Sudbury 115kV Capacitor Installation

Proposed Plan Application Analysis

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1.0 Executive Summary

NSTAR plans to install a new 118kV, 52.5 MVAR capacitor bank at Sudbury Station. The new unit will be a trailer mounted “mobile” style bank that includes an 115kV isolating breaker equipped with a synchronous closing/opening controller to minimize transient switching voltages.

The capacitor bank is needed to raise sagging transmission voltage in the western part of the NSTAR North service territory during summer loading conditions, and to maintain adequate voltage support after potential contingencies.

The expected in service date in June 1, 2006.

2.0 Introduction

NSTAR plans to install a new 118kV, 52.5 MVAR capacitor bank at Sudbury Station 342, which when operated at 115kV results in a 49.5 MVAR output. The new unit will be a trailer mounted “mobile” style bank that includes an 115kV isolating breaker equipped with a synchronous closing/opening controller to minimize transient switching voltages.

The new capacitor bank will tap the 115kV bus between existing breakers #3 and #6 and will become bifurcated with line # 416-527 (Sudbury to Maynard). The expected in-service date is June 1, 2006.

The objective of the new capacitor bank is to reinforce the transmission voltage in the Sudbury, Speen Street and Maynard area. Voltage in this area has been sagging during summer loading conditions for the last several years due to load growth and the insufficient reactive compensation to support the growth. Loadflow studies have confirmed this problem, and have further revealed that under contingency conditions, particularly for loss of the 433-507 line between Speen St and Framingham, transmission voltage sags even further to unacceptably low levels. Studies have shown that the addition of an 118kV, 52.5 MVAR capacitor bank at Sudbury helps raise transmission voltage under both normal and contingency conditions to acceptable levels.

See the Figure 1 below for the proposed location.

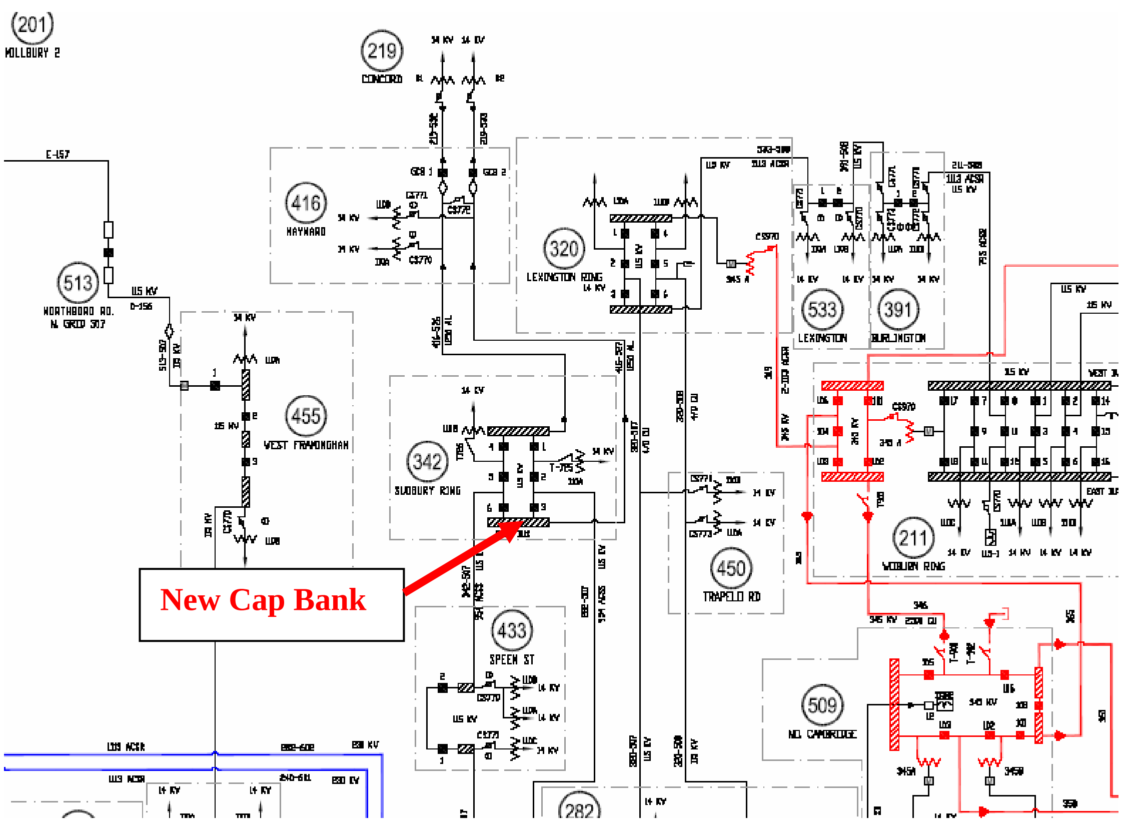


Figure 1 – Location of Sudbury Capacitor Bank

3.0 Background

The station loads in the study area including Sudbury, Maynard, Concord Municipal and Speen St. accounted for approximately 268 MVA during the 2002 Summer peak which grew to 286 MVA during the recent 2005 Summer peak. This represented a 2.2% annual growth rate over this three year period. The latest load forecast predicts the load to increase to 294 MVA by 2008. Refer to the table below for station load totals.

Station	**2002 Actual**	**2005 Actual**	**2008 Forecast**
Sudbury	39	45**	43
Maynard	80	85**	82
Concord Municipal	42	43	44
Speen St	107	113	125
Total	**268**	**286**	**294**

**2005 load exceeding 2008 forecasted load

Table 1 – Study Area Peak Loads

Transmission voltages in this area have been sagging under normal summer peak load conditions. As an example, refer to the Figure 2 below of voltage data from the NSTAR PI/SCADA system, which graphs the measured transmission voltage at Speen St. during the July 27, 2005 summer peak day over the entire 24 hours. Each vertical line represents a 1 hour period starting from midnight on the left side. The voltage is shown to drop below the nominal 115kV level for about 6 hours during the heavy load hours of 12 noon to 6pm, with a low of 113.3kV between 2 -3 pm. Similar levels existed at the other stations in the area with Speen Street being the worst.

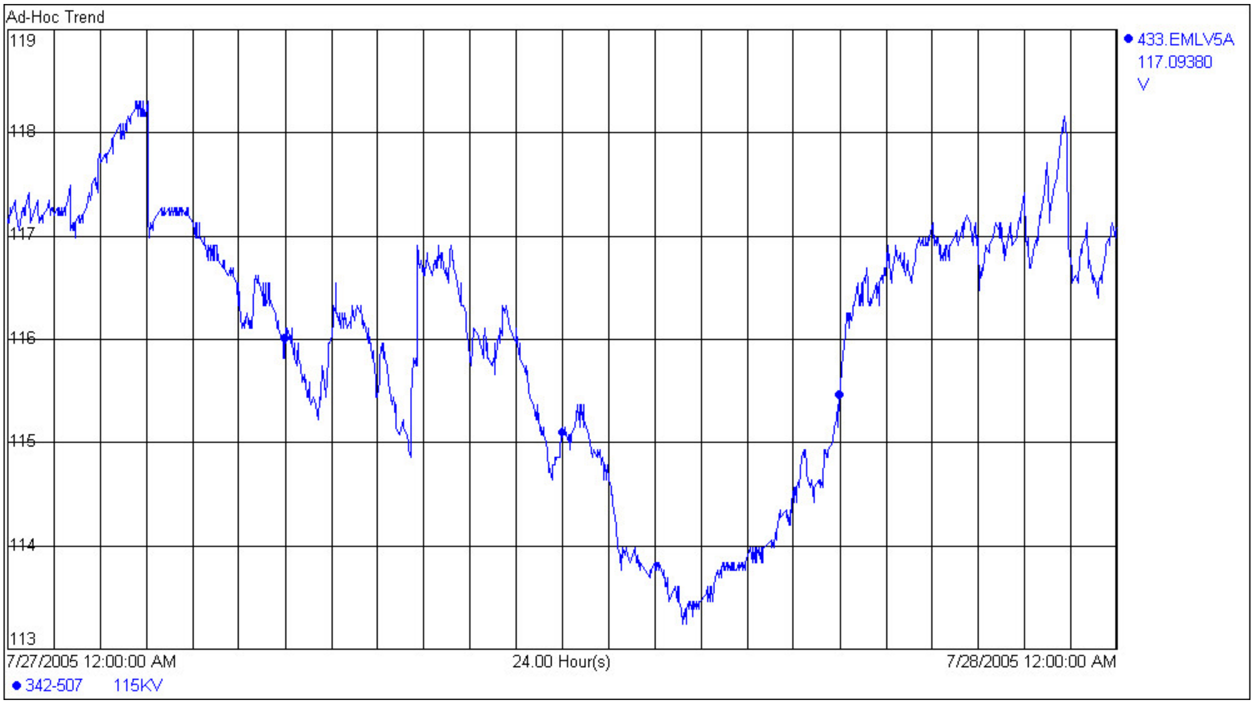


Figure 2 – Peak Load Voltage Profile at Speen St

4.0 Study Methodology

4.1 Base Case

A PSS/E loadflow basecase originally taken from the 2001 NPCC Library was used and modified to reflect a 2006 summer peak load from the April 1, 2003 CELT report. See Table 2 below.

NEPOOL Load Levels (MW) – 4/1/03 CELT	
Load Level	**2006**
Peak (90/10)	27,910

Table 2 – NEPOOL Load

The following transmission system upgrades in the Boston area were modeled:

1) NSTAR 345kV Transmission Reliability Project
2) 433-507 Line Relocation Project*
3) North Shore Upgrades (NEMA/Boston)
4) Central MA Transmission Upgrades
5) NSTAR Colburn St 115-14kV substation
6) 2nd Putnam to E.Cambridge 115kV Cable & E.Cambridge 115-14kV substation

*The 433-507 Line Relocation Project eliminates the 433-507 / 282-602 DCT

The following generating units were considered retired from service:

1) New Boston 1

Table 3 below details the interface transfers simulated in the 2006 base case.

Base Case	**Interface Flows**					
	Boston Import	**N-S**	**SEMA/RI**	**E-W**	**Phase II**	**NY-NE**
06peak	**3970**	**2235**	**864**	**-187**	**2000**	**569**

Table 3 - Base Case Interface Flows

To represent a stressed condition on the NSTAR 115kV system, the Mystic 9 generator was assumed unavailable and out of service. The Salem Harbor Units 1-4 were adjusted to maintain Boston import at 3900MW.

Refer to Appendix I for the PSS/E base case summary.

4.2 Contingency List

Similar to a typical planning study, all of the contingencies in the Boston area were tested. However, only the following contingencies are relevant in the study area, and are the focus of this analysis:

1) 115kV Line 433-507 Framingham to Speen St
2) 115kV Line 342-507 Speen St to Sudbury
3) 115kV Line 282-507 Sudbury to Waltham
4) 115kV Line 416-527 Sudbury to Maynard + new capacitor
5) 230kV Line 282-602 W.Medway to Waltham

4.3 Voltage Criteria

The following voltage criteria was applied:

Base kV	Post-contingency Bus Voltage Criteria		
	Lower Limit (pu)	Upper Limit (pu)	Voltage Deviation
345 kV and 230 kV	0.95	1.05	5%
115 kV	0.95	1.05	5%

5.0 Study Results

As a benchmark, loadflow studies done using 2005 loads (similar to Table 1) have produced similar results to those shown in Figure 2 above under normal summer peak load conditions at Speen St (0.98Vpu) as well as Maynard and Sudbury. Contingency analysis at these loads has shown that loss of the 433-507 circuit between Framingham and Speen St is the worst in the area (assuming the 433-507 line relocation project is implemented which eliminates the 433-507 / 282-602 double circuit tower contingency). Loss of the 433-507 circuit results in a radial supply out of Waltham for all the station loads at Speen, Sudbury, Maynard and Concord, with the largest Speen load at the end of the line. Loadflow results showed very low transmission voltages in entire area, with Speen Street falling as low 102kV or 0.89Vpu. This value is below the NSTAR criteria of 0.95Vpu following a contingency. In addition, loss of the 433-507 line also results in an outage of the 110C transformer at Speen Street since this unit is bifurcated with the transmission line. Station loads are automatically transferred to the 110A and 110B transformers, but 14kV bus voltages also become low at 12.8kV (0.89Vpu) with both LTCs at maximum raise.

Since the proposed Sudbury capacitor bank is targeted to be place in-service in June 2006 at about the same time as the NSTAR 345kV Project, analysis was done assessing the impact of the 345kV Project. Table 4 below shows the results of voltage analysis. Values shown are in voltage per unit on an 115kV base. As shown in the table, the 345kV Project has a positive impact in this area of about 1.4% pre-contingency and about 3.5% post-contingency, assuming the 345kV cable charging will be used to generally raise all transmission voltages in NSTAR North during peak load. That positive impact helps satisfy the voltage violations for the all-lines-in case and the 282-507 contingency case. However, as shown in Table 4, for the worst case 433-507 contingency, the 345kV Project in not enough support, and the Sudbury capacitor bank is needed to raise voltages further to within acceptable levels.

As an operational note, the last column in Table 4 shows the incremental improvement that can be gained post-contingency by backing off the setting of the Waltham phase shifting transformers (from +4 to neutral). Reducing the loading on the phase shifters reduces the voltage drop across the transformers, and therby raises voltages down stream to Speen St for the radial condition that exists when the 433-507 is out of service.

Station	All Lines IN Existing	All Lines IN + 345kV	All Lines IN + 345kV+Cap	L/O 282-507 Existing	L/O 282-507 + 345kV	L/O 282-507 + 345kV+CAP	L/O 433-507 Existing	L/O 433-507 + 345kV	L/O 433-507 + 345kV+CAP	L/O 433-507 CAP + Waltam PAR Adjustment
Speen St	0.986	1.00	1.02	0.95	0.99	1.02	0.89	0.917	0.96	0.972
Sudbury	0.988	1.00	1.023	0.94	0.98	1.025	0.905	0.93	0.973	0.985
Maynard	0.988	1.00	1.02	0.94	0.98	1.022	0.9	0.93	0.968	0.98

Table 4 – Voltage Analysis Results **(Voltage per unit on 115kV base)**

Refer to Appendix II for select loadflow plots.

A Delta V test was also done for the all-lines-in case including the 345kV Project. The simulation was performed by switching the capacitor bank and solving the base case using the FDNS option of PSS/E with taps and phase shifters locked. The results showed a 2.5% increase at Sudbury and a 2% increase at Speen St and Maynard. These results are typical and within acceptable limits.

5.1 Sudbury Stuck Breaker Testing

At the request of the Transmission Task Force, Sudbury 115kV stuck breaker testing was performed for breakers #3 and #6. A failure of either of these breakers at Sudbury removes from service the East bus section that the new capacitor bank is proposed to be connected to, as well as 115kV line 416-527 and either 115kV circuit 282-507 or 342-507. In addition, stuck breaker testing was also performed for breakers #1 and #4 that are connected to the West bus section at the opposite side of the station. For comparison, the analysis was done with the new capacitor bank connected to the proposed East bus section and the West bus section. This comparison may identify which bus section is better to connect the capacitor bank with regard to voltage performance after these stuck breaker faults at Sudbury. However, it is not feasible to physically locate the new capacitor at the other side of the station near the West bus due to space constraints. Substantial addition cost would be required to connect the capacitor bank to the West bus, and for that reason it was not recommended.

Refer to the Table 5 below for results.

Station	Sudbury SB #3 + Cap connected to East bus	Sudbury SB #3 + Cap connected to West bus	Sudbury SB #6 + Cap connected to East bus	Sudbury SB #6 + Cap connected to West bus	Sudbury SB #1 + Cap connected to East bus	Sudbury SB #1 + Cap connected to West bus	Sudbury SB #4 + Cap connected to East bus	Sudbury SB #4 + Cap connected to West bus
Speen St	0.96	0.99	1.01	1.01	1.0	0.99	1.0	0.99
Sudbury	0.95	0.99	0.97	1.0	1.0	0.99	1.0	0.99
Maynard	0.94	0.98	0.95	0.99	0.99	0.98	0.99	0.98

Table 5 – Sudbury Stuck Breaker Results **(Voltage per unit on 115kV base)**

The results in Table 5 show that connection of the capacitor bank to the West bus is slightly better than connection to the proposed East bus for stuck breaker contingencies #3 and #6, but that connection to the proposed East bus is slightly better following stuck breaker contingencies #1 and #4. Overall, these results do not overwhelmingly support connection to the West bus versus the East bus and both are acceptable.

6.0 Conclusion

The addition of an 118kV, 52.5 MVAR capacitor bank at Sudbury Station was shown to be an effective solution to mitigate the voltage criteria violations that exist under summer peak load conditions. The study results confirm that the new capacitor bank will not have a significant adverse system impact on the reliability or operating characteristics of the NSTAR transmission facilities or the transmission facilities of another Transmission Owner, or the system of a Market Participant.

Appendix 1

Base Case Summary

2006 PEAK,27910MW,PAR(4,4),PHASE 11 2000,STAGE 1, NORTH BIAS
NB,M9 OFF K4,SALEM 1-4,MYSTIC7,8 ON

GENERATION

		V	MAX	MW	MX			V	MAX	MW	MX			V	MAX	MW	MX
73562	MILL#2	0.988	904	862	71	73563	MILL#3	0.986	1146	1146	71	73555	MIDDTN#2	1.010	117	117	34
73556	MIDDTN#3	0.988	233	108	34	73557	MIDDTN#4	0.995	400	400	59	73558	MONTV#5	0.000	81	0	0
73559	MONTV#6	1.011	402	402	151	73549	SMD1112J	0.000	93	0	0	73550	SMD1314J	0.000	93	0	0
73551	NORHAR#1	0.000	162	0	0	73552	NORHAR#2	0.000	168	0	0	73646	BPTHBR#1	0.000	0	0	0
73647	BPTHBR#2	0.000	170	0	0	73648	BPTHBR#3	1.010	375	375	199	73649	BPTHBR#4	0.000	22	0	0
73651	NH HARBR	0.988	447	447	130	73553	DEVON#7	0.000	107	0	0	73554	DEVON#8	0.000	107	0	0
71739	TAUNTON	0.000	0	0	0	72372	BP #1 GN	1.029	241	238	120*	72375	BP #2 GN	0.000	241	0	0
72370	BP #3 GN	1.020	605	350	49	72371	BP #4 GN	1.018	425	430	37	72661	MANCH09A	1.013	119	100	35*
72662	MANCH10A	0.000	119	0	0	72663	MANCH11A	1.013	119	99	35*	72666	FRSQ SC1	0.995	46	46	-5
72667	FRSQ SC2	0.000	46	0	0	72668	FRSQ SC3	0.000	46	0	0	71522	SOM G6	0.000	105	0	0
71531	OSP1 PF	0.000	77	0	0	71532	OSP2 PF	0.000	77	0	0	71533	OSP3 PF	0.000	108	0	0
71534	OSP4 PF	1.006	77	55	0	71535	OSP5 PF	1.004	77	77	0	71536	OSP6 PF	1.003	108	108	0
71084	NEA GTPF	1.049	111	111	40*	71085	NEA GTPF	1.049	110	110	40*	71086	NEA STPF	1.066	80	80	55*
71251	CANAL G1	1.040	566	566	239*	71252	CANAL G2	1.017	576	576	120*	71094	PLGRM G1	1.040	702	670	165
71060	MYST G4	0.000	133	0	0	71061	MYST 5G	0.000	129	0	0	71062	MYST G6	0.000	136	0	0
71063	MYST G7	1.028	565	565	157	71067	MYS8 GTS	1.046	554	430	157	71068	MYS8 ST	1.074	312	276	157
71069	MYS9 GTS	0.000	554	0	0	71070	MYS9 ST	0.000	312	0	0	71126	KEND CT	1.096	187	187	115*
71073	N.BOST 1	0.000	380	0	0	71074	N.BOST 2	0.000	380	0	0	72066	LOWELL	0.000	94	0	0
71946	SALEM G1	0.000	81	0	0	71947	SALEM G2	0.000	78	0	0	71948	SALEM G3	1.026	143	150	34
71949	SALEM G4	1.028	400	331	101	72869	SBRK G1	1.004	1265	1150	364*	72868	NWNGT G1	0.000	422	0	0
72702	CONEDG1	0.000	169	0	0	72703	CONEDG2	0.000	169	0	0	72704	CONEDG3	0.000	195	0	0
72870	SCHILLER	1.010	48	48	25*	72871	SCHILLER	1.010	50	50	25*	72872	SCHILLER	1.010	48	48	25*
72866	MERMK G1	1.035	113	113	26	72867	MERMK G2	1.035	320	320	74	70365	WF WY #1	1.017	57	57	10
70366	WF WY #2	1.017	57	57	10	70367	WF WY #3	1.016	125	125	20	70368	WF WY #4	1.046	636	626	242*
70705	VTYAK G	0.992	563	496	150*	73083	NRTHFD12	1.025	540	540	151	73084	NRTHFD34	1.025	540	540	151
72512	BRSWP G1	0.984	294	280	49	72513	BRSWP G2	0.984	294	280	49	73085	MT.TOM	0.000	146	0	0
70375	MASON G4	0.000	33	0	0	70376	MASON G5	0.000	33	0	0	70377	AEC G1	1.057	58	57	16
70378	AEC G2	1.057	58	57	16	70379	AEC G3	1.057	58	57	16	72373	MPLP 1PF	1.044	109	80	53*
72374	MPLP 2PF	1.026	45	44	27*	73652	BE 11	0.992	170	170	26	73653	BE 12	0.992	170	170	26
72986	BERKPWR	1.049	305	280	70	73654	BE 10 ST	0.990	180	180	26	73072	ALT12 PF	1.024	65	65	14
73073	ALT34 PF	1.023	81	80	14	73069	MAPR1 PF	1.043	106	56	47*	73070	MAPR2 PF	0.000	106	0	0
73071	MAPR3 PF	0.000	95	0	0	73080	WSPFLD 3	0.976	107	107	-20	70389	BUCKS G4	1.040	191	180	53
70060	MIS GT1	1.067	179	179	88	70061	MIS GT2	1.067	179	179	88	70062	MIS ST	1.066	191	190	88
70386	WBK G1	1.024	185	131	47*	70387	WBK G2	0.000	185	0	0	70388	WBK G3	0.000	196	0	0
70381	RPA CG1	1.040	179	200	53	70382	RPA SG2	1.040	94	100	22	73566	LAKERD#2	0.000	310	0	0
73565	LAKERD#1	0.000	310	0	0	73567	LAKERD#3	0.000	310	0	0	71095	ANPBLCK1	1.077	9999	290	103
71096	ANPBLCK2	1.084	9999	115	103	72671	RISE G1	1.054	176	176	83	72672	RISE G2	1.054	176	176	83
72673	RISE G3	1.052	196	196	83	72377	BELL #1	1.093	290	290	150*	72378	BELL #2	0.000	290	0	0
91787	UAE-CT1	0.000	207	0	0	91786	UAE-CT2	0.000	207	0	0	91787	UAE-CT1	0.000	207	0	0
71950	GRANRDG1	1.034	280	250	24	71951	GRANRDG2	1.033	280	250	22	72701	AESSTG	1.030	250	250	6

	MW	MX		MW	MX		MW	MX
MILLSTONE	2008	142	BRPT-Energy	0	0	MIDDLETOWN	625	126
MONTVILLE	402	151	NORWALK	0	0	BRIDGEPORT	895	277
NHHARBOUR	447	130	DEVON	0	0	BRAYTONPT	1018	206
MANCHSTRST	245	65	SOMERSET	0	0	OSP	240	0
NEA	301	135	PAWTKTPWR	64	-11	ENRON	124	80
CANAL	1142	359	PILGRIM	670	165	MYSTIC	1271	472
NEWBOSTON	0	0	SALEMHBR	481	135	SEABROOK	1150	364
NEWINGTON	0	0	SCHILLER	145	75	MERRIMACK	433	100
STONYBROOK	0	0	WYMAN	865	282	VTYANKEE	496	150
BEARSWAMP	560	99	NORTHFIELD	1080	302	MASSPWRR	56	47
ANP-BELLINGHAM	290	150	ANP-BLACKSTONE	405	206	EMI-TIVERTON	281	104
EMI-DIGHTON	0	0	MILLENNIUM	390	58	ALTRESCO	146	28
MIS	548	264	AEC	171	49	RPA	300	75
Westbrook	131	47	Bucksport	180	53	Meriden	610	110
Wallingford	0	0	HOPE-RISE	548	248	Berkshire	280	70
LakeRd	0	0	Granite-Ridge	750	51	Fore_River	276	-2
Kendall	251	130	UAE_Lowell	0	0	UAE_TEWKS	0	0

INTERFACE FLOWS

BOSTON IMPORT	3600	3970	-249*	NB-NE	700	712	-46	NORWLK-STAMFORD	1000	958	-121
SEMA/RI EXPORT	2200	864	17*	MAINE-NH	1400	1382	-75	NNE-SCOBIE+394	2550	972	-31*
NORTH-SOUTH	3400	2235	-196	SEABROOK-SOUTH	1400	1136	94	CMFD/MOORE-SO	920	212	-60
EAST-WEST	2000	-187	11	SNDYPOND-SOUTH	4000	2502	-53	CONN EXPORT	2100	-1100	135
NY-NE	2200	569	-171	SW CONN IMPORT	1700	1235	100	NEMA/BOS IMPORT	4000	4422	-271*
PLAT PAR	600	116	-6	SEMA EXPORT		161	-237	CONN IMPORT	2500	1106	-195

HVDC TRANSFERS FROM H-Q

HIGHGATE = 215 PHII-P1 = 1000 PHII-P2 = 1000

BUS VOLTAGES

	V	LMT		V	LMT		V	LMT	
72694 SEBRK345 345	353.		71789 TEWKS 345	356.		70786 STOUGHTN 345	356.		
70759 MYSTIC 345	360.		71797 MILLBURY 345	354.		70772 W MEDWAY 345	356.		
70780 WWALP345 345	355.		70783 PILGRIM 345	358.		70773 NEA 336 345	358.		
71193 CANAL 345	358.		70781 HOLBROOK 345	355.		70795 FRMNGHAM 230	234.		
70789 WALTHAM 230	231.		70836 K-ST-1 115	116.		70794 MDWLT230 230	239.	H	
70818 MYSTC MA 115	116.		71891 SALEM HR 115	119.		72096 MILLBURY 115	115.		126.0 *

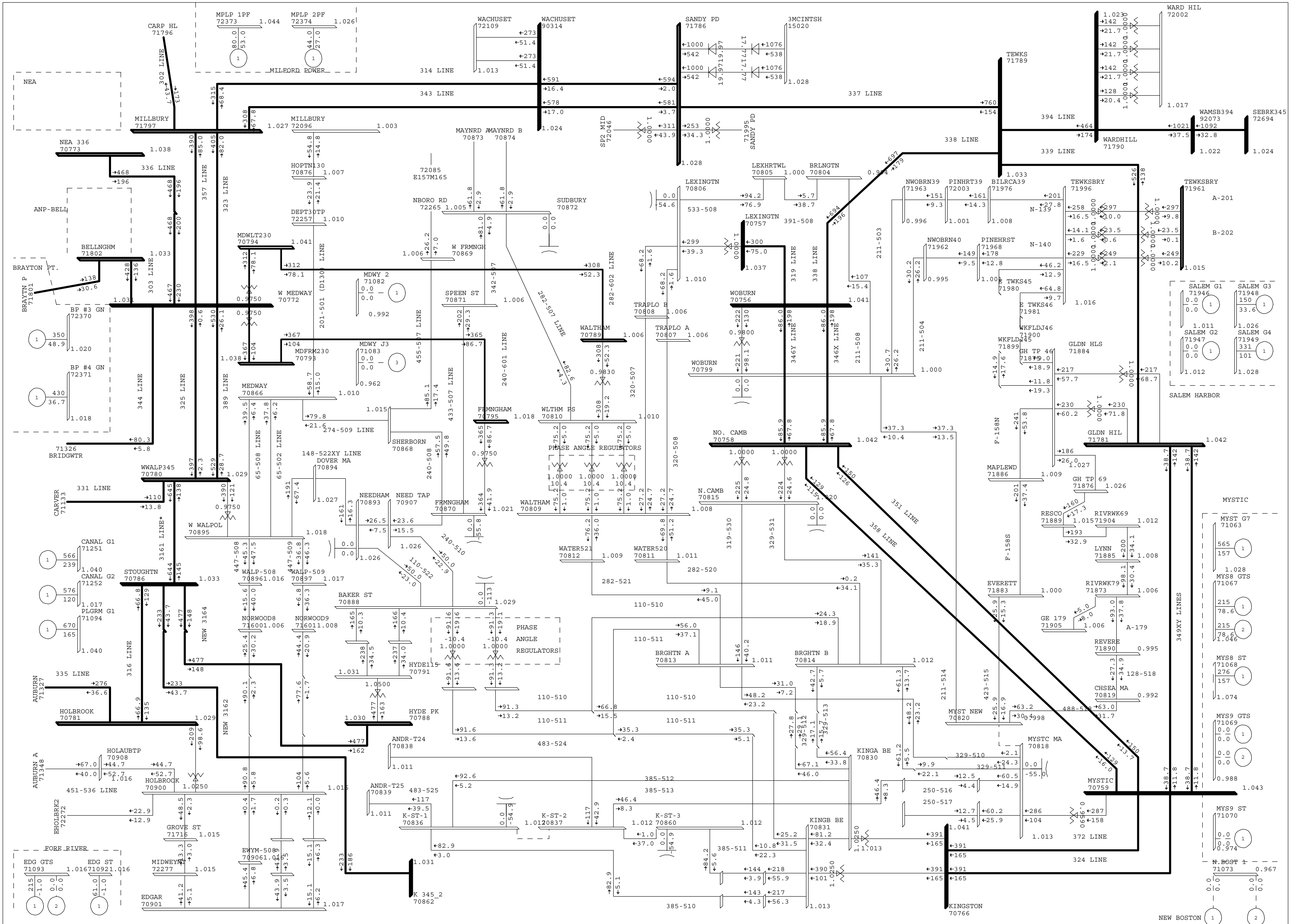
AREA/ZONE TOTALS

NEPOOL_GEN 24377 NEPOOL_LOAD 27216 NEPOOL_LOSS 710 NEPOOL_INT -3555

Appendix 2

Loadflow Diagrams

Plot 1: All Lines In_Pre-Sudbury Cap
Plot 2: All Lines In_Post-Sudbury Cap
Plot 3: L/O 433-507_Pre-Sudbury Cap
Plot 4: L/O 433-507_Post-Sudbury Cap
Plot 5: L/O 433-507_Post-Sudbury Cap_PAR Adjust

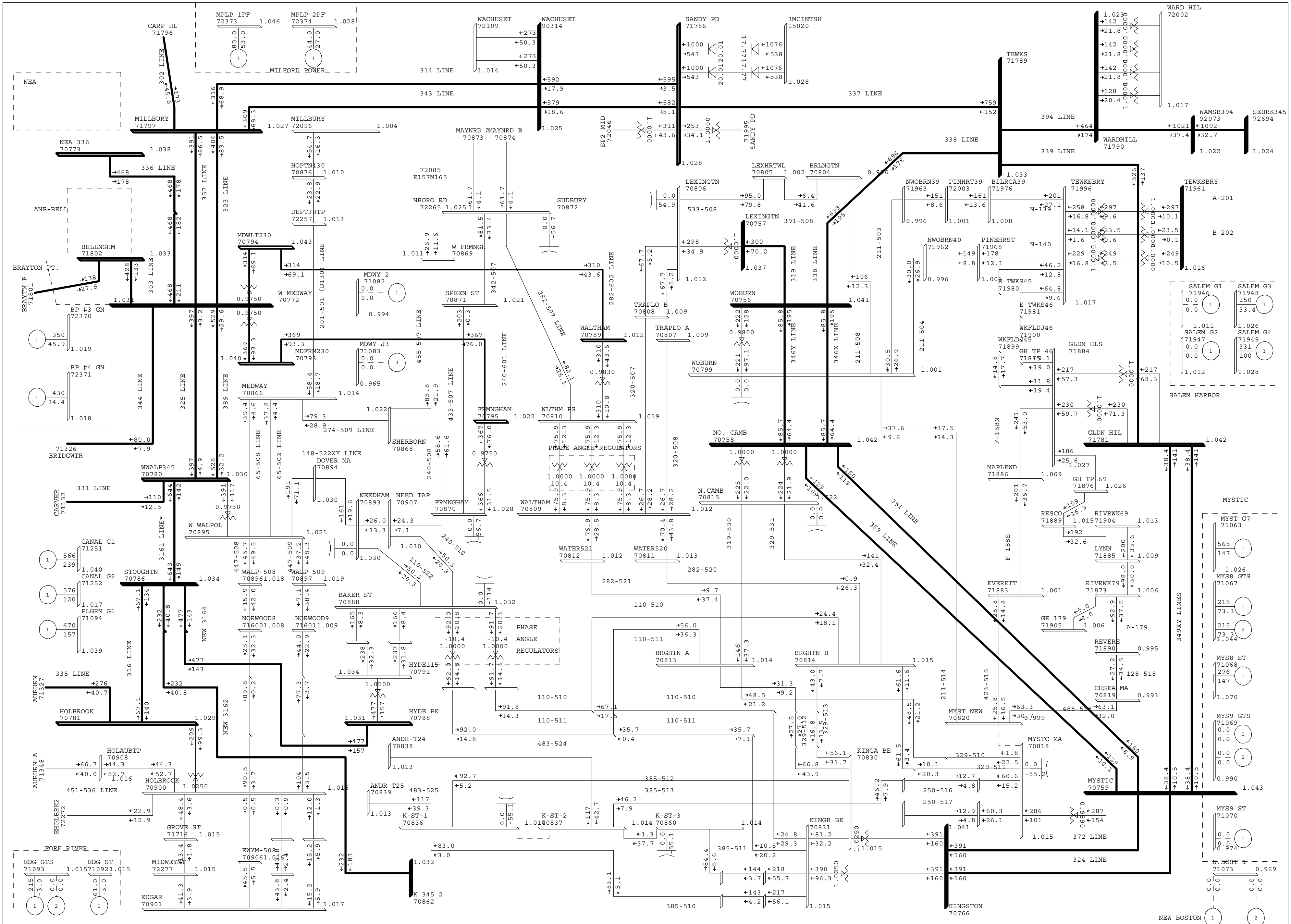


2006 PEAK,27910MW,PAR(4,4),PHASE 11 2000,STAGE 1, NORTH BIAS
NB,M9 OFF K4,SALEM 1-4,MYSTIC7,8 ON
PLOT 1: ALL LINES IN - EXISTING THU, FEB 02 2006 9:36

100% RATEA
0.950 UV 1.050 OV
KV: ≤115 ,≤230 ,≤345

BUS - VOLTAGE(PU)
BRANCH - MW/MVAR
EQUIPMENT - MW/MVAR

POWER TECHNOLOGIES, INC.



2006 PEAK,27910MW,PAR(4,4),PHASE 11 2000,STAGE 1, NORTH BIAS NB,M9 OFF K4,SALEM 1-4,MYSTIC7,8 ON PLOT 2: ALL LINES IN + SUDBURY CAP THU, FEB 02 2006 9:39	100% RATEA 0.950UV 1.050OV KV: ≤115 ,≤230 ,≤345
	BUS -VOLTAGE(PU) BRANCH -MW/MVAR EQUIPMENT -MW/MVAR

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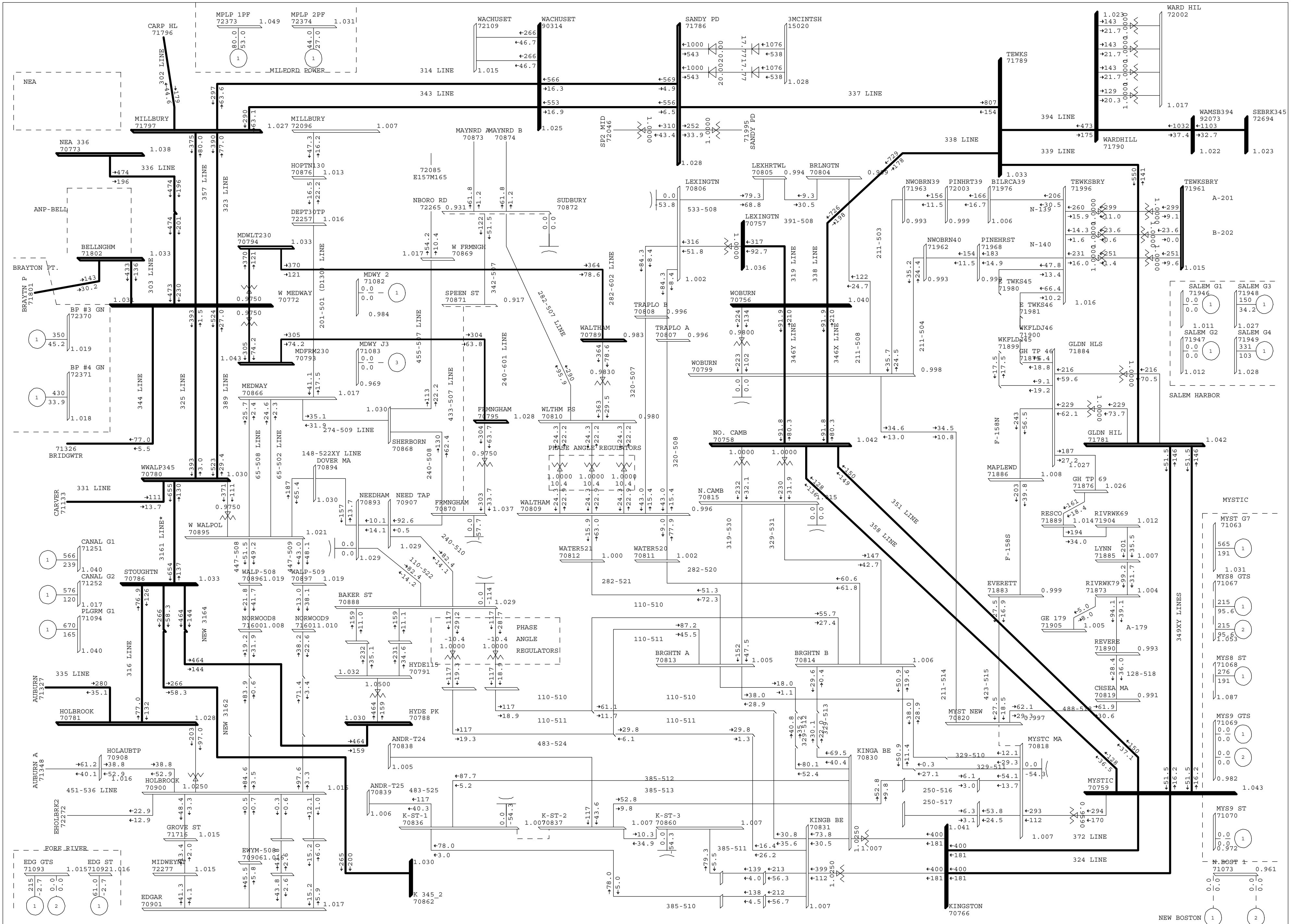

2006 PEAK,27910MW,PAR(4,4),PHASE 11 2000,STAGE 1, NORTH BIAS NB,M9 OFF K4,SALEM 1-4,MYSTIC7,8 ON PLOT 3: L/O 433-507, Existing THU, FEB 02 2006 10:07	100% RATEA 0.950UV 1.050OV KV: ≤115 ,≤230 ,≤345	BUS -VOLTAGE(PU) BRANCH -MW/MVAR EQUIPMENT -MW/MVAR

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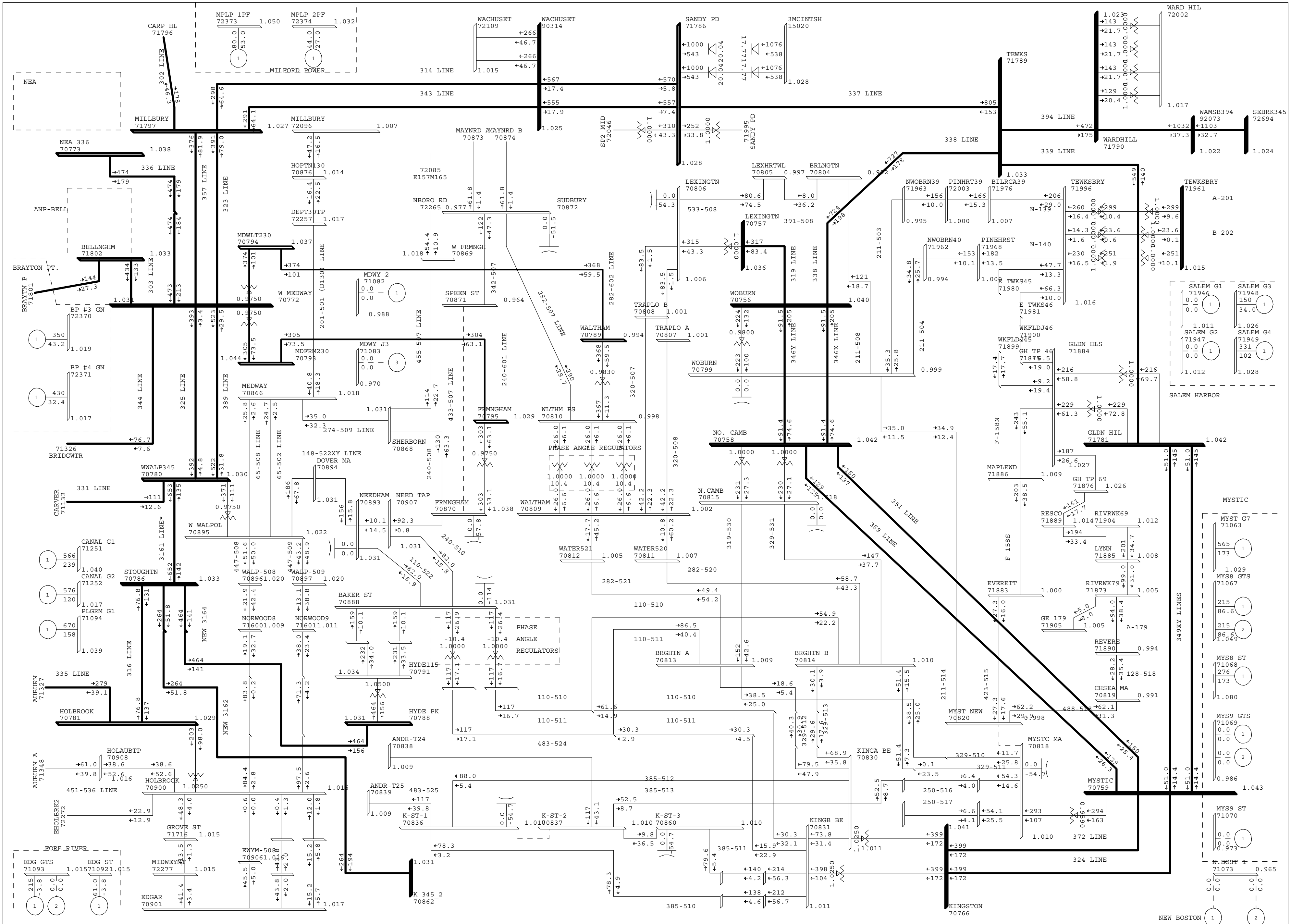
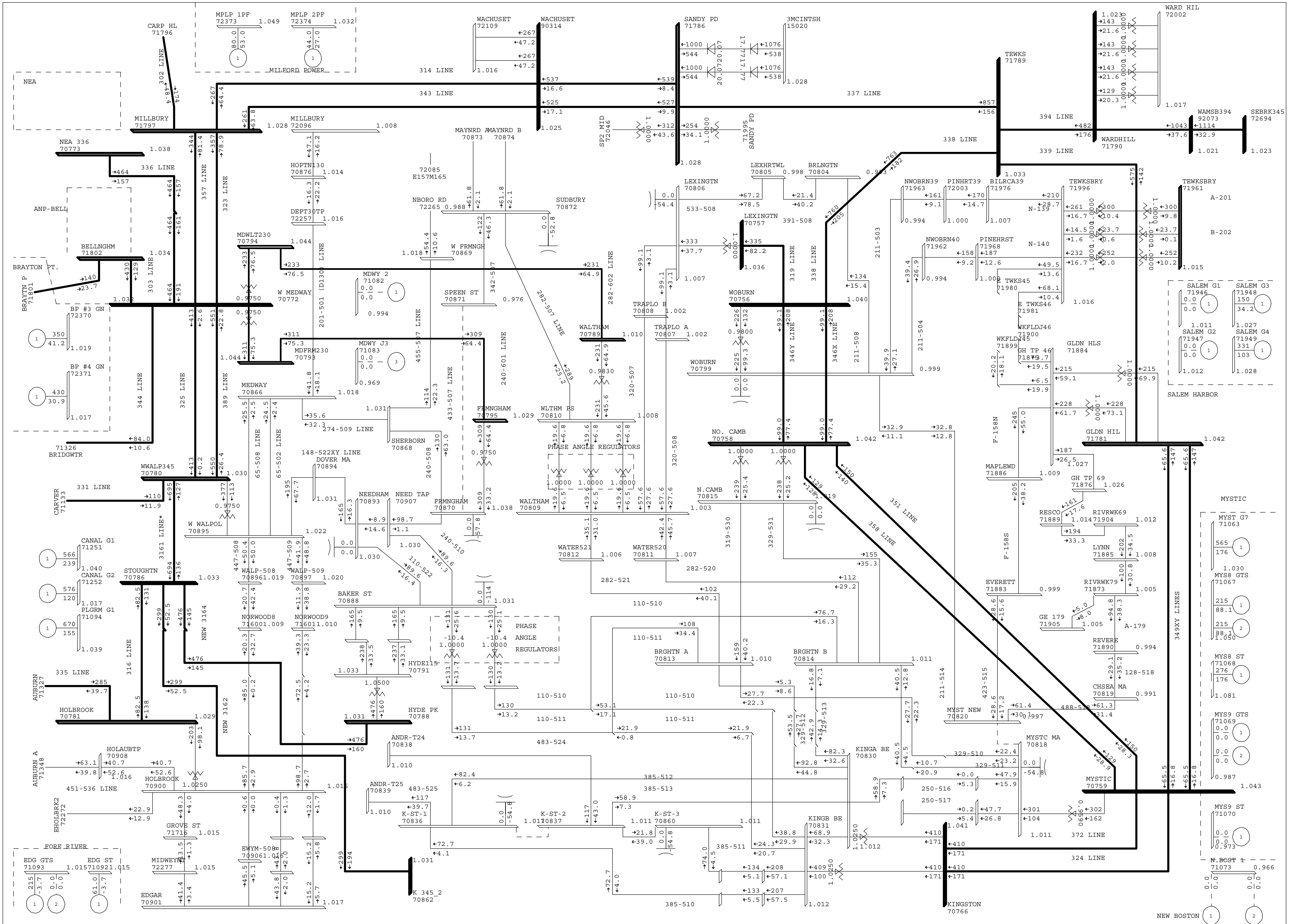


2006 PEAK,27910MW,PAR(4,4),PHASE 11 2000,STAGE 1, NORTH BIAS	100% RATEA	BUS -VOLTAGE(PU)
NB,M9 OFF K4,SALEM 1-4,MYSTIC7,8 ON	0.950UV 1.050OV	BRANCH -MW/MVAR
PLOT 4: L/O 433-507 + SUDBURY CAP THU, FEB 02 2006 10:06	KV: ≤115 ,≤230 ,≤345	EQUIPMENT -MW/MVAR

POWER TECHNOLOGIES, INC.



2006 PEAK,27910MW,PAR(4,4),PHASE 11 2000,STAGE 1, NORTH BIAS
NB,M9 OFF K4,SALEM 1-4,MYSTIC7,8 ON
PLOT 5: L/O 433-507,SUD CAP,PAR ADJUST THU, FEB 02 2006 11:09

100% RATEA
0.950 UV 1.050 OV
KV: ≤115 , ≤230 , ≤345

BUS - VOLTAGE(PU)
BRANCH - MW/MVAR
EQUIPMENT - MW/MVAR

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