Connecticut Cable Resonance Study for Dual DC Option (Case 5b) in Middletown to Norwalk Project

Summary Report
August 2004

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GE Energy
NU MN XLPE Dual DC Case 5b Report.doc

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Foreword

This document was prepared by General Electric Company in Schenectady, New York. It is submitted to Northeast Utilities (NU). Technical and commercial questions and any correspondence concerning this document should be referred to:

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Introduction

GE Energy's Energy Consulting group has performed a resonance study of a dual dc option in the Northeast Utilities (NU) Middletown to Norwalk 345 kV transmission cable project that is proposed in southwestern Connecticut. This option (Case 5b) has two HVDC links: one between East Devon 345 kV and Beseck 345 kV and the other between Norwalk 345 kV and Singer 345 kV. In this study, the two ac cables between Singer and East Devon were represented as 3000 kcmil XLPE cable, and one of the two HPFF cables between Plumtree and Norwalk was removed.

The objectives of this study were

- to investigate the change in the first resonance with the above modifications as compared to the proposed all-ac HPFF double circuit configuration and the XLPE alternative, and
- to investigate the effect of representing reduced generation in the area.

The study has been performed with the Electromagnetic Transients Program (ATP/EMTP), which is recognized as an industry standard for simulating the transient performance and frequency response of electric utility systems [www.emtp.org].

System Representation

The system model used in the Middletown to Norwalk study was used in this study with modifications.

Figure 1 shows the configuration of VSC-HVDC converter terminals and ac XLPE cables for the dual dc option. The impacts of this dual dc option on ac system frequency response, exclusive of the complex interactions associated with ac-dc interactions, were simulated by removing the ac line from East Devon to Beseck 345 kV and removing the ac cables from Norwalk to Singer 345 kV. More detailed representation of the VSC-HVDC was judged unnecessary to obtain a preliminary estimate of the impact on ac system resonances. The requirements for filters in a VSC-HVDC system, which are much less than for a conventional HVDC system, are dependent on details of the converter design and the ac system characteristics. Therefore, the small amount of ac shunt capacitance[1] they might contribute to the system resonant behavior was intentionally ignored.

[1] Typical VSC-HVDC converter ac harmonic filters might contribute MVARs equal to about 10% of the power rating, and would be on the low-voltage side of an interfacing transformer.

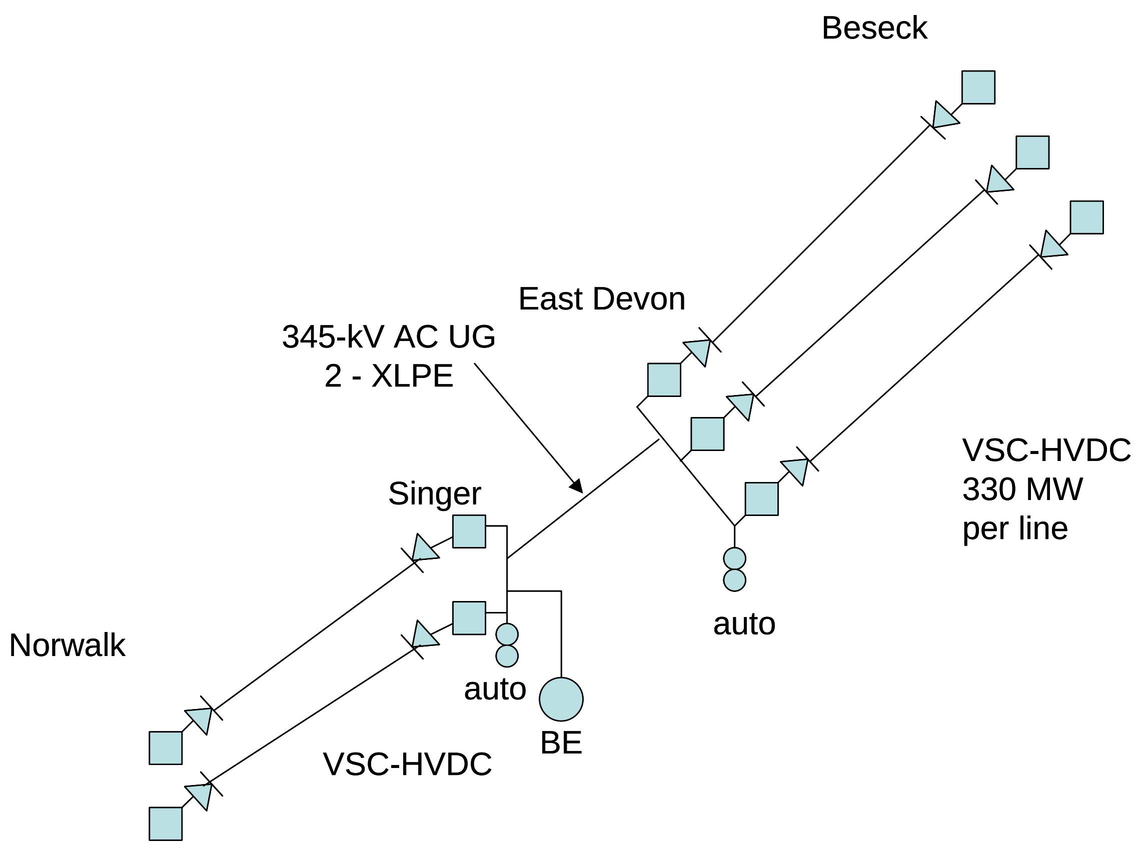


Figure 1. Dual DC Option Configuration

The charging capacitance of the 3000 kcmil XLPE cables is approximately 60% of that of the 2500 kcmil HPFF cables. The following parameters were used to represent the 3000 kcmil XLPE cables (per circuit in pu on a 100 MVA base):

East Devon to Singer - 8.1 miles
Rpos=0.0001817 pu
Rzero=0.0018715 pu
Xpos=0.00217497 pu
Xzero=0.0012426 pu
Bposzero=1.0261907 pu

In addition to the above changes, one of the two 9.7-mile HPFF cable circuits between Plumtree and Norwalk was removed.

NU determined that the two capacitor banks at Norwalk 115 kV would be removed with the addition of the Middletown to Norwalk project, and were removed from the model accordingly. Table 1 shows the modified capacitor bank data for this study, and indicates the total MVAR at each bus and the capacitor bank MVAR in service under peak and light load conditions. This study considered conditions with all capacitor banks in service and all capacitor banks out of service. Table 2 shows the generators included in the original ASPEN file, and the modified status originally provided for the Middletown to Norwalk (M/N) project, which indicates the generators that are on or off during peak and light load conditions. An additional generator dispatch scenario is given for "Light Post-Project," which depicts a more realistic scenario with more local generation off. This study considered the original light load dispatch of generators and the Light Post-Project dispatch with more local generation off.

Table 1. Modified Shunt Capacitor Conditions for System Model

Shunt Capacitors			**All Banks**	**Peak Load**	**Light Load**
Substation	**Voltage (kV)**	**# Units**	**MVAR (total)**	**MVAR**	**MVAR**
Southington 1	115	3	157.2	157.2	
Southington 2	115	3	157.2	157.2	
Frost Bridge	115	5	262.0	262.0	
Berlin	115	3	132.0	132.0	
Plumtree	115	2	92.2	0	
Glenbrook	115	5	190.8*	151.2	
Darien	115	1	39.6	39.6	
Waterside	115	1	39.6	39.6	
Norwalk	115	0	0	0	
East Shore	115	2	84.0	84.0	
No. Haven	115	1	42.0	42.0	
Sackett	115	1	42.0	42.0	
Rocky River	115	1	25.2	25.2	
Stony Hill	115	1	25.2	25.2	
Cross Sound Filters	200	3	103.0 (61 – 25th, 32 – 41st, 10 – 21st)	103.0	103.0

* Actual maximum including Glenbrook Statcom is 335 MVAR (additional MVAR not included in analysis)

Table 2. Modified Generator Conditions for System Model

GENERATOR	KV	ID	ST	STATUS (PEAK)	STATUS (LIGHT)	Light Post-Project	IDENTIFI-CATION NOTES
MILLSTON	22.8	1	1	on	on	On	
MILLSTON	22.8	1	1	on	on	On	
RESCO	115	1	1	on	on	On	Bridgeport
ROCKY RV	13.8	1	1	on	on	Off	
ROCKY RV	13.8	1	1	on	on	Off	
ROCKY RV	13.8	1	1	on	on	Off	
STEVENSO	6.9	1	1	off	off	Off	
NORWALK	27.6	1	0	off	off	Off	
BULLS BR	27.6	1	1	on	on	Off	
FORESTVI	13.8	1	1	on	on	On	
brdgphbr	18.4	2	1	off	off	Off	
brdgphbr	20.2	3	1	on	on	Off	
brdgphbr	13.68	jt	1	off	off	Off	
COSCOBGE	13.8	1	1	off	off	Off	
COSCOBGE	13.8	2	1	off	off	Off	
COSCOBGE	13.8	3	1	off	off	Off	
DEVON 11	13.8	1	1	off	off	Off	
DEVON 12	13.8	1	1	off	off	Off	
DEVON 13	13.8	1	1	off	off	Off	
DEVON 14	13.8	1	1	off	off	Off	
English	13.68	8	1	off	off	Off	
English	13.68	7	1	off	off	Off	
ESHOREGE	13.8	1	1	on	on	Off	New Haven
G1/G2	13.8	1	1	off	off	Off	Wallingford
G3/G4	13.8	1	1	off	off	Off	Wallingford
G5	13.8	1	1	off	off	Off	Wallingford
GT1 (11)	16	1	1	off	off	Off	BE
GT2 (12)	16	1	1	off	off	Off	BE
Middleto	22	1	1	on	off	Off	Middletown
Milford	20.9	1	1	on	on	Off	
Milford	20.9	1	1	off	off	Off	
one (Meriden)	21	1	1	on	off	Off	Meriden
Shepaug	13.8	1	1	on	on	Off	
so norwa	4.8	1	1	off	off	Off	
so norwa	4.8	1	1	off	off	Off	
so norwa	13.8	1	1	off	off	Off	
ST1 (10)	16	1	1	off	off	Off	BE
Temp Gen (Waterside)	13.8	3	0	off	off	Off	Waterside
Temp Gen (Waterside)	13.8	1	0	off	off	Off	Waterside
Temp Gen (Waterside)	13.8	2	0	off	off	Off	Waterside
three (Meriden)	21	1	1	on	off	Off	Meriden

GENERATOR	KV	ID	ST	STATUS (PEAK)	STATUS (LIGHT)	Light Post-Project	IDENTIFI-CATION NOTES
two (Meriden)	21	1	1	on	off	Off	Meriden
Unit 10	13.8	1	1	off	off	Off	Devon 10
Unit 6J- (Norwalk)	17.1	1	1	off	off	Off	Norwalk-1
Unit 6J- (Norwalk)	13.8	1	1	off	off	Off	Norwalk -10
Unit 6J- (Norwalk)	19	1	1	off	on	Off	Norwalk-2
Unit 7	13.2	1	1	on	off	Off	Devon
Unit 8	13.2	1	1	on	off	Off	Devon
walrecge	4.16	1	1	on	off	Off	

Resonance Results

The resonance effects of the dual dc option was analyzed by evaluating the driving-point impedance versus frequency at various locations, with all capacitor banks in and out of service, and with the original light load and light post-project generator (local generation off) dispatches.

Table 3 shows the cases that were performed for the dual dc option and the resonant frequencies that were observed along with the corresponding impedance value at those frequencies, with the original light load generation dispatch. The resonant frequency is indicated by its harmonic number (HN), in per unit of 60 Hz, and impedance magnitude is in ohms. The corresponding driving-point impedance plots are provided in Appendix A. Table 4 shows the results with the local generation off (light post-project generator dispatch), and the corresponding driving-point impedance plots are provided in Appendix B.

Table 3. Resonant Frequencies for M/N-XLPE Project with Light Load Generation Beseck-East Devon & Singer-Norwalk DC Links

Case	Location	Capacitor Banks	Resonant Frequency & Impedance (pu of 60Hz, Ohm)					
			Low		Middle		High	
			HN	Z(Ω)	HN	Z(Ω)	HN	Z(Ω)
M/N-XLPE-DC_1B	Plumtree 345 kV	All in Service	2.9	134	4.4 6.1	155 216	7.9	224
M/N-XLPE-DC_1C	Plumtree 345 kV	All Out of Service	3.8	156	5.0	549		
M/N-XLPE-DC_2B	Plumtree 115 kV	All in Service	2.9	21	4.4 6.1	26 53	10.0	90
M/N-XLPE-DC_2C	Plumtree 115 kV	All Out of Service	3.8	19	5.0	48	14.0	125
M/N-XLPE-DC_3B	Norwalk 345 kV	All in Service	2.9	152	4.4 6.1	181 179	7.8	344
M/N-XLPE-DC_3C	Norwalk 345 kV	All Out of Service	3.8	187	5.0	639		
M/N-XLPE-DC_4B	Norwalk 115 kV	All in Service	2.9	17	4.5	16		
M/N-XLPE-DC_4C	Norwalk 115 kV	All Out of Service	3.8	17	5.0	29	8.5 15.9	20 37
M/N-XLPE-DC_5B	Southington 345 kV	All in Service	2.9	66	4.3	105	12.1	129
M/N-XLPE-DC_5C	Southington 345 kV	All Out of Service	3.7	49	4.9	66	9.5	285
M/N-XLPE-DC_6B	Southington 115 kV	All in Service	2.9	11	4.3 5.3	25 28	9.4	125
M/N-XLPE-DC_6C	Southington 115 kV	All Out of Service	3.7	8			9.3	28
M/N-XLPE-DC_7B	East Shore 345 kV	All in Service	2.9	63	6.2	226	14.6	571
M/N-XLPE-DC_7C	East Shore 345 kV	All Out of Service	3.7	67			9.2	218
M/N-XLPE-DC_8B	Devon 115 kV	All in Service	2.9	13				
M/N-XLPE-DC_8C	Devon 115 kV	All Out of Service	3.9	22				
M/N-XLPE-DC_9B	Frost Bridge 115 kV	All in Service	2.9	19	4.3 5.3	27 28	8.4	31
M/N-XLPE-DC_9C	Frost Bridge 115 kV	All Out of Service	3.8	11	5.0	14	9.2	22
M/N-XLPE-DC_10B	Glenbrook 115 kV	All in Service	2.9	18	4.3 4.5	21 23		
M/N-XLPE-DC_10C	Glenbrook 115 kV	All Out of Service	3.8	17	5.0	24	8.1 16.0	41 57
M/N-XLPE-DC_11B	Singer 345 kV	All in Service	2.9	248	4.4	2083		
M/N-XLPE-DC_11C	Singer 345 kV	All Out of Service	3.9	1002				
M/N-XLPE-DC_12B	Devon 345 kV	All in Service	2.9	248	4.4	2085		
M/N-XLPE-DC_12C	Devon 345 kV	All Out of Service	3.9	1002	5.1	564		
M/N-XLPE-DC_13B	Beseck 345 kV	All in Service	2.9	55	4.3	81	12.1	394
M/N-XLPE-DC_13C	Beseck 345 kV	All Out of Service	3.7	50	4.9	68	9.5	354

Table 4. Resonant Frequencies for M/N-XLPE Project with Local Generators Off Beseck-East Devon & Singer-Norwalk DC Links

Case	Location	Capacitor Banks	Resonant Frequency & Impedance (pu of 60Hz, Ohm)					
			Low		Middle		High	
			HN	Z(Ω)	HN	Z(Ω)	HN	Z(Ω)
M/N-XLPE2-DC_1B	Plumtree 345 kV	All in Service	2.6	97	4.3	146	7.7	240
					6.0	198		
M/N-XLPE2-DC_1C	Plumtree 345 kV	All Out of Service	3.4	111	5.0	489		
M/N-XLPE2-DC_2B	Plumtree 115 kV	All in Service	2.6	16	4.3	26	9.9	88
					6.0	50		
M/N-XLPE2-DC_2C	Plumtree 115 kV	All Out of Service	3.3	15	5.0	44	13.9	115
M/N-XLPE2-DC_3B	Norwalk 345 kV	All in Service	2.6	113	4.3	165	7.7	352
					6.0	167		
M/N-XLPE2-DC_3C	Norwalk 345 kV	All Out of Service	3.4	134	5.0	570		
M/N-XLPE2-DC_4B	Norwalk 115 kV	All in Service	2.6	14	4.3	16		
M/N-XLPE2-DC_4C	Norwalk 115 kV	All Out of Service	3.4	14	5.0	28	8.4	19
							15.8	35
M/N-XLPE2-DC_5B	Southington 345 kV	All in Service	2.5	51	4.2	107	12.1	127
M/N-XLPE2-DC_5C	Southington 345 kV	All Out of Service	3.3	43	4.9	64	9.4	264
M/N-XLPE2-DC_6B	Southington 115 kV	All in Service	2.5	9	4.2	24	9.4	118
					5.3	23		
M/N-XLPE2-DC_6C	Southington 115 kV	All Out of Service	3.3	8			9.1	27
M/N-XLPE2-DC_7B	East Shore 345 kV	All in Service	2.5	68	6.1	256	14.2	456
M/N-XLPE2-DC_7C	East Shore 345 kV	All Out of Service	3.3	70			9.1	245
M/N-XLPE2-DC_8B	Devon 115 kV	All in Service	2.6	15	4.2	12		
M/N-XLPE2-DC_8C	Devon 115 kV	All Out of Service	3.4	21				
M/N-XLPE2-DC_9B	Frost Bridge 115 kV	All in Service	2.6	13	4.2	29	8.3	32
					5.3	26		
M/N-XLPE2-DC_9C	Frost Bridge 115 kV	All Out of Service	3.3	9	4.9	13	9.0	21
M/N-XLPE2-DC_10B	Glenbrook 115 kV	All in Service	2.6	15	4.3	23		
					5.3	17		
					6.1	18		
M/N-XLPE2-DC_10C	Glenbrook 115 kV	All Out of Service	3.4	14	4.9	24	8.4	39
							15.9	55
M/N-XLPE2-DC_11B	Singer 345 kV	All in Service	2.6	242	4.3	1528		
M/N-XLPE2-DC_11C	Singer 345 kV	All Out of Service	3.5	628	5.0	532		
M/N-XLPE2-DC_12B	Devon 345 kV	All in Service	2.6	242	4.3	1529		
M/N-XLPE2-DC_12C	Devon 345 kV	All Out of Service	3.5	628	5.0	533		
M/N-XLPE2-DC_13B	Beseck 345 kV	All in Service	2.5	44	4.2	83	12.1	387
M/N-XLPE2-DC_13C	Beseck 345 kV	All Out of Service	3.3	44	4.9	67	9.4	325

Conclusions

Table 5 summarizes the variation in frequencies of the first resonance points for the M/N project, for the XLPE alternative, and for the dual dc option, with the original light load generator dispatch. Table 6 summarizes the variation in frequencies of the first resonance points in the light post-project dispatch with more local generation off. With the dual dc option and with the original light load generator dispatch, the first resonance is between 2.9 and 3.8 pu of 60 Hz at most 345 kV buses, with all capacitor banks in and out of service, respectively. With the dual dc option and with more local generation off, the first resonance is between 2.6 and 3.4 pu of 60 Hz at most 345 kV buses, with all capacitor banks in and out of service, respectively.

Table 5. Variation in Frequency of First Resonance Points (pu 60 Hz) with Original Light Load Generator Dispatch

115 kV Capacitor Bank Conditions	M/N Project with HPFF Cable	M/N Project with XLPE Cable	Dual DC Option (Case 5b)
All in service	2.4	2.8	2.9
All out of service	2.8	3.5	3.8

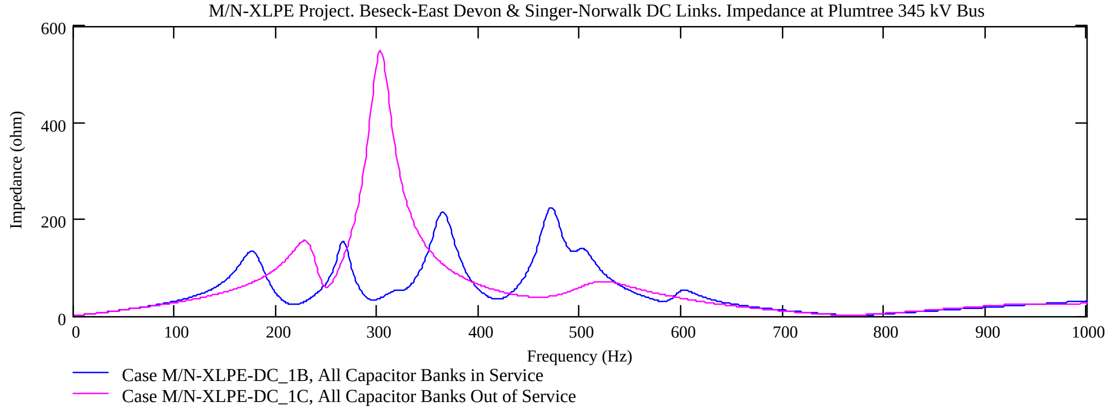
Table 6. Variation in Frequency of First Resonance Points (pu 60 Hz) in Light Post-Project Dispatch with More Local Generators Off

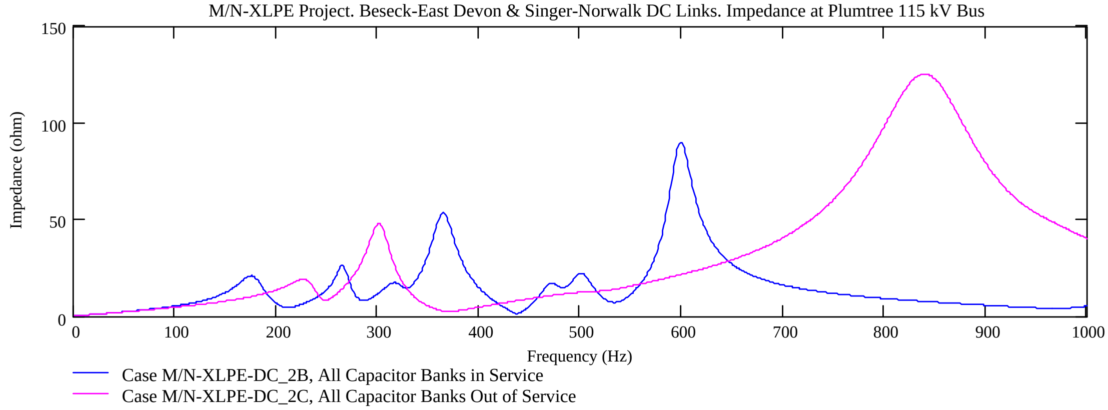
115 kV Capacitor Bank Conditions	M/N Project with HPFF Cable	M/N Project with XLPE Cable	Dual DC Option (Case 5b)
All in service	-	2.5	2.6
All out of service	-	3.3	3.4

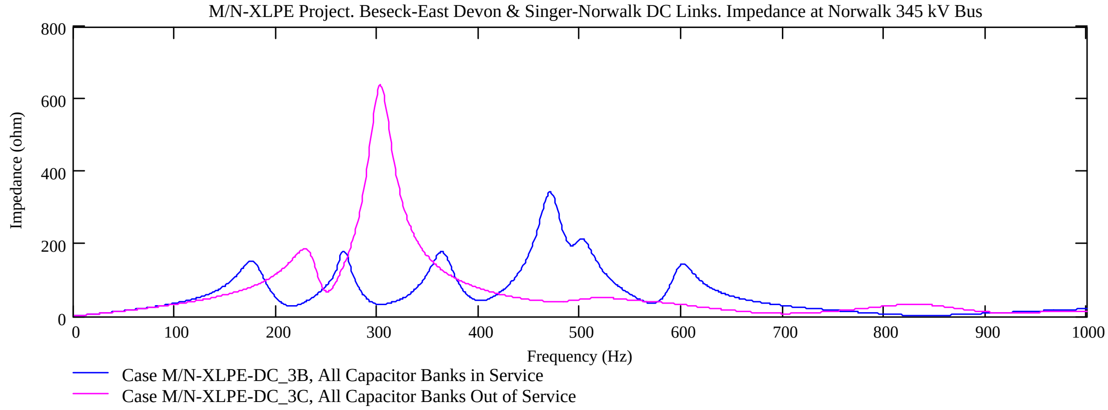
The replacement of overhead line from East Devon to Beseck and cables from Norwalk to Singer with two VSC-HVDC links results in a slightly higher frequency of the first resonance, as compared to the all-ac XLPE alternative. Although the dc link from Norwalk to Singer removes ac cable charging, it also reduces short-circuit strength of the 345 kV system, resulting in resonances below 3rd harmonic. With the original light load generator dispatch and all capacitor banks in service, the frequency is 2.9 pu of 60 Hz. Risk of sustained overvoltages due to transformer inrush is increased when resonances are near 3rd harmonic or below. System outages are another important consideration, since a variety of outages would similarly cause variation in resonant frequencies, because of the effect of changing either the strength of the system or the effective charging capacitance in the system. Consideration of minimum generator dispatches and system outages (such as an outage of the line from Plumtree to Long Mountain) which would weaken the system together with the maximum allowable 115 kV capacitor bank dispatches and 345 kV cable charging capacitance would result in the lowest frequencies of the first resonance. If all first resonances were located above 3rd harmonic, under such a range of variations, the risk of sustained overvoltages due to transformer inrush would be reduced. However, if varying system conditions result in resonances below 3rd harmonic, then extensive transient studies should be performed to investigate transformer inrush scenarios, under a range of system conditions. Fault and clear scenarios are particularly critical since special circuit breaker closing enhancements have no effect. If the dual dc option studied here is to be considered, then extensive transient studies would be recommended.

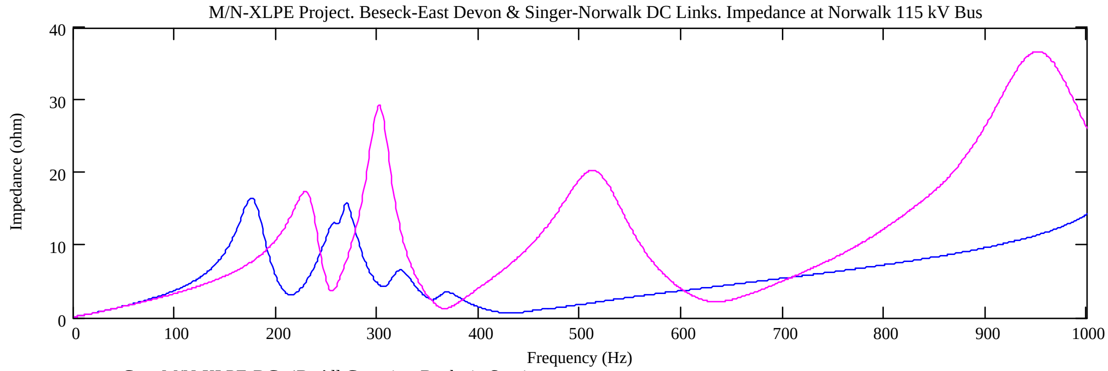
In addition to the resonances observed below 3rd harmonic, resonances at slightly higher frequencies are also of significant concern. At Singer and East Devon 345 kV, the XLPE cable system has been isolated from the rest of the 345 kV ac system due to the dc links, and resonances of very high magnitude are observed between 4th and 5th harmonic frequencies. These resonances, which are extremely poorly damped, would be expected to contribute to significant oscillatory behavior during transient disturbances. This XLPE cable system, connecting to dc converters at each end and autotransformers, are expected to have significant transient and temporary overvoltage issues. Additionally, the VSC-HVDC controls must be designed carefully to perform properly with the resonance characteristics observed at Singer and East Devon 345 kV. This dual dc option, having an ac cable system in the middle, appears technically inadvisable.

Appendix A Driving-Point Impedance Plots with Light Load Generation

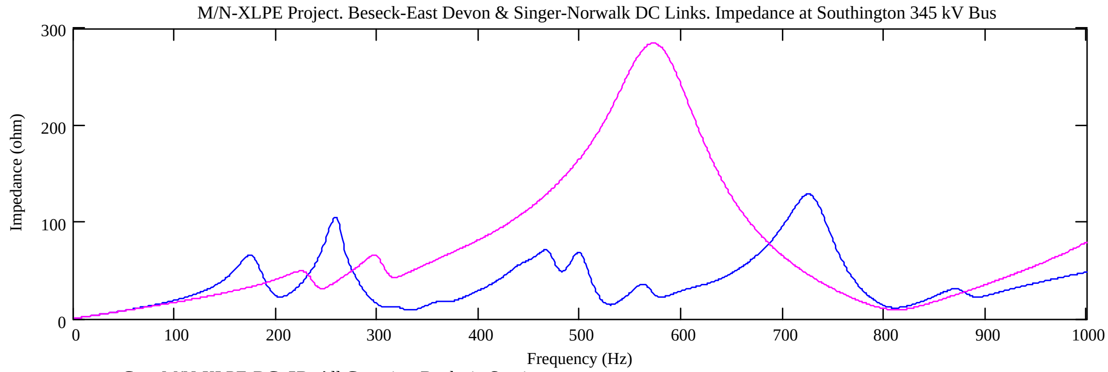




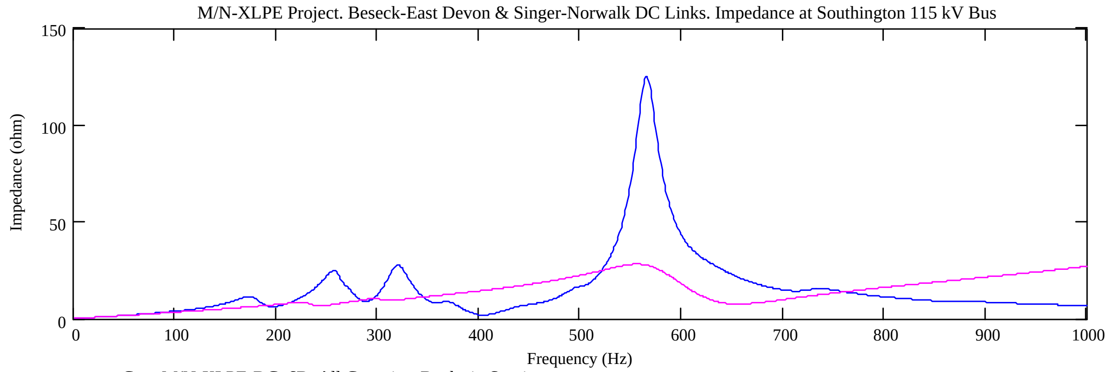




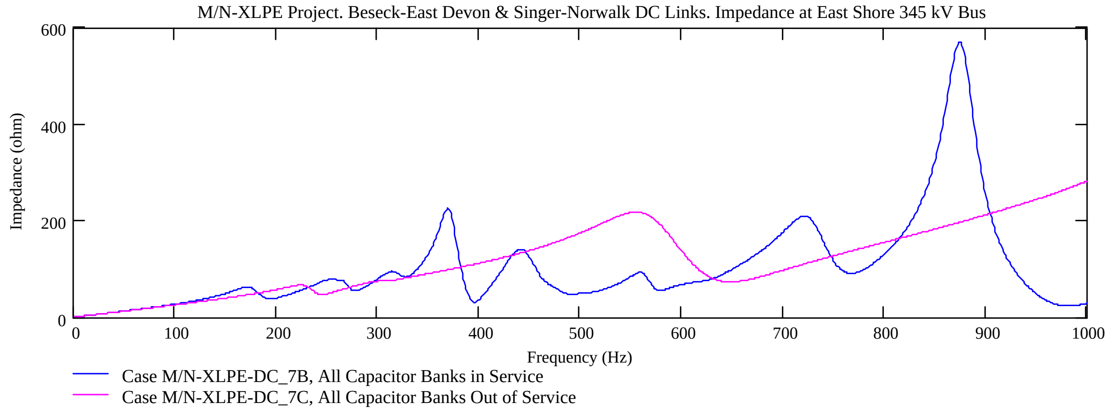
Case M/N-XLPE-DC_4B, All Capacitor Banks in Service
Case M/N-XLPE-DC_4C, All Capacitor Banks Out of Service

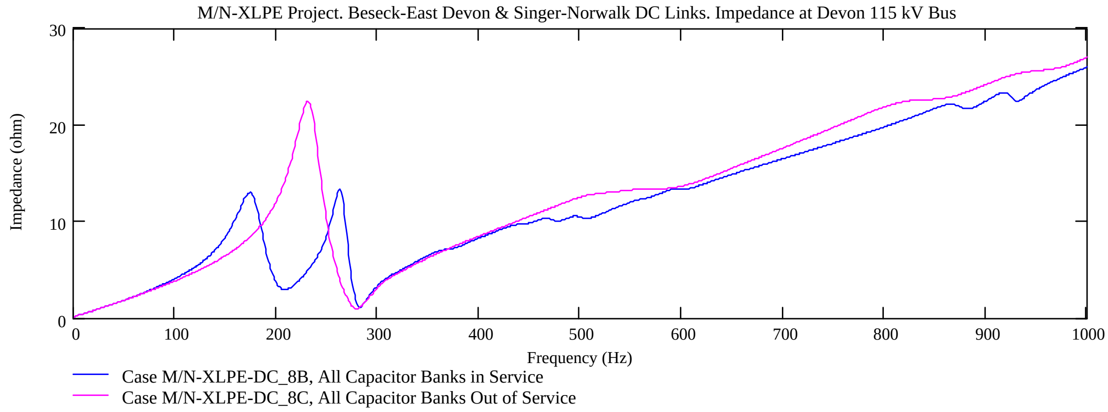


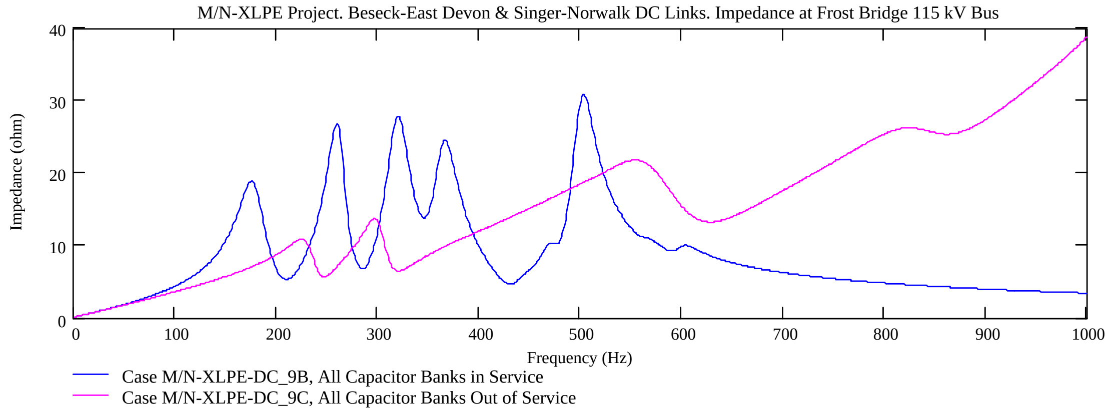
Case M/N-XLPE-DC_5B, All Capacitor Banks in Service
Case M/N-XLPE-DC_5C, All Capacitor Banks Out of Service

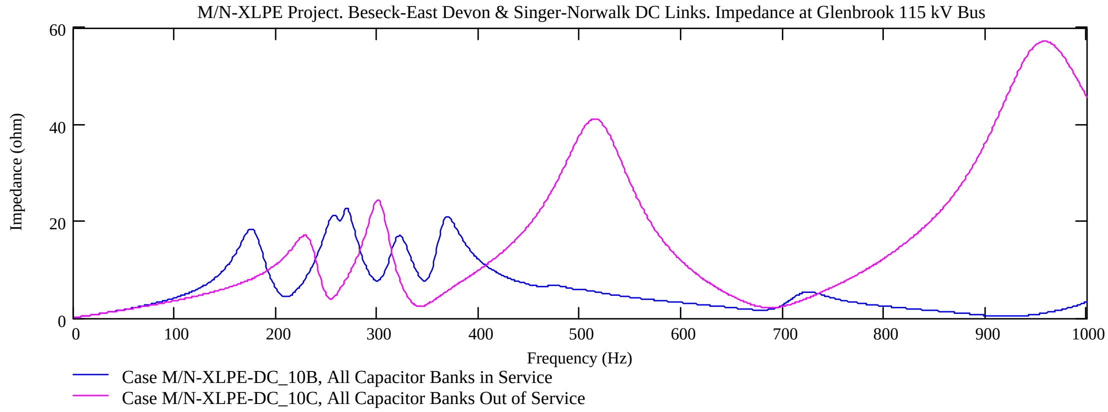


Case M/N-XLPE-DC_6B, All Capacitor Banks in Service
Case M/N-XLPE-DC_6C, All Capacitor Banks Out of Service

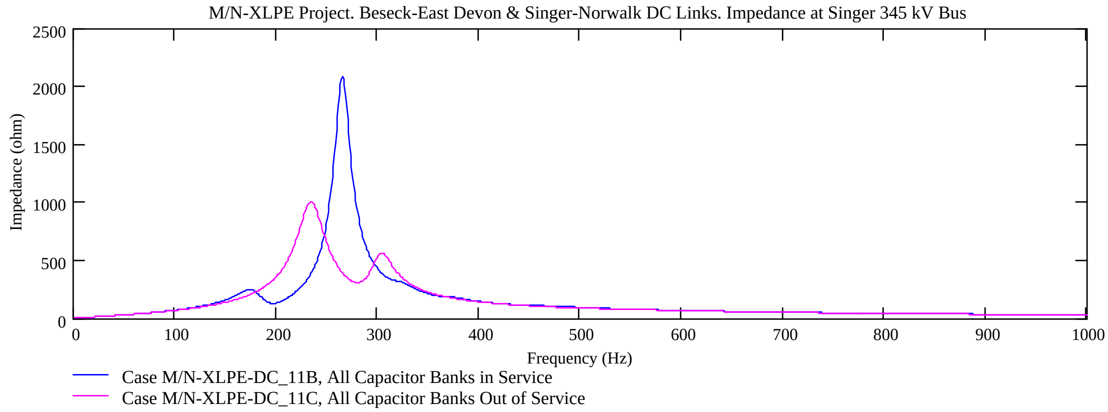

M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at East Shore 345 kV Bus
Impedance (ohm)
0
200
400
600
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE-DC_7B, All Capacitor Banks in Service
Case M/N-XLPE-DC_7C, All Capacitor Banks Out of Service


M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Devon 115 kV Bus
Impedance (ohm)
0
10
20
30
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE-DC_8B, All Capacitor Banks in Service
Case M/N-XLPE-DC_8C, All Capacitor Banks Out of Service

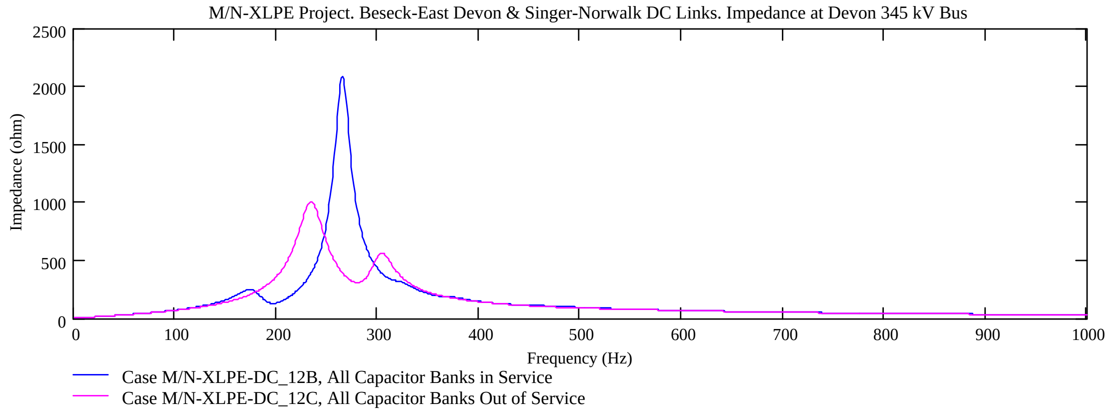

M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Frost Bridge 115 kV Bus
Impedance (ohm)
0
10
20
30
40
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE-DC_9B, All Capacitor Banks in Service
Case M/N-XLPE-DC_9C, All Capacitor Banks Out of Service



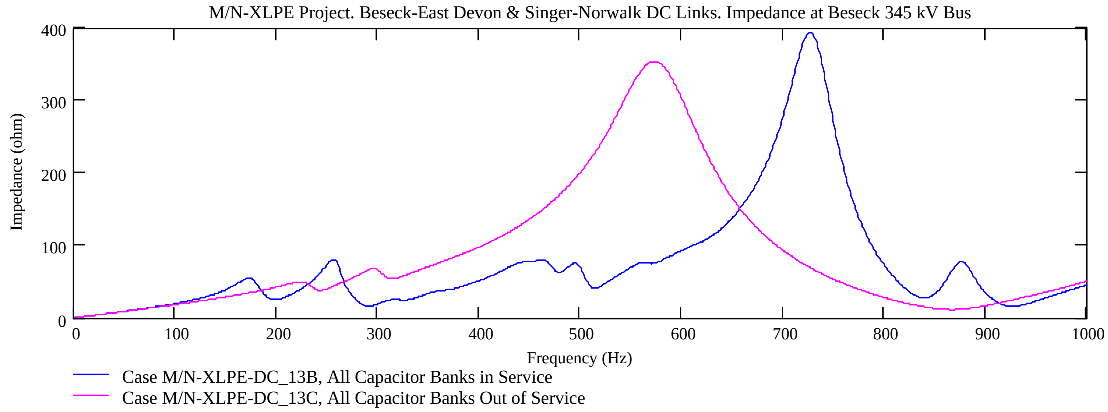
M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Glenbrook 115 kV Bus
Impedance (ohm)
Frequency (Hz)
Case M/N-XLPE-DC_10B, All Capacitor Banks in Service
Case M/N-XLPE-DC_10C, All Capacitor Banks Out of Service



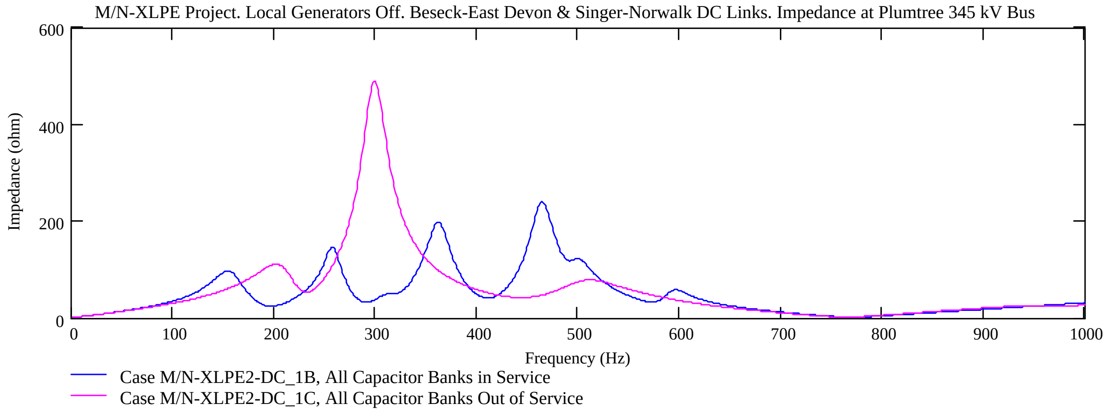
M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Singer 345 kV Bus
Impedance (ohm)
Frequency (Hz)
Case M/N-XLPE-DC_11B, All Capacitor Banks in Service
Case M/N-XLPE-DC_11C, All Capacitor Banks Out of Service

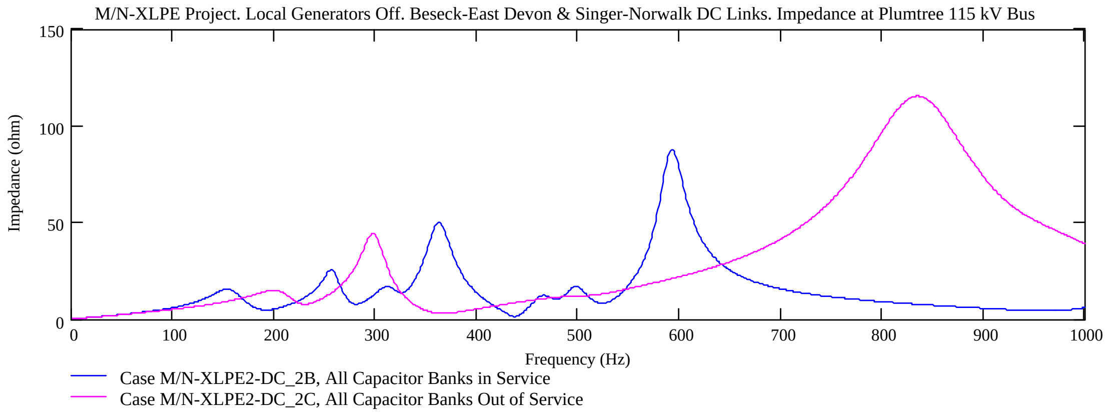


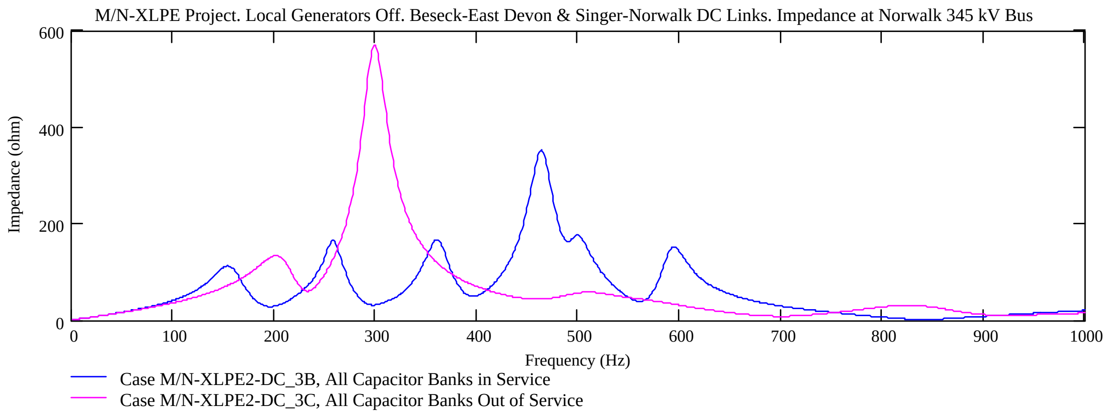
M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Devon 345 kV Bus
Impedance (ohm)
Frequency (Hz)
Case M/N-XLPE-DC_12B, All Capacitor Banks in Service
Case M/N-XLPE-DC_12C, All Capacitor Banks Out of Service

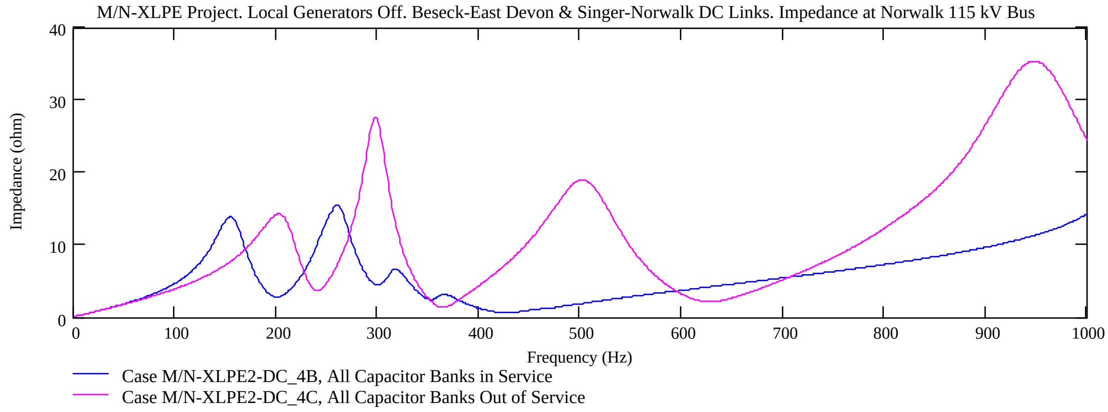

M/N-XLPE Project. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Beseck 345 kV Bus
Impedance (ohm)
0
100
200
300
400
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE-DC_13B, All Capacitor Banks in Service
Case M/N-XLPE-DC_13C, All Capacitor Banks Out of Service

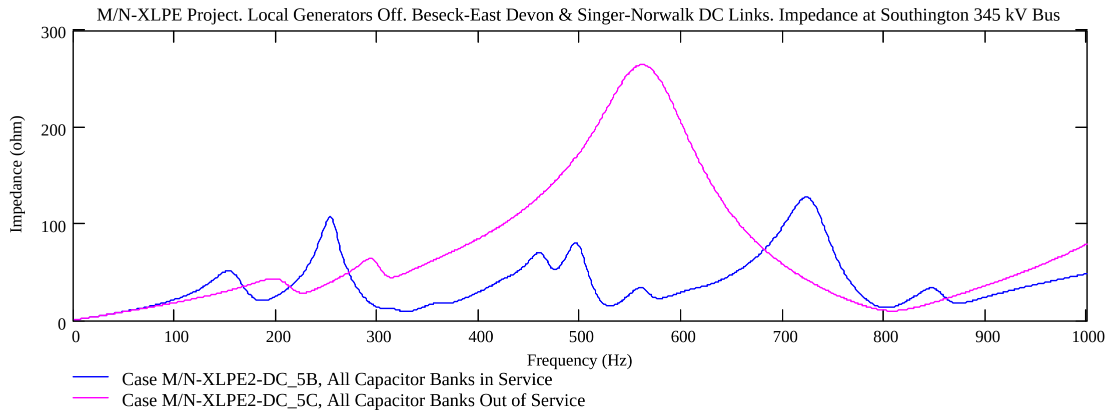
Appendix B Driving-Point Impedance Plots with Local Generators Off

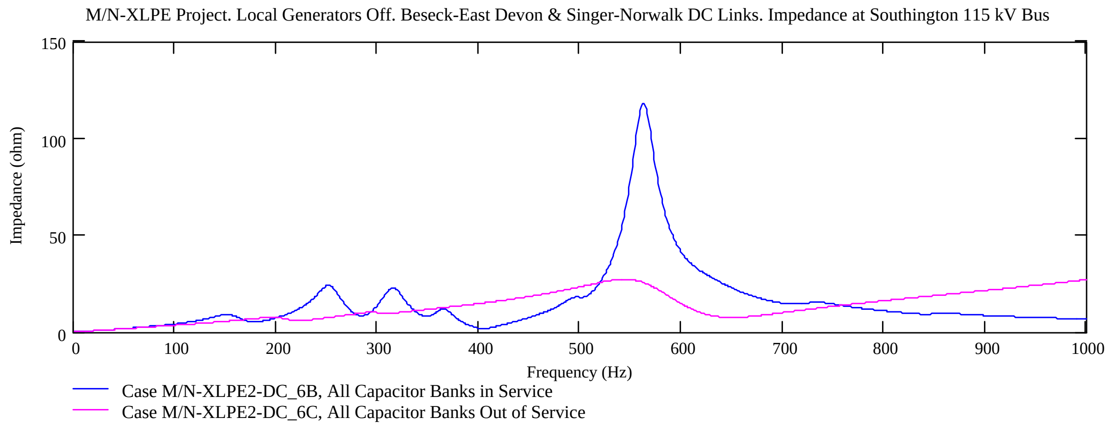


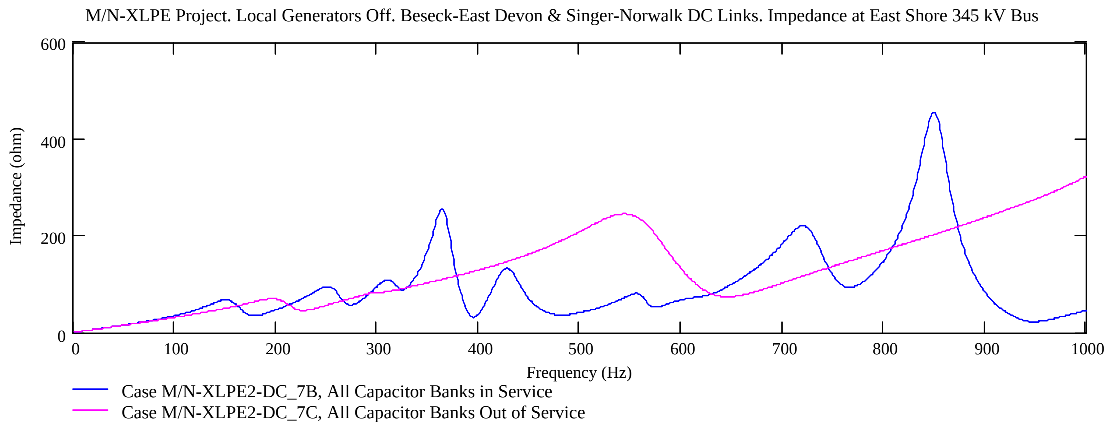


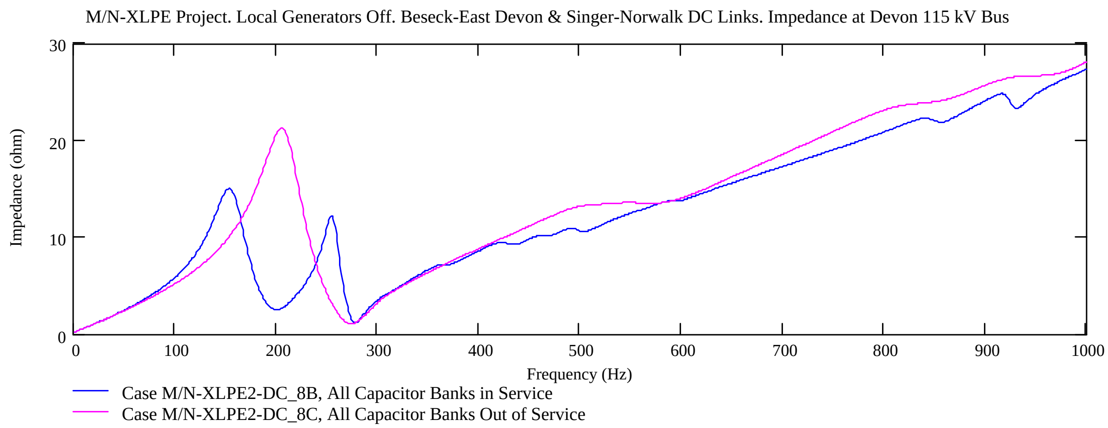


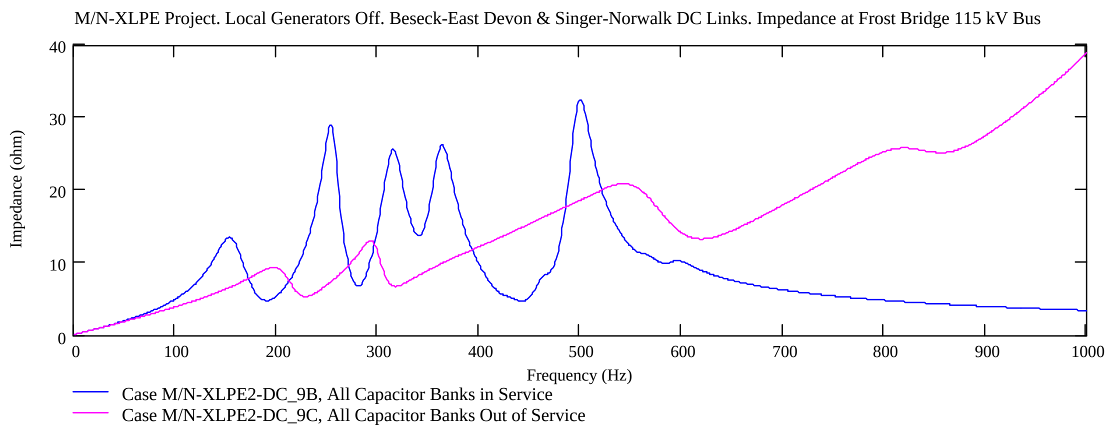

M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Norwalk 115 kV Bus
Impedance (ohm)
0
10
20
30
40
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_4B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_4C, All Capacitor Banks Out of Service

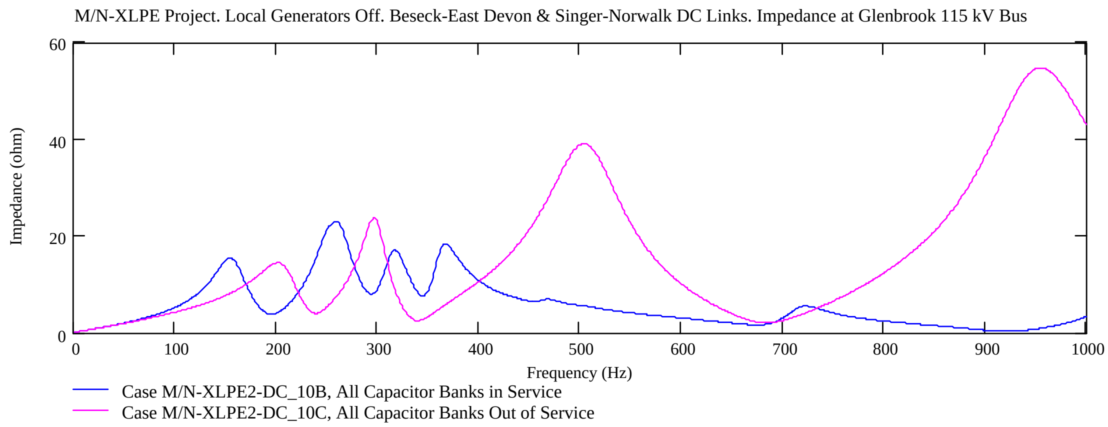

M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Southington 345 kV Bus
Impedance (ohm)
0
100
200
300
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_5B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_5C, All Capacitor Banks Out of Service

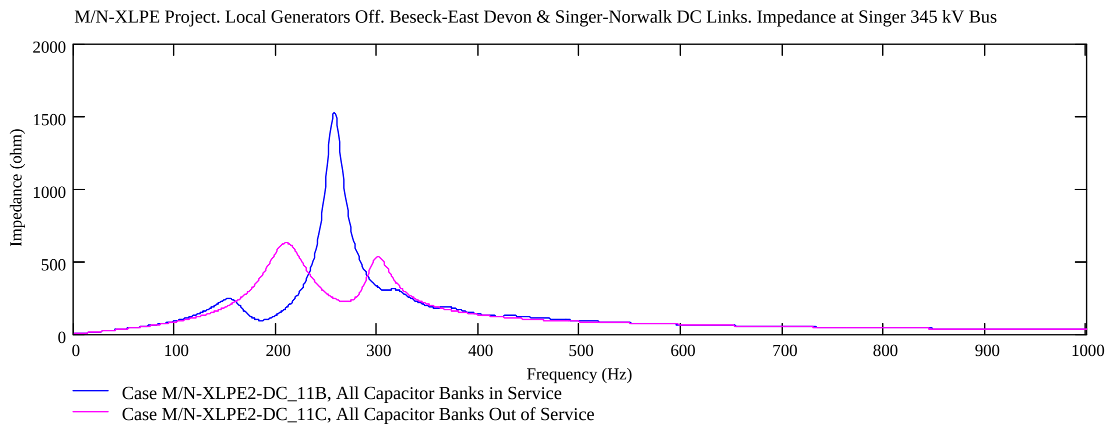

M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Southington 115 kV Bus
Impedance (ohm)
0
50
100
150
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_6B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_6C, All Capacitor Banks Out of Service

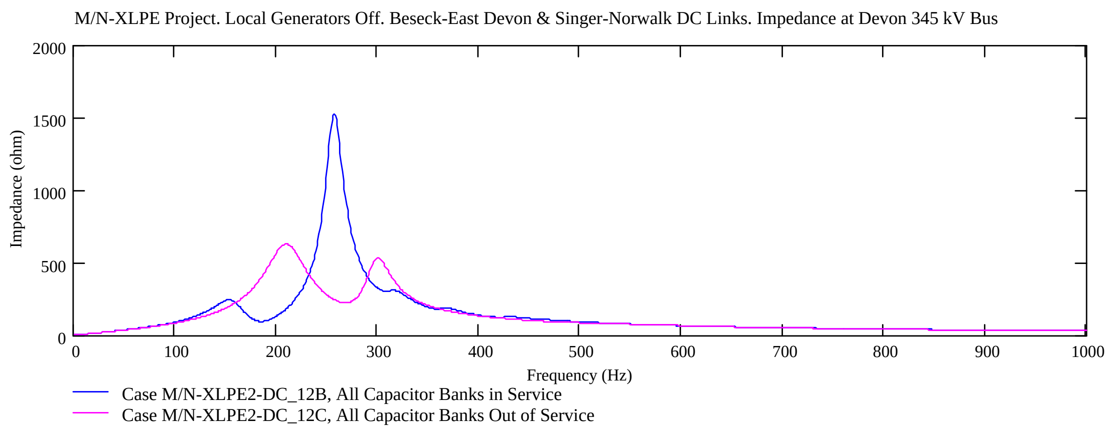

M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at East Shore 345 kV Bus
Impedance (ohm)
0
200
400
600
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_7B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_7C, All Capacitor Banks Out of Service

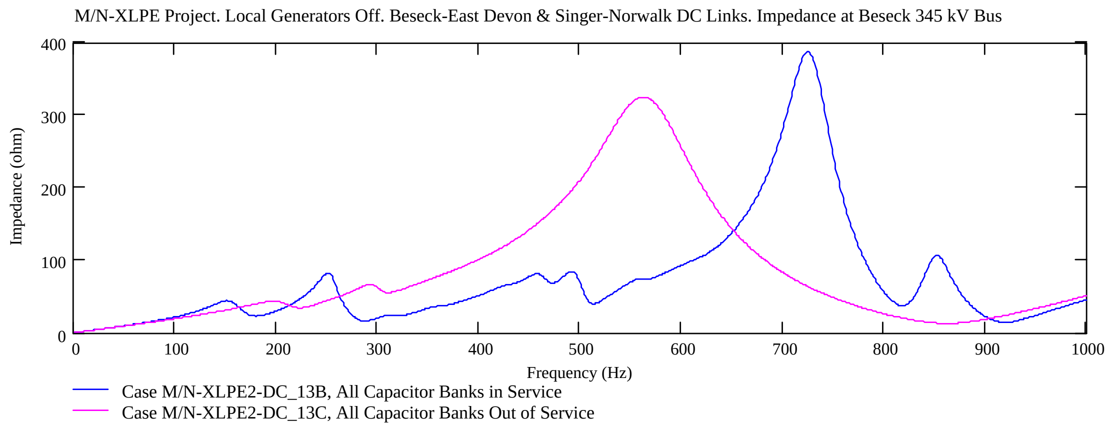

M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Devon 115 kV Bus
Impedance (ohm)
0
10
20
30
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_8B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_8C, All Capacitor Banks Out of Service


M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Frost Bridge 115 kV Bus
Impedance (ohm)
0
10
20
30
40
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_9B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_9C, All Capacitor Banks Out of Service


M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Glenbrook 115 kV Bus
Impedance (ohm)
0
20
40
60
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_10B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_10C, All Capacitor Banks Out of Service


M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Singer 345 kV Bus
Impedance (ohm)
0
500
1000
1500
2000
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_11B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_11C, All Capacitor Banks Out of Service


M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Devon 345 kV Bus
Impedance (ohm)
0
500
1000
1500
2000
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_12B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_12C, All Capacitor Banks Out of Service



M/N-XLPE Project. Local Generators Off. Beseck-East Devon & Singer-Norwalk DC Links. Impedance at Beseck 345 kV Bus
Impedance (ohm)
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case M/N-XLPE2-DC_13B, All Capacitor Banks in Service
Case M/N-XLPE2-DC_13C, All Capacitor Banks Out of Service