating Area electrical system following a complete shutdown.

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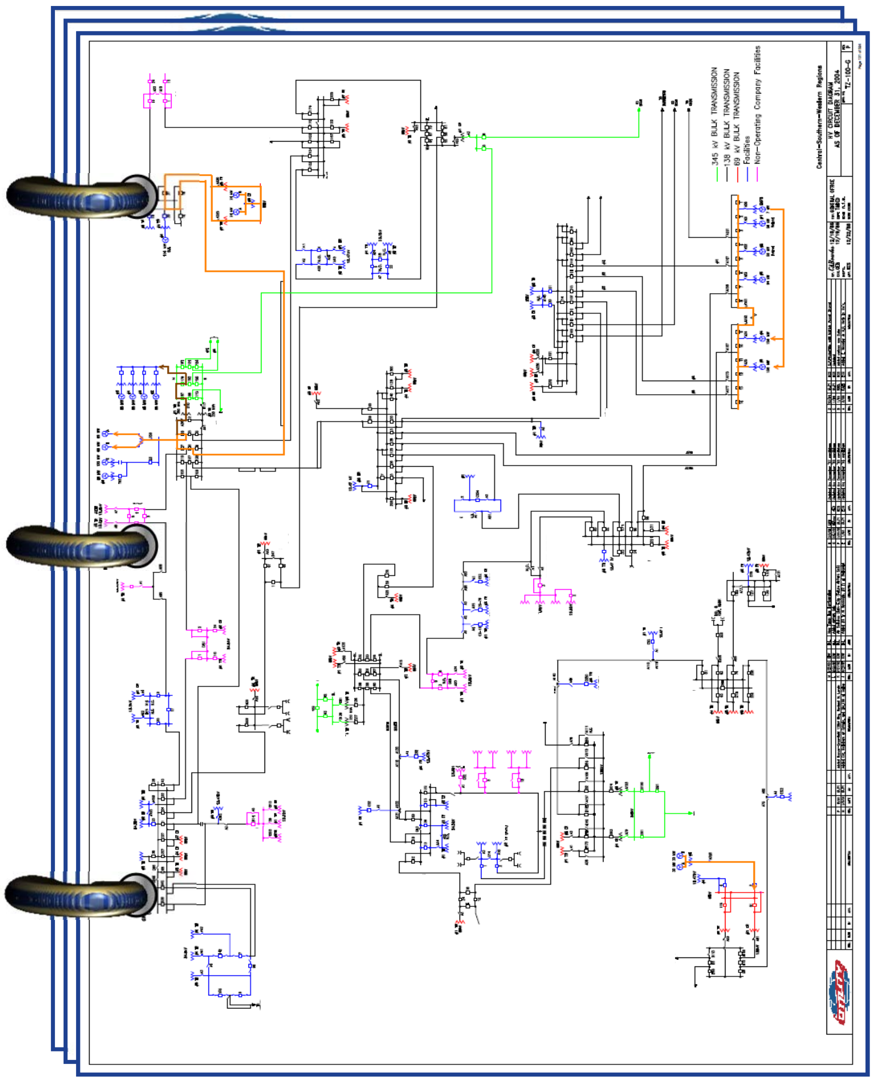

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- The plan should provide a logical sequence of events for the safe isolation and restart of the Transmission Owner's Operating Area electrical system following a complete shutdown.
- The plan will typically layout a procedure which calls for setting specific breaker configurations at each transmission and transmission fed distribution substation, in order to minimize issues with battery loss of life which can prevent breaker operation during restart.

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Standard Power Flow & Dynamics Databases

- Determine the power flow year and forecasted load to use for the simulation runs.
  - Summer Peak Forecasted Load
  - Light Load

- Obtain the corresponding dynamics database for the power flow database.

- Note that these databases will need to be modified (in some cases significantly), but will be an excellent starting point based on the full transmission model and standard dynamic models.

Reliability Criteria

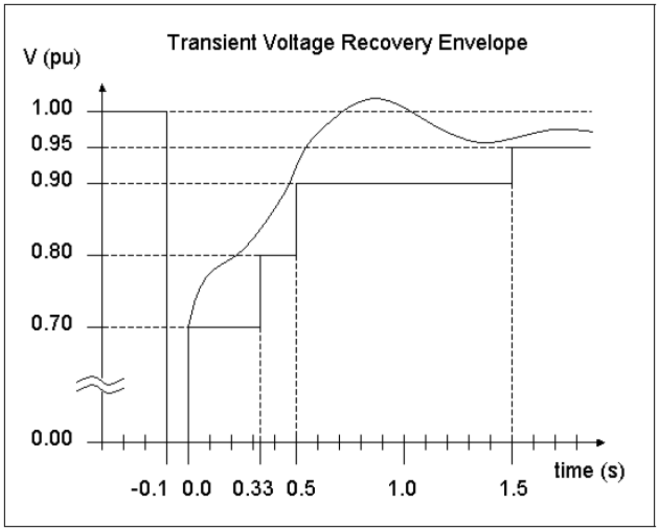
Table 1 - Voltage Limits

Limit	500kV	230/ 345kV	138/115kV		69/46/34.5 kV	25/23 kV
	ALL	ALL	PJM BES	PJM Non-BES	ALL	ALL
Maximum	1.10	1.05	1.05	1.05	1.05	1.075
Normal Minimum	1.00	0.95	0.95	0.95	0.92	0.92
Emergency Minimum	0.97	0.92	0.92	0.90	0.90	0.90
Maximum Deviation * (Pre to Post Contingency and On to Off Peak)	0.05	0.08	0.10	0.10	0.10	0.10

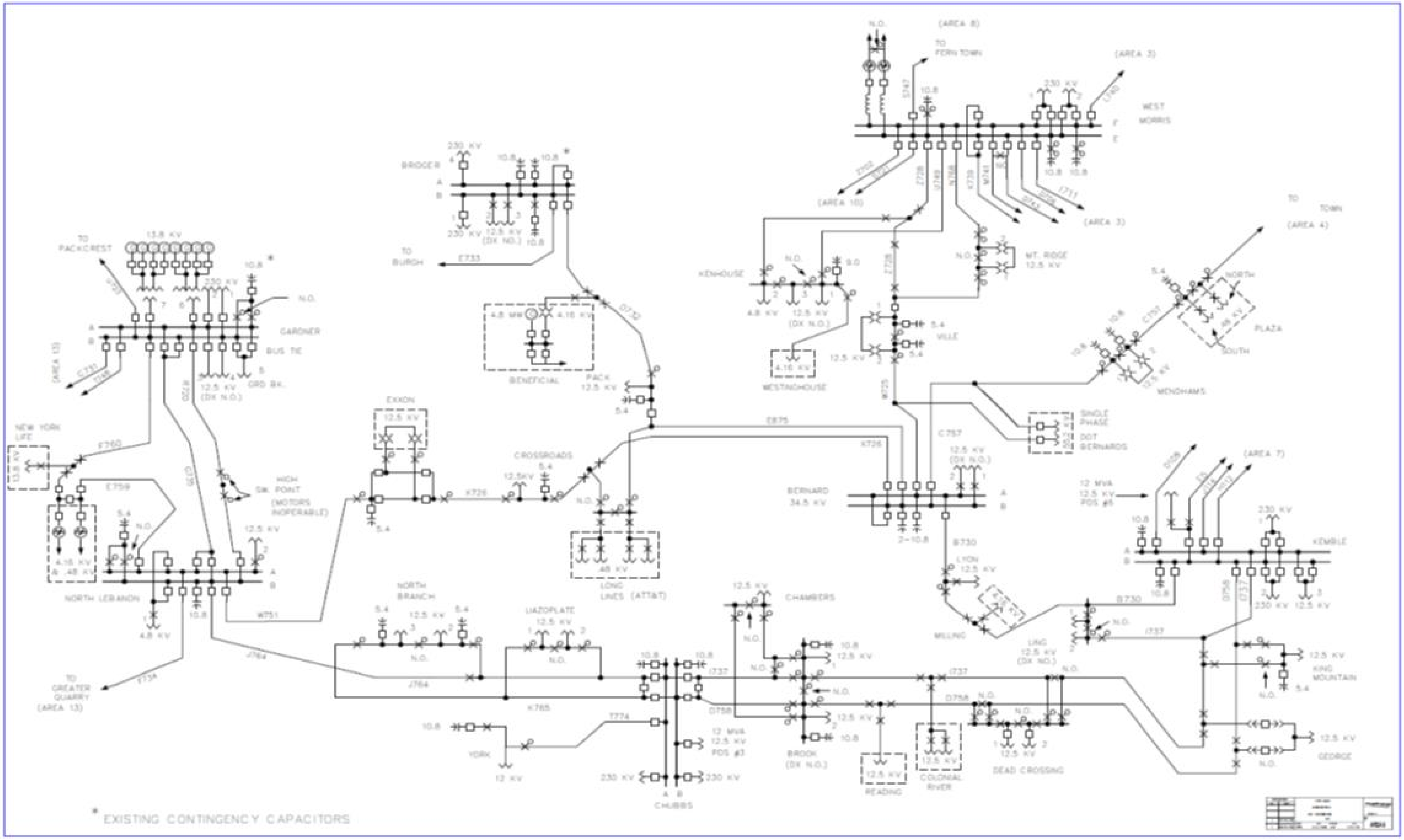
Thermal Requirements

- For normal system conditions with no line, transformer, or generation unit out of service all transmission facilities should not exceed their normal (continuous) rating.
- For a contingency loss of any one facility (line, transformer, or generator), the system should not exceed its emergency (4 hour) rating.
- For a contingency loss of any one facility (line, transformer, or generator) and the discrete outage of one generator, the system should not exceed its emergency (4 hour) rating.

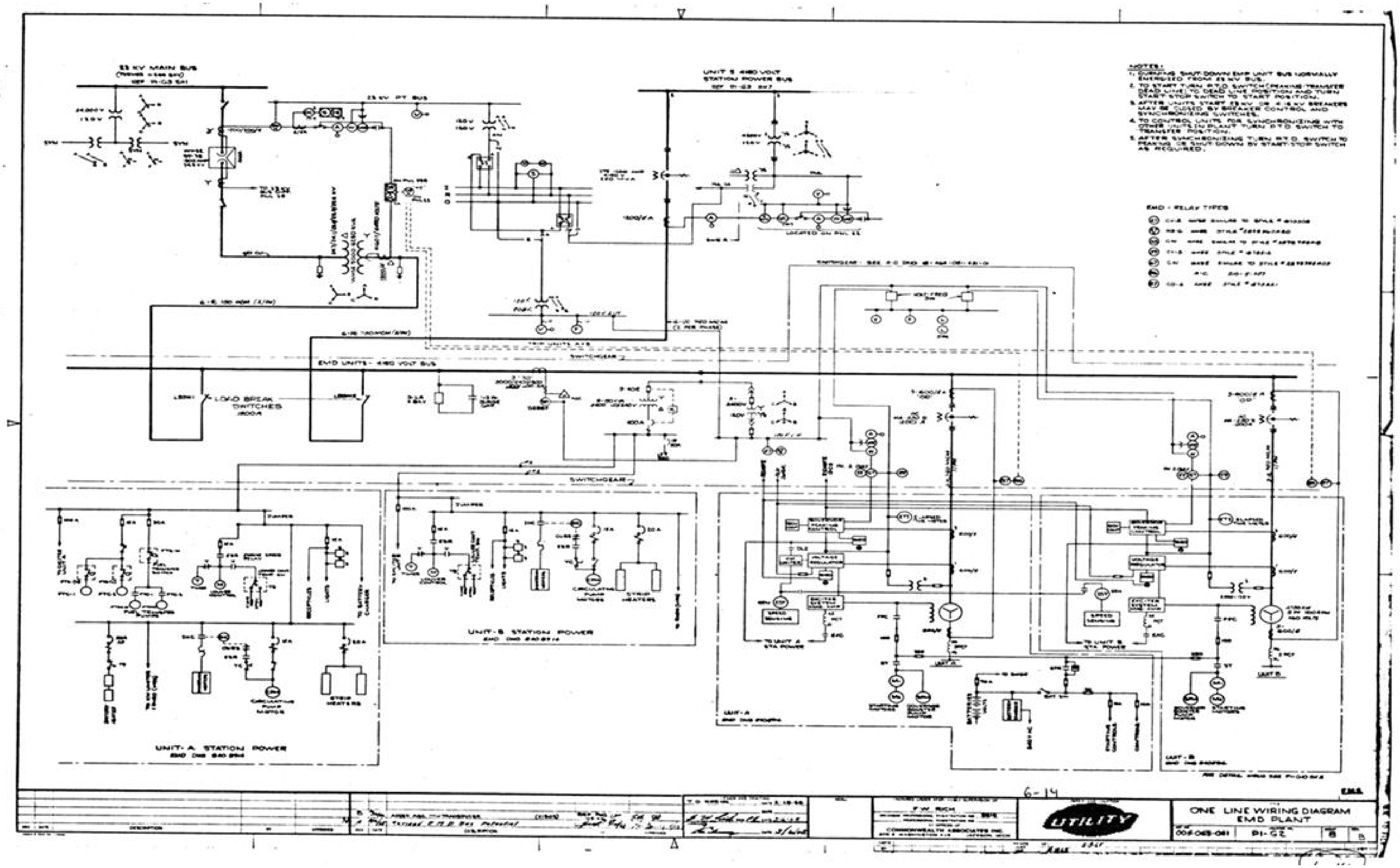
Bus Name	Frequency Limit Low	Frequency Limit High
500 kV	59.67 Hz	60.33 Hz
230 kV	59.67 Hz	60.33 Hz



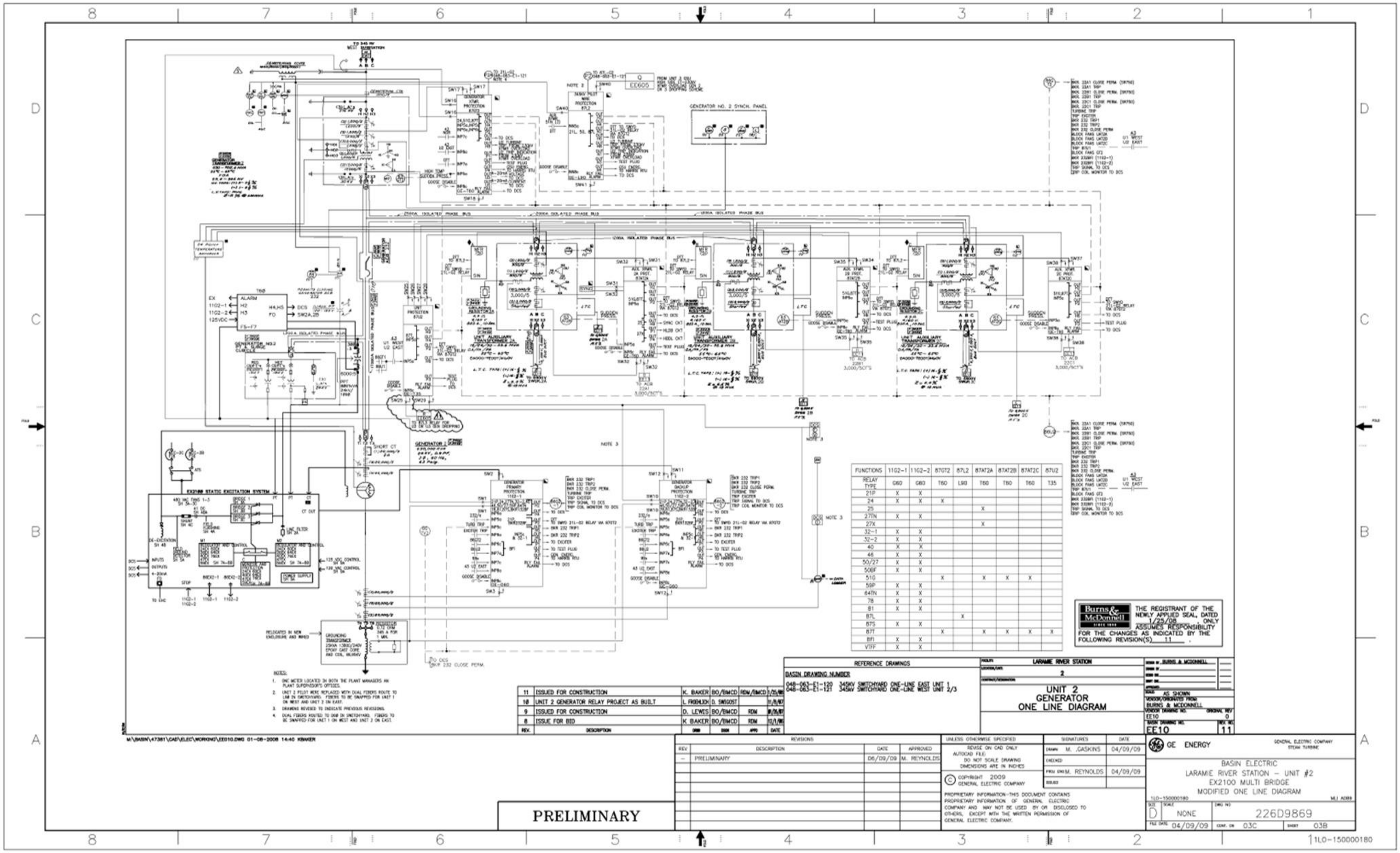
Transmission System Breaker Diagrams



Black Start Unit One-Line Diagram



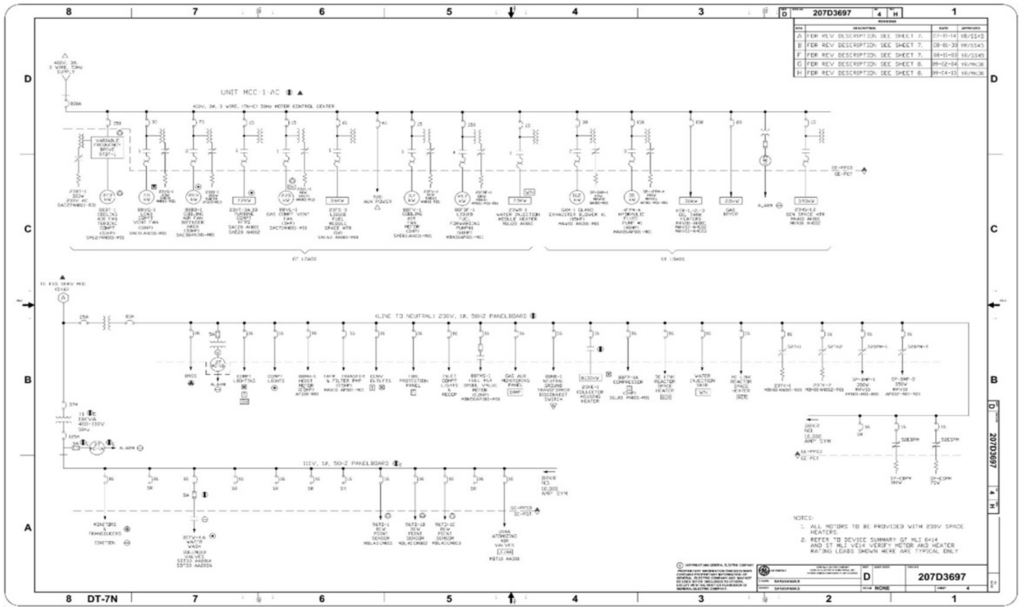
Power Plant One-Line Diagram

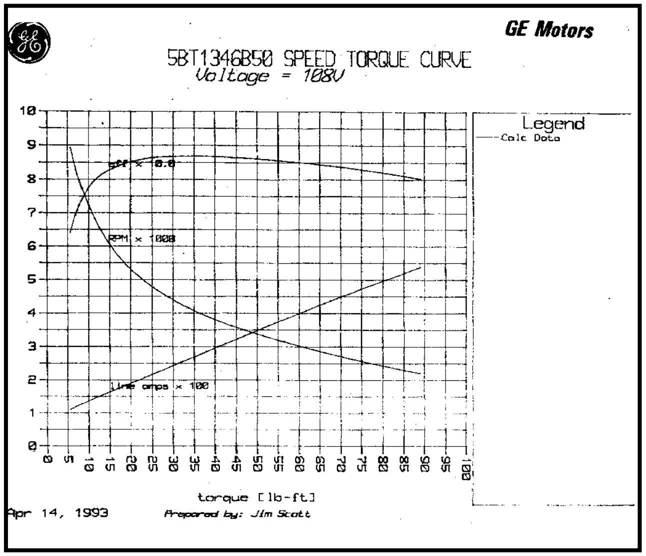


Power Plant Auxiliaries

Unit No.1 Auxiliary Load	HP	MW
Ash Disposal Pump No. 1	200	0.1492
Boiler Feed Pump No. 1A	1500	1.119
Boiler Feed Pump No. 1B	1500	1.119
Boiler Feed Pump No. 1C	1500	1.119
Condensate Pump No. 1A	300	0.2238
Condensate Pump No. 1B	300	0.2238
Circ. Water Pump No. 1B	400	0.2984
Circ. Water Pump No. 1A	400	0.2984
SOOT Blower Air Comp. No.1	300	0.2238
Forced Draft Blower No.1B	2000	1.492
Forced Draft Blower No.1A	2000	1.492
Coal Crusher #1 FWD	600	0.4476
Coal Crusher #2 FWD	600	0.4476
AQC Ash Water Supply Pump A	250	0.1865
	11850	**8.84**

Unit No.2 Auxiliary Load	HP	MW
Force Draft Blower #2B	2000	1.492
Force Draft Blower #2A	2000	1.492
SOOT Blower Air Comp. No.2	500	0.373
Circ. Water Pump No. 2A	400	0.2984
Circ. Water Pump No. 2B	400	0.2984
Condensate Pump No. 2A	300	0.2238
Condensate Pump No. 2B	300	0.2238
Boiler Feed Pump No. 2A	1500	1.119
Boiler Feed Pump No. 2B	1500	1.119
Boiler Feed Pump No. 2C	1500	1.119
Boiler Cooling Fan No. 1	250	0.1865
Ash Disposal Pump No. 2	200	0.1492
AQC Ash Water Supply Pump B	250	0.1865
	11100	**8.28**





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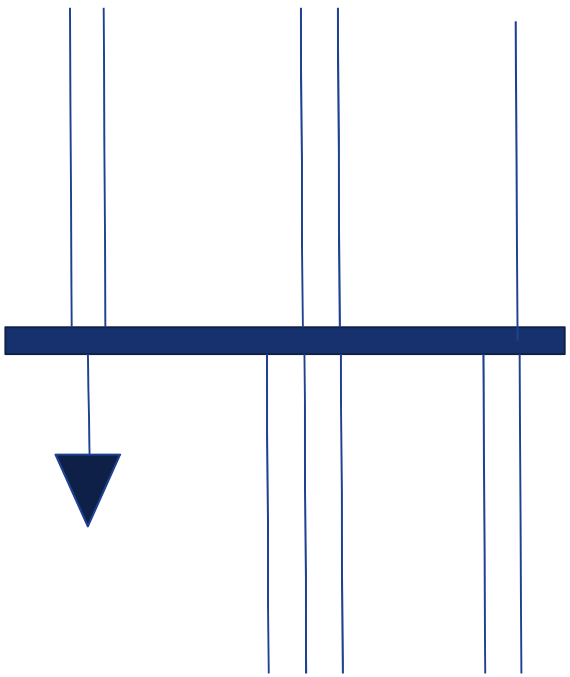
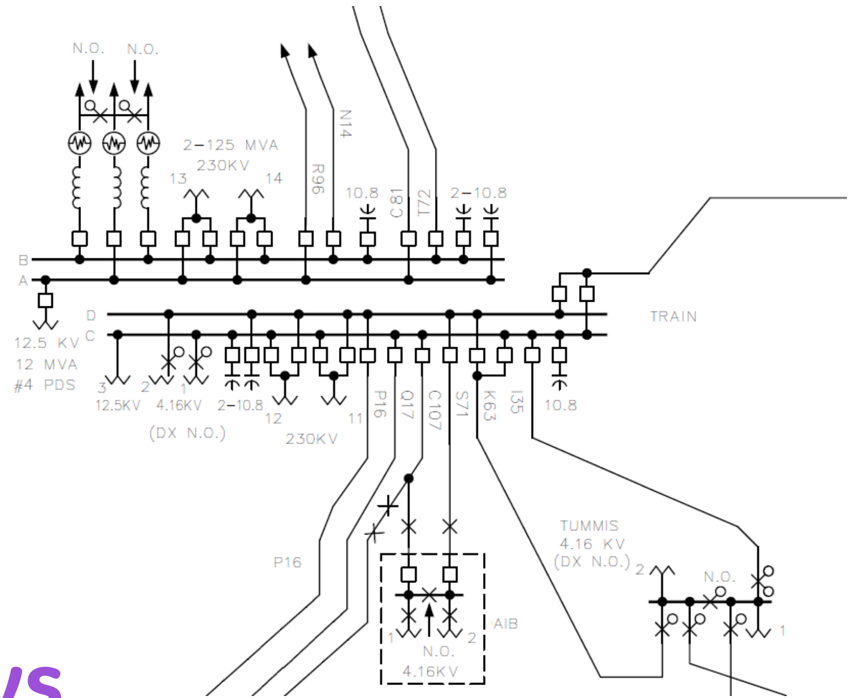
Transmission Fed Distribution Substations



vs.



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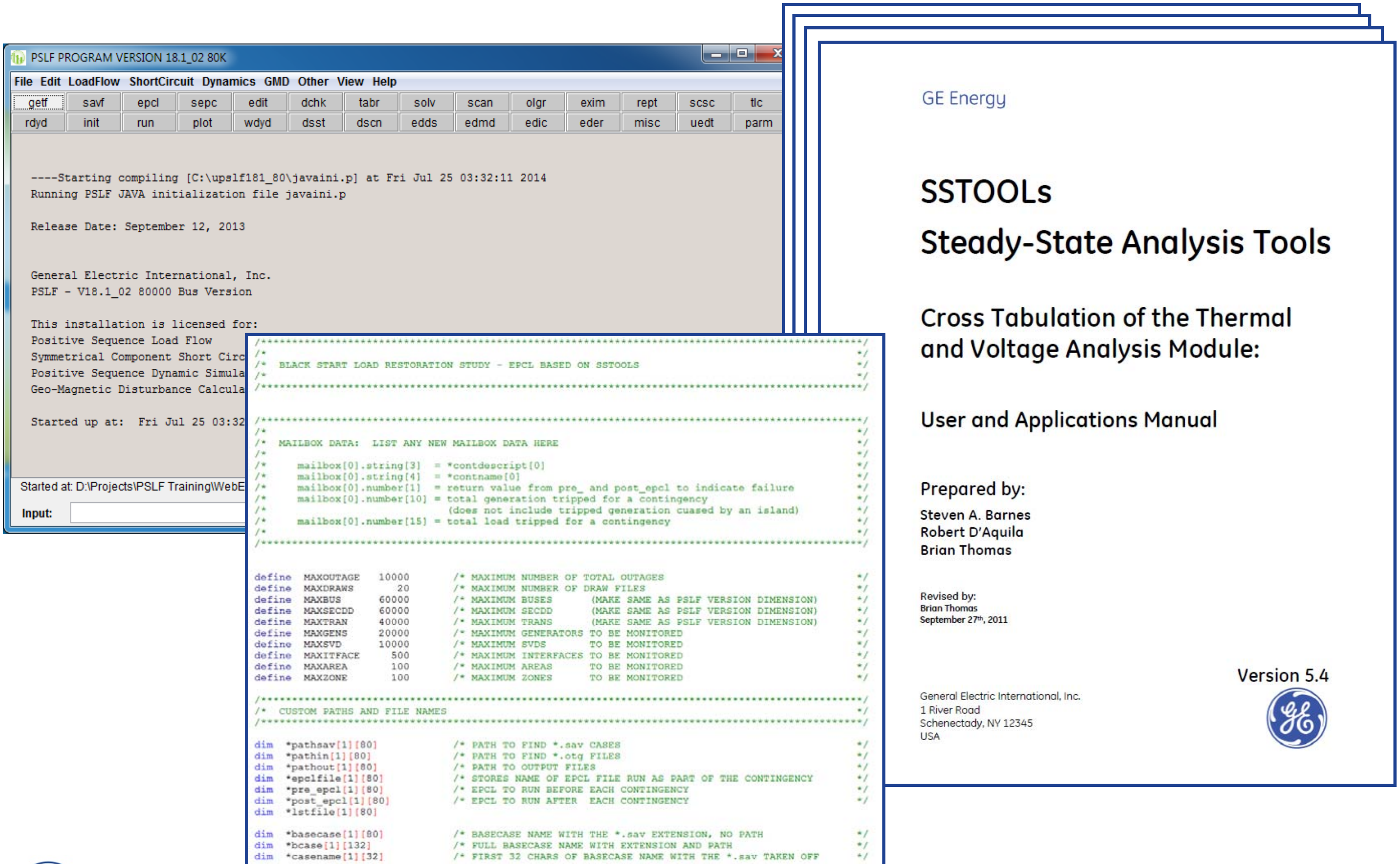
An Automated Software Program Tool



Good Engineering Judgment and Knowledge!!!!

- The engineer performing this study needs to have a good understanding of numerous power system analysis techniques, simulation models, operating practices for both generation and transmission.
  - Power System Analysis Techniques:
    - Steady-State Analysis
    - Dynamic Stability Analysis
    - Transient Analysis
  - Simulation Modeling:
    - Power Plant Models (Generator, Excitation, Governor, Prime Mover, etc.)
    - Load & Motor Modeling (Power Plant Auxiliaries, Residential, Commercial, Industrial, Composite)
    - Transmission System Models (MSC, SVC, STATCOM,etc.)
    - Electromagnetic transient modeling
  - Operating Practices:
    - Planning Engineer needs to think like a Generator Operator.
    - Planning Engineer needs to think like a Transmission Operator.
    - Planning Engineer needs to be able to think “What Could Go Wrong?”

Study Approach

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Study Objectives

The primary objectives of this type of study are:

- Evaluate the TO's Black Start Plan for it's Operating Area(s).
- Asses the likelihood that the black-start units will perform as expected, and the system can be restored per the existing black start plan.
- Identify and evaluate any limiting issues that arise during the black start restoration procedure.
- Provide a methodology to allow the TO to perform evaluation of black start power flow and dynamic stability studies in the future.

Steady-State Database Modifications

- Isolation of the System
- Distribution of System Loads
- Modeling the Black Start Capable Power Plants
- Modeling of Black Started Power Plants

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Isolation of the System

1. All equipment is turned off.
   { gens[ ].st = load[ ].st = secdd[ ].st = tran[ ].st = shunt[ ].st = svd[ ].st = dcl[ ].st = dcc[ ].st = 0 }
2. All scheduled bus voltages are set to 1.00 per unit.
   { busd[ ].vsched = 1.00 }
3. All bus voltages are set to 1.00 per unit.
   { volt[ ].vm = 1.00 }
4. All bus angles are set to 0.00 degrees.
   { volt[ ].va = 0.00 }
5. All generator buses are set to be swing machines.
   { busd[ ].type = 0 }
6. All generating units are set to regulate their own terminal voltage.
   { gens[ ].ireg = gens[ ].ibgen }
7. All generating units are set to zero active power output.
   { gens[ ].pgen = 0 }
8. All generating units are set to zero reactive power output.
   { gens[ ].qgen = 0 }

Distribution of System Loads

For traditional transmission planning studies, loads are lumped and modeled directly connected to the transmission and sub-transmission systems. For a black start study, the lumped loads needed to be divided up in order to represent the individual circuits fed off of the grid. This would allow us to connect each individual load during the load restoration process.

Typically a black start plan lays out where each individual feeder circuit is connected to the grid and an approximation of the total load fed on those circuits. Using the summer peak baseline case, these load values were used in place of the values stated in the black start plan, unless specified differently by the TO. The load power factor was maintained for each individual circuit to account for the reactive load.

For each year that the black start plan is studied, the new load growth needs to be taken into consideration and distribute the total load accordingly.

Load Distribution

Original 2013 Summer Peak Load:					Individual Load Representation:					
BUS	ID	PLOAD	QLOAD	PF	BUS	ID	ST	BLACK START PLAN	2013 SP LOAD	Represents:
3325 KINLEY 23	C	0.530	0.200	0.936	3325 KINLEY 23	C1	1	0.500	0.530	Restores Kinley Substation
3325 KINLEY 23	O	1.430	0.390	0.965	3325 KINLEY 23	O1	1	1.500	1.430	Restores Kinley Substation
3326 WEASCO 23	C	2.280	0.940	0.925	3326 WEASCO 23	C1	1	2.000	2.280	Restores Interstate Processor & Indalex Customer Substations
3330 DIRT 23	O	7.070	1.920	0.965	3330 DIRT 23	O1	1	1.000	1.010	D-86 4.16 kV Circuit @ Wirt 23
					3330 DIRT 23	O2	1	2.000	2.020	D-87 4.16 kV Circuit @ Wirt 23
					3330 DIRT 23	O3	1	2.000	2.020	D-85 4.16 kV Circuit @ Wirt 23
					3330 DIRT 23	O4	1	2.000	2.020	D-260 4.16 kV Circuit @ Wirt 23
3225 MOUNT 23	O	2.090	0.570	0.965	3225 MOUNT 23	O1	1	2.000	2.090	Restores Mount Substation
3226 WA.PUMP+ 23	C	0.520	0.150	0.961	3226 WA.PUMP+ 23	C1	1	1.000	0.520	Restores Warrenton City Sewage Pumping Substation
3252 WAR.SEW+ 23	C	0.830	0.120	0.961	3252 WAR.SEW+ 23	C1	1	1.000	0.830	Restores Warrenton City Sewage Pumping Substation
3166 EAST 23	O	2.340	0.640	0.965	3166 EAST 23	O1	1	2.000	2.340	East 23.00 kV Circuit
3165 CITY 23	O	4.490	1.220	0.965	3165 CITY 23	O1	1	5.000	4.490	City 23.00 kV Circuit
3179 ROCKY 69	O	8.970	2.440	0.965	3179 ROCKY 69	O1	1	2.000	2.243	Overlook 4.16 kV Circuit @ Rockyhill 69
					3179 ROCKY 69	O2	1	3.000	3.364	Simpson 4.16 kV Circuit @ Rockyhill 69
					3179 ROCKY 69	O3	1	3.000	3.364	Chestnut 4.16 kV Circuit @ Rockyhill 69
3178 SOUTHWES 69	O	17.100	4.650	0.965	3178 SOUTHWES 69	O1	1	2.000	2.012	Freedom 4.16 kV Circuit @ Southwest 69
					3178 SOUTHWES 69	O2	1	2.000	2.012	Liberty 4.16 kV Circuit @ Southwest 69
					3178 SOUTHWES 69	O3	1	5.000	5.029	Lake Park 12.47 kV Circuit @ Southwest 69
					3178 SOUTHWES 69	O4	0	8.000	8.047	Plaza 12.47 kV Circuit @ Southwest 69
1861 EAGLE 138	O	32.800	8.910	0.965	1861 EAGLE 138	O1	1	3.000	3.075	W-176 12.47 kV Circuit @ Eagle 138
					1861 EAGLE 138	O2	0	7.000	7.175	W-177 12.47 kV Circuit @ Eagle 138
					1861 EAGLE 138	O3	0	8.000	8.200	W-178 12.47 kV Circuit @ Eagle 138
					1861 EAGLE 138	O4	0	8.000	8.200	W-179 12.47 kV Circuit @ Eagle 138
					1861 EAGLE 138	O5	0	6.000	6.150	W-180 12.47 kV Circuit @ Eagle 138
3349 RIVER 23	O	5.430	1.510	0.963	3349 RIVER 23	O1	1	3.000	2.715	T-390 22.86 kV Circuit @ River 23
					3349 RIVER 23	O2	1	3.000	2.715	T-391 22.86 kV Circuit @ River 23
					3349 RIVER 23	O3	0	13.000	0.000	T-380 22.86 kV Circuit @ River 23
1391 BORDER 23	O	2.860	0.780	0.965	1391 BORDER 23	O1	1	3.000	2.860	D-45 4.16 kV Circuit @ Border 23
1390 BORDER 138	O	37.190	10.110	0.965	1390 BORDER 138	O1	1	6.000	6.031	W-48 12.47 kV Circuit @ Border 138
					1390 BORDER 138	O2	0	8.000	8.041	W-44 12.47 kV Circuit @ Border 138
					1390 BORDER 138	O3	0	8.000	8.041	W-46 12.47 kV Circuit @ Border 138
					1390 BORDER 138	O4	0	8.000	8.041	W-49 12.47 kV Circuit @ Border 138
					1390 BORDER 138	O5	0	7.000	7.036	W-50 12.47 kV Circuit @ Border 138
1397 BRIDGE 138	O	30.190	8.210	0.965	1397 BRIDGE 138	O1	1	3.000	2.922	Oakdale 12.47 kV Circuit @ Bridge 138
					1397 BRIDGE 138	O2	0	6.000	5.843	Comstock 12.47 kV Circuit @ Bridge 138
					1397 BRIDGE 138	O3	0	8.000	7.791	Reo 12.47 kV Circuit @ Bridge 138
					1397 BRIDGE 138	O4	0	4.000	3.895	Althea 12.47 kV Circuit @ Bridge 138
					1397 BRIDGE 138	O5	0	5.000	4.869	Woodside 12.47 kV Circuit @ Bridge 138
					1397 BRIDGE 138	O6	0	5.000	4.869	Jamestown 12.47 kV Circuit @ Bridge 138
3217 ST.JOES 23	C	0.610	-0.030	0.999	3217 ST.JOES 23	C1	1	2.000	**1.000**	Restores St. Joseph Hospital Substation
3383 CHURCH 69	O	22.550	6.130	0.965	3383 CHURCH 69	O1	1	4.000	3.469	D-228 8.32 kV Circuit @ Church 69
					3383 CHURCH 69	O2	1	5.000	4.337	D-226 8.32 kV Circuit @ Church 69
					3383 CHURCH 69	O3	1	5.000	4.337	D-227 8.32 kV Circuit @ Church 69
					3383 CHURCH 69	O4	1	6.000	5.204	D-229 8.32 kV Circuit @ Church 69
					3383 CHURCH 69	O5	0	6.000	5.204	D-225 8.32 kV Circuit @ Church 69
3273 WINDY 69	O	6.840	1.860	0.965	3273 WINDY 69	O1	1	4.000	3.909	Grove 12.47 kV Circuit @ Windy 69
					3273 WINDY 69	O2	0	3.000	2.931	Jewel 12.47 kV Circuit @ Windy 69
3264 GARRETTS 69	O	8.080	2.200	0.965	3264 GARRETTS 69	O1	1	2.000	2.309	825-A 12.47 kV Circuit @ Garretts 69
					3264 GARRETTS 69	O2	1	5.000	5.771	825-E 12.47 kV Circuit @ Garretts 69
1561 GARDEN 138	O	26.480	7.200	0.965	1561 GARDEN 138	O1	1	6.000	6.355	Candlelight 12.47 kV Load @ Garden 138
					1561 GARDEN 138	O2	1	5.000	5.296	Avalon 12.47 kV Load @ Garden 138
					1561 GARDEN 138	O3	1	6.000	6.355	Normar 12.47 kV Load @ Garden 138
					1561 GARDEN 138	O4	1	8.000	8.474	Fairhill 12.47 kV Load @ Garden 138
1521 MAPLE 138	C	71.380	24.950	0.944	1521 MAPLE 138	C1	1	7.000	7.000	Maximum Amount of Load WCI Can Restore
1770 MCD ST 138	C	2.580	0.090	0.999	1770 MCD ST 138	C1	1	4.000	**3.000**	Restores McDonald Steet Substation
1443 CENTRAL 138	M1	30.890	19.390	0.847	1443 CENTRAL 138	O1	1	8.000	8.000	Maximum Amount of Load Central Can Restore
1443 CENTRAL 138	M2	36.430	21.910	0.857						
1447 CORTLAND 138	O	20.330	5.530	0.965	1447 CORTLAND 138	O1	1	7.000	6.777	Mecca 12.47 kV Circuit @ Cortland 138
					1447 CORTLAND 138	O2	1	7.000	6.777	Colonial 12.47 kV Circuit @ Cortland 138
					1447 CORTLAND 138	O3	1	7.000	6.777	Jacoby 12.47 kV Circuit @ Cortland 138
1506 FERN 138	O	20.930	5.690	0.965	1506 FERN 138	O1	1	8.000	7.611	Bazetta 12.47 kV Circuit @ Fern 138
					1506 FERN 138	O2	1	6.000	5.708	Perkins-Jones 12.47 kV Circuit @ Fern 138
					1506 FERN 138	O3	1	8.000	7.611	Ivy Hill 12.47 kV Circuit @ Fern 138
3180 BEECHWOOD 69	O	18.930	5.140	0.965	3180 BEECHWOOD 69	O1	0	22.000	18.930	Beechwood Substation Load

Green: Part of Eastern (Delta Blackstart) Restoration Plan
Orange: Part of Southern (Wylie Blackstart) Restoration Plan
Pink: Unable to Locate Load in Database
Bold: Value Used after Discussions with TO Staff

Modeling the Power Plants

A primary objective of this study is to investigate the black start capable power plant's ability to start local auxiliary loads and black-started power plants capable to serve system load when the transmission system is restored. In order to accomplish this task, each power plant has to be modeled in slightly more detail than may be provided in the original database.

Based on the power plant one-line diagrams, high level representations of each plant's internal power system needs to be modeled. The details associated with these power plant models will be discussed later.

Note that these "detailed" models can either model the entire auxiliary system or a high-level, yet conservative estimation.

If further detail is required, the complete power plants electrical system would need to be modeled.

Dynamic Database Modifications

- Auxiliary Load Model Representation
- System Load Model Representation
- Power Plant Unit Representation

Load Models

All load models were modeled based on the paper written by the IEEE Task Force on Load Representation for Dynamic Performance.

IEEE Transactions on Power Systems, Vol. 10, No. 3, August 1995

Standard Load Models for Power Flow and Dynamic Performance Simulation

IEEE Task Force on Load Representation for Dynamic Performance*

System Dynamic Performance Subcommittee
Power System Engineering Committee

Abstract - We recommend standard load models for power flow and dynamic simulation programs. The goal of this paper is to promote better load modeling and advanced load modeling, and to facilitate data exchange among users of various production-grade simulation programs. Flexibility of modeling is an important consideration.

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Auxiliary & System Load Models

Table 3: Typical Induction Motor Data [13,14][a]

Type	R_s	X_{so}	X_m	R_r	X_{ro}	*A*	*B*	*D*	*H*	*Load Factor*
1	0.031	0.1	3.2	0.018	0.18	1	0	0	0.7	0.6
2	0.013	0.067	3.8	0.009	0.17	1	0	0	1.5	0.8
3	0.013	0.14	2.4	0.009	0.12	1	0	0	0.8	0.7
4	0.013	0.14	2.4	0.009	0.12	1	0	0	1.5	0.7
5	0.077	0.107	2.22	0.079	0.098	1	0	0	0.74	0.46
6	0.035	0.094	2.8	0.048	0.163	1	0	0	0.93	0.6
7	0.064	0.091	2.23	0.059	0.071	0.2	0	0	0.34	0.8

a. Data is suitable for large-scale simulations where motors do not stall
Type 1: Small industrial motor.
Type 2: Large industrial motor.
Type 3: Water pump.
Type 4: Power plant auxiliary.
Type 5: Weighted aggregate of residential motors.
Type 6: Weighted aggregate of residential and industrial motors.
Type 7: Weighted aggregate of motors dominated by air conditioning.

Auxiliary Load Model:
The type 4 model, which represents typical power plant auxiliaries, can be used as a generic model.

System Load Models:
The type 5 model, which represents a weighted aggregate of typical residential motor load, can be used for the majority of the transmission and sub-transmission load models. For select customer loads, the type 2 model, which represents large industrial motors, can be used if the known location is purely industrial in nature.

Load Model Sensitivity

As part of a sensitivity analysis, five variations in load modeling can be compared:

1. 100% Static Load.
2. 25% Motor Load / 75 % Static Load
3. 50% Motor Load / 50% Static Load
4. 75% Motor Load / 25% Static Load, and
5. 100% Motor Load.

All static load model representation can be of constant current real power and constant impedance reactive power load. Most transient stability results should be based on the conservative approach of 100% motor modeling with the other variations being used if the system restoration simulation step can not survive or operating limits are in violation.

Power Plant Unit Representation

Accurate modeling of the individual generating units in the dynamics dataset are determined to be of the **highest importance** in performing this type of analysis.

The original models provided by NERC/ISOs/TOs/Utilities can be used for this type of study, but past experience has determined that some of the models were of poor quality or inaccurate in modeling the correct behavior of the equipment.

This is especially true with an Eastern Interconnect case versus one used in ERCOT or WECC. Established and ongoing generator testing and model validation programs in these regions are more likely to provide these better models. There may still be instances where models need to be modified.

System Restoration Procedure Tools

- Steady-State Restoration Analysis Tool
  - Modified version of SSTOOLs
- Dynamic Restoration Analysis Tool
  - Modified version of DYTOOLs
- Specialized EPCLs

Examples from a Black Start / System Restoration Study

The TO, Power Plants, and Substations names have been changed in order to protect the guilty!!!

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Define System Criteria

- Steady-State Criteria

✓ Absolute voltage magnitude for 69 kV and above must be between 0.95 and 1.05 per unit.
✓ Absolute voltage magnitude for 23 kV and below must be between 0.95 and 1.07 per unit.
✓ All branches and transformers cannot violate their continuous thermal ratings.
✓ The power reserves of online power plants must not be depleted.
✓ The reactive reserves of online power plants must not be depleted.

- Transient Stability Criteria

✓ Excessive voltage dips that may affect motor stalling, contactor dropout or line / generator tripping.
✓ Excessive frequency dips that may affect line / turbine tripping.
✓ Sustained high reactive power output that may affect OEL performance.
✓ Undamped or excessive power/angle oscillations that may cause various system responses.

Define System Criteria

In order to determine if any off nominal frequency event could lead to a turbine trip, the following settings were observed.

Modern Gas Turbines:

Instantaneous Trip:	< 56.4 Hz
Instantaneous Trip:	> 64.8 Hz
Unlimited Operation:	Between 56.4 to 64.8 Hz

Modern Steam Turbines[8]:

60 HZ Units

Lifetime Limit	Frequency Range	
Unlimited	57.0 to 62.5 Hz	
90 minutes	56.5 to 57.0 Hz	62.5 to 63.0 Hz
12 minutes	56.0 to 56.5 Hz	63.0 to 63.5 Hz
1 minute	55.0 to 56.0 Hz	63.5 to 65.0 Hz

Older Steam Turbines[9]:

TURBINE CUMULATIVE OFF–FREQUENCY LIMITS

Operation Time to Some Damage	Variation From Rated Frequency (Hz)
Unlimited	± 0.6
90 Minutes	± 0.6 to ± 1.4
12 Minutes	± 1.4 to ± 1.9
1 Minute	± 1.9 to ± 2.4

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Eastern Area Load Restoration

1. Isolation of the Local Transmission System

2. Startup of Auxiliary Load via the Delta Generation Station Gas Turbine

3. Setting Up the Local Transmission System Prior to Load Restoration

4. Local Area Load Restoration via the Delta Generating Station Units 1 and 2.

Eastern Area Load Restoration

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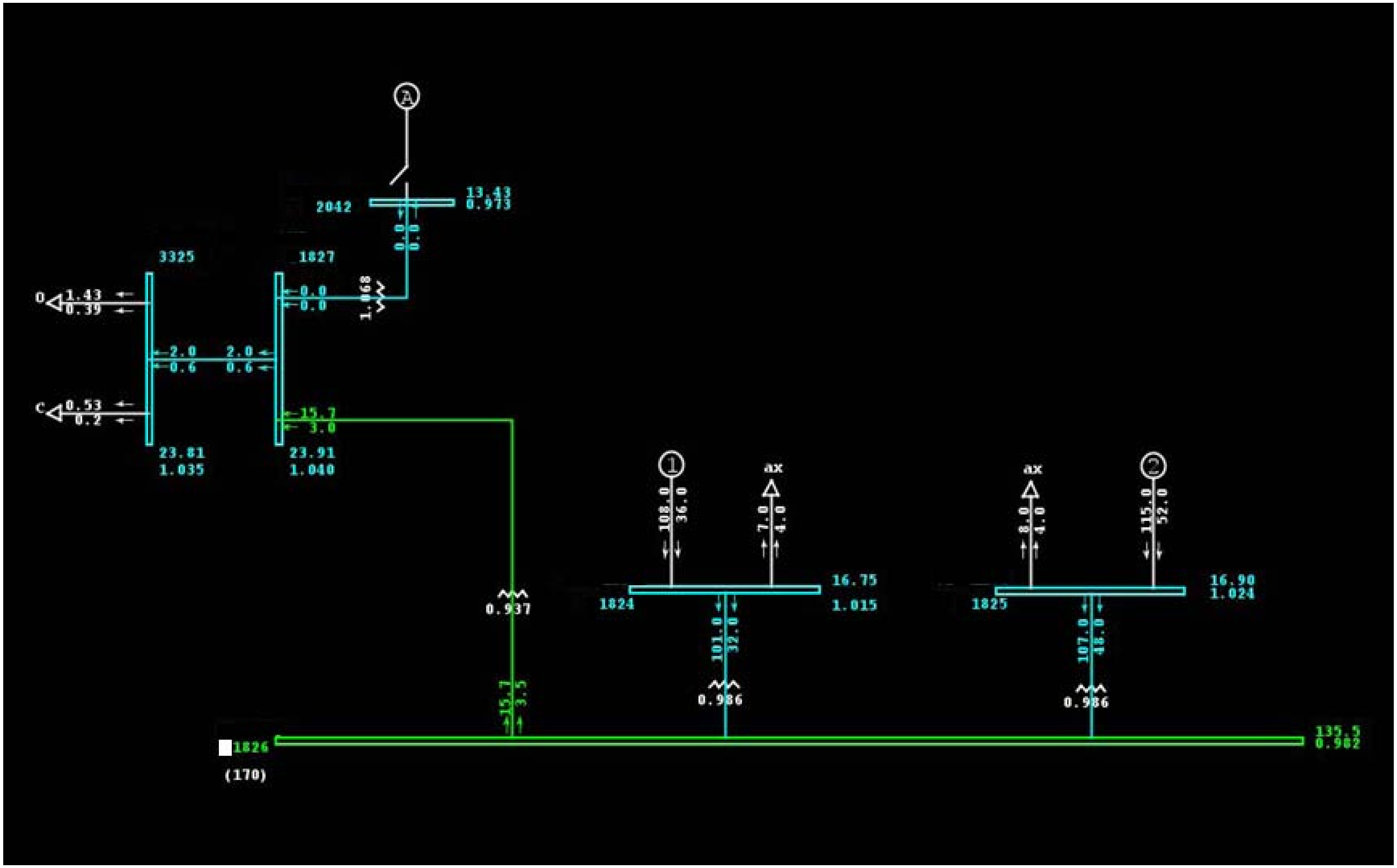
Eastern Area Load Restoration

1. Isolation of the Local Transmission System
2. **Startup of Auxiliary Load via the Delta Generation Station Gas Turbine**
3. Setting Up the Local Transmission System Prior to Load Restoration
4. Local Area Load Restoration via the Delta Generating Station Units 1 and 2.

Modeling the Delta Generating Station (Before)



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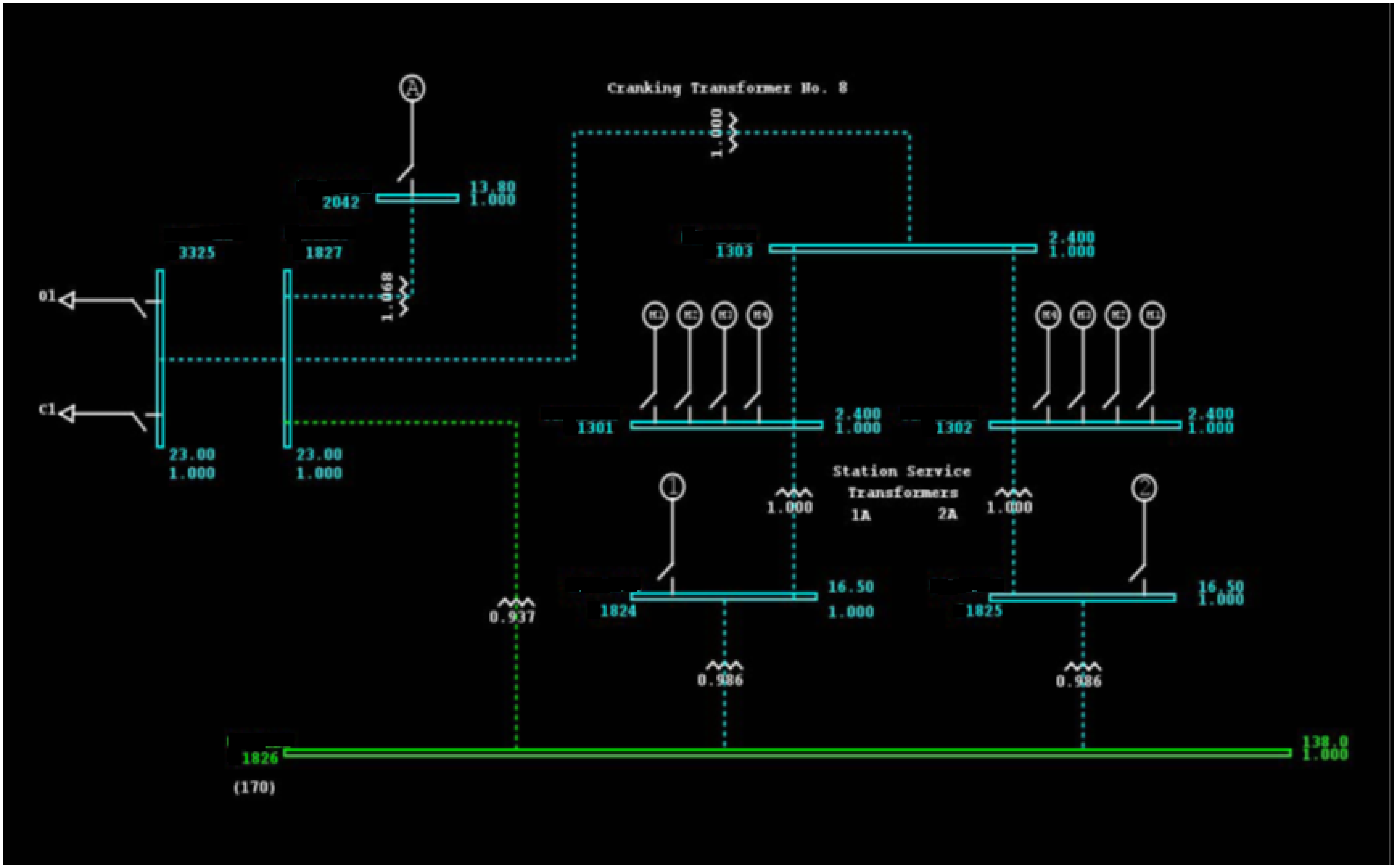
Modeling the Delta Generating Station (After)



Delta Auxiliary Load

Unit No.1 Auxiliary Load	HP	MW
Forced Draft Blower No.1A	2000	1.4920
Forced Draft Blower No.1B	2000	1.4920
Boiler Feed Pump No. 1A	1500	1.1190
Boiler Feed Pump No. 1B	1500	1.1190
Boiler Feed Pump No. 1C	1500	1.1190
Coal Crusher No. 1 FWD	600	0.4476
Coal Crusher No. 2 FWD	600	0.4476
Circ. Water Pump No. 1A	400	0.2984
Circ. Water Pump No. 1B	400	0.2984
Condensate Pump No. 1A	300	0.2238
Condensate Pump No. 1B	300	0.2238
SOOT Blower Air Comp. No.1	300	0.2238
AQC Ash Water Supply Pump A	250	0.1865
Ash Disposal Pump No. 1	200	0.1492
	11850	**8.84**

Unit No.2 Auxiliary Load	HP	MW
Force Draft Blower No. 2A	2000	1.4920
Force Draft Blower No. 2B	2000	1.4920
Boiler Feed Pump No. 2A	1500	1.1190
Boiler Feed Pump No. 2B	1500	1.1190
Boiler Feed Pump No. 2C	1500	1.1190
SOOT Blower Air Comp. No.2	500	0.3730
Circ. Water Pump No. 2A	400	0.2984
Circ. Water Pump No. 2B	400	0.2984
Condensate Pump No. 2A	300	0.2238
Condensate Pump No. 2B	300	0.2238
Boiler Cooling Fan No. 1	250	0.1865
AQC Ash Water Supply Pump B	250	0.1865
Ash Disposal Pump No. 2	200	0.1492
	11100	**8.28**

Restoration Procedure

Contingency No:	Contingency Description:
base	Base system (n-0)
close001	Closing in Delta Black Start Unit GSU
close002	Energizing Delta Black Start Unit
close003	Close Kinley Load D-69 4.16 kV Breaker 121-B-2
close004	Close Delta Black Start Auxiliary Transformer 23/2.3 kV and Motor Branches
close005	Energizing Delta Unit 1 Equivalent Auxiliary Load (M1)
close006	Energizing Delta Unit 1 Equivalent Auxiliary Load (M2)
close007	Energizing Delta Unit 1 Equivalent Auxiliary Load (M3)
close008	Energizing Delta Unit 1 Equivalent Auxiliary Load (M4)
close009	Energizing Delta Unit 2 Equivalent Auxiliary Load (M1)
close010	Energizing Delta Unit 2 Equivalent Auxiliary Load (M2)
close011	Energizing Delta Unit 2 Equivalent Auxiliary Load (M3)
close012	Energizing Delta Unit 2 Equivalent Auxiliary Load (M4)

Restoration Procedure (SSTOOLS)

```
# BLACK START PLAN
#
# Eastern Area (Delta Plant) Combustion Turbine Startup
#
####################################################################################################
#                                                                                                  #
# STEP #1:  Connect Delta Black Start Unit to Kinley Load to Stabilize Unit                        #
#                                                                                                  #
####################################################################################################
#
close001          "Closing in Delta to Kinley 23 kV Line"
 line  1827  3325  "1 " 1 1
 savf "close001.sav"
0
#
close002          "Energizing Delta Black Start Unit"
 gens  2042  "A " 1
 tran  1827  2042  "7 " 1
 savf "close002.sav"
0
#
close003          "Energizing Kinley  D-69 4.16 kV Load"
 load  3325 "01" 1
 load  3325 "C1" 1
 savf "close003.sav"
0
#
close004          "Closing in Delta No. 8 Cranking TR 23/2.4 kV"
 tran  1827  1303  "8 " 1
 line  1303  1301  "1 " 1 1
 line  1303  1302  "1 " 1 1
 order
 savf "close004.sav"
0
#
close005          "Energizing Delta Unit 1 Equivalent Auxiliary Load (M1)"
 gens  1301  "M1 " 1
 savf "close005.sav"
0
#
close006          "Energizing Delta Unit 1 Equivalent Auxiliary Load (M2)"
 gens  1301  "M2 " 1
 savf "close006.sav"
0
#
close007          "Energizing Delta Unit 1 Equivalent Auxiliary Load (M3)"
 gens  1301  "M3 " 1
 savf "close007.sav"
0
#
close008          "Energizing Delta Unit 1 Equivalent Auxiliary Load (M4)"
 gens  1301  "M4 " 1
 savf "close008.sav"
0
#
```

Restoration Procedure (SSTOOLS)

```
DATACHECK 0
# DRAWING   "CE_Region1.drw" "draws\b1_ld1_v1_c0\"
SAVEPATH  "cases\b1_ld1_v1_c0\"
OUTPATH   output\

CASES
# save case name          case id       outage file       control file    output file       pre_epcl, post_epcl, open/append
# ----------------------  ------------  --------------    ------------    -----------       --------- ---------  -----------
  b1_ld1_v1_c0.sav        b1_ld1_v1_c0  Delta.otg         Delta.cntl      b1_ld1_v1_c0.crf
end
```

```
rating  1 1
# monitor zone/area       from   to      kv range     base pu      cont pu     delta
monitor voltage   area     100   100   34.5  345.0   0.95 1.05   0.95 1.05    0.025
monitor voltage   area     100   100    1.0   23.0   0.95 1.07   0.95 1.07    0.025
monitor flows     area     100   100    1    900
monitor load      area     100   100
monitor gens      area     100   100    1
monitor svd       area     100   100    1    900
monitor           area     100   100

LTC       1 0       LTC  solution option
SVD       1 0       SVD  solution option  (0) disabled, (1) enabled
PAR       1 0       PhSh solution option
dctap     1 0       DC   solution option
area      0 0       AI   solution option
```

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Steady-State Results

	Unit Conditions:				Steady-State Violations		
Restoration Step	CT Pgen (MW)	CT Pres (MW)	CT Qgen (MVAr)	CT Qres (MVAr)	Absolute Voltage Issues	Branch Loading Issues	Reactive Limit Issues
close001	0.0	30.0	0.0	0.0	---	---	---
close002	0.0	30.0	0.0	18.4	---	---	---
close003	2.0	28.0	0.6	17.8	---	---	---
close004	2.0	28.0	0.6	17.8	---	---	---
close005	4.0	26.0	1.6	16.8	---	---	---
close006	6.0	24.0	2.6	15.8	---	---	---
close007	8.0	22.0	3.7	14.7	---	---	---
close008	10.0	20.0	5.0	13.4	---	---	---
close009	12.0	18.0	6.3	12.1	---	---	---
close010	14.0	16.0	7.8	10.6	---	---	---
close011	16.0	14.0	9.4	9.0	---	Overload	---
close012	18.0	12.0	11.2	7.2	---	Overload	---

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Steady-State Results

The Delta gas turbine was able to supply the Kinley substation load (approximately 2 MW) as well as the auxiliary load for both Delta Units 1 and 2 (8 MW each). The Delta Gas Turbine also had adequate real and reactive power reserves post motor startup.

Issues of Concern:

Delta Gas Turbine Serving 16 MW of Auxiliary Load.

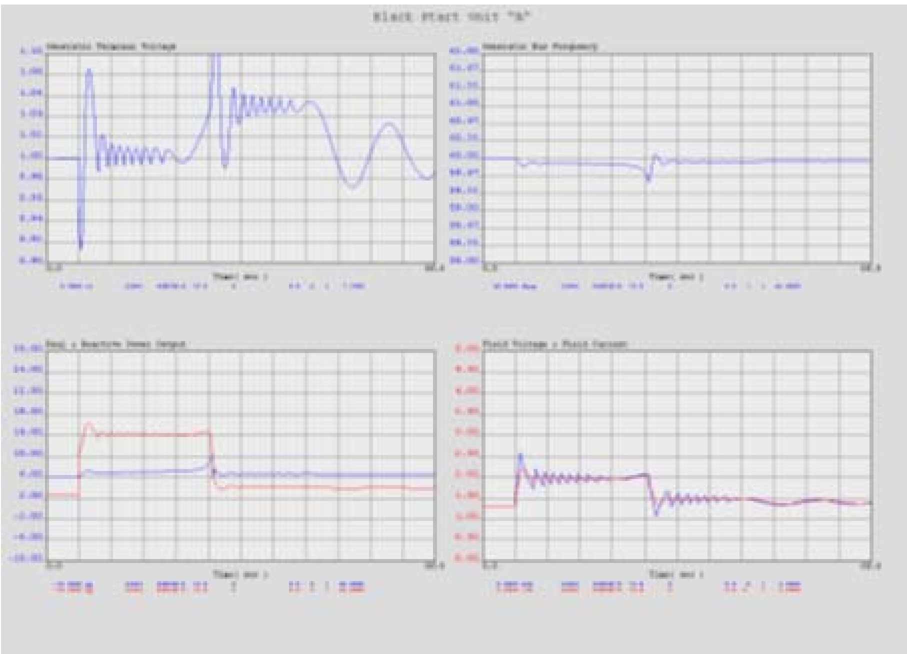
The FA rating of the cranking transformer no. 8 would be violated for the startup of all 16 MWs of auxiliary load.

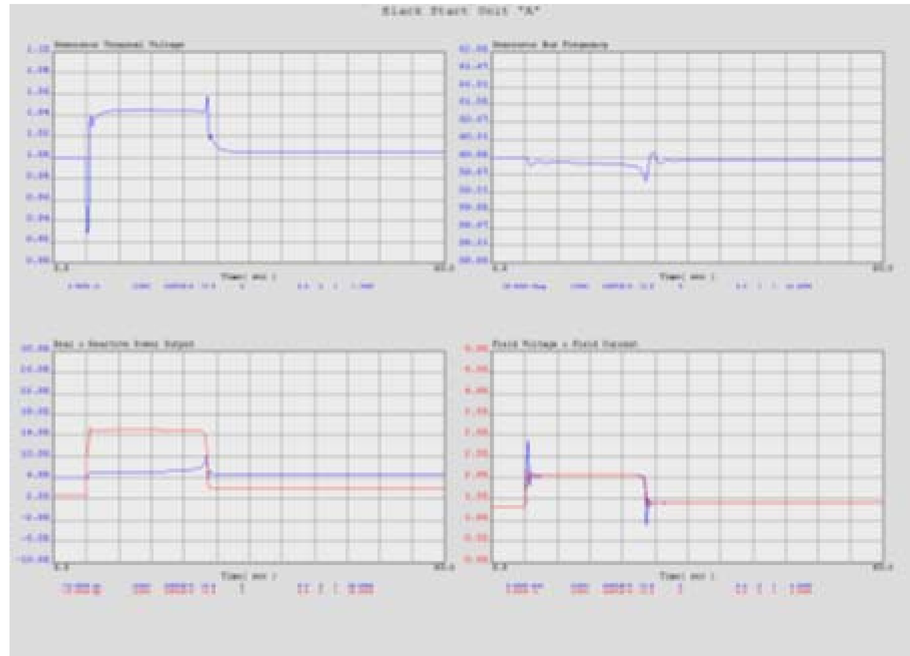
Resolution:

The TO should have discussion with plant personnel on the impact of energizing both Delta Generating Station unit's auxiliaries with the respect to overloading the cranking transformer, although the likelihood that the operators would perform a startup in the manner simulated is remote..

Dynamic Modeling Concerns

Delta Gas Turbine-Generator Excitation System Modeling Issues: EXDC4 versus EXAC1





Delta Gas Turbine-Governor Modeling Issues: GAST versus GGOV1

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Restoration Procedure

```
DATACHECK     0                      /* Data Check Flag:  (0) Off        (1) Read Only                                  */
MODSTAT       0                      /* Run Model Status: (0) Don't Run  (1) Run                                        */
TIMEUNIT      0                      /* Time Units Flag:  (0) Seconds    (1) Cycles                                     */
ENDTIME       60                     /* Total Simulation End-Time                                                       */
CLEARTIME     5.00  0.0667  0.1000   /* Transit End Time; Clearing Time 1 After Fault; Clearing Time 2 After Fault      */
SAVEPATH      cases\reruns4\         /* Folder Path Where Power Flow *.sav Files Are Located                            */
DYDPATH       dyds\                  /* Folder Path Where Dynamic Models *.dyd & Fault Definition EPCL *.p Files Are Located */
CHFPATH       chans\reruns4\         /* Folder Path Where To Store Channel *.chf Output Files                           */
SORTDYD       0  1                   /* Sort Flag For *.dyd Files 1,2...10: (0) Do Not Sort, (1) Sort                   */
FIXDATA       1                      /* Fix Bad Data Flag: (0) Do Not Fix Bad Data  (1) Fix Bad Data                    */
NUMPLOT       9  3  21               /* Plot Number Intervals Of Pre-, During-, and Post-Fault                          */
CONVMON       0                      /* Convergence Monitor Flag: (0) Off, (1) On                                       */
STEPSIZE      0.0041667              /* Time Step Size (Seconds)                                                        */

CASES
# save case name    pre-epcl  post-epcl  in-run epcl  fault epcl      channel output            dyd[1]                      dyd[2]      dyd[3]
# --------------    --------  ---------  -----------  ----------      --------------            ----------                  ----------  ----------
#
#
# DELTA UNIT #1 & UNIT #2 AUXILIARY MOTOR STARTING CASES
# close004-100m.sav   none      none       none         close005-100.p  m100-close004-005-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close005-100m.sav   none      none       none         close006-100.p  m100-close005-006-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close006-100m.sav   none      none       none         close007-100.p  m100-close006-007-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close007-100m.sav   none      none       none         close008-100.p  m100-close007-008-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close008-100m.sav   none      none       none         close009-100.p  m100-close008-009-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close009-100m.sav   none      none       none         close010-100.p  m100-close009-010-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close010-100m.sav   none      none       none         close011-100.p  m100-close010-011-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
# close011-100m.sav   none      none       none         close012-100.p  m100-close011-012-mod-100.chf  delta-gens-modification.dyd  meters.dyd  motors.dyd
end
```

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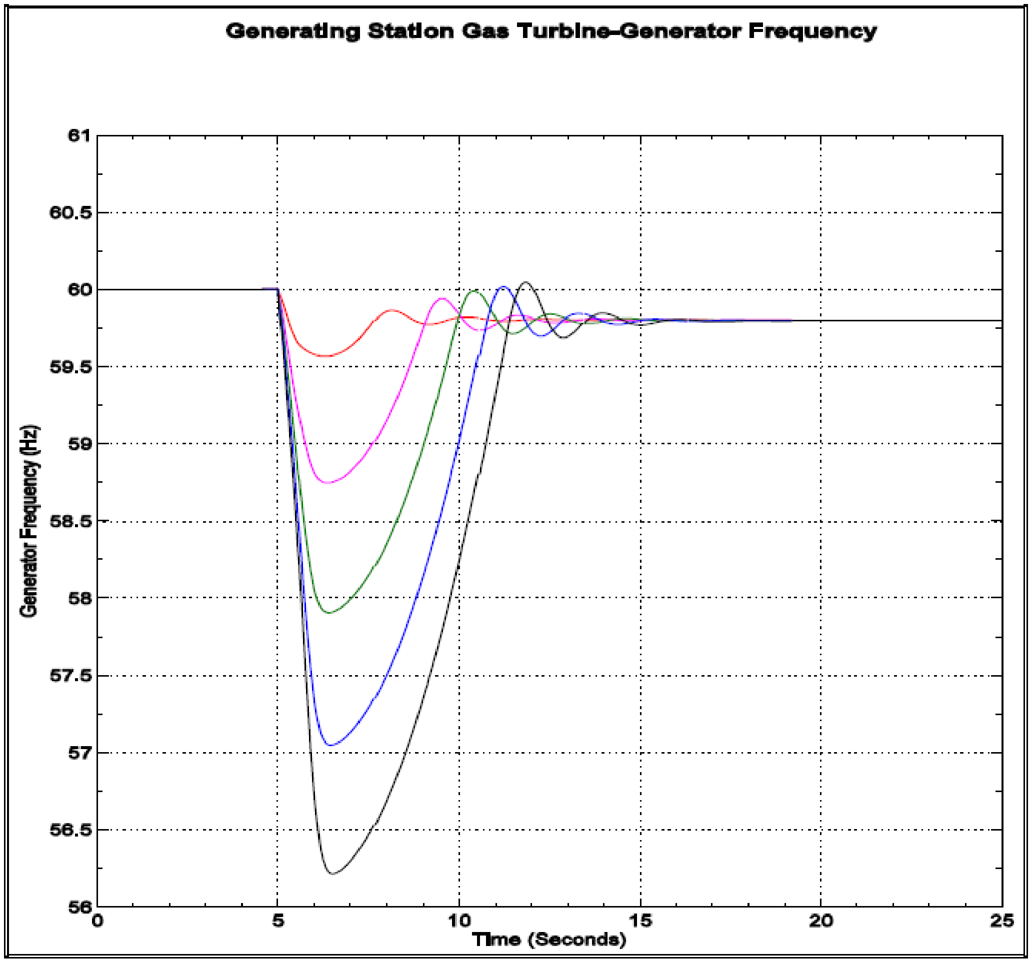
Transient Stability Results

	Unit Conditions:				Transient Stabiltiy Violations		
Restoration Step	CT Pgen (MW)	CT Pres (MW)	CT Qgen (MVAr)	CT Qres (MVAr)	Voltage Dip Issues	Frequency Dip Issues	OEL Concerns
close001	0.0	30.0	0.0	0.0	---	---	---
close002	0.0	30.0	0.0	18.4	---	---	---
close003	2.0	28.0	0.6	17.8	---	Remote Chance of GT Trip	---
close004	2.0	28.0	0.6	17.8	---	---	---
close005	4.0	26.0	1.6	16.8	---	---	---
close006	6.0	24.0	2.6	15.8	---	---	---
close007	8.0	22.0	3.7	14.7	---	---	---
close008	10.0	20.0	5.0	13.4	---	---	---
close009	12.0	18.0	6.3	12.1	---	---	---
close010	14.0	16.0	7.8	10.6	---	---	19 MVAR for 21 Seconds
close011	16.0	14.0	9.4	9.0	---	---	21 MVAR for 22 Seconds
close012	18.0	12.0	11.2	7.2	---	---	22 MVAR for 23 Seconds

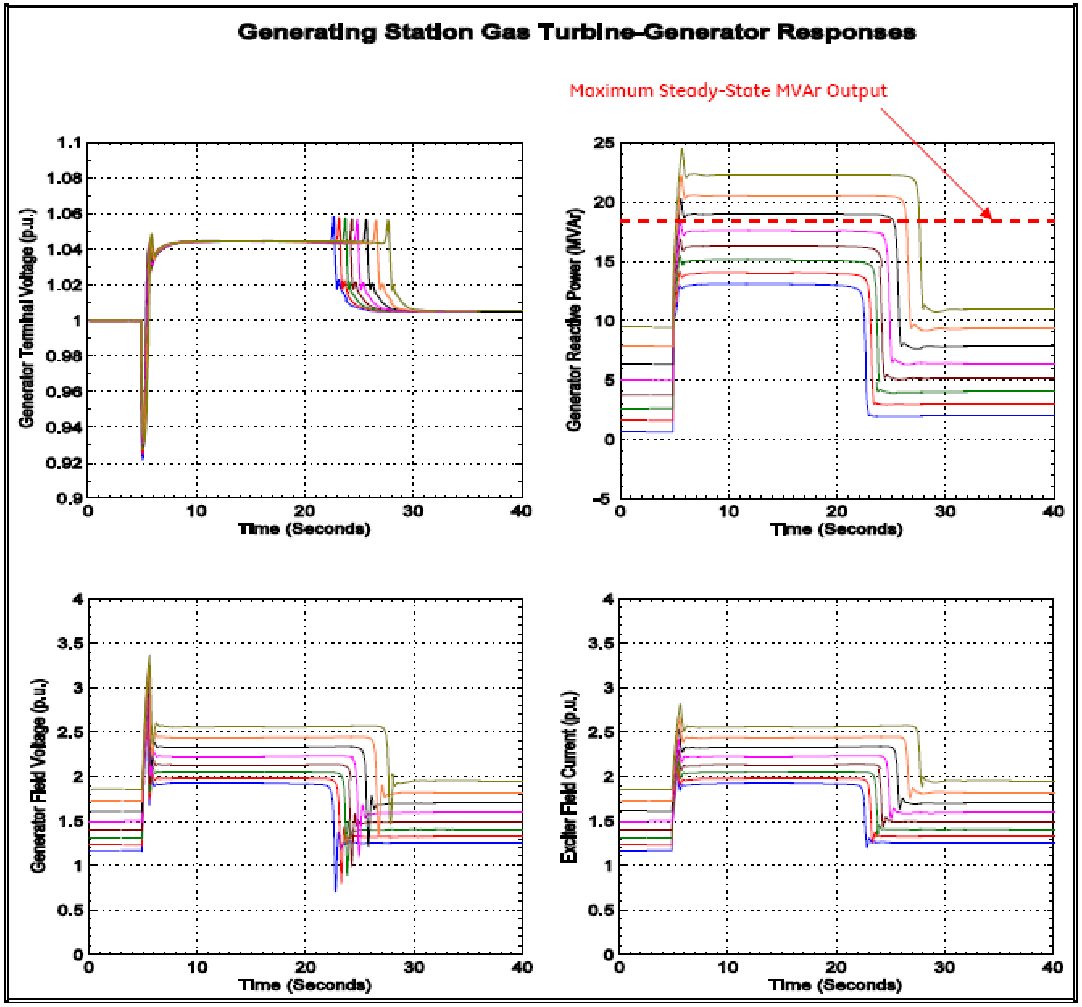
Transient Stability Results

Frequency Dip after Energization of Kinley Substation



Transient Stability Results

Reactive Output Concerns During Startup of Delta Unit #2 Auxiliary Load



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Transient Stability Resolutions

Power Plant Model Verification

Delta Gas Turbine-Generator Underfrequency Trip Settings

- Verify GT Underfrequency Trip Setpoints
- Energization of Kinley Substation Load in Two Steps

Delta Gas Turbine-Generator Over-Excitation Limiter Settings

- Verify Delta GT OEL Setpoints
- Discussions with Plant Personnel on Startup of all Auxiliary Motors

Eastern Area Load Restoration

1. Isolation of the Local Transmission System

2. Startup of Auxiliary Load via the Delta Generation Station Gas Turbine

3. **Setting Up the Local Transmission System Prior to Load Restoration**

4. Local Area Load Restoration via the Delta Generating Station Units 1 and 2.

Restoration Procedure

Contingency No:	Contingency Description:
close013	Closing in Maple - James 138 kV Line
close014	Closing in No. 1 TR 138/23 kV at Maple Substation
close015	Closing in N0. 1 TR 138/23 kV at Mahoningside Substation
close016	Closing in No.1 138/23 kV & No.3 TR 138/69 kV at Newton Substation
close017	Closing in No.1 TR 138/23 kV at James Substation
close018	Closing in No.1 TR 138/23 kV at Springs Substation
close019	Closing in No.2 TR 138/69 kV at Springs Substation
close020	Closing in No.1 TR 138/23 kV at River Substation
close021	Closing in Eagle - Walter 138 kV Line
close022	Closing in No.2 TR 138/69 kV at Eagle Substation
close023	Closing in No.2 TR 138/69 kV at Malury Substation
close024	Closing in No.3 TR 138/23 kV at Board Substation
close025	Closing in No.1 TR 138/69 kV At Knoxville Substation

Eastern Area Load Restoration

1. Isolation of the Local Transmission System

2. Startup of Auxiliary Load via the Delta Generation Station Gas Turbine

3. Setting Up the Local Transmission System Prior to Load Restoration

4. **Local Area Load Restoration via the Delta Generating Station Units 1 and 2.**

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Restoration Procedure

Contingency No:	Contingency Description:
close026	Energizing Unit #1 at Delta
close027	Closing in Springs - Delta 138 kV Line
close028	Closing in Reagan Park - Mosey - Dirt 23 kV Path
close029	Energizing Load at Dirt Substation 4.16 kV (D-87)
close030	Energizing Load at Dirt Substation 4.16 kV (D-85)
close031	Energizing Load at Dirt Substation 4.16 kV (D-260)
close032	Closing in Maple - Delta 138 kV Line
close033	Closing in Maple - Warren Sewage - Peak 23 kV Path
close034	Closing in Maple - High Water 138 kV Line (Circuit 2)
close035	Closing in Maple - High Water 138 kV Line (Circuit 1)
close036	Closing in Springs - High Water 138 kV Line
close037	Closing in Blueberry - Delta 138 kV Line
close038	Closing in No.1 TR 138/23 kV at Blueberry and 23 kV Line to East Substation
close039	Closing in No.1 TR 138/23 kV at Blueberry and 23 kV Line to City Substation
close040	Closing in Blueberry - Knox 138 kV Line
close041	Closing in Knox - Fairy - Beechwood - Rocky - Northwest 69 kV Path
close042	Energizing Jessica 4.16 kV Load at Rocky
close043	Energizing Chesnut 4.16 kV Load at Rocky
close044	Energizing Freedom 4.16 kV Load at Northwest
close045	Energizing Ocean Park 12.47 kV Load at Northwest
close046	Closing in Eagle - Blueberry 138 kV Line
close047	Closing in Eagle - Walter 138 kV Line
close048	Closing in Masury - Springs 138 kV Line
close049	Closing in No.1 Cranking Transformer 138/23 kV at Delta Substation
close050	Delta Unit 1 Auxiliary Load Transfered to Unit #1
close051	Closing in Springs - River 138 kV Line
close052	Restores T-390 22.86 KV Circuit at River Substation
close053	Restores T-391 22.86 KV Circuit at River Substation
close054	Closing in Boardn - Cliff - River 138 kV Path

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Restoration Procedure

Contingency No:	Contingency Description:
close055	Board No. 8 TR & No. 9 TR - Energized by BKR 101-B-83
close056	Closing in Maple - Frank - Bridge - James 138 kV Path
close057	Closing in No.1 TR 138/23 kV at James Substation
close058	Closing in James - Mahonning 23 kV Line & St. Joe Hospital Load
close059	Closing in No.2 TR 138/69 kV at Springs Substation
close060	Closing in Springs - Church 69 kV Line & Church 8.32 kV Load
close061	Energizing Church 8.32 kV Load (D-226)
close062	Energizing Church 8.32 kV Load (D-227)
close063	Energizing Church 8.32 kV Load (D-229)
close064	Closing in Newton - GM - Todd - High Water 138 kV Path
close065	Closing in Newton - Wind - Garrett 69 kV Path & Load at Wind
close066	Energizing Garrett 825-A 12.47 kV Load
close067	Energizing Garrett 825-E 12.47 kV Load
close068	Closing in Mahonning - High Water 138 kV Line
close069	Closing in James - Mahonning 138 kV Line

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Restoration Procedure

Contingency No:	Contingency Description:
close070	Energizing Unit #2 at Delta
close071	Closing in Pack - James 138 kV Line
close072	Closing in Garden - Fern - Pack 138 kV Path & Candle 12.47 kV load
close073	Energizing Avalon 12.47 kV Load
close074	Energizing Normar 12.47 kV Load
close075	Energizing Fairhill 12.47 kV Load
close076	Energizing WCI Load
close077	Closing in Delta - McDonald - Central 138 kV Path & Central Load
close078	Energizing Central Load - Not To Exceed 8 MW
close079	Closing in Fern - Cort 138 kV Line & Mecca 12.47 kV Load
close080	Energizing General 12.47 kV Load
close081	Energizing Jacob 12.47 kV Load
close082	Energizing Bazettaville 12.47 kV Load
close083	Energizing Jones 12.47 kV Load
close084	Energizing Ivy Mountain 12.47 kV Load

Steady-State Results

close037	13.2	101.8	-0.4	36.4	---	---	---	---	High 23 kV	---	---
close038	15.5	99.5	0.3	35.7	---	---	---	---	High 23 kV	---	---
close045	38.9	76.1	8.9	27.1	---	---	---	---	Low 69 kV	---	---
close046	42.0	73.0	8.5	27.5	---	---	---	---	Low 69 kV	---	---
close061	78.1	36.9	13.1	22.9	---	---	---	---	Low 69 kV	---	---
close062	82.5	32.5	14.6	21.4	---	---	---	---	Low 69 kV	---	---
close063	87.8	27.2	16.6	19.4	---	---	---	---	Low 69 kV	---	---
close064	87.8	27.2	15.0	21.0	---	---	---	---	Low 69 kV	---	---
close065	91.8	23.2	16.3	19.7	---	---	---	---	Low 69 kV	---	---
close066	94.1	20.9	17.2	18.8	---	---	---	---	Low 69 kV	---	---
close067	100.0	15.0	19.5	16.5	---	---	---	---	Low 69 kV	---	---
close068	100.0	15.0	19.0	17.0	---	---	---	---	Low 69 kV	---	---
close069	100.0	15.0	18.9	17.1	---	---	---	---	Low 69 kV	---	---

Steady-State Results

close076	100.0	15.0	16.4	19.6	33.7	81.3	13.3	38.7	Low 69 kV	---	---
close077	100.0	15.0	16.4	19.6	36.7	78.3	13.2	38.8	Low 69 kV	---	---
close078	100.0	15.0	19.2	16.8	44.8	70.2	15.7	36.3	Low 69 kV	---	---
close079	100.0	15.0	20.3	15.7	51.7	63.3	16.7	35.3	Low 69 kV	---	---
close080	100.0	15.0	21.7	14.3	58.6	56.4	18.0	34.0	Low 69 kV	---	---
close081	100.0	15.0	23.2	12.8	65.5	49.5	19.3	32.7	Low 69 kV	---	---
close082	100.0	15.0	24.8	11.2	73.3	41.7	20.8	31.2	Low 69 kV	---	---
close083	100.0	15.0	26.1	9.9	79.1	35.9	22.1	29.9	Low 69 kV	---	---

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Steady-State Results

During the load restoration process, various voltage violations occur throughout the Eastern Area.

Issues of Concern:

Closing In The Delta – Blueberry 138 kV Transmission Line
[HIGH 23 kV Bus Voltages]

Energization of Local Load at the Rocky and Northwest 69 kV Substations
[LOW 69 kV Bus Voltages]

Energization of the Ivy Mountain 12.47 kV Load at the Fern 138 kV Substation
[LOW 69 kV Bus Voltages]

Steady-State Resolutions

Closing In The Delta– Blueberry 138 kV Transmission Line:

Lowering the voltage control reference of Delta Generating Station Unit #1, in turn lowering the reactive power output of the unit, can alleviate the high voltage violations seen near Blueberry 23 kV. It was observed that by dropping the control voltage by as little as 1% was sufficient enough in preventing the 23 kV voltage from going to above their high voltage limit. A decrease in voltage reference of 1% increased the reactive power reserves of the machine by less than 0.5 MVAr. Once the East and City 23 kV circuits have been reconnected, the Delta Generating Station Operator could resume normal terminal voltage regulation.

Steady-State Resolutions

Energization of Local Load at the Rocky and Northwest 69 kV Substations:

In order to alleviate the low 69 kV voltages experienced at and near the Rocky and Northwest 69 kV substations, the Delta Generating Station Operator could raise the control voltage reference by 1%. This was sufficient in bringing the 69 kV voltages within the normal voltage bandwidth. By raising the control voltage by 1%, the reactive reserves dropped by 0.5 MVAr.

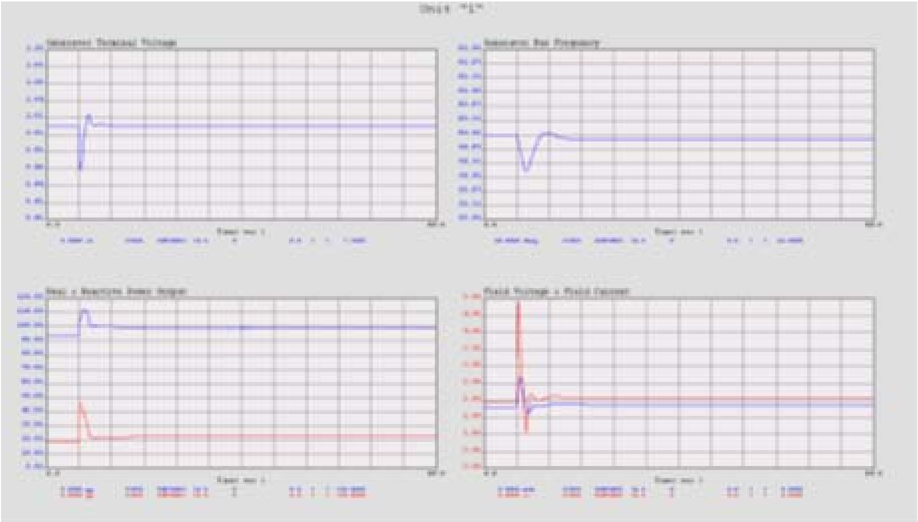
Steady-State Resolutions

Energization of the Ivy Mountain 12.47 kV Load at the Fern138 kV Substation:

The 138 kV low voltages near Cort and Garden can also be brought back within normal operating range by raising the control voltage reference 1%. A second possible procedure to adjust the low 138 kV bus voltages is to close in the Garden to Central 138 kV transmission system. This would create a 138 kV loop in the area, in turn reducing the electrical distance between Cort/Garden and the Delta Generating Station sources, allowing the voltages to remain within limits.

Dynamic Modeling Concerns

Delta Steam Turbine-Generators Excitation System Modeling Issues: EXDC4 versus ESDC4B



Delta Steam Turbine-Governor Modeling Issues: TGOV1 versus IEEEG1 versus CCBT1

Transient Stability Results

	Unit Conditions:								Transient Stabiltiy Violations		
Restoration Step	Unit 1 Pgen / Pres (MW)		Unit 1 Qgen / Qres (MVAr)		Unit 2 Pgen / Pres (MW)		Unit 2 Qgen / Qres (MVAr)		Voltage Dip Issues	Frequency Dip Issues	OEL Concerns
close028	3.3	111.7	1.0	35.0	---	---	---	---	---	---	---
close050	51.9	63.1	7.6	28.4	---	---	---	---	---	---	---
close055	66.4	48.6	10.5	25.5	---	---	---	---	---	---	---
close067	100.0	15.0	19.5	16.5	---	---	---	---	---	---	---
close072	100.0	15.0	11.3	24.7	6.4	108.6	9.3	42.7	---	---	---
close075	100.0	15.0	14.9	21.1	26.7	88.3	12.1	39.9	---	---	---
close078	100.0	15.0	19.2	16.8	44.8	70.2	15.7	36.3	Depressed 69 kV	---	Sustained Reactive Output
close084	100.0	15.0	27.9	8.2	86.9	28.1	10.2	8.2	Depressed 69 kV	---	---

Transient Stability Results

Transfer of Delta Generating Station Unit #1 Auxiliary Load (Method Unknown)
Energization of Central Substation Load
Energization of the Ivy Mountain 12.47 kV Load at the Fern138 kV Substation

Transient Stability Resolutions

Power Plant Model Verification

Delta Generating Station Auxiliary Load Transfer

- Verify Transfer Method
- Possible Issues with Reduced Voltage Transfer and All Auxiliary Motors Online
- More Detail Modeling may be needed.

Energization of Central Load

- Verify GT and ST OEL Setpoints
- Connect Central Load in Smallest Increments Possible

Rocky and Northwest 69 kV Substations

- Most Susceptible due to Electrical Distance from Sources
- Maintain constant monitoring of local buses

Conclusions & Recommendations

Accurate Power Plant Dynamic Modeling:

The biggest concern seen in this study is the uncertainty in dynamic models for the power plants. TOs should try to obtain the correct dynamic system models to accurately depict the unit's response to voltage and frequency excursions. While obtaining up to date models from the manufacturer is acceptable, it is highly recommended that the data be obtained, by a proven method, such as model validation tests. NERC Standard now MOD-25,26 & 27.

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Conclusions & Recommendations

Continuous System Voltage Monitoring and Regulation:

Through most of the Eastern Area system restoration process, it was observed that several areas would experience events causing their bus voltages to go out of normal operating limits. The 23kV substations near Blueberry would often see sustained voltage rises, while the 69kV substations near Rocky and Northwest would experience voltage depressions on a relatively regular basis. It was observed that all steady-state and transient stability voltage violations could be quelled through raising or lowering of the Delta Generating Station voltage control references by small increments. It is highly recommended that during a load restoration procedure, all system voltages be monitored closely and that communication with power plants for use of voltage regulation be available at all times.

Conclusions & Recommendations

Verification of Black Start Capable Units Protection Settings:

During the auxiliary motor startup procedures, it was observed that the Delta Generation Station Gas Turbine-Generator could experience a trip due to unknown protection settings. The most likely actions could come from an underfrequency trip for the Delta Gas Turbine or an over-excitation limiter for both units. It is recommended that TOs confirm all unit protection settings with plant owners.

Conclusions & Recommendations

Review of Internal Power Plant Black Start Procedures:

A considerable amount of unknowns that take place in this study are the exact methods used internally at the power plant during the restoration process (i.e. motor energization order, auxiliary load transfer, etc.) It is recommended, that if possible, some detail be included in the Black Start Plan in order to confirm the plans true effectiveness.

Conclusions & Recommendations

<u>Proposed Additions to the Existing Black Start Plan</u>:

It is recommended that the TOs Black Start Plan received at the onset of this study be modified to include the following section:

1. The Kinley Substation Connection should be performed in smaller load increments (1 MW or less).

Conclusions & Recommendations

Final Conclusion:

In implementing the proposed additions to the existing TOs Black Start plan and implementing the recommendation in a practical manner, it was found that the existing plan for the Eastern Area is capable of restoring system load after a local grid blackout with no major concerns as they apply to steady-state and dynamic/transient stability point of view up to the point studied.

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Questions?

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