Connecticut Cable Transient and Harmonic Study for Middletown to Norwalk Project

East Devon-Beseck 40-mile Cable Option (M/N-P1)

Final Report
November 2003

Prepared for:
Northeast Utilities

Connecticut Cable Transient and Harmonic Study for Middletown to Norwalk Project

East Devon-Beseck 40-mile Cable Option (M/N-P1)

Final Report
November 2003

Principal Contributors:
Goran Drobnjak
Murray A. Eitzmann
Sang Y. Lee
Elizabeth R. Pratico
Reigh A. Walling

Power Systems Energy Consulting
General Electric International, Inc.
One River Road
Schenectady, NY 12345 USA

Foreword

This document was prepared by General Electric International, Inc. (GEII) acting through its Power Systems Energy Consulting (PSEC) located 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:

Elizabeth R. Pratico
Power Systems Energy Consulting
General Electric International, Inc.
1 River Road
Building 5, Room 310
Schenectady, New York 12345
Phone: (518) 385-5624
Fax: (518) 385-2860
E-mail: elizabeth.pratico@ps.ge.com

Legal Notice

This report was prepared by General Electric International, Inc.'s Power Systems Energy Consulting as an account of work sponsored by Northeast Utilities (NU). Neither NU nor PSEC, nor any person acting on behalf of either:

1. Makes any warranty or representation, expressed or implied, with respect to the use of any information contained in this report, or that the use of any information, apparatus, method, or process disclosed in the report may not infringe privately owned rights.

2. Assumes any liabilities with respect to the use of or for damage resulting from the use of any information, apparatus, method, or process disclosed in this report.

Table of Contents

Executive Summary

Study Objectives

GE Power Systems Energy Consulting (PSEC) has performed several switching transient and harmonic studies of the Northeast Utilities (NU) Bethel to Norwalk and Middletown to Norwalk 345 kV transmission cable projects that are proposed in southwestern Connecticut. In the most recent study[1], harmonic and switching transient analyses were performed for the Middletown to Norwalk (M/N) project, with Devon-Beseck configured as a 33-mile overhead line.

The focus of the study, documented in this report, is to further analyze switching transients and harmonic characteristics of the Middletown to Norwalk project with Devon-Beseck configured with 40-mile underground cables (three parallel cables). In this report, this is referred to as the "M/N-P1" configuration. This cable addition increases the total 345 kV cable charging capacitance from about 1500 MVAR (for Plumtree to Norwalk and Norwalk to East Devon cables) to about 4000 MVAR. The objective of the study is to investigate the harmonic impacts of this cable option and evaluate switching transients with particular emphasis on equipment duty and power quality. This study was intended to investigate potential fatal flaws of the M/N-P1 configuration, rather than the more comprehensive study of the M/N base configuration.

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].

Conclusions and Recommendations

With the addition of 40 miles of three parallel 345 kV cables between East Devon and Beseck, the charging capacitance of 345 kV cables is increased by about 2500 MVAR. This results in a driving-point impedance resonance at the 2^{nd} harmonic frequency observed throughout the Bethel to Norwalk and Middletown to Norwalk cable region and around the 345 kV loop. Designing a system configuration which results in an impedance resonance at 2^{nd} harmonic is potentially very risky and is not recommended.

Under normal circumstances, there is little stimulus of the 2^{nd} harmonic because most nonlinear loads produce virtually all of their current distortion in the odd-order harmonics (exceptions are arc furnaces, lamp dimmers, and some consumer-device half-wave dc power supplies). However, there are a number of circumstances where substantial 2^{nd} harmonic stimulus can take place. This includes transformer inrush following transformer energization or fault clearing, and continuous asymmetric transformer saturation during geomagnetic disturbances. The resulting harmonic distortion can further interact with power electronic devices and loads to increase the severity of the distortion and possibly result in control or

[1] Final Report dated November 2003

protection misoperation.[2] There have also been documented cases of closed-loop interaction between power electronic devices (HVDC) and 2nd harmonic system resonances which have resulted in instability of these devices, even with no outside (i.e., inrush or geomagnetic disturbance) stimulus of the 2nd harmonic.

Attempts to avoid the 2nd harmonic resonance by adding 2nd harmonic filters would not be practical. Conversion of existing 115 kV capacitor banks into 2nd harmonic filters would require increased size and cost on the order of about two to three times the replacement costs of the existing capacitor banks. It would also be a significant challenge to design such a system of distributed filters.

While controlled closing can nearly eliminate overvoltage and severe voltage distortion resulting from cable and transformer switching, it cannot eliminate overvoltages and distortion resulting from faults. For such events, the criterion is that consequential equipment damage or misoperation should not occur. Fault application and clearing cause both transient and temporary overvoltages which appear both locally and sometimes at remote locations in the system. Some very high overvoltages at 115 kV capacitor bank locations were simulated in this study, resulting from the oscillatory transient introduced by application of a 345 kV system fault. The natural-frequency oscillations of the 345 kV cable system appear to interact with the resonances of the 115 kV capacitor banks, greatly amplifying the transient. These overvoltages were much higher with the 40-mile cable option from Devon to Beseck than with the overhead line. Transient overvoltages would be limited sufficiently by surge arresters to protect the insulation of utility equipment, but utility customer loads may not be protected by these arresters. Ability of the arresters on the 115 kV system to withstand this transient voltage duty should be further evaluated.

Temporary overvoltages, resulting from fault clearing in the M/N-P1 configuration were not as severe from a peak overvoltage criterion as those observed in the base M/N configuration in the prior study. Harmonic distortion was severe in the M/N-P1 configuration, as it was in the base system. The difference is that the distortions in the base system (M/N) tended to be in such a phase relationship that they added considerably to the peak of the phase-ground voltage. These distortions consisted of significant 2nd, 3rd, and 4th harmonic voltage components. In the M/N-P1 configuration, with a 2nd harmonic impedance resonance of the system, the distortion was predominately at the 2nd harmonic. The phase relationship between the harmonic and fundamental voltage components was such that the components did not result in peak voltages of the severity observed previously in the base M/N system; however, slight variation in system conditions could change these phase relationships to yield more severe results. Changes in system configuration could easily move the resonance below 2nd harmonic, such as insertion of the 7% series reactor at Devon 345 kV, loss of lines or generators, or addition of cables or capacitor banks at 115 kV. All of these examples, which could weaken the system or add capacitance, are very likely to occur either during

---

[2] Second harmonic distortion, caused by a geomagnetic disturbance, interacted with the control and protection of a static var compensator during a geomagnetic disturbance in Quebec in 1989, ultimately resulting in a total blackout of that province.

normal operation or in planned upgrades to the NU system. Designing the system with a resonance at 2nd harmonic could result in severe power system disturbances and is not recommended.

1. Introduction

GE Power Systems Energy Consulting (PSEC) has performed several switching transient and harmonic studies of the Northeast Utilities (NU) Bethel to Norwalk and Middletown to Norwalk 345 kV transmission cable projects that are proposed in southwestern Connecticut. In the most recent study[1], harmonic and switching transient analyses were performed for the Middletown to Norwalk (M/N) project, with Devon-Beseck configured as a 33-mile overhead line.

The focus of the study, documented in this report, is to further analyze switching transients and harmonic characteristics of the Middletown to Norwalk project with Devon-Beseck configured with 40-mile underground cables (three parallel cables). In this report, this is referred to as the "M/N-P1" configuration. This cable addition increases the total 345 kV cable charging capacitance from about 1500 MVAR (for Plumtree to Norwalk and Norwalk to East Devon cables) to about 4000 MVAR. The objective of the study is to investigate the harmonic impacts of this cable option and evaluate switching transients with particular emphasis on equipment duty and power quality. This study was intended to investigate potential fatal flaws of the M/N-P1 configuration, rather than the more comprehensive study of the M/N base configuration.

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].

[1] Final Report dated November 2003

2. Study Approach

The study was organized into two tasks:

1. Harmonic Analysis
2. Switching Transient Analysis

Task 1. Harmonic Analysis

The large shunt charging capacitance of cables can significantly affect the harmonic frequency response of the system. Resonances in the low-order harmonic range can be expected. There is an ambient level of harmonic distortion in any power system, due to nonlinear loads and power electronic equipment distributed throughout the system. The resonances formed by the cable charging can potentially amplify the ambient distortion to unacceptable levels. Harmonic currents may also add to the heating of the cable, and potentially constrain cable loadability. Harmonic resonance concerns were addressed by performing harmonic screening simulations. Frequency-domain simulations were performed using the EMTP model[1] to calculate the positive-sequence driving-point impedance versus frequency at Plumtree, Norwalk, Southington, East Shore, Devon, Frostbridge, Glenbrook, Singer, Devon, and Beseck. Comparison cases were performed with variation of the 115 kV capacitor banks in the system.

A total of 39 cases were performed to calculate the positive-sequence driving-point impedance with the 40-mile cable option between Devon and Beseck. The results of the harmonic analysis are provided in Section 4.

Task 2. Switching Transient Analysis

The switching transient analysis simulations included energization, de-energization, transformer switching, and fault and clear cases to determine switching transient overvoltages and temporary overvoltages for evaluation of equipment duty and power quality. Equipment recommendations are focused on surge arresters and switchgear.

Except in the limited case of some recently introduced circuit breakers with synchronous switching, the timing of circuit breaker closing is essentially random with respect to the point on voltage wave. There is also typically a variation between the closing times of the individual breaker poles (phases). Some transient results are sensitive to the exact timing of switching. Because of the complexities involved, it is virtually impossible to precisely predict the breaker timing which produces the most severe transient results. For this reason, detailed design studies typically use extensive Monte Carlo analysis of randomly selected breaker timings. However, for the purpose of this study, breaker timing rules-of-thumb were utilized to produce results which roughly approach the worst-case results. Most energization cases were performed using fixed point-on-wave circuit breaker closing angles, e.g., closing

---

[1] The EMTP model is described in Section 3.

at voltage peaks or zeroes for cable energization cases, and voltage zeroes for transformer energization (to maximize inrush harmonics). Using fixed point-on-wave closing angles was sufficient to determine the switching transient issues associated with the cables and transformers. Circuit breakers were modeled with uncontrolled closing with closing angles adjusted based on the previous study experience, for comparison with the MN base configuration cases of the previous study. Since this study was focused on fatal flaw analysis, statistical analysis was not performed, and it should be noted that actual transient overvoltages could be higher than those presented in this report. Variation of fault application and clearing times were also based on the experience of the previous study for evaluation of temporary overvoltages.

Cable switching and faults can create transient oscillations which can potentially be magnified at buses with capacitor banks in the lower voltage systems interconnected with the cable transmission project. Voltage magnification can occur when resonances form between the 345 kV cable capacitance, 345 kV driving-point impedance, the 115 kV bank capacitance, and the impedance between them. Voltages at nearby capacitor installations were monitored during cable switching and fault simulations to screen for such magnification. This issue may require extensive analysis in any future design study.

Twenty-two simulation cases were performed to complete this part of the study. The results of the transient analysis are provided in Section 5.

3. System Model

An extensive model of the NU system in southwestern Connecticut was developed in the previous studies, including explicit representation of the 345 kV transmission system as far as Pleasant Valley, Manchester, Card, and Montville and the 115 kV transmission system as far as Campville, Berlin, East Meriden, and Green Hill. The 138 kV undersea cables to Northport were also included in the model. The transmission system beyond the extent of the model was represented by equivalent sources at each point where the model interfaces with the external system. Capacitor banks and load transformers were modeled throughout the explicitly-represented 115 kV system.

The model of the Middletown to Norwalk project was refined in the previous study and included a 33.3-mile overhead line between East Devon and Beseck 345 kV. In this study, the overhead line was replaced by three parallel 345 kV cables each with a length of 40 miles between East Devon and Beseck. This cable addition increases the total 345 kV cable charging capacitance from about 1500 MVAR (for Plumtree to Norwalk and Norwalk to East Devon cables) to about 4000 MVAR. Figure 3-1 shows the configuration of cables and shunt reactors between East Devon and Beseck as modeled for this study. Note that the actual circuit breaker configuration may be different, but the model is functionally equivalent and fully adequate to model the switching operations of the 40-mile cable option. Circuit breakers indicated by lettered and numbered squares are used to describe the case simulation conditions. Each of the 18 variable (75-150 MVAR) shunt reactors on the 40-mile cables was modeled with tap settings at 150 MVAR.

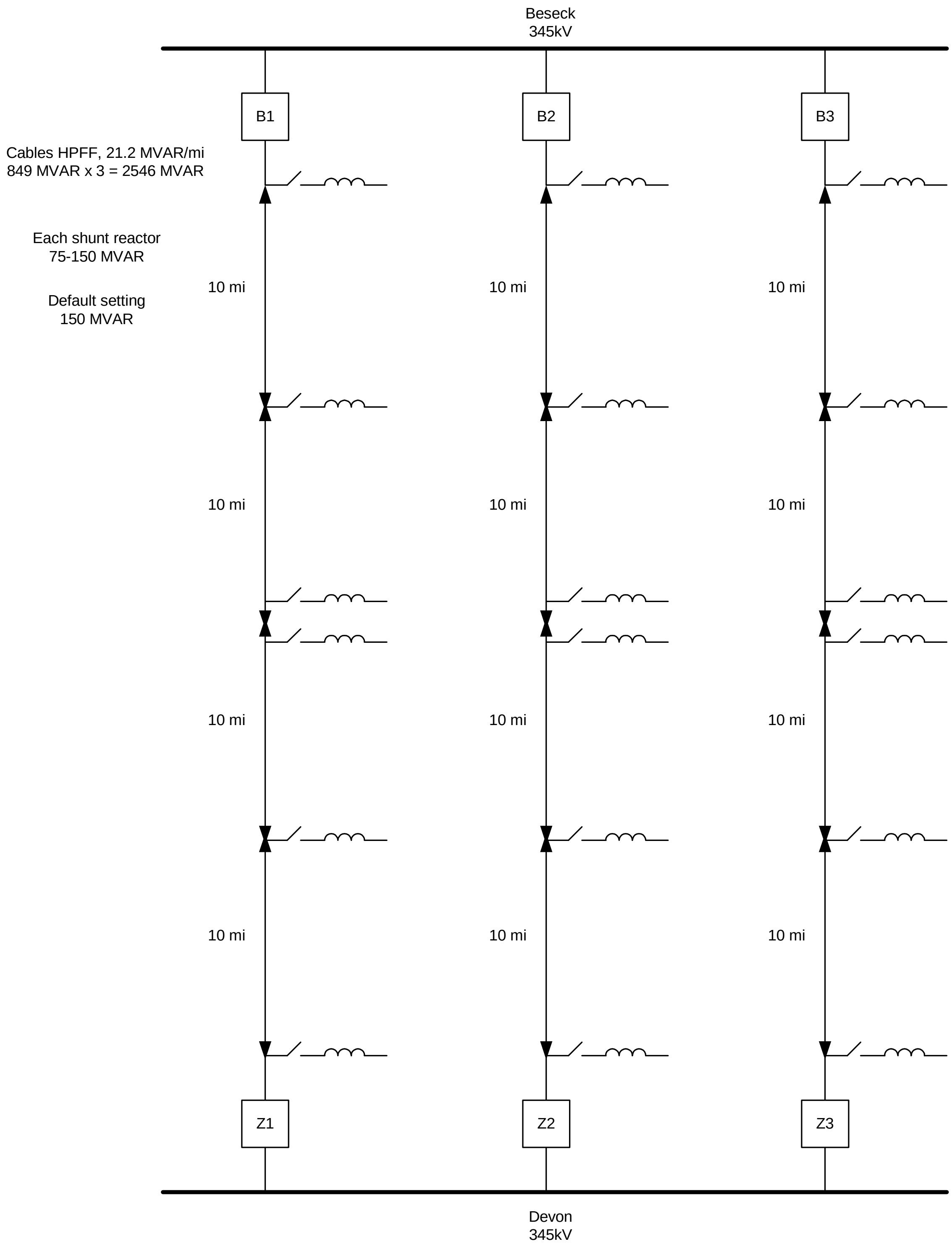


Figure 3-1. One-Line Diagram of Devon-Beseck 40-mile Cable Option

4. Harmonic Analysis

The harmonic impact of the Devon-Beseck 40-mile cable option was analyzed by evaluating the driving-point impedance versus frequency at various locations.

Driving-Point Impedance

Harmonic screening simulations were performed to calculate the positive-sequence driving-point impedance versus frequency at the Plumtree, Norwalk, Singer, Devon, Beseck, Southington, and East Shore 345 kV buses and at the Plumtree, Norwalk, Southington, Devon, Frost Bridge and Glenbrook 115 kV buses. Cases were performed for the M/N-P1 configuration with various capacitor bank allocations. Table 4-1 shows the cases that were performed for the M/N-P1 configuration and the resonant frequencies that were observed along with the corresponding impedance value at those frequencies. The resonant frequency is indicated by its harmonic number (HN), in per unit of 60 Hz, and impedance magnitude is in ohms. For comparison purposes, the M/N base configuration cases from the previous study are shown in Table 4-2. The driving-point impedance plots for M/N-P1 are provided in Appendix A.

Table 4-1. Driving-Point Impedance Cases for M/N-P1 Configuration

			Resonant Frequency & Impedance (pu of 60Hz, Ohm)					
			Low		Middle		High	
Case	Location	Capacitor Banks	HN	Z(Ω)	HN	Z(Ω)	HN	Z(Ω)
PH2P_1A	Plumtree 345 kV	Light Load	2.2	121	6.8	192	10.9	177
PH2P_1B	Plumtree 345 kV	All in Service	2.0	102	6.3 7.7	105 116	11.6	286
PH2P_1C	Plumtree 345 kV	All Out of Service	2.2	122	6.8	192	10.9	173
PH2P_2A	Plumtree 115 kV	Light Load	2.2	13	10.8	60	13.7	112
PH2P_2B	Plumtree 115 kV	All in Service	2.0	13	6.3	67	9.4	52
PH2P_2C	Plumtree 115 kV	All Out of Service	2.2	13	10.8	60	13.7	112
PH2P_3A	Norwalk 345 kV	Light Load	2.2	154	6.8	91		
PH2P_3B	Norwalk 345 kV	All in Service	2.0	121	7.7	115		
PH2P_3C	Norwalk 345 kV	All Out of Service	2.2	155	6.8	92		
PH2P_4A	Norwalk 115 kV	Light Load	2.2	10	6.7	22		
PH2P_4B	Norwalk 115 kV	All in Service	2.0	10	4.5	25	15.5	165
PH2P_4C	Norwalk 115 kV	All Out of Service	2.2	10	6.7	22		
PH2P_5A	Southington 345 kV	Light Load	2.2	93			10.8	120
PH2P_5B	Southington 345 kV	All in Service	2.0	85	4.6	35	8.3 11.6	57 57
PH2P_5C	Southington 345 kV	All Out of Service	2.2	93			10.8	119
PH2P_6A	Southington 115 kV	Light Load	2.1	8				
PH2P_6B	Southington 115 kV	All in Service	2.0	9	5.4	45	9.4	133
PH2P_6C	Southington 115 kV	All Out of Service	2.1	8				
PH2P_7A	East Shore 345 kV	Light Load	2.1	55	4.8	155	14.1	315
PH2P_7B	East Shore 345 kV	All in Service	2.0	52	4.7 7.2	166 186	14.0	701
PH2P_7C	East Shore 345 kV	All Out of Service	2.1	53			14.0	349

			Resonant Frequency & Impedance (pu of 60Hz, Ohm)					
Case	Location	Capacitor Banks	Low		Middle		High	
			HN	Z(Ω)	HN	Z(Ω)	HN	Z(Ω)
PH2P_8A	Devon 115 kV	Light Load	2.1	10				
PH2P_8B	Devon 115 kV	All in Service	2.0	9				
PH2P_8C	Devon 115 kV	All Out of Service	2.1	10				
PH2P_9A	Frost Bridge 115 kV	Light Load	2.1	10			10.7	29
PH2P_9B	Frost Bridge 115 kV	All in Service	2.0	12	4.8	74	8.4	32
PH2P_9C	Frost Bridge 115 kV	All Out of Service	2.1	10			10.7	29
PH2P_10A	Glenbrook 115 kV	Light Load	2.1	9	6.6 8.2	29 40	16.0	55
PH2P_10B	Glenbrook 115 kV	All in Service	2.0	10	4.5	45		
PH2P_10C	Glenbrook 115 kV	All Out of Service	2.1	9	6.6 8.2	29 40	16.0	55
PH2P_11A	Singer 345 kV	Light Load	2.2	160			10.9	70
PH2P_11B	Singer 345 kV	All in Service	2.0	123	4.9	91	11.6	133
PH2P_11C	Singer 345 kV	All Out of Service	2.2	160			10.9	68
PH2P_12A	Devon 345 kV	Light Load	2.2	163			10.9	65
PH2P_12B	Devon 345 kV	All in Service	2.0	124			11.6	140
PH2P_12C	Devon 345 kV	All Out of Service	2.2	163			10.9	63
PH2P_13A	Beseck 345 kV	Light Load	2.2	135			10.9	67
PH2P_13B	Beseck 345 kV	All in Service	2.0	105			11.6	144
PH2P_13C	Beseck 345 kV	All Out of Service	2.2	136			10.9	65

Table 4-2. Driving-Point Impedance Cases for M/N Base Configuration

			Resonant Frequency & Impedance (pu of 60Hz, Ohm)					
Case	Location	Capacitor Banks	Low		Middle		High	
			HN	Z(Ω)	HN	Z(Ω)	HN	Z(Ω)
PH2_1A	Plumtree 345 kV	Light Load	2.8	192			10.5	449
PH2_1B	Plumtree 345 kV	All in Service	2.4	128			11.3	620
PH2_1C	Plumtree 345 kV	All Out of Service	2.8	194			10.5	445
PH2_2A	Plumtree 115 kV	Light Load	2.8	19	10.5	93	13.9	109
PH2_2B	Plumtree 115 kV	All in Service	2.4	17	6.6	70		
PH2_2C	Plumtree 115 kV	All Out of Service	2.8	19	10.5	93	13.9	109
PH2_3A	Norwalk 345 kV	Light Load	2.8	243				
PH2_3B	Norwalk 345 kV	All in Service	2.4	149	5.0	70		
PH2_3C	Norwalk 345 kV	All Out of Service	2.8	245				
PH2_4A	Norwalk 115 kV	Light Load	2.8	16	7.9	24		
PH2_4B	Norwalk 115 kV	All in Service	2.4	15	5.0	18	15.6	181
PH2_4C	Norwalk 115 kV	All Out of Service	2.8	16	7.9	24		
PH2_5A	Southington 345 kV	Light Load	2.8	60			10.4	259
PH2_5B	Southington 345 kV	All in Service	2.4	61	4.3	81	8.2	88
PH2_5C	Southington 345 kV	All Out of Service	2.8	60			10.3	250
PH2_6A	Southington 115 kV	Light Load					10.2	29
PH2_6B	Southington 115 kV	All in Service	4.3	26	5.4	38	11.3	126
PH2_6C	Southington 115 kV	All Out of Service					10.1	28
PH2_7A	East Shore 345 kV	Light Load	4.7	167			10.2	212
PH2_7B	East Shore 345 kV	All in Service	4.3	111	7.2	188	12.5 14.6	261 519
PH2_7C	East Shore 345 kV	All Out of Service					10.1	239

			Resonant Frequency & Impedance (pu of 60Hz, Ohm)					
Case	Location	Capacitor Banks	Low		Middle		High	
			HN	Z(Ω)	HN	Z(Ω)	HN	Z(Ω)
PH2_8A	Devon 115 kV	Light Load	2.8	13				
PH2_8B	Devon 115 kV	All in Service	2.4	11				
PH2_8C	Devon 115 kV	All Out of Service	2.8	13				
PH2_9A	Frost Bridge 115 kV	Light Load	2.8	11			10.4	30
PH2_9B	Frost Bridge 115 kV	All in Service	2.4	14	4.3 5.4	31 40	8.3	34
PH2_9C	Frost Bridge 115 kV	All Out of Service	2.8	11			10.4	29
PH2_10A	Glenbrook 115 kV	Light Load	2.8	14	8	42	16.0	56
PH2_10B	Glenbrook 115 kV	All in Service	2.4	15	5.0	45		
PH2_10C	Glenbrook 115 kV	All Out of Service	2.8	14	8	42	16.0	56
PH2_11A	Singer 345 kV	Light Load	2.8	237			10.5	136
PH2_11B	Singer 345 kV	All in Service	2.4	144	5.0	74	11.3	231
PH2_11C	Singer 345 kV	All Out of Service	2.8	239			10.5	135
PH2_12A	Devon 345 kV	Light Load	2.8	228			10.5	173
PH2_12B	Devon 345 kV	All in Service	2.4	139	5.0	67	11.3	318
PH2_12C	Devon 345 kV	All Out of Service	2.8	230			10.5	171
PH2_13A	Beseck 345 kV	Light Load	2.8	67			10.4	280
PH2_13B	Beseck 345 kV	All in Service	2.4	57			12.5	277
PH2_13C	Beseck 345 kV	All Out of Service	2.8	67			10.4	270

Comparison of the driving-point impedance results indicate that with the 40-mile cable option, the lowest-frequency impedance resonance shifts down to 2nd harmonic (from 2.4 to 2.0), with all capacitor banks in service. This 2nd harmonic resonance is observed throughout the Bethel to Norwalk and Middletown to Norwalk cable region. In these cases, the light load capacitor bank configuration is similar to the configuration with all capacitors out of service, except that the filter banks are in service at Cross Sound.

Resonances are also appearing locally near 5th, 7th, and 11th harmonics with the 40-mile cable option in the M/N-P1 configuration. The resonant peak magnitudes at 5th harmonic are higher at some locations and lower at other locations. Resonances at 7th harmonic are appearing at more locations. The 5th and 7th harmonic resonances appear to be more dependent on local conditions. The 11th harmonic resonances are generally lower in magnitude with the M/N-P1 configuration.

Comparisons of harmonic resonance characteristics at 345 kV can be examined at Plumtree and Norwalk with different cable project configurations. Figure 4-1 shows the driving-point impedance vs. frequency at Plumtree 345 kV with the existing system, with the Bethel to Norwalk project, with the Middletown to Norwalk project base configuration, and with the Middletown to Norwalk project P1 configuration, with all capacitor banks in service. With the addition of each cable project, the resonances move from 3rd harmonic to 2nd harmonic. The magnitude is higher with the B/N project but is lower with the M/N project due to the increased strength with the 345 kV loop. The impedance resonance with the M/N-P1 configuration is tuned right at 2nd harmonic with a magnitude similar to that of the existing system at 3rd harmonic. Currents injected by typical harmonic sources tend to decrease as a function of 1/(HN), so this shift of impedance resonance from 3rd to 2nd harmonic with M/N-

P1 would be expected to result in voltage distortion at 2nd harmonic that is about 1.5 times higher than existing distortion at 3rd harmonic.

Figure 4-2 shows the driving-point impedance vs. frequency at Norwalk 345 kV with the B/N project, with the M/N project base configuration, and with the M/N-P1 configuration, with all capacitor banks in service. The impedance resonance characteristics at Norwalk 345 kV are similar to those at Plumtree 345 kV, except that the 5th harmonic resonance is more pronounced at Norwalk and the 11th harmonic resonance is much higher at Plumtree. Figure 4-3 shows the driving-point impedance vs. frequency at Devon 345 kV with the M/N project base configuration and with the M/N-P1 configuration, with all capacitor banks in service and with all capacitor banks out of service. The plot indicates that the resonant frequencies do not vary with 115 kV capacitors as much with the M/N-P1 project as they do with the M/N project. This is because the capacitance of the 345 kV cables is so large compared with all of the 115 kV capacitor banks in the area. Impedance resonances are also shifting in magnitude and frequency near 5th and 11th harmonics.

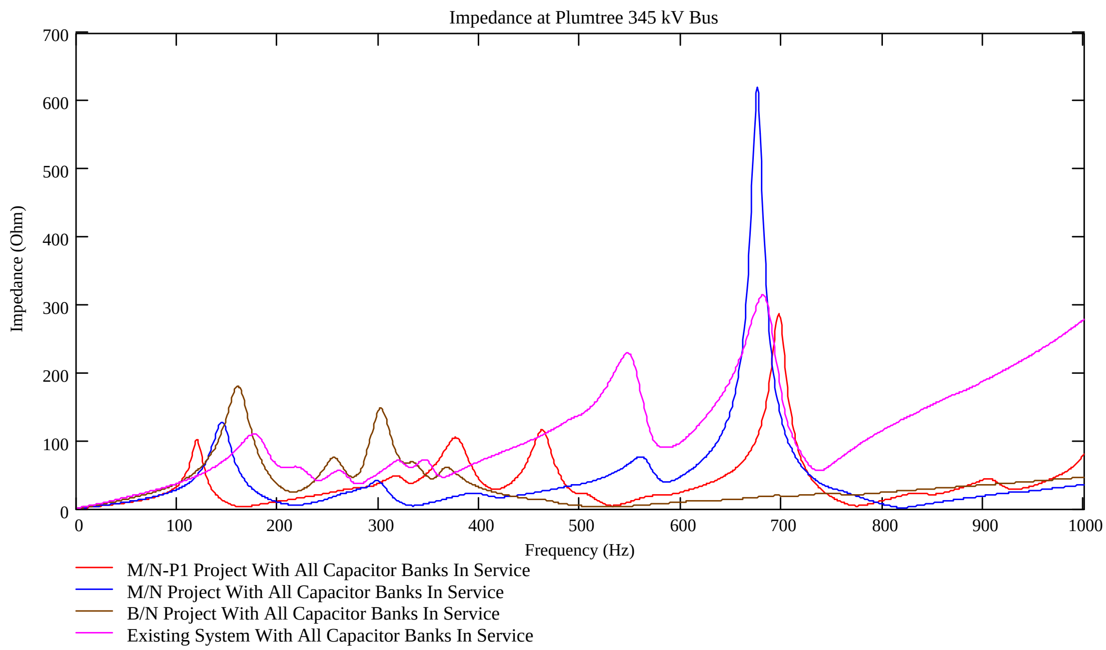


Figure 4-1. Impedance vs. Frequency at Plumtree 345 kV

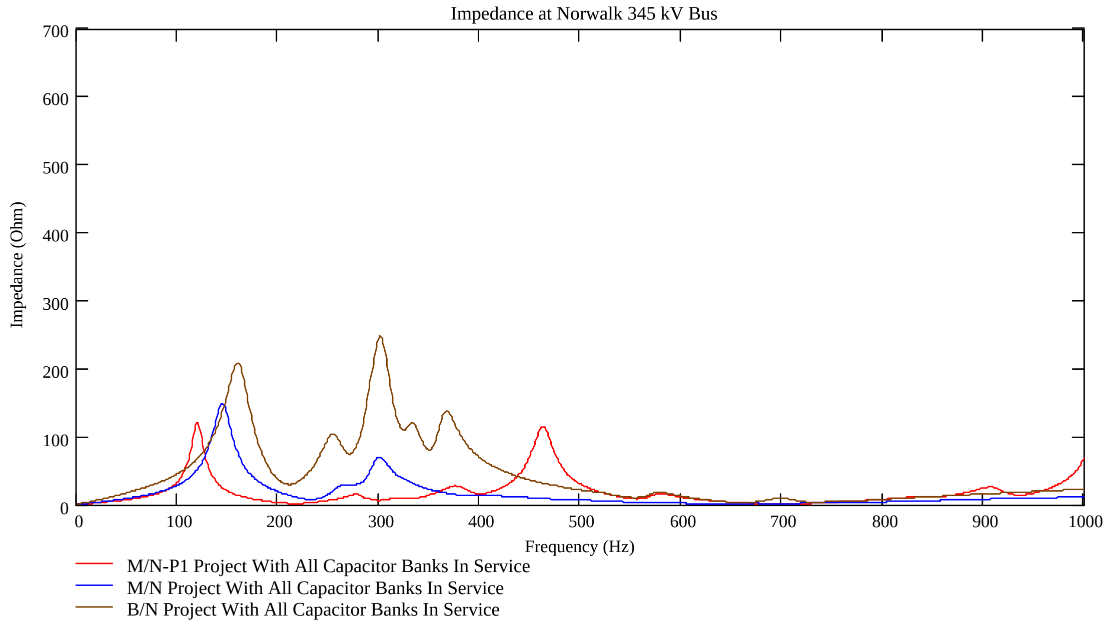


Figure 4-2. Impedance vs. Frequency at Norwalk 345 kV

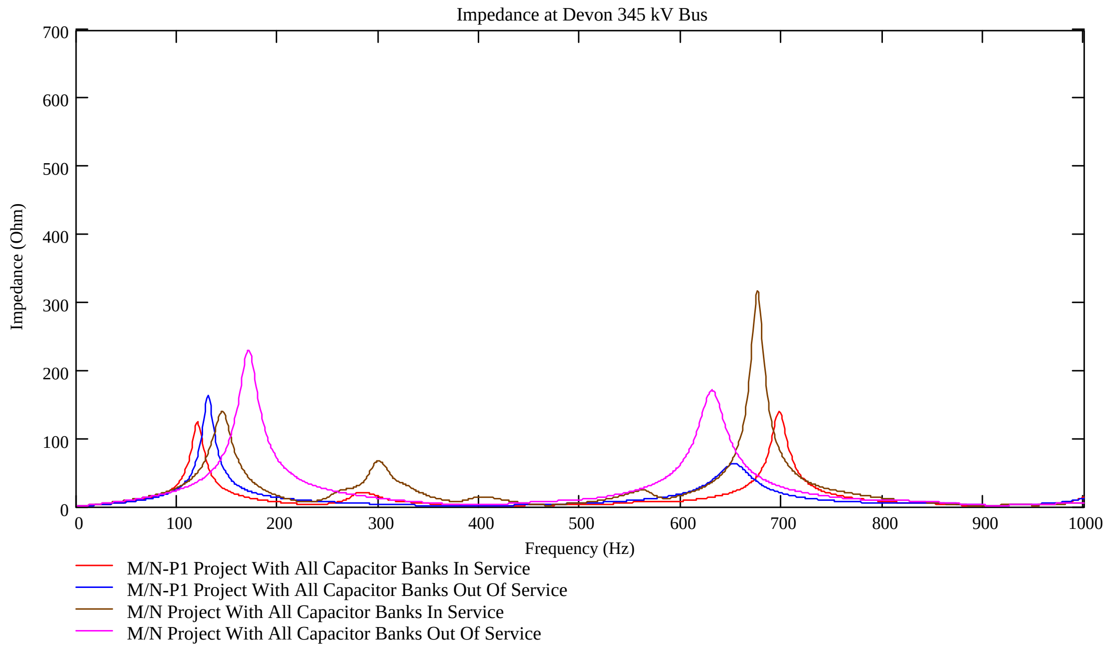


Figure 4-3. Impedance vs. Frequency at Devon 345 kV

Second Harmonic Resonance Risk Evaluation

Under normal circumstances, there is little stimulus of the 2nd harmonic because most nonlinear loads produce virtually all of their current distortion in the odd-order harmonics (exceptions are arc furnaces, lamp dimmers, and some consumer-device half-wave dc power supplies). However, there are a number of circumstances where substantial 2nd harmonic stimulus can take place. Existence of system driving point impedance resonances near the 2nd harmonic increase the risk of severe distortion and consequent elevated peak overvoltages and complex control and protection interactions. Designing a system configuration which results in an impedance resonance at 2nd harmonic is potentially very risky and is not recommended.

The most significant source for 2nd harmonic stimulus in a power system is transformer exciting current. Transformer exciting current is very highly distorted, and is composed almost entirely of odd-order harmonics during normal excitation. With asymmetric (i.e., offset) saturation, both even- and odd-order harmonics are produced, which tend to decrease as a function of 1/(HN). Thus, transformers characteristically produce large 2nd harmonic components during offset saturation. Large-scale injection of these current harmonics in a system resonant in the same frequency range can result in severe voltage distortion and elevated peak voltages.

Asymmetric transformer saturation is usually the result of flux offsets due to transformer energization and fault clearing. Inrush can persist for many seconds. Another source of asymmetric saturation is geomagnetic disturbances, which can be present for periods of several days. Severe geomagnetic disturbances, resulting from solar storms, can cause currents at very low frequency (or quasi-dc currents) to flow in the earth. These currents are known as geomagnetically-induced currents (GIC) which can flow into the power system through grounded-wye transformers and can cause asymmetric transformer saturation throughout the power system. The resulting transformer exciting currents, rich in 2nd harmonic, can result in severe and persistent voltage distortion.[1] A blackout of Hydro-Quebec in 1989 has been attributed to second harmonic distortion due to GIC interacting with a protective scheme. GIC issues have been frequently observed in the Hudson Valley region of New York, and in New Jersey where large GSU transformers were destroyed at a nuclear power plant (not due to harmonic distortion, however this indicates that GIC is present in the Northeast).

Severe distortion at a particular harmonic, resulting from asymmetric transformer saturation, often occurs when the system is resonant just below that harmonic. This was observed in the study of the M/N project, in which the system was tuned below 3rd harmonic (between 2.4 and 2.8). When a system is resonant below the given harmonic, the system impedance is inherently capacitive at that harmonic (which can be seen as impedance decreasing with frequency at that harmonic; i.e., negative slope). The capacitive nature of the system forms a resonance with the non-linear inductance of the transformer, which can result in severe

[1] R. A. Walling, A. H. Khan, "Characteristics of Transformer Exciting-Current During Geomagnetic Disturbances," IEEE Transactions on Power Delivery, Vol. 6, No. 4, October 1991, pp.1707-1713.

voltage distortion during inrush situations, such as energization or inrush following fault clearing.

The same relationship applies to a system that is resonant at 2nd harmonic. However, the severity of the distortion would be expected to be even more severe since the 2nd harmonic currents are about 1.5 times higher than 3rd harmonic currents. In the M/N-P1 configuration, it was found that the system is resonant at 2nd harmonic, with all cables and lines in service and all 115 kV capacitor banks in service. Changes in system configuration could easily move the resonance below 2nd harmonic, such as insertion of the 7% series reactor at Devon 345 kV, loss of lines or generators, or addition of cables or capacitor banks at 115 kV. All of these examples, which could weaken the system or add capacitance, are very likely to occur either during normal operation or in planned upgrades to the NU system.

In a system that is resonant at 2nd harmonic, the potential for control interactions of certain power electronic equipment is increased. These include HVDC converter terminals, Statcoms, Static Var Compensators (SVCs), and drive system loads. Complex interactions between conventional HVDC systems and system 2nd harmonic resonance, resulting in system instability, have been documented. The HVDC terminal at nearby Cross Sound is a voltage-source-inverter-based converter. The vulnerability of this new technology to 2nd harmonic interactions has not been reported in the literature. A Statcom is currently in the plans for installation at Glenbrook 115 kV, which is very close to Norwalk. The potential for interaction between this Statcom and system 2nd harmonic resonance is also not known. Control schemes should be evaluated with the expected impedance resonance characteristics in a cycle-by-cycle transient analysis. Controls for drive system loads could also be affected by a 2nd harmonic resonance in the system. The potential effects of a 2nd harmonic resonance on control interactions could be widely distributed, and vulnerable locations could be difficult to identify.

The potential for misoperation of particular protection schemes can be increased in a system that is resonant at 2nd harmonic. For example, schemes that are based on phase comparison or that monitor zero crossings could be prone to misoperation if currents have a high harmonic content.

While not as severe an issue as distortion driven by transformer saturation, a resonance at 2nd harmonic will tend to aggravate the issue of steady-state even-order harmonic distortion caused by the minority of loads injecting even harmonics. Some suggest that current guidelines for 2nd harmonic distortion current injection are too high.[2] Existence of a system resonance at 2nd harmonic has the same impact on voltage distortion as a large increase in harmonic current injection.

[2] Orr, J.A.; Emanuel, A.E., "On the need for strict second harmonic limits," Proceedings of 8th International Conference on Harmonics and Quality of Power, 1998, Vol. 1, Oct. 1998, pp. 176 –181.

5. Switching Transient Analysis

The critical issues that were examined in regard to switching cables and transformers, and clearing faults, in the M/N-P1 configuration were power quality and equipment duty. Different criteria were applied for evaluation of transient and temporary overvoltages and distortion resulting from routine switching operations, and results from contingencies such as faults and equipment failures. Sustained and distorted overvoltages, resulting from routine cable and transformer switching, are not acceptable when considering power quality throughout the system. For fault and equipment failure events, avoidance of consequential equipment damage was the driving criterion. Equipment must be able to withstand temporary overvoltages, and circuit breakers must be capable of successfully interrupting under these conditions. In this fatal flaw analysis of the M/N-P1 configuration, selected cases were simulated to evaluate routine switching operations and to investigate scenarios where the impedance resonance at 2^{nd} harmonic could adversely impact the switching transient and temporary overvoltages.

Table 5-1 provides a case list of the switching transient simulations that were performed and includes the operating breaker, open breakers, fault type and location, shunt reactor settings, capacitor bank dispatch, switch timing, and other system conditions. The corresponding simulation case plots can be found in Appendix B. Six pages of plots for each case are included in the Appendix, and the complete set of plots is included separately on a CD. The first summary page includes the Norwalk-Singer and Singer-Devon cable end voltages, surge arrester energies, and circuit breaker voltages. Quantities at each cable end are superposed on each plot. The second summary page includes the Devon-Beseck cable end voltages for one circuit (superimposed on the plots) and the three cable circuit currents. Two pages of 345 kV bus voltages and two pages of 115 kV bus voltages are also included.

Several cases were simulated to energize each of the three 40-mile cables from each end, with uncontrolled closing. Case results indicated that some form of controlled closing would be needed based on high overvoltages observed at various 115 kV capacitor bank locations.

Energization of the Devon 345/115 kV transformer was simulated with uncontrolled closing, resulting in a temporary overvoltage that persists for a long time. Figure 5-1 shows the nearby 345 kV bus voltages. Second harmonic currents were observed in the 345 kV cables as shown in Figures 5-2 and 5-3. This case confirms the need for controlled closing on the transformers and also demonstrates the effect of transformer inrush on second harmonic currents in the system and resulting voltage distortion. The voltage distortion during transformer energization was more severe with the 40-mile cables than it was with the overhead line between Devon and Beseck.

The most severe temporary overvoltage distortion cases with the M/N configuration, in the previous study, were due to three-phase-to-ground fault and clear cases, in which the combined effects of inrush from multiple transformers resulted in highly distorted overvoltages. However, with the M/N-P1 configuration, the 345 kV voltage distortion was not as severe, but a higher degree of voltage magnification was observed at 115 kV capacitor

Table 5-1. Switching Transient Simulation Case List

Switching Cases: Devon-Beseck modeled as 40-mile cables (M/N-P1)

						Shunt Reactor Settings (MVAR)														
						Dev-Bes 1,2,3	Nor-Sng1		Nor-Sng2		Sng-Dev1		Sng-Dev2		Plum-Norw					
Case #	**Operation**	**Operating Breaker**	**Open Breakers**	**Fault Type**	**Fault Location**	**(Setting of each of 18 reactors)**	**Nor**	**Sng**	**Nor**	**Sng**	**Sng**	**Dev**	**Sng**	**Dev**	**Plm**	**Nor1**	**Nor2**	**Cap Banks**	**Switch Timing**	**System Conditions**
Energize Cable Devon to Beseck																				
PH2P-Z1- 1	Energize	Z1	B1			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vpeak-PhA	
PH2P-Z1- 2	Energize	Z1	B1,Z2,B2			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vpeak-PhA	
PH2P-Z1- 3	Energize	Z1	B1,Z2,B2,Z3,B3			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vpeak-PhA	
Energize Cable Beseck to Devon																				
PH2P-B1- 1	Energize	B1	Z1			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vpeak-PhA	
PH2P-B1- 2	Energize	B1	Z1,Z2,B2			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vpeak-PhA	
PH2P-B1- 3	Energize	B1	Z1,Z2,B2,Z3,B3			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vzero-PhA	
Energize Cable Devon to Singer																				
PH2P-Y1- 1	Energize	Y1	X1			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vpeak-PhA	
Energize Devon Transformer																				
PH2P-6- 1	Energize	6	7			150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Vzero-all	
Fault and Clear Devon Transformer (apply fault at 1 cy)																				
PH2P-DTF- 1	De-energize	7,6		A-g	Devon Xfr 115 kV	150	100	100	100	100	75	75	75	75	75	150	75	Pk. Load	Bkr 6 last	flt at 0 deg, open t=5,11cy
Fault and Clear Cable Norwalk to Singer (apply fault at 1 cy)																				
PH2P-NSF- 1	De-energize	V1,W1		ABC-g	Singer end	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy
PH2P-NSF- 1-90	De-energize	V1,W1		ABC-g	Singer end	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 90 deg, open t=5cy
PH2P-NSF- 2	Stub Fault & Clr	Fault		ABC-g	Singer 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 90 deg, open t=5cy
PH2P-NSF- 3	Stub Fault & Clr	Fault		ABC-g	Norwalk 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 90 deg, open t=5cy
PH2P-NSF- 3-0	Stub Fault & Clr	Fault		ABC-g	Norwalk 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy
PH2P-NSF- 4	Stub Fault & Clr	Fault		A-g	Singer 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy
PH2P-NSF- 5	Stub Fault & Clr	Fault		A-g	Norwalk 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy
Fault and Clear Cable Singer to Devon (apply fault at 1 cy)																				
PH2P-SDF- 1	De-energize	X1,Y1		ABC-g	Singer end	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy
Fault and Clear Cable Devon to Beseck (apply fault at 1 cy)																				
PH2P-BDF- 1	De-energize	B1,Z1		ABC-g	Devon end	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy
PH2P-BDF- 2	Stub Fault & Clr	Fault		ABC-g	Devon 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy BAC neg
PH2P-BDF- 3	Stub Fault & Clr	Fault		A-g	Devon 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy neg
Fault and Clear at Plumtree (apply fault at 1 cy)																				
PH2P-PF- 1	Stub Fault & Clr	Fault		ABC-g	Plumtree 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy BAC neg
PH2P-PF- 2	Stub Fault & Clr	Fault		A-g	Plumtree 345 kV	150	150	150	150	150	150	150	150	150	150	150	150	Pk. Load		flt at 0 deg, open t=5cy neg

bank locations. For example, Figure 5-4 shows the 345 kV bus voltages during a three-phase-to-ground stub fault applied at Singer 345 kV and subsequently cleared. The resulting voltages are distorted, but not that severe in terms of peak voltage magnitude. With the impedance resonance at 2^{nd} harmonic, the system impedance is lower at 3^{rd} harmonic, and the harmonic currents due to inrush are not having the same additive effect in the M/N-P1 configuration as observed in the M/N configuration. However, the voltage distortion could be much more severe with slight variation in system conditions, including tuning the system resonance just below second harmonic or closer to 3^{rd} harmonic.

Figure 5-5 shows the voltages at some of the 115 kV capacitor bank locations during the same stub fault and clear case. Note that the transient voltage at Rocky River is 3.4 pu. The fault initiates natural-frequency oscillations of the 345 kV system. Evidently, these oscillations coincide with resonances involving the 115 kV capacitor banks. There is a widely-documented phenomenon, called voltage magnification, where oscillations between two coupled resonant circuits can result in magnified voltage oscillations in the second circuit due to oscillations in the first. Magnification is most severe when the driving circuit (the 345 kV system in this case) has a much larger capacitance than the driven system (115 kV capacitor bank). This phenomenon is most commonly reported as the result of switching a large capacitor bank in the vicinity of a smaller capacitor bank nearby on a lower-voltage system. However, in the case of the M/N and M/N-P1 configurations, the 345 kV fault oscillations appear to instigate this magnification phenomenon, and it is more severe in the M/N-P1 configuration. A surge arrester at Rocky River would limit the transient voltage, but would discharge significant current in this case. Transient overvoltages on the 115 kV system would need to be evaluated with respect to arrester discharge characteristics.

While the switching transient analysis did not indicate severe voltage distortion results normally expected with a 2^{nd} harmonic impedance resonance, slight variation in system conditions could yield more severe results.

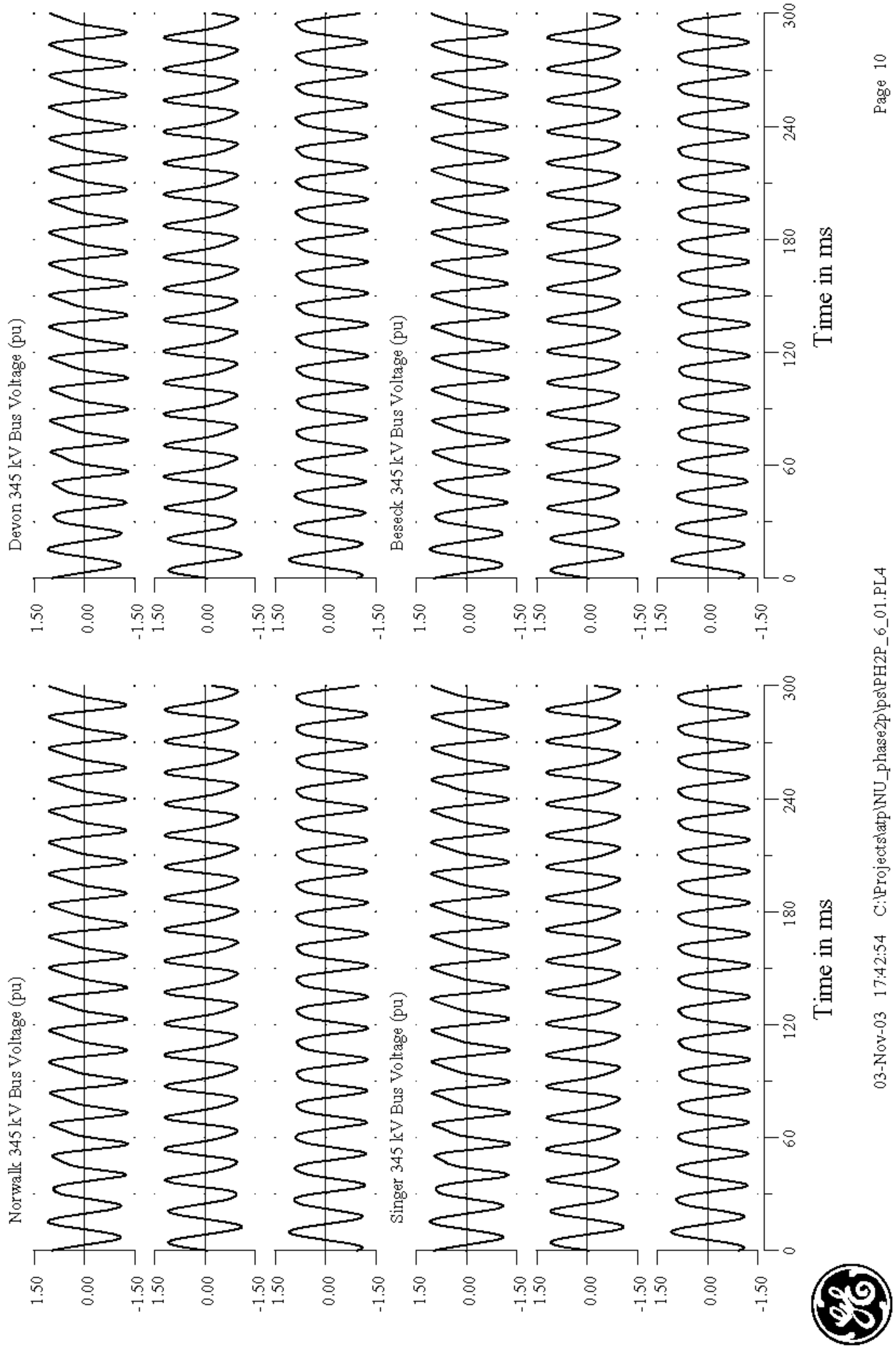


Figure 5-1. Devon Transformer Energization – 345 kV Bus Voltages (Case 6-1)

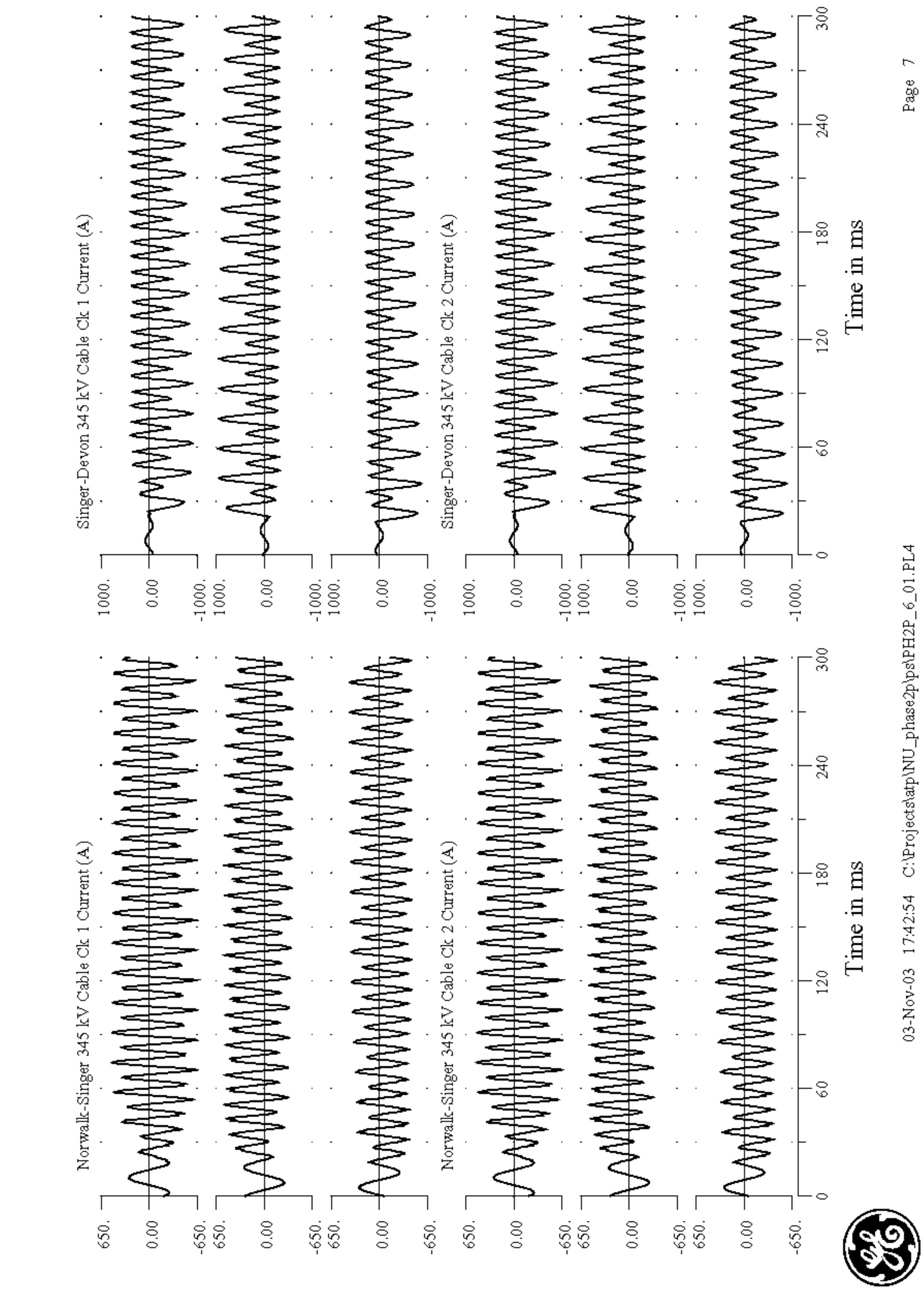


Figure 5-2. Devon Transformer Energization – M/N Cable Currents (Case 6-1)

Figure 5-3. Devon Transformer Energization – B/N Cable Currents (Case 6-1)

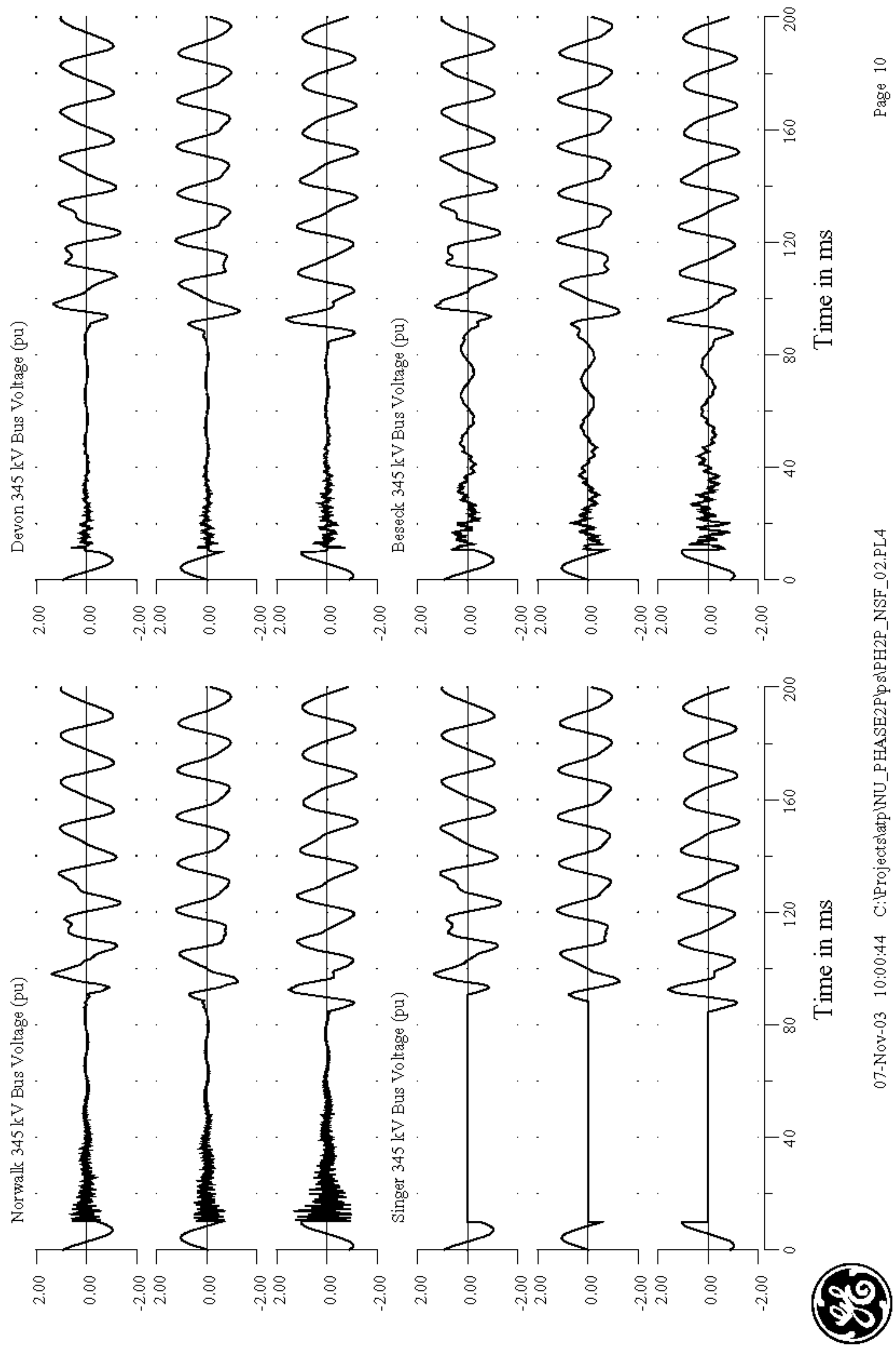


Figure 5-4. Stub Fault and Clear at Singer 345 kV – 345 kV Bus Voltages (Case NSF-2)

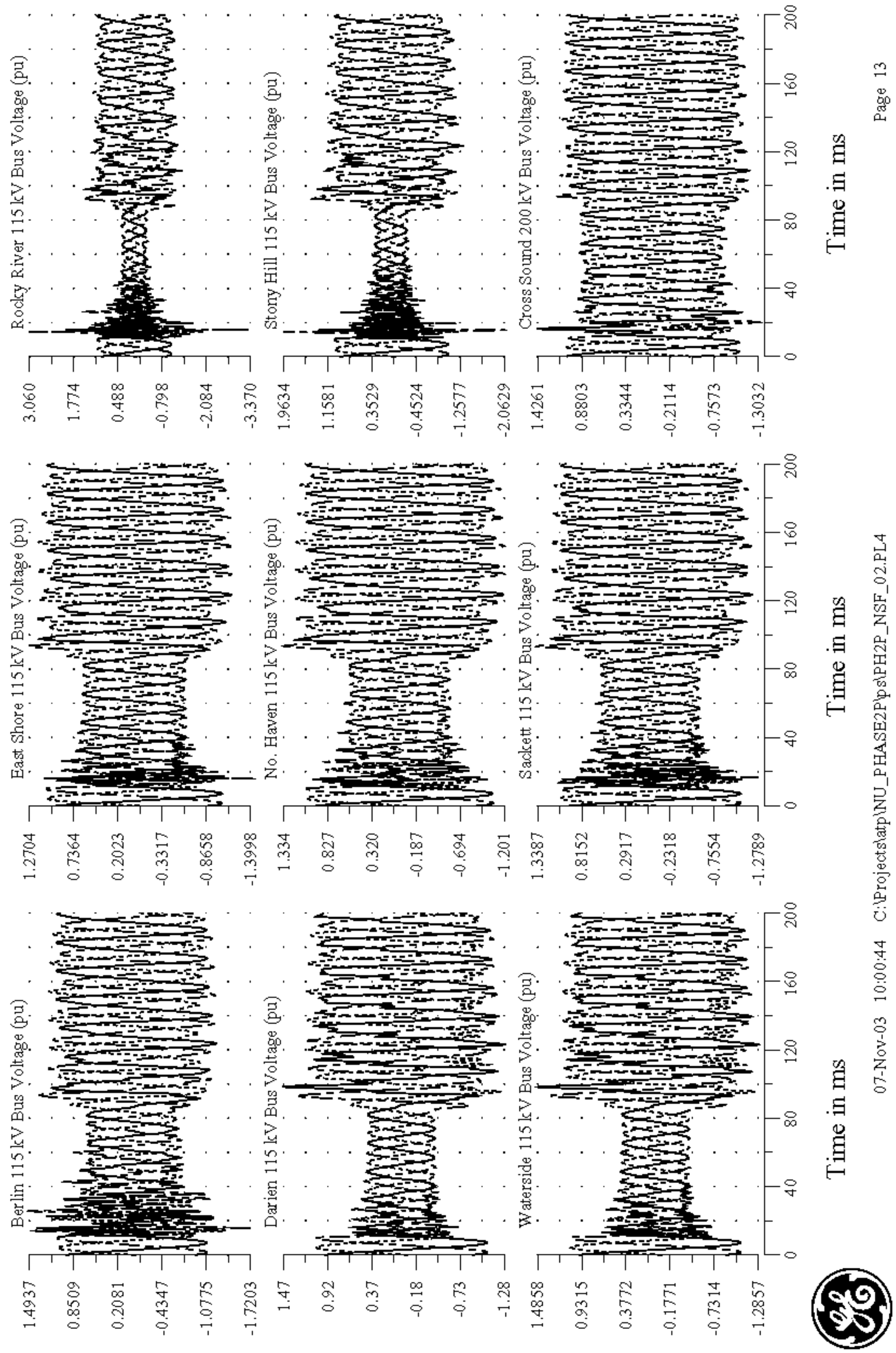


Figure 5-4. Stub Fault and Clear at Singer 345 kV – 115 kV Bus Voltages (Case NSF-2)

6. Conclusions and Recommendations

With the addition of 40 miles of three parallel 345 kV cables between East Devon and Beseck, the charging capacitance of 345 kV cables is increased by about 2500 MVAR. This results in a driving-point impedance resonance at the 2^{nd} harmonic frequency observed throughout the Bethel to Norwalk and Middletown to Norwalk cable region and around the 345 kV loop. Designing a system configuration which results in an impedance resonance at 2^{nd} harmonic is potentially very risky and is not recommended. There are several risk areas which include severe distortion due to transformer inrush, possible control interactions of certain standard power electronic equipment, potential misoperation of particular protection schemes, and possible large-scale effects from geomagnetic disturbances.

Attempts to avoid the 2^{nd} harmonic resonance by adding 2^{nd} harmonic filters would not be practical. Conversion of existing 115 kV capacitor banks into 2^{nd} harmonic filters would require increased size and cost on the order of about two to three times the replacement costs of the existing capacitor banks. It would also be a significant challenge to design such a system of distributed filters.

Switching transient results indicated an increased level of 2^{nd} harmonic current flowing in the system. However, with the impedance resonance at 2^{nd} harmonic, the system impedance is lower at 3^{rd} harmonic, and the harmonic currents due to inrush are not having the same additive effect in the M/N-P1 configuration as observed in the M/N configuration. However, the voltage distortion could be much more severe with slight variation in system conditions, including tuning the system resonance just below second harmonic.

Changes in system configuration could easily move the resonance below 2^{nd} harmonic, such as insertion of the 7% series reactor at Devon 345 kV, loss of lines or generators, or addition of cables or capacitor banks at 115 kV. All of these examples, which could weaken the system or add capacitance, are very likely to occur either during normal operation or in planned upgrades to the NU system.

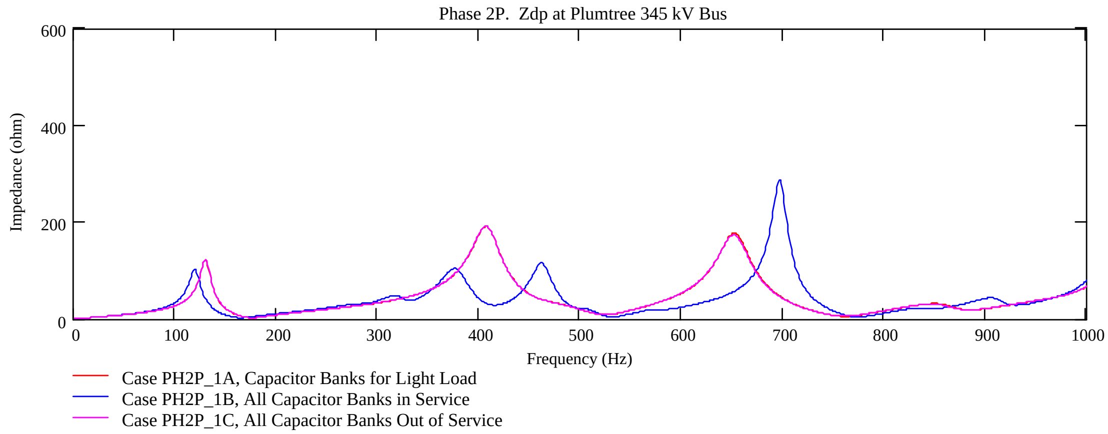
High overvoltages were observed at some 115 kV capacitor bank locations, particularly at Rocky River and Stony Hill during fault events. The natural-frequency oscillations of the 345 kV cable system due to application of a 345 kV system fault appear to interact with the resonance of the 115 kV capacitor banks, greatly amplifying the transient. In the actual system, surge arresters located on the 115 kV system would limit these overvoltages.[1] These overvoltages at 115 kV buses were much higher in the M/N-P1 configuration than with the M/N configuration. Transient overvoltages would be limited sufficiently by surge arresters to protect the insulation of utility equipment, but utility customer loads may not be protected by these arresters. Ability of the arresters on the 115 kV system to withstand this transient voltage duty should be further evaluated.

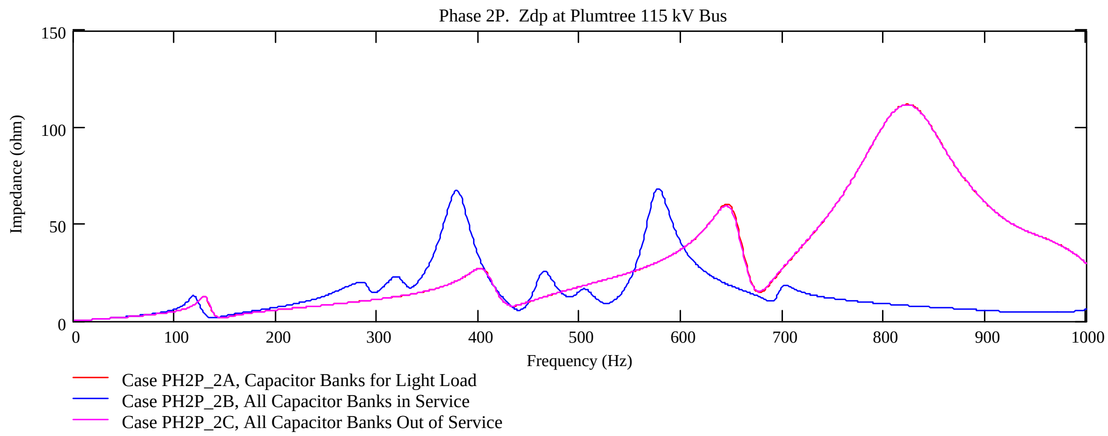
[1] Also, damping of the system at the relatively high frequency of this interaction (600 Hz – 1 kHz) may be greater than represented in the simulation model, due to skin effects in the transmission cables and overhead 1ines.

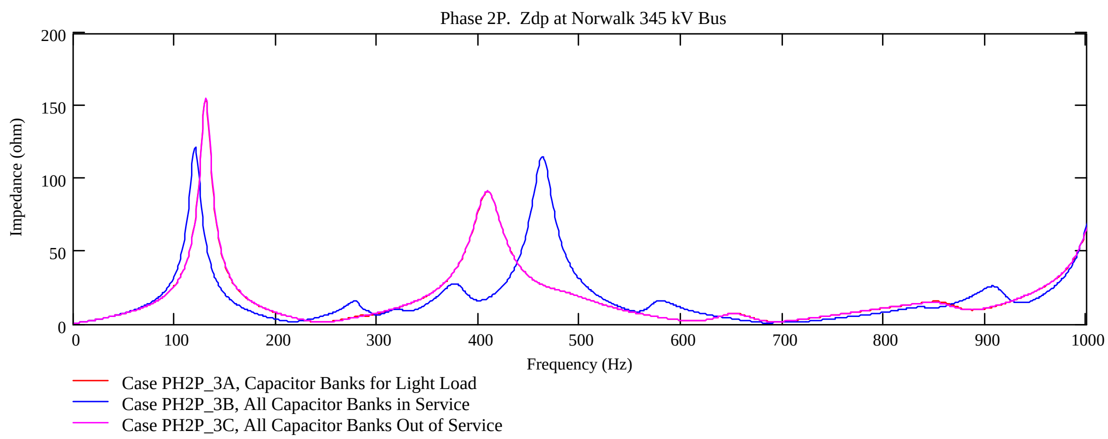
While the switching transient analysis did not indicate severe temporary overvoltage distortion from a peak overvoltage criterion, as might be expected with a 2^{nd} harmonic impedance resonance, slight variation in system conditions could yield more severe results. Designing the system with a resonance at 2^{nd} harmonic could result in severe power system disturbances and is not recommended.

Appendix A – Driving-Point Impedance Plots

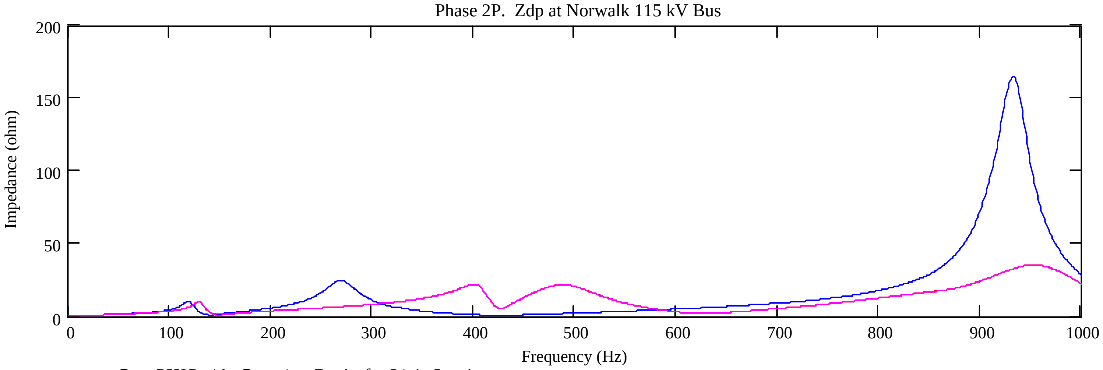
Driving Point Impedance





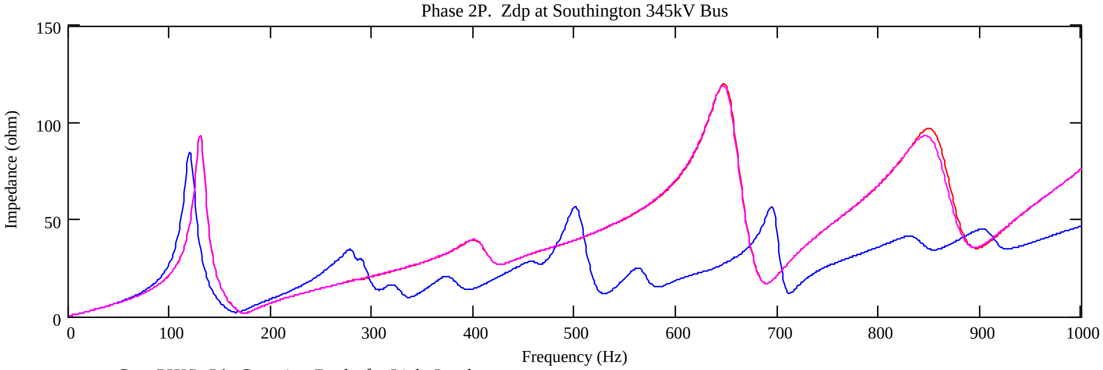


Phase 2P. Zdp at Norwalk 115 kV Bus



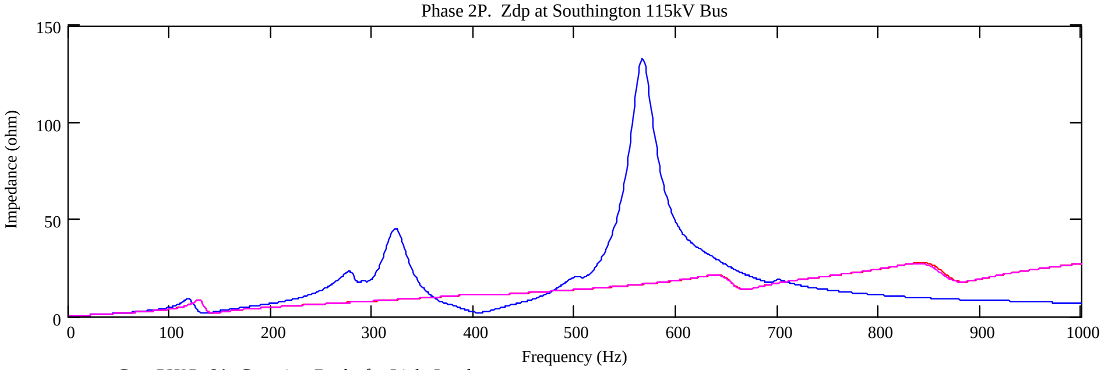
Case PH2P_4A, Capacitor Banks for Light Load
Case PH2P_4B, All Capacitor Banks in Service
Case PH2P_4C, All Capacitor Banks Out of Service

Phase 2P. Zdp at Southington 345kV Bus

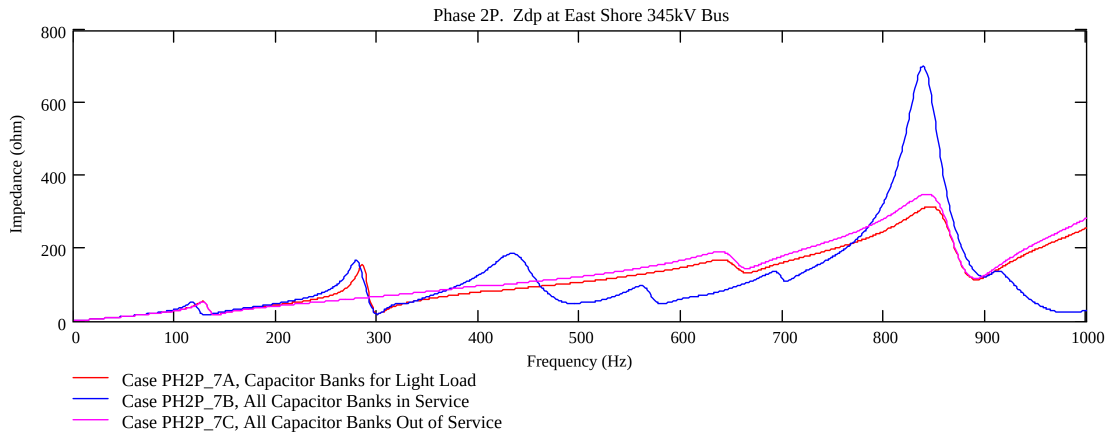


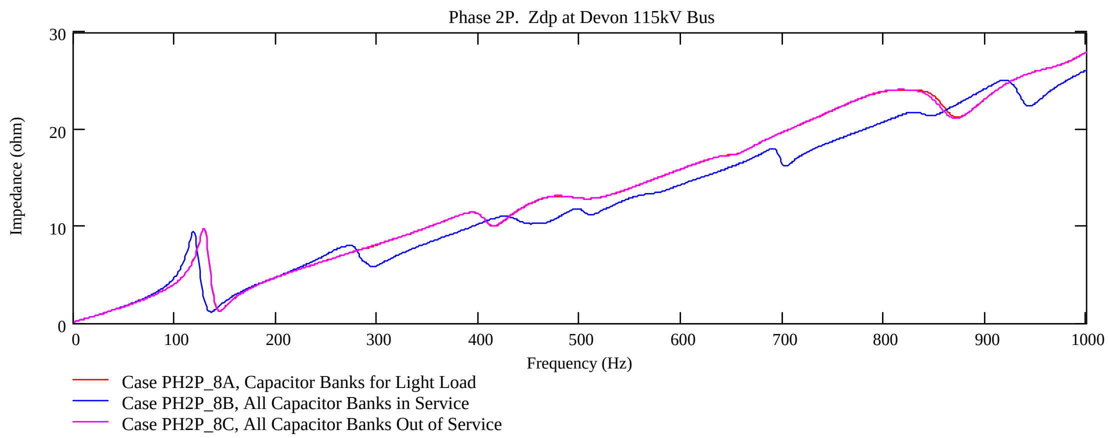
Case PH2P_5A, Capacitor Banks for Light Load
Case PH2P_5B, All Capacitor Banks in Service
Case PH2P_5C, All Capacitor Banks Out of Service

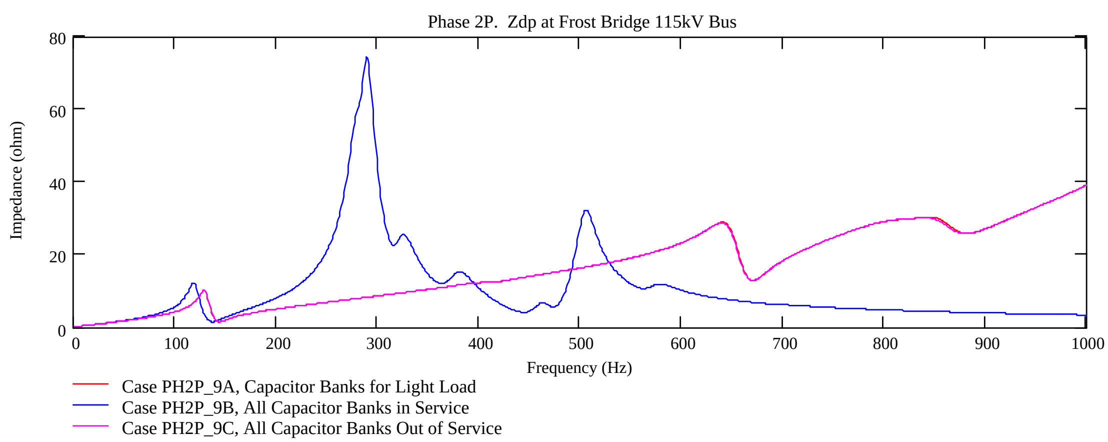
Phase 2P. Zdp at Southington 115kV Bus

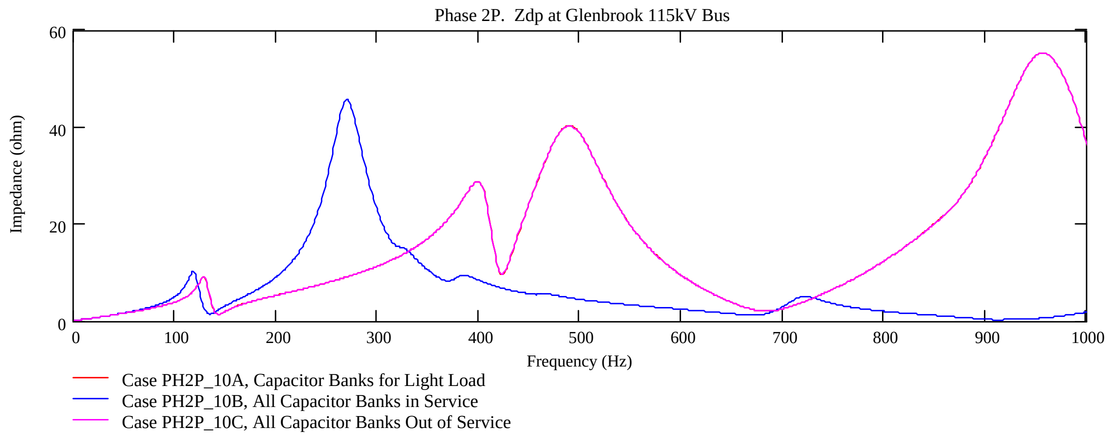


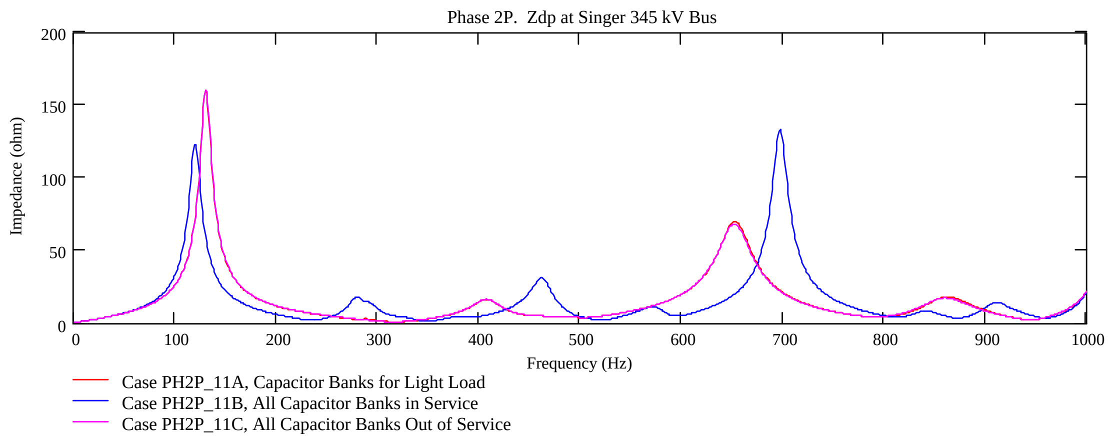
Case PH2P_6A, Capacitor Banks for Light Load
Case PH2P_6B, All Capacitor Banks in Service
Case PH2P_6C, All Capacitor Banks Out of Service

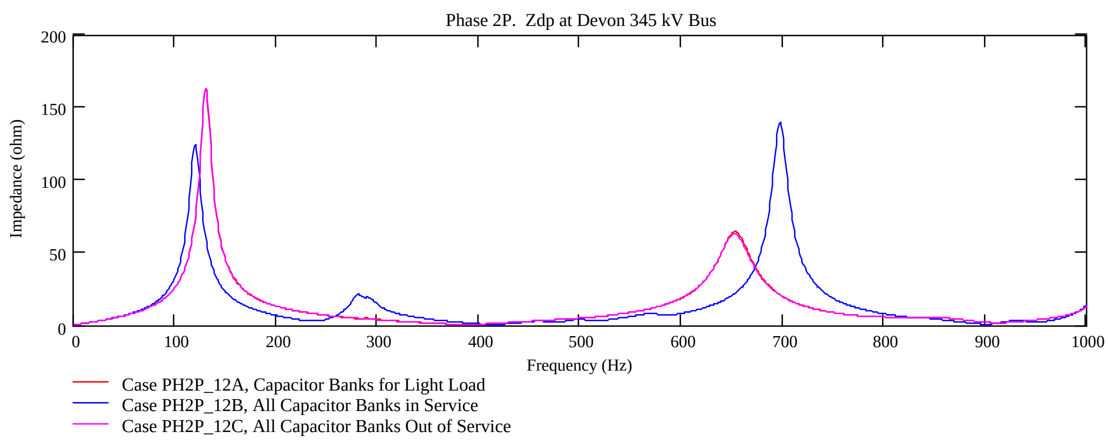

Phase 2P. Zdp at East Shore 345kV Bus
Impedance (ohm)
0
200
400
600
800
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_7A, Capacitor Banks for Light Load
Case PH2P_7B, All Capacitor Banks in Service
Case PH2P_7C, All Capacitor Banks Out of Service

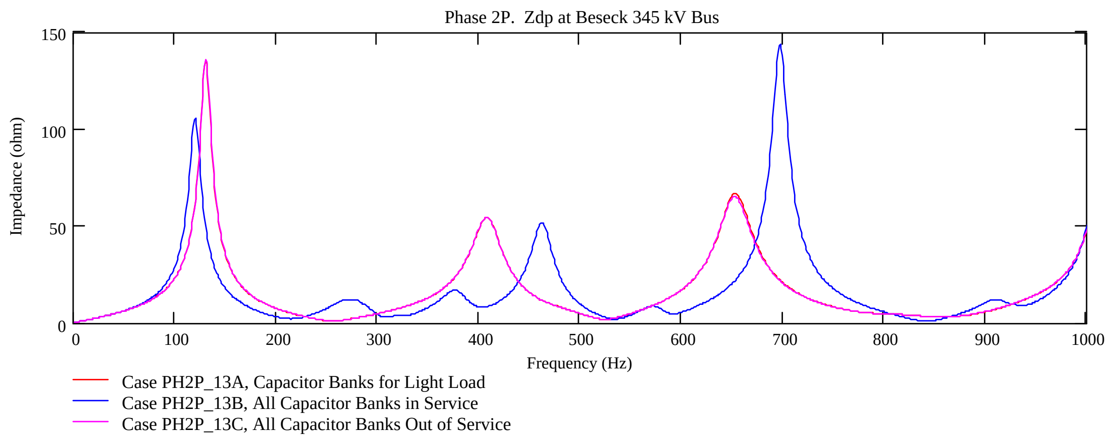

Phase 2P. Zdp at Devon 115kV Bus
Impedance (ohm)
0
10
20
30
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_8A, Capacitor Banks for Light Load
Case PH2P_8B, All Capacitor Banks in Service
Case PH2P_8C, All Capacitor Banks Out of Service


Phase 2P. Zdp at Frost Bridge 115kV Bus
Impedance (ohm)
0
20
40
60
80
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_9A, Capacitor Banks for Light Load
Case PH2P_9B, All Capacitor Banks in Service
Case PH2P_9C, All Capacitor Banks Out of Service


Phase 2P. Zdp at Glenbrook 115kV Bus
Impedance (ohm)
0
20
40
60
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_10A, Capacitor Banks for Light Load
Case PH2P_10B, All Capacitor Banks in Service
Case PH2P_10C, All Capacitor Banks Out of Service


Phase 2P. Zdp at Singer 345 kV Bus
Impedance (ohm)
0
50
100
150
200
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_11A, Capacitor Banks for Light Load
Case PH2P_11B, All Capacitor Banks in Service
Case PH2P_11C, All Capacitor Banks Out of Service


Phase 2P. Zdp at Devon 345 kV Bus
Impedance (ohm)
0
50
100
150
200
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_12A, Capacitor Banks for Light Load
Case PH2P_12B, All Capacitor Banks in Service
Case PH2P_12C, All Capacitor Banks Out of Service

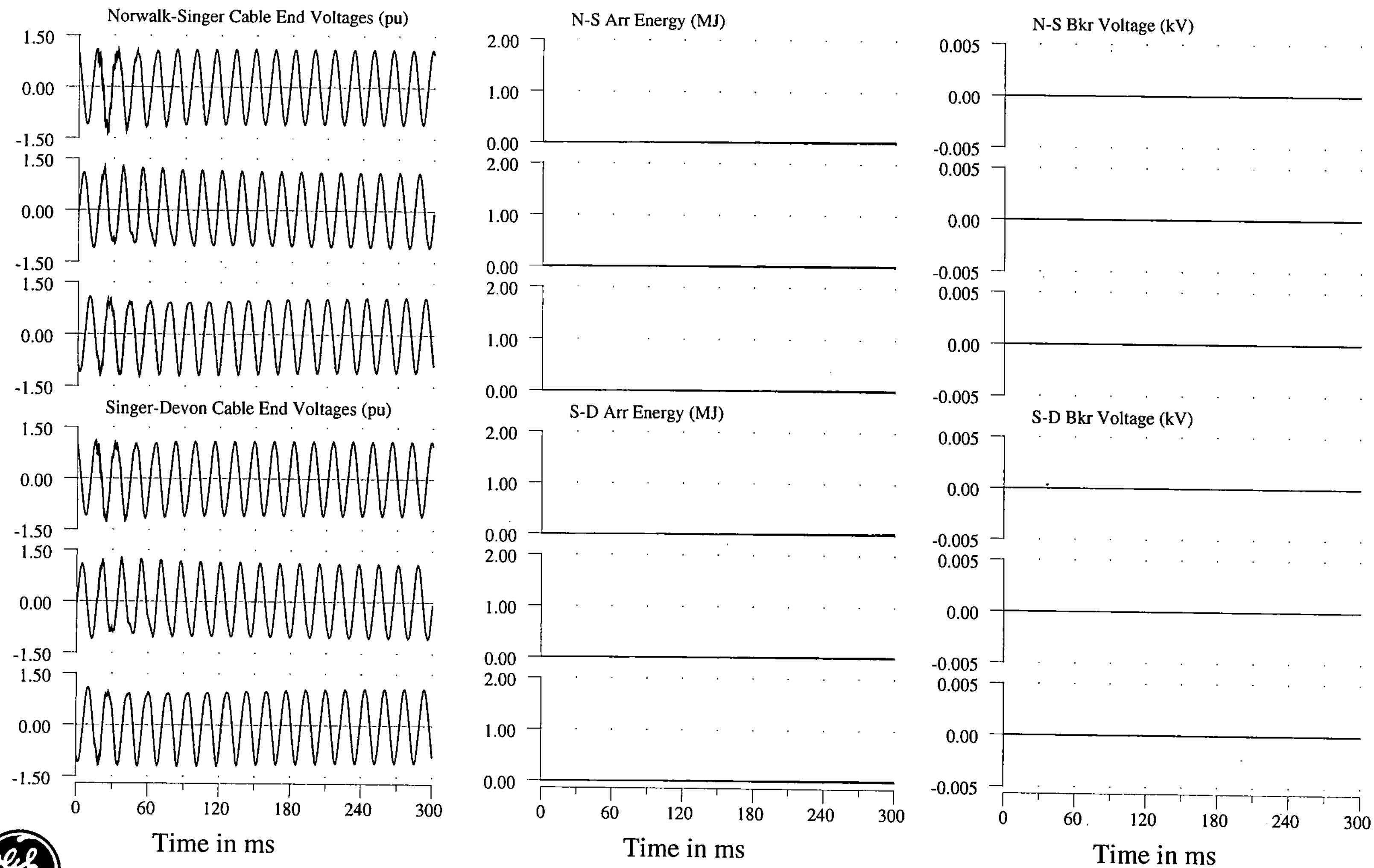

Phase 2P. Zdp at Beseck 345 kV Bus
Impedance (ohm)
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)
Case PH2P_13A, Capacitor Banks for Light Load
Case PH2P_13B, All Capacitor Banks in Service
Case PH2P_13C, All Capacitor Banks Out of Service

Appendix B – Switching Simulation Case Plots

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

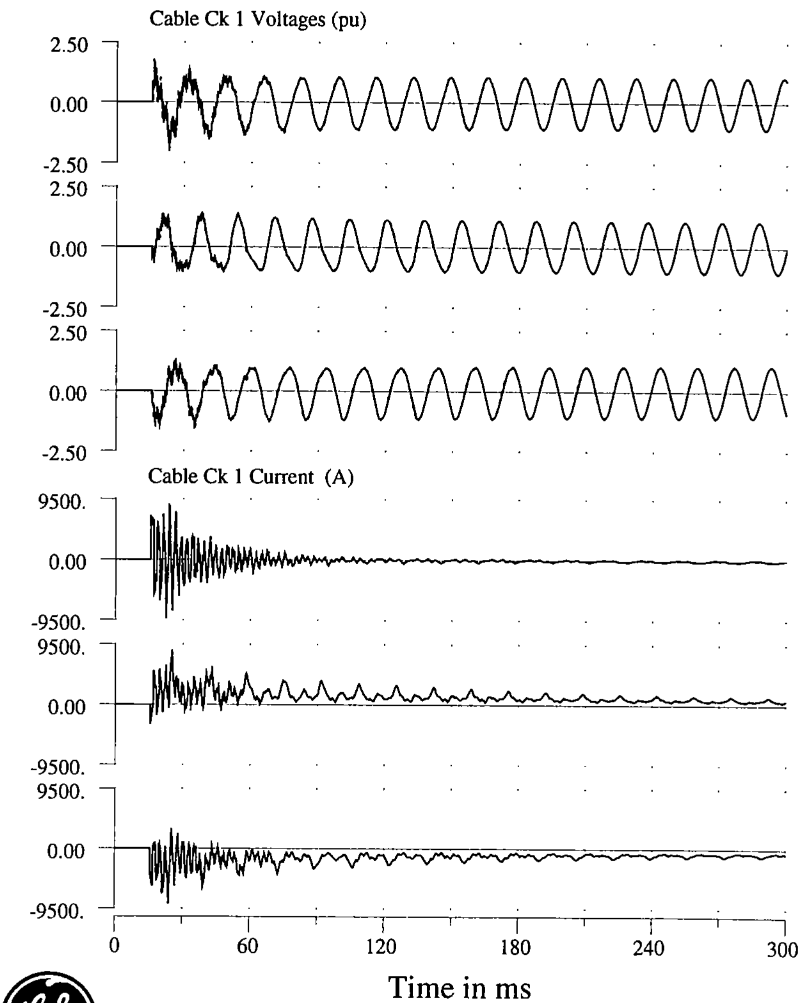


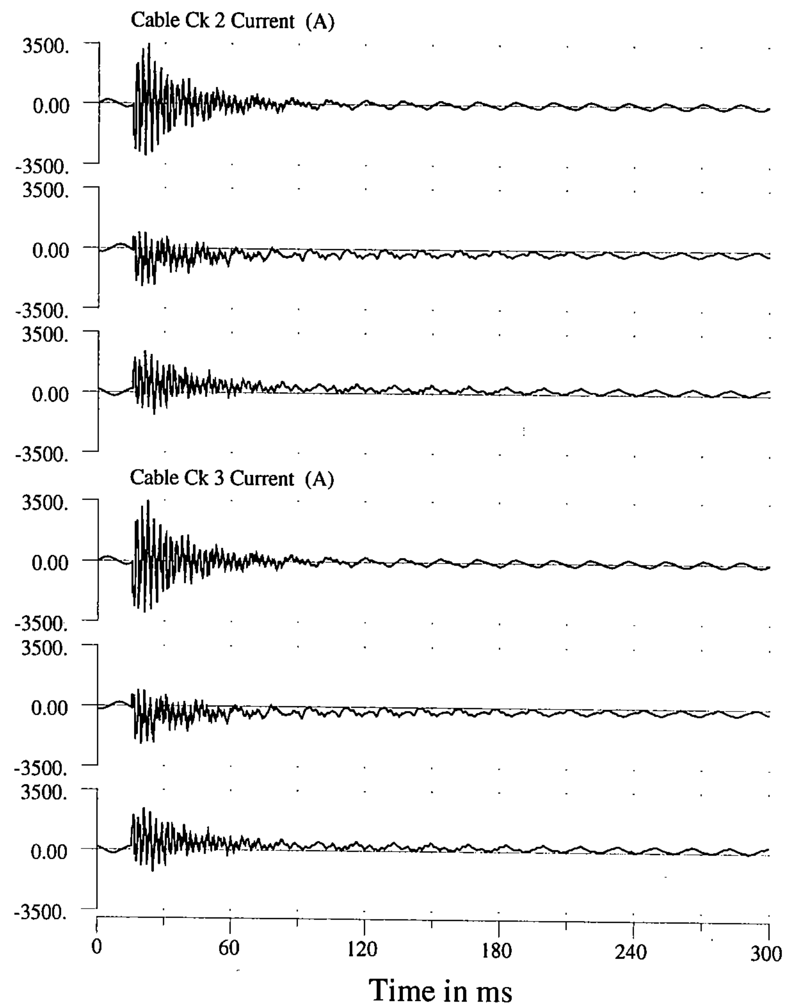
03-Nov-03 17:22:15 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_01

Devon-Beseck 345 kV Cables



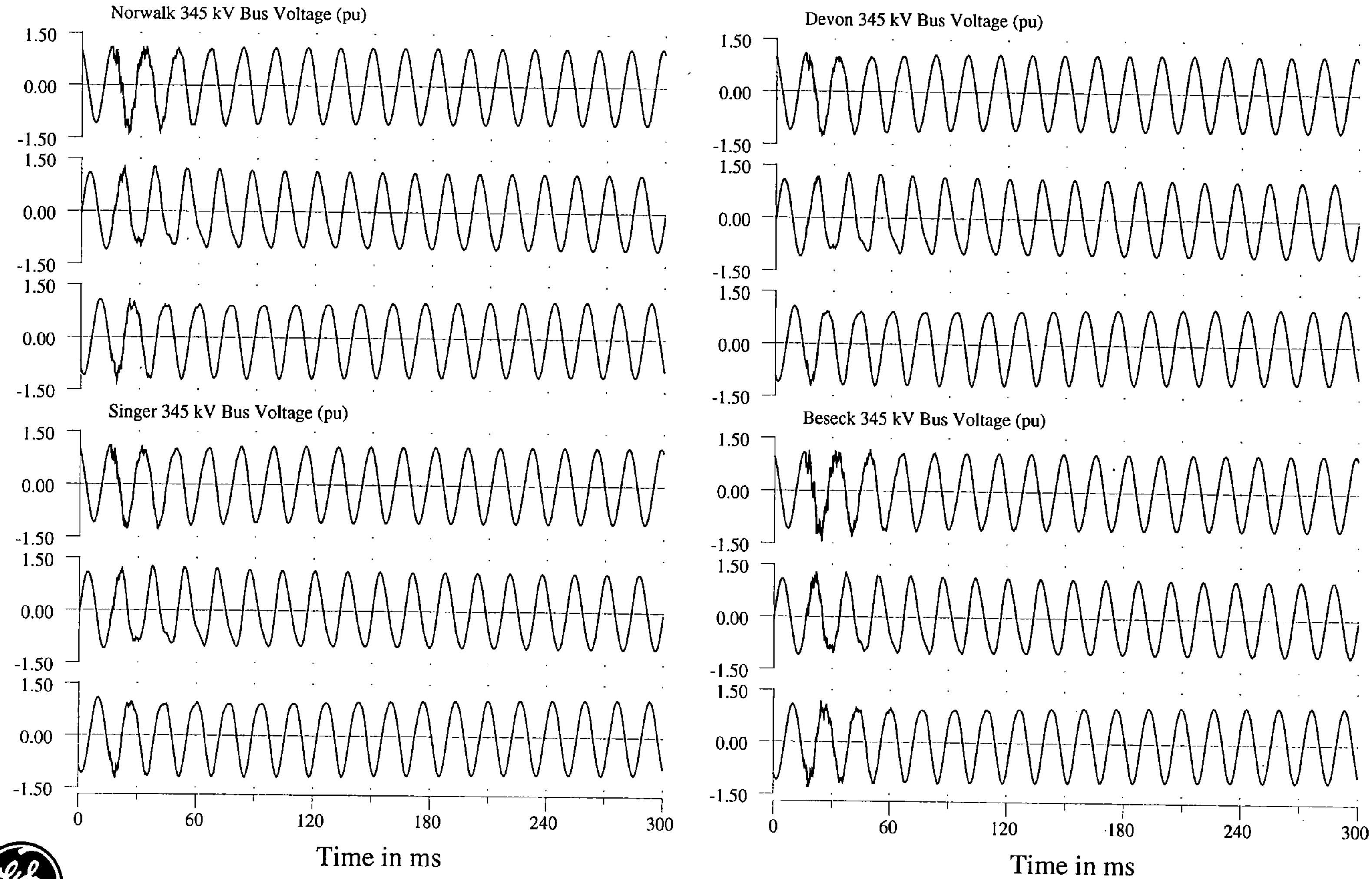


03-Nov-03 17:22:15 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_01

345 kV Bus Voltages

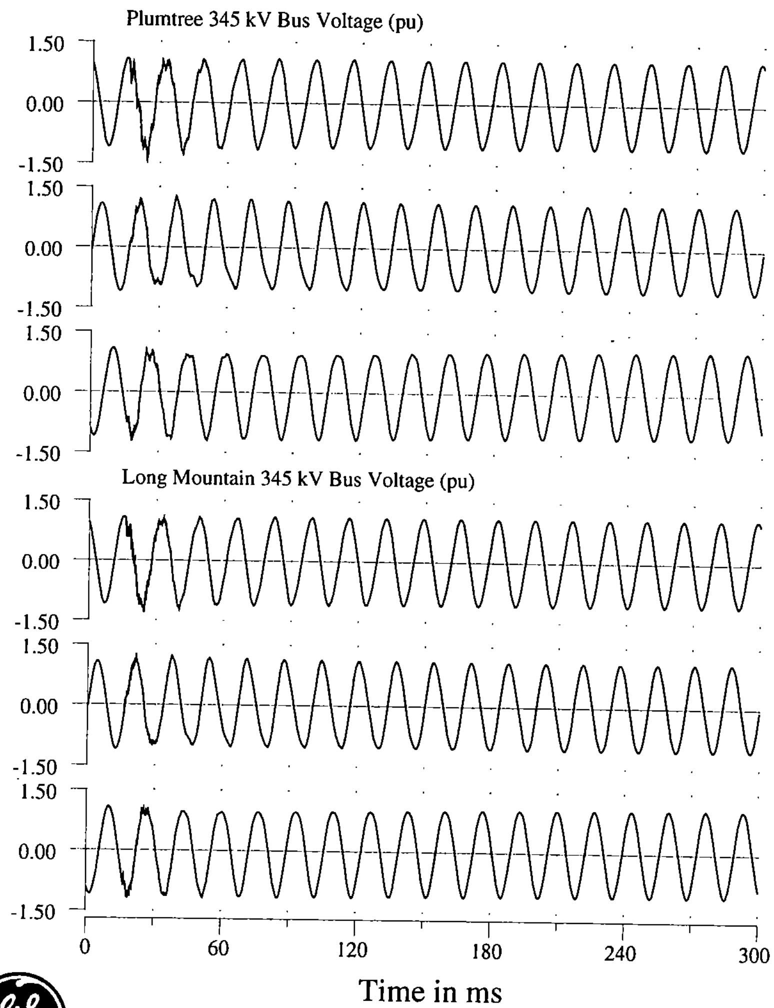


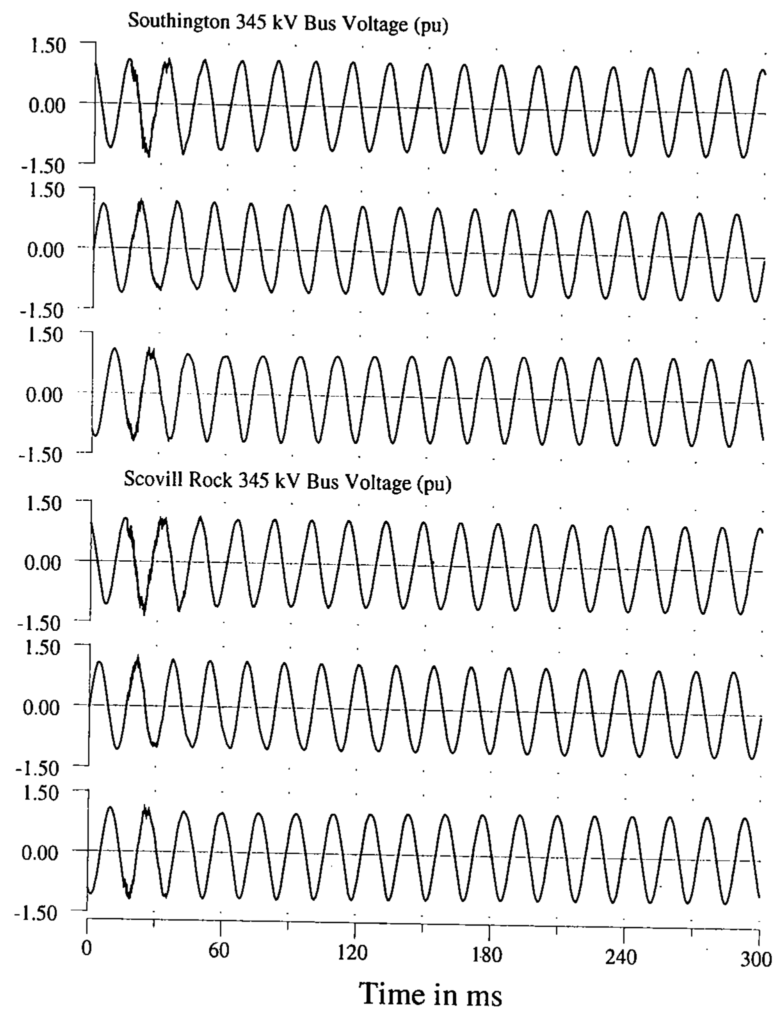
03-Nov-03 17:22:15 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_01

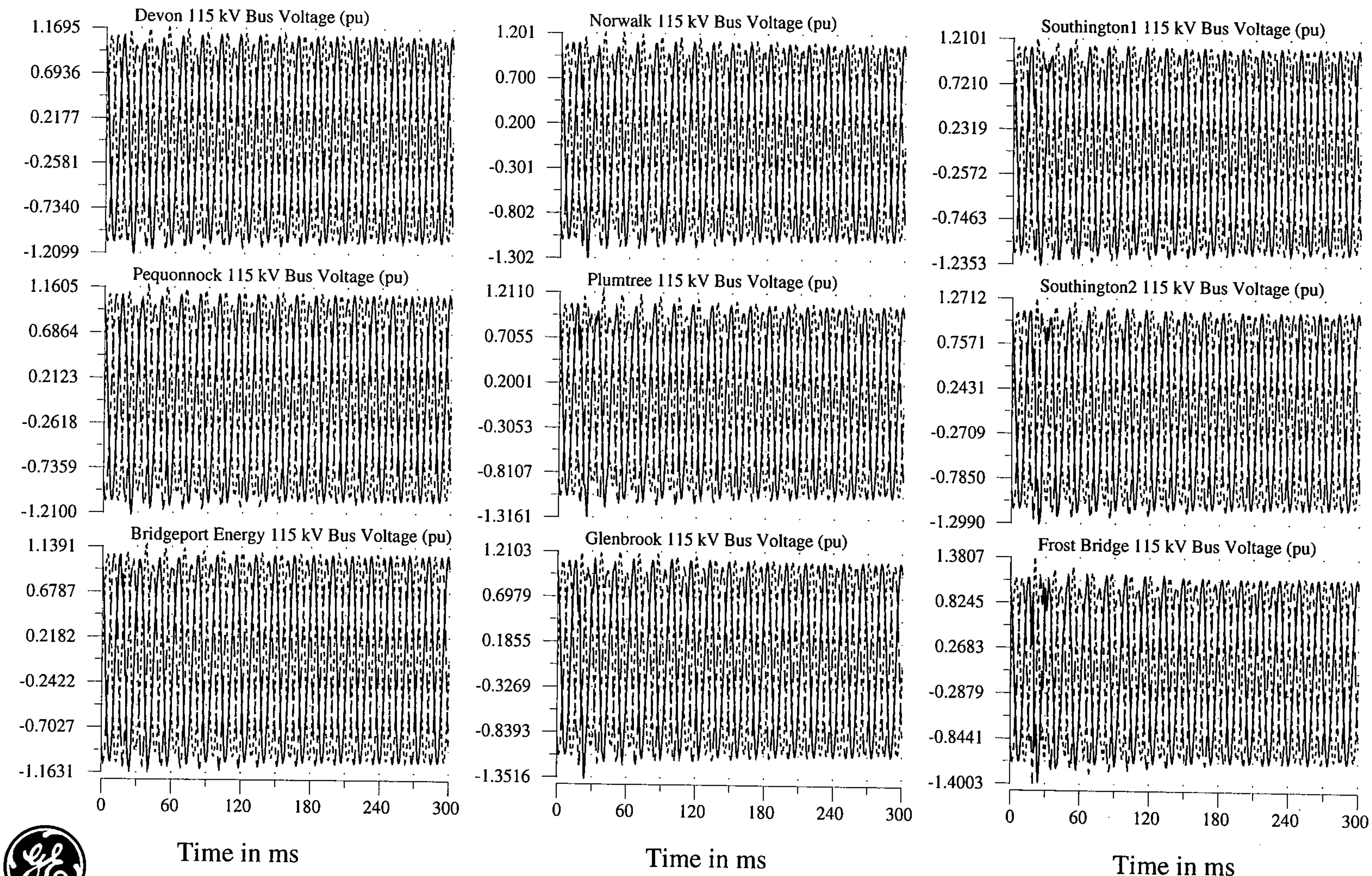
345 kV Bus Voltages





03-Nov-03 17:22:15 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_Z1_01
115 kV Bus Voltages and Capacitor Bank Locations

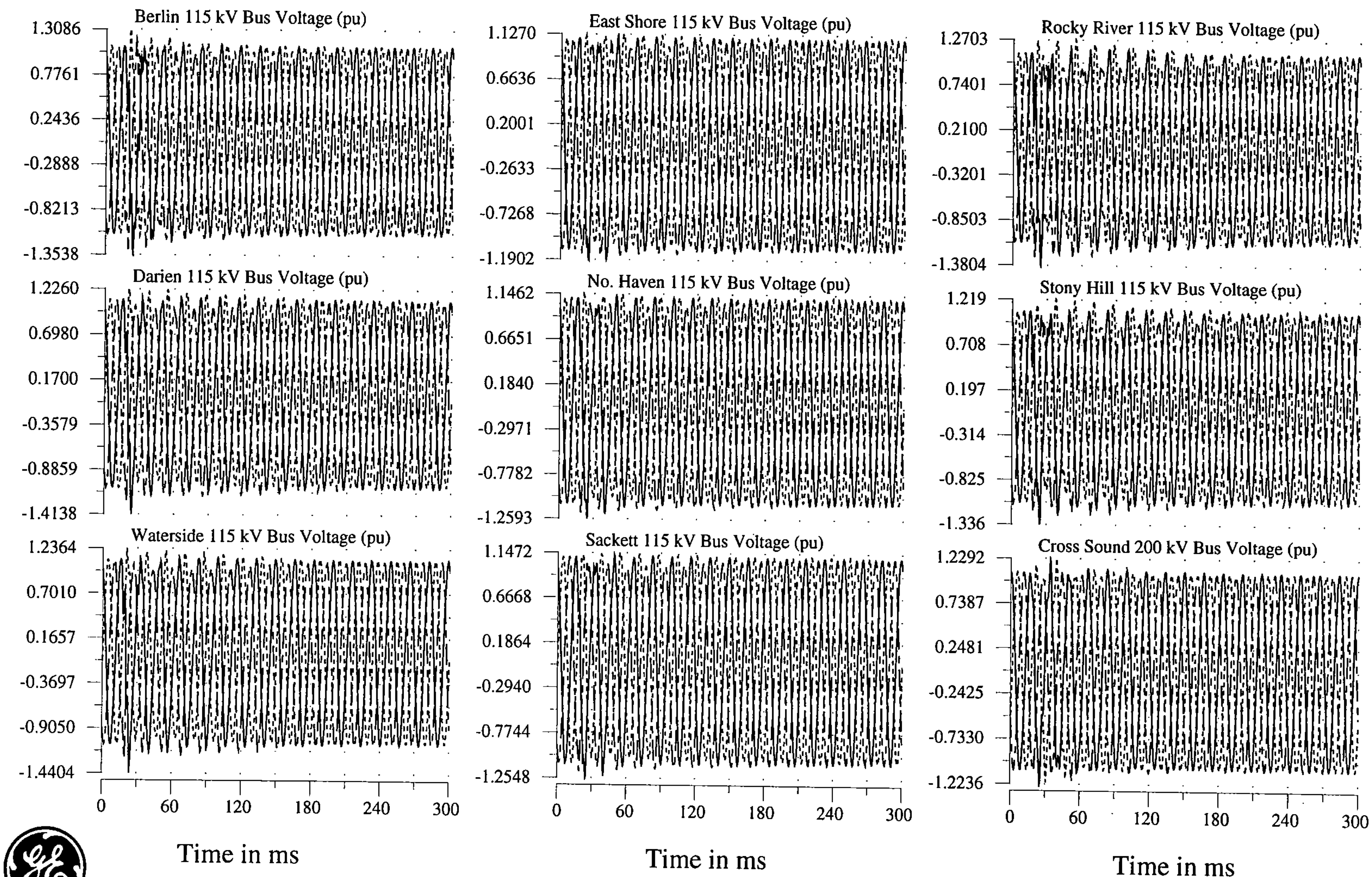


03-Nov-03 17:22:15 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_01

115 kV Bus Voltages and Capacitor Bank Locations

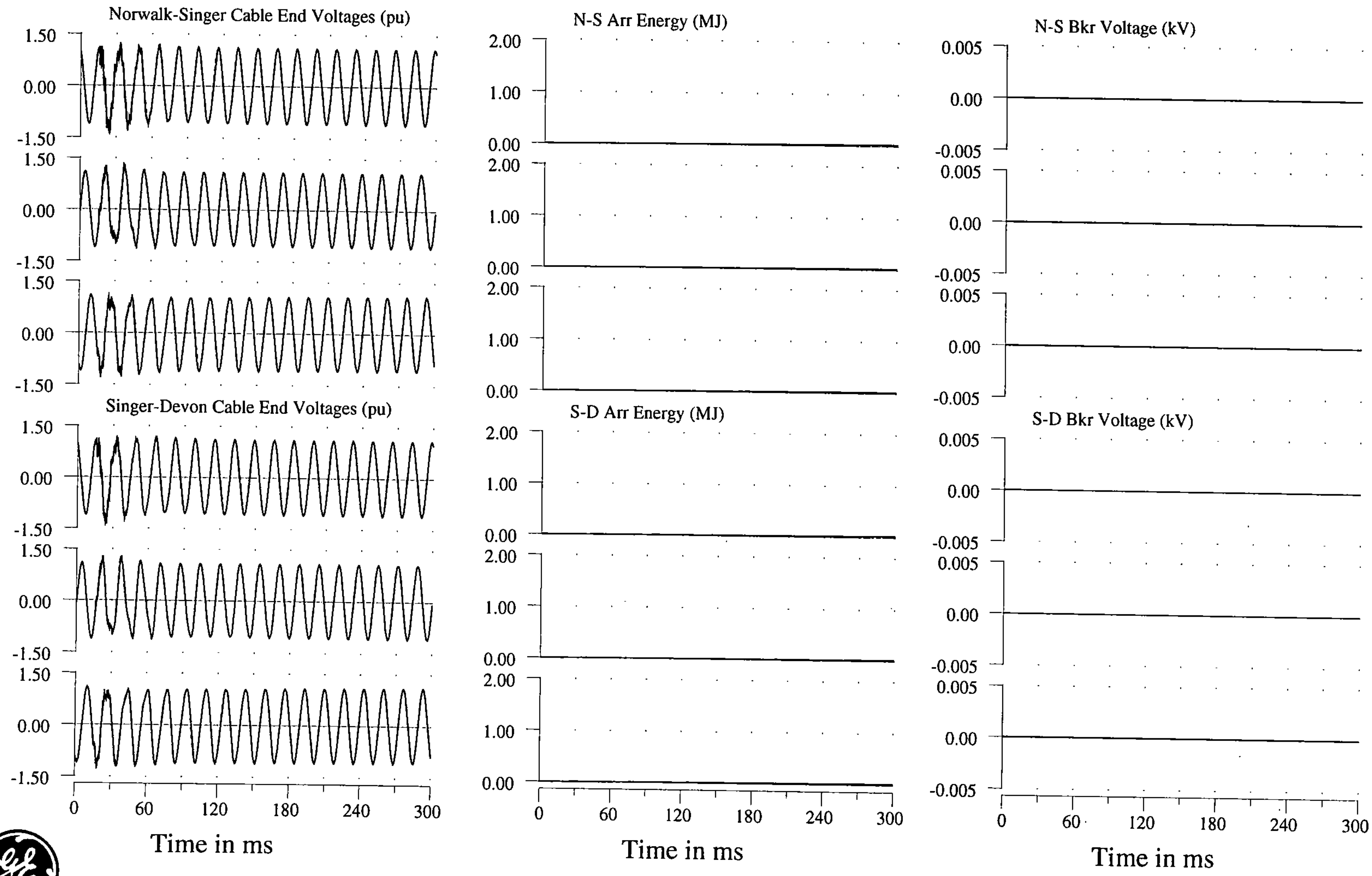


03-Nov-03 17:22:15 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_02

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

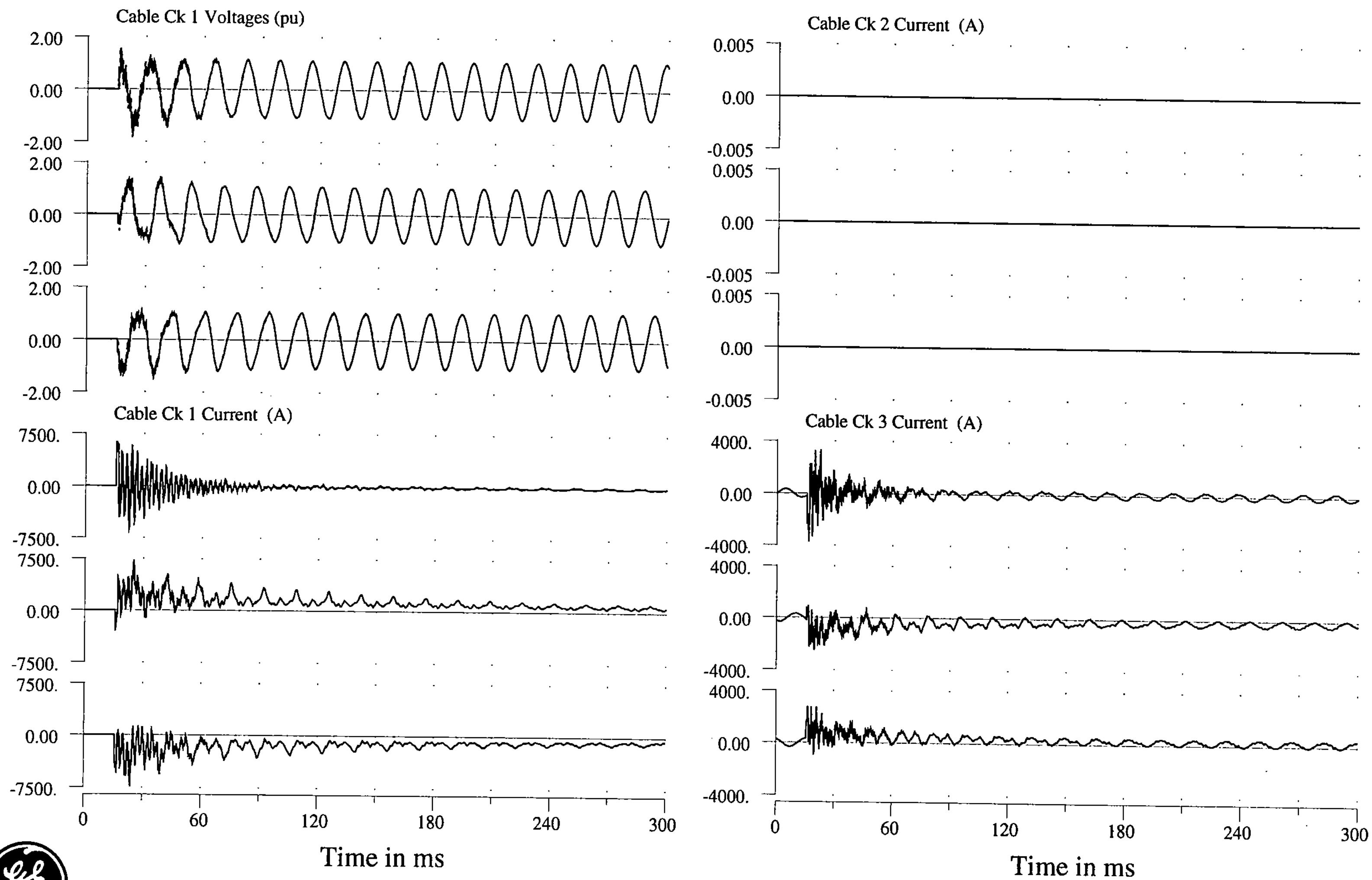


03-Nov-03 17:25:09 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

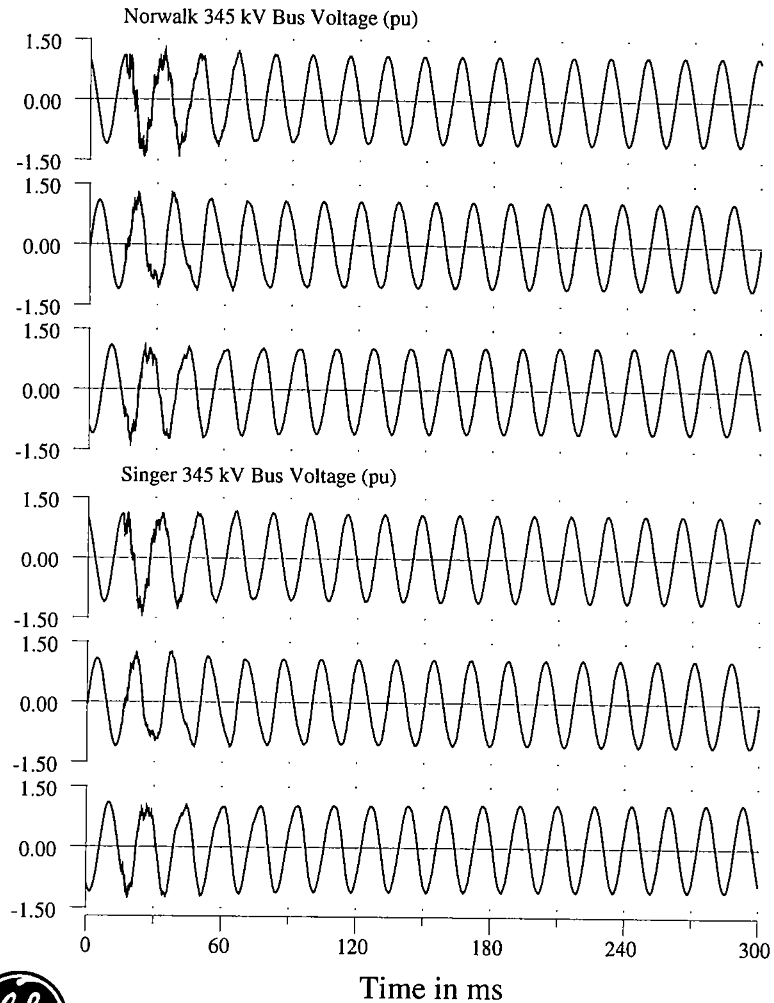
PH2P_Z1_02

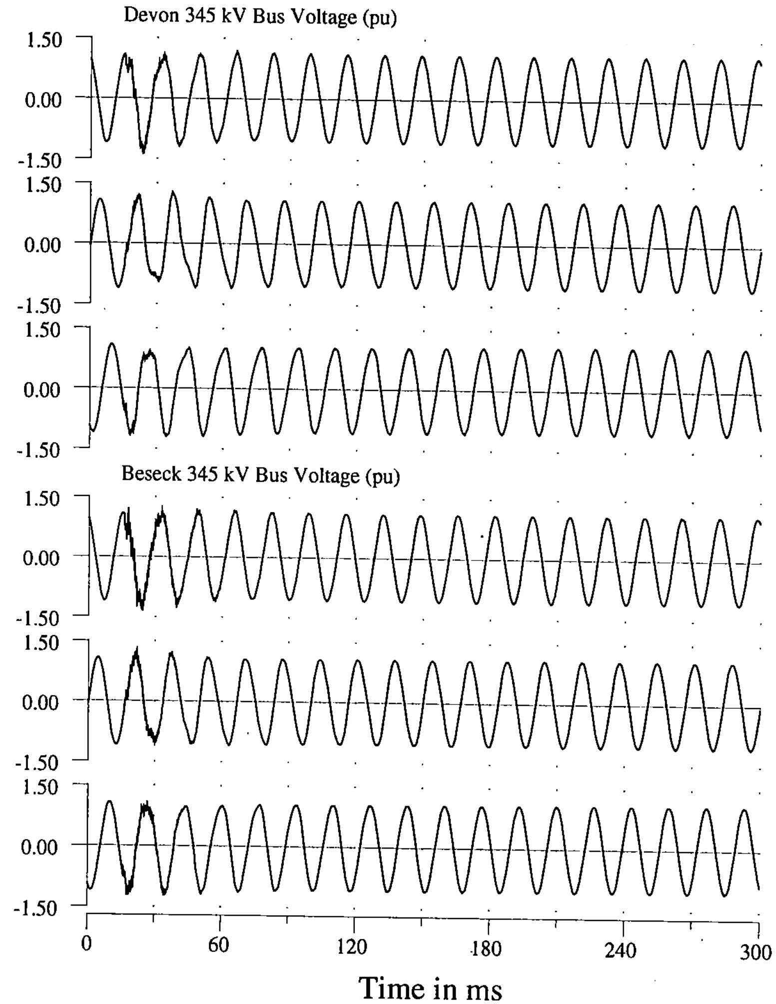
Devon-Beseck 345 kV Cables



03-Nov-03 17:25:09 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_Z1_02
345 kV Bus Voltages



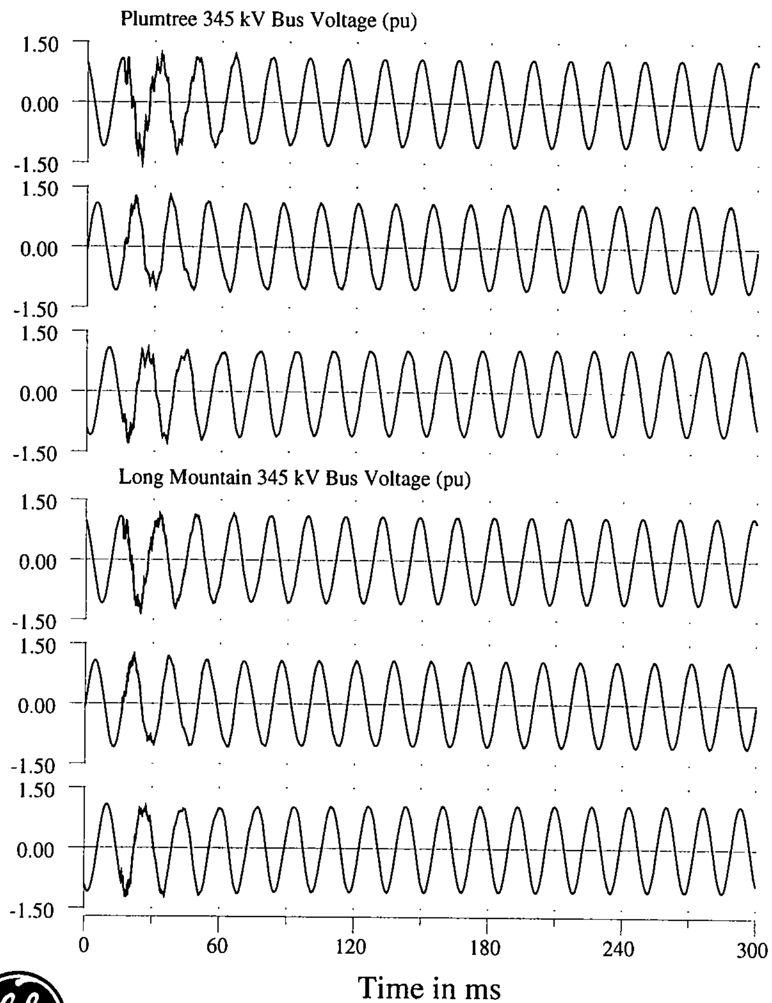


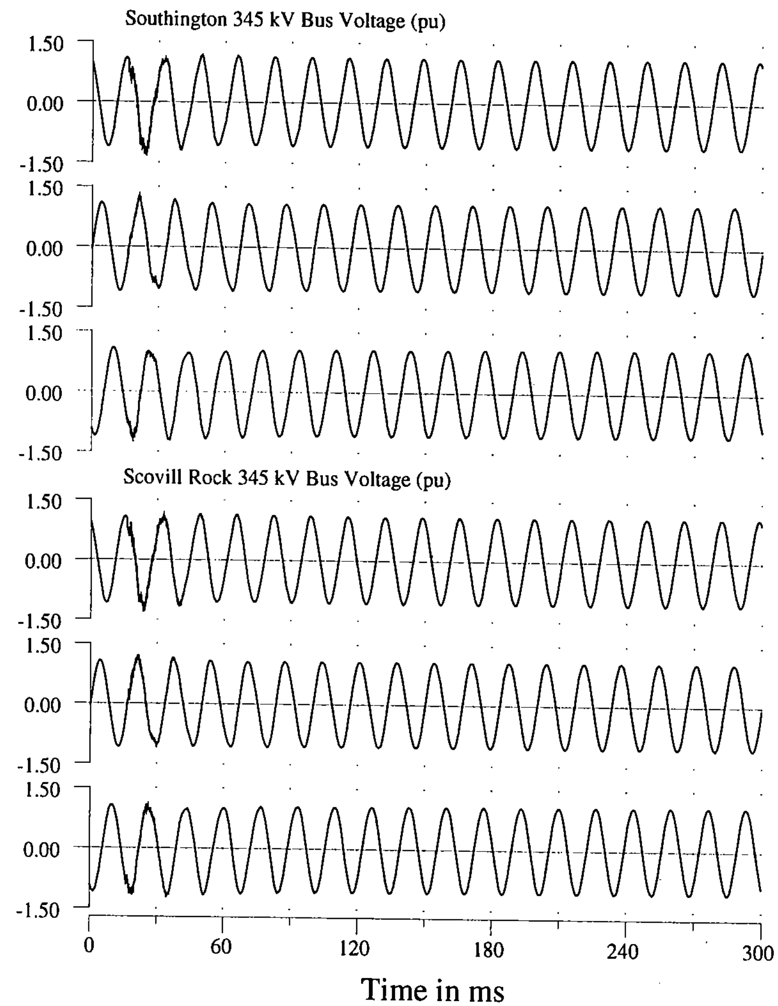
03-Nov-03 17:25:09 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_02

345 kV Bus Voltages



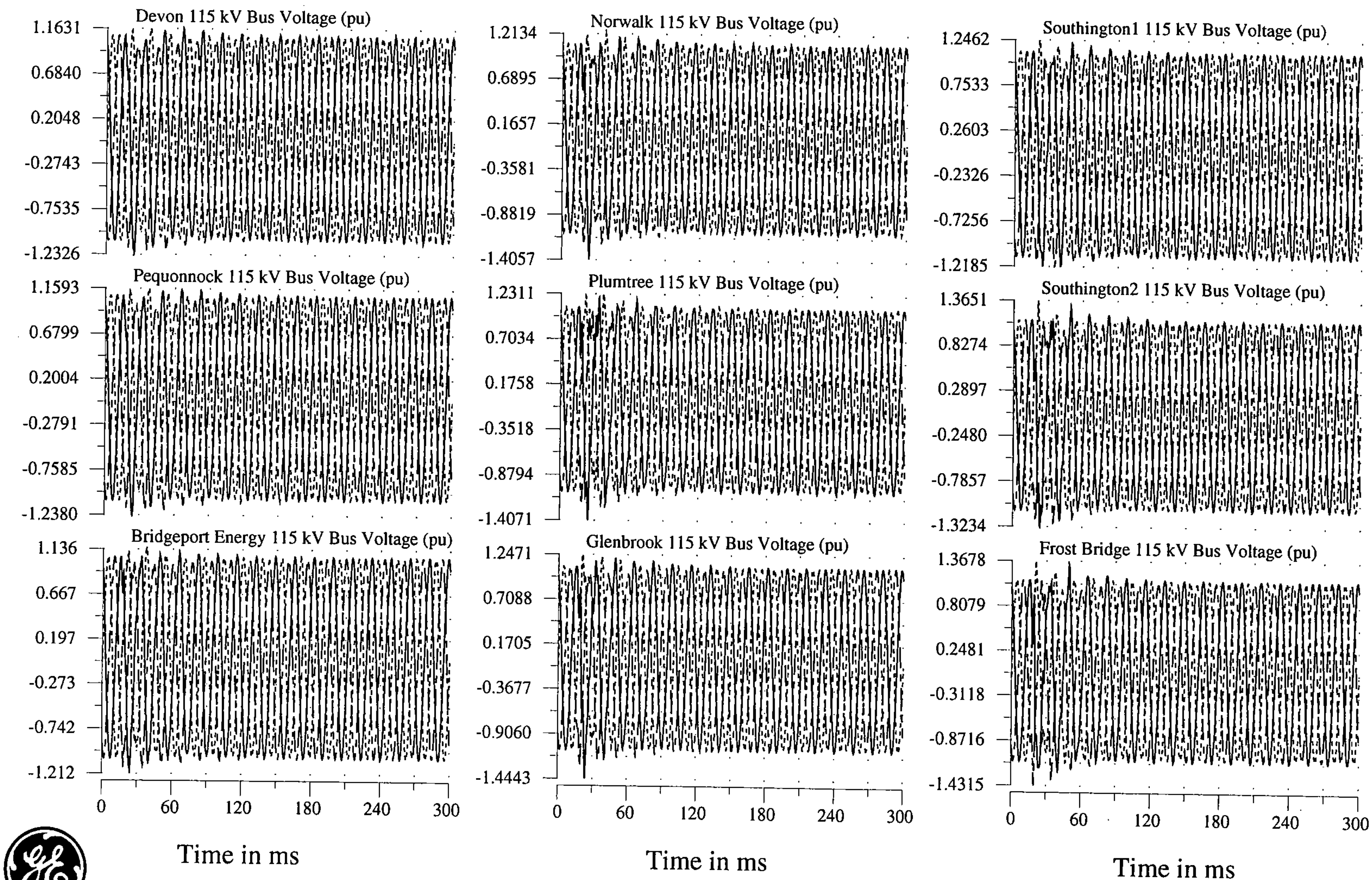


03-Nov-03 17:25:09 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_02

115 kV Bus Voltages and Capacitor Bank Locations

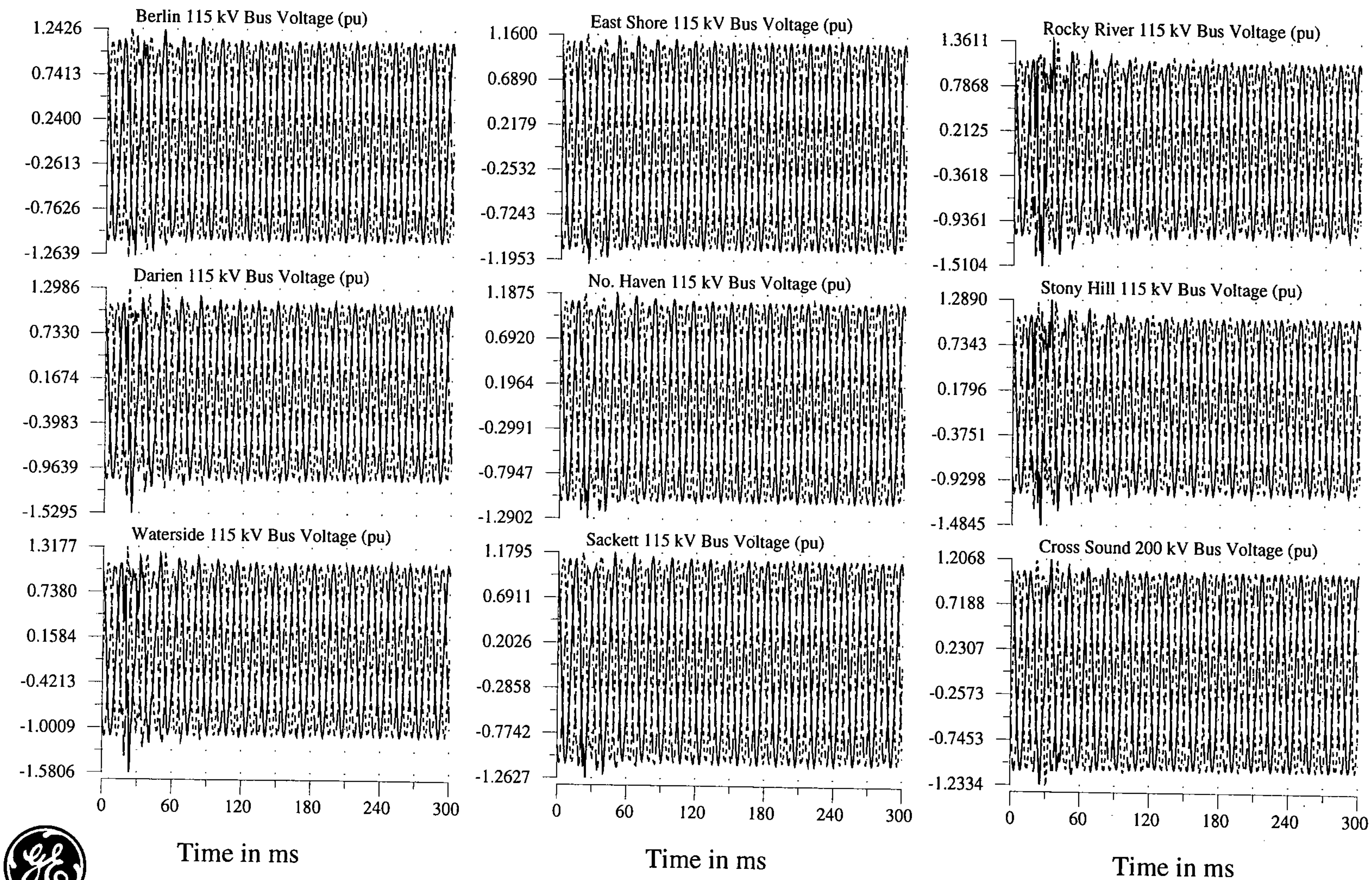


03-Nov-03 17:25:09 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

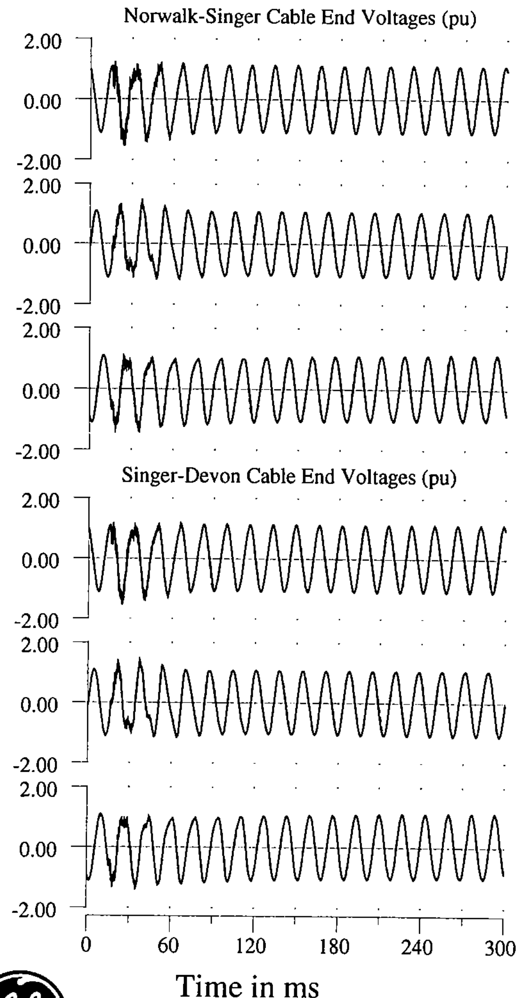
PH2P_Z1_02

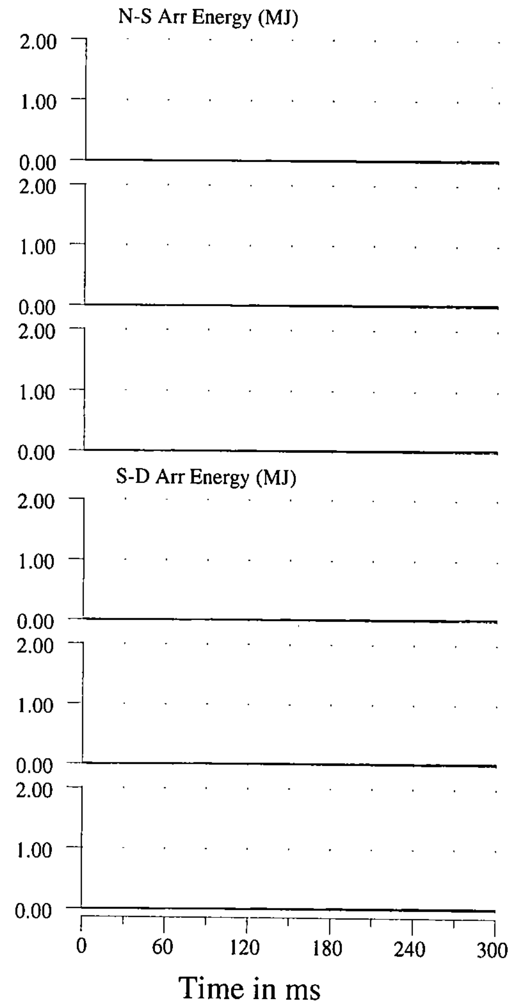
115 kV Bus Voltages and Capacitor Bank Locations

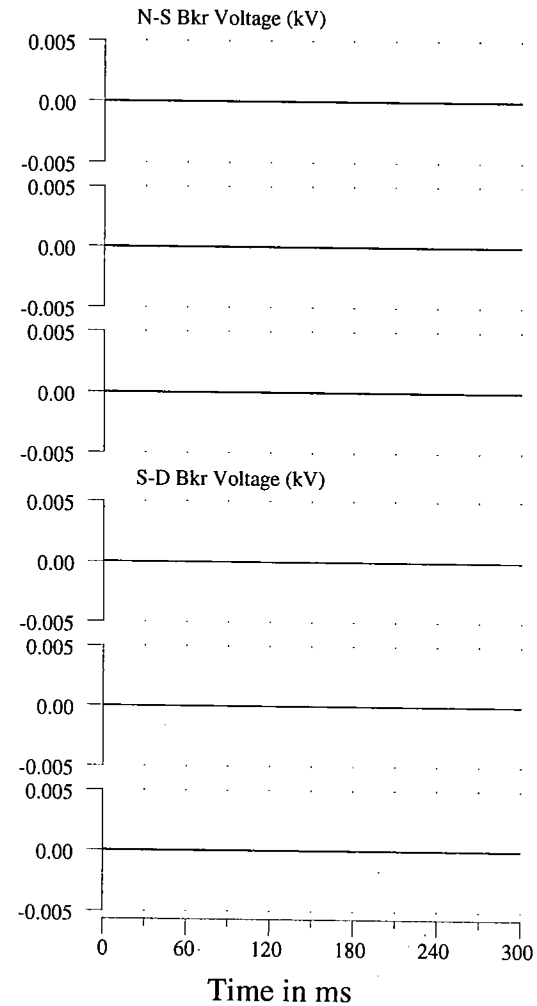


03-Nov-03 17:25:09 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_Z1_03
Case Summary Plots for Phase 2 345 kV Cables (Ck 1)





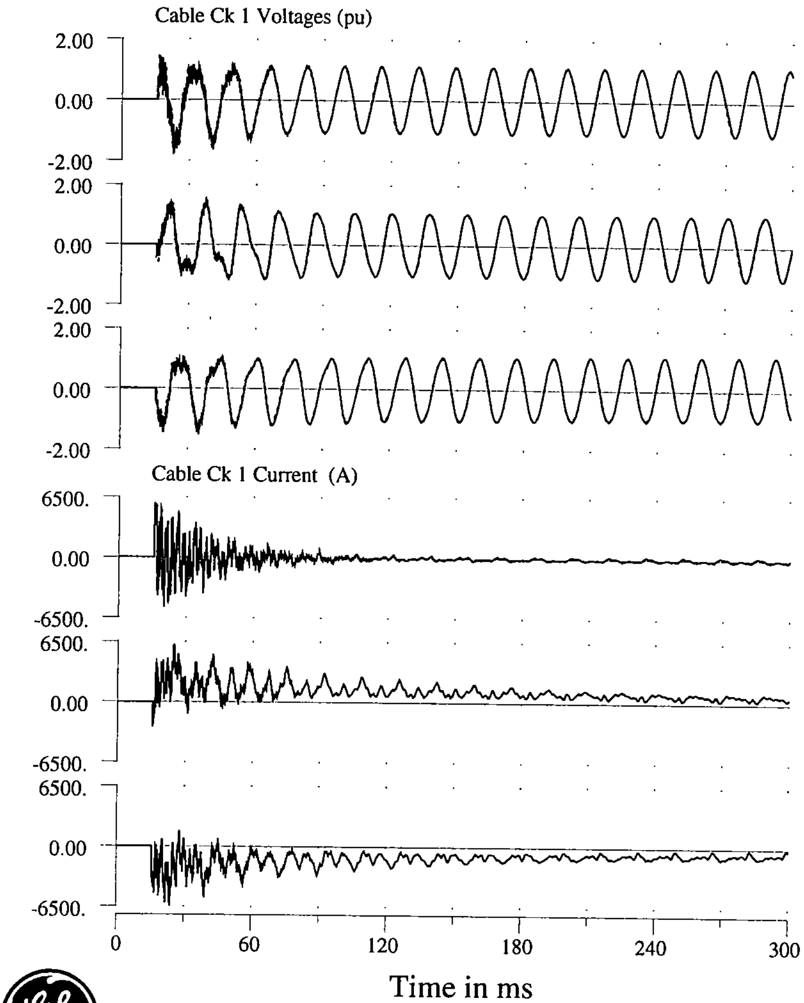


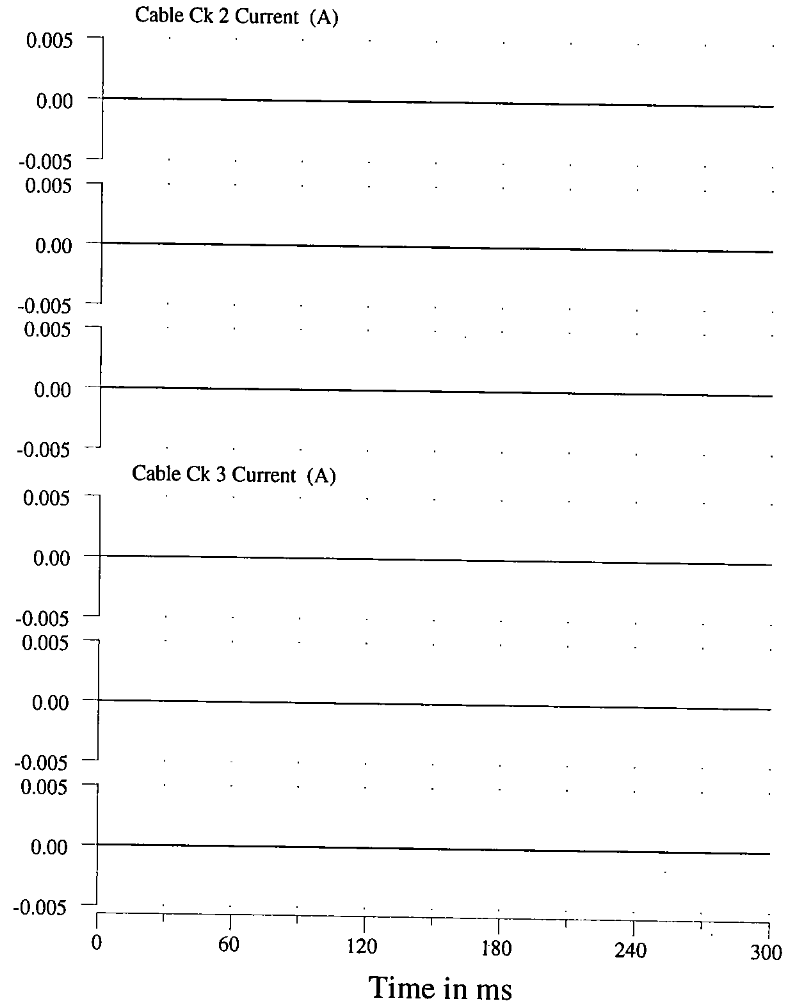
03-Nov-03 17:28:06 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_03

Devon-Beseck 345 kV Cables



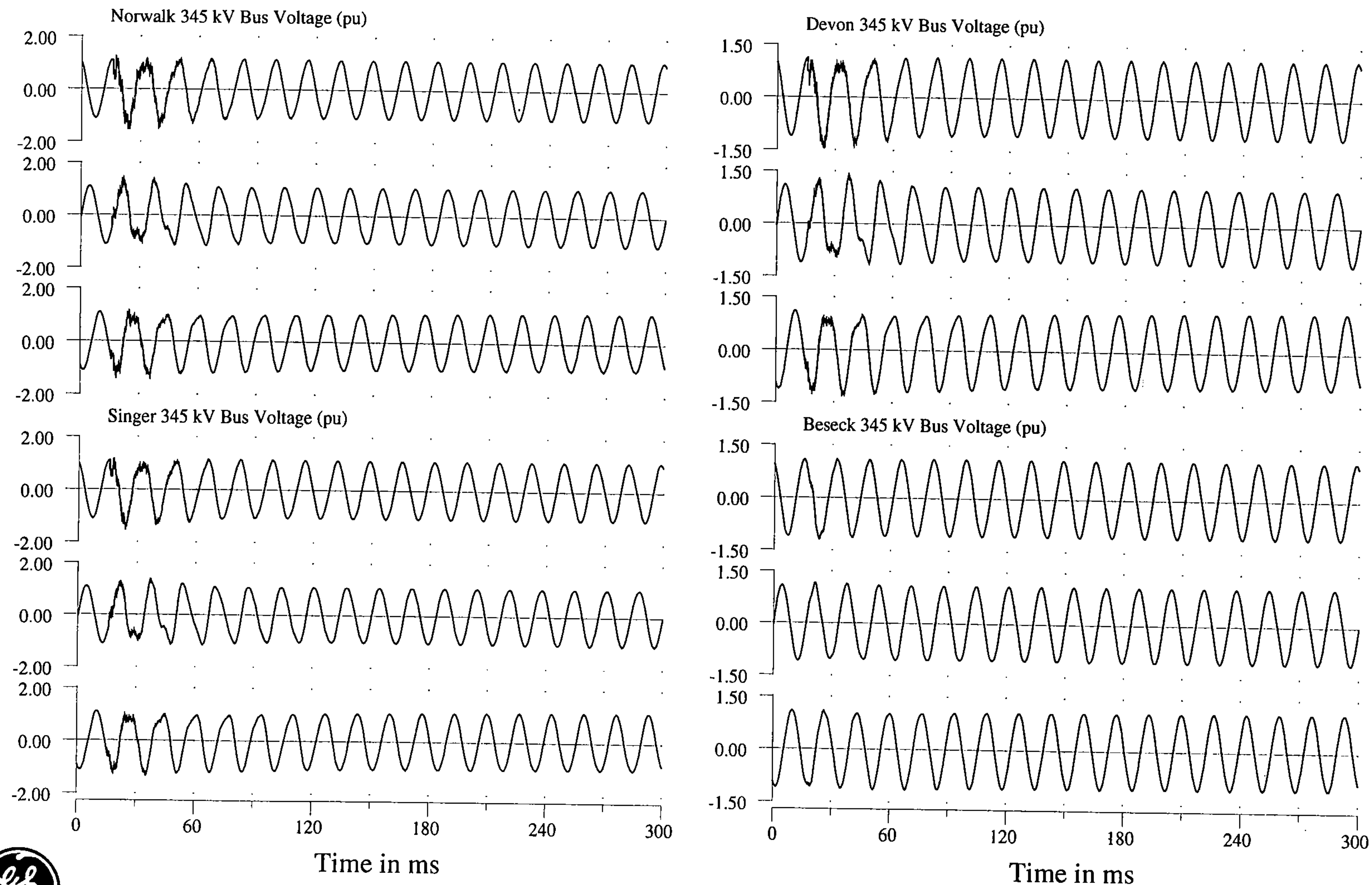


03-Nov-03 17:28:06 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_03

345 kV Bus Voltages

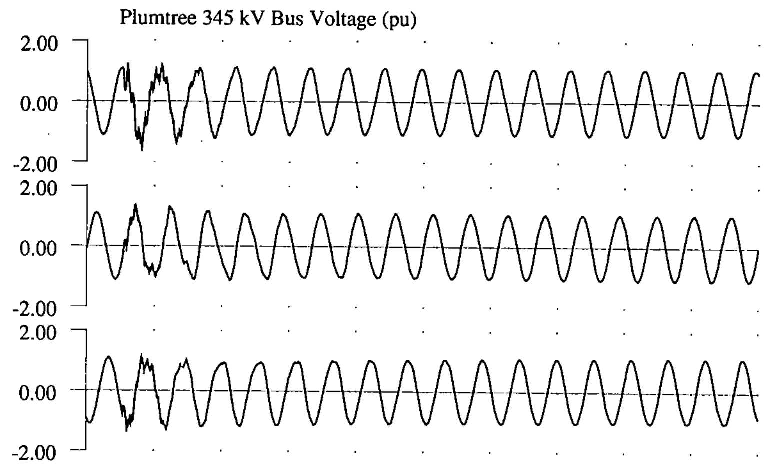


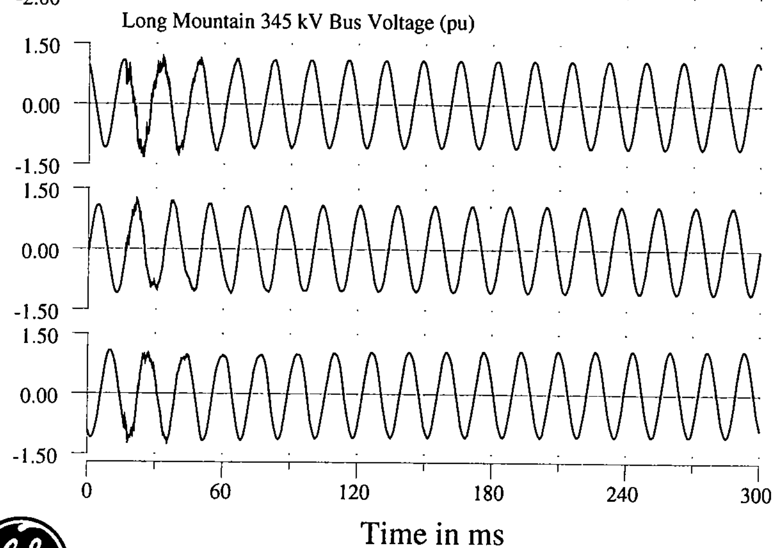
03-Nov-03 17:28:06 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_03.PL4

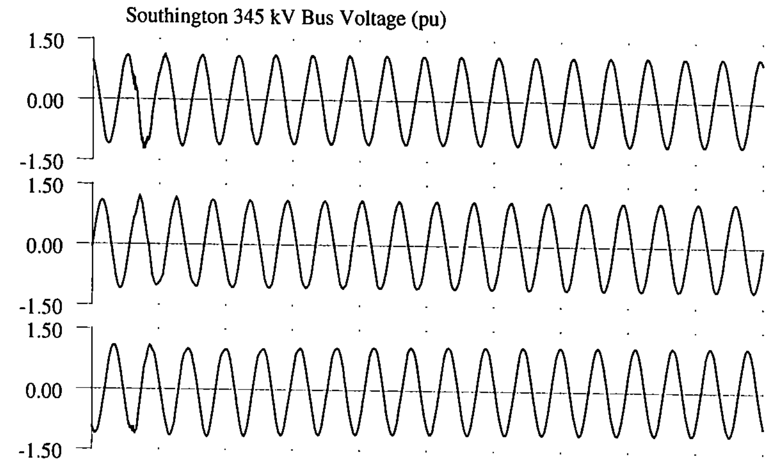
Northeast Utilities: Phase 2 Cable Transient Study

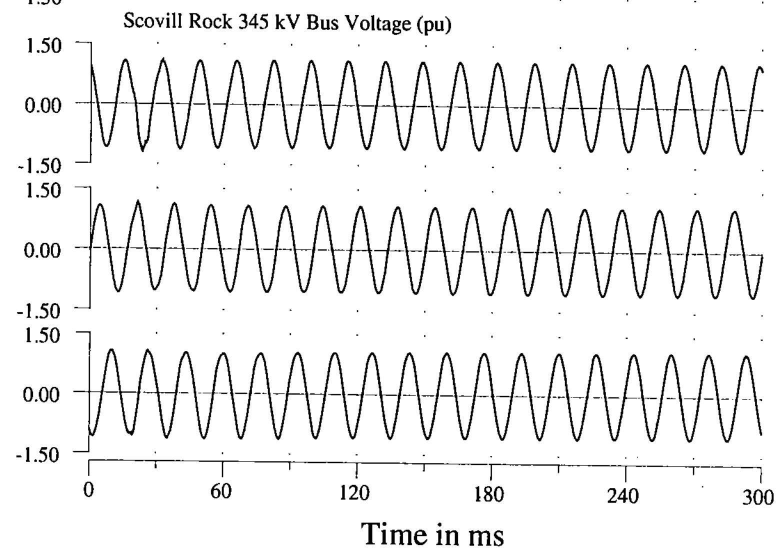
PH2P_Z1_03

345 kV Bus Voltages







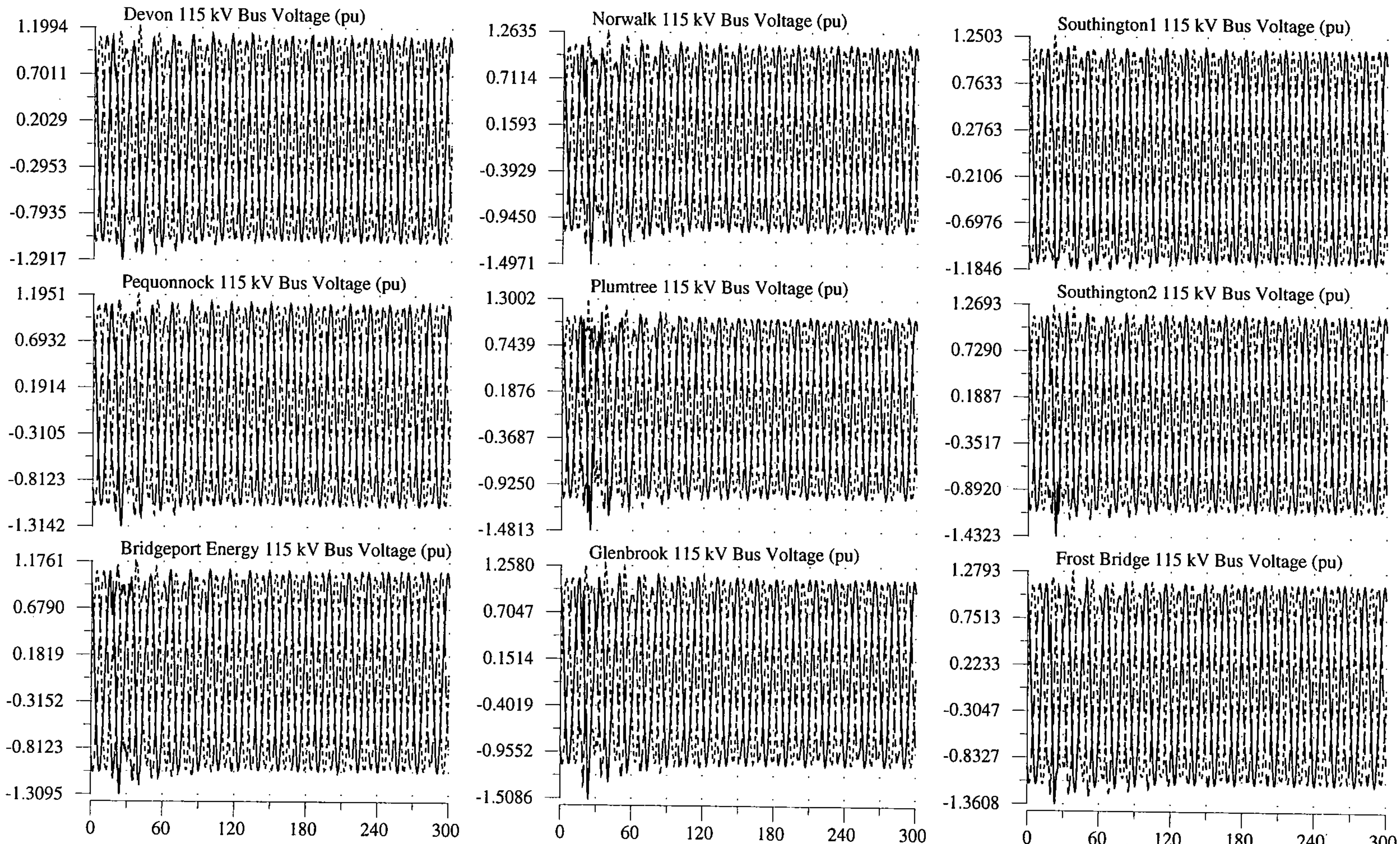


03-Nov-03 17:28:06 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_03

115 kV Bus Voltages and Capacitor Bank Locations

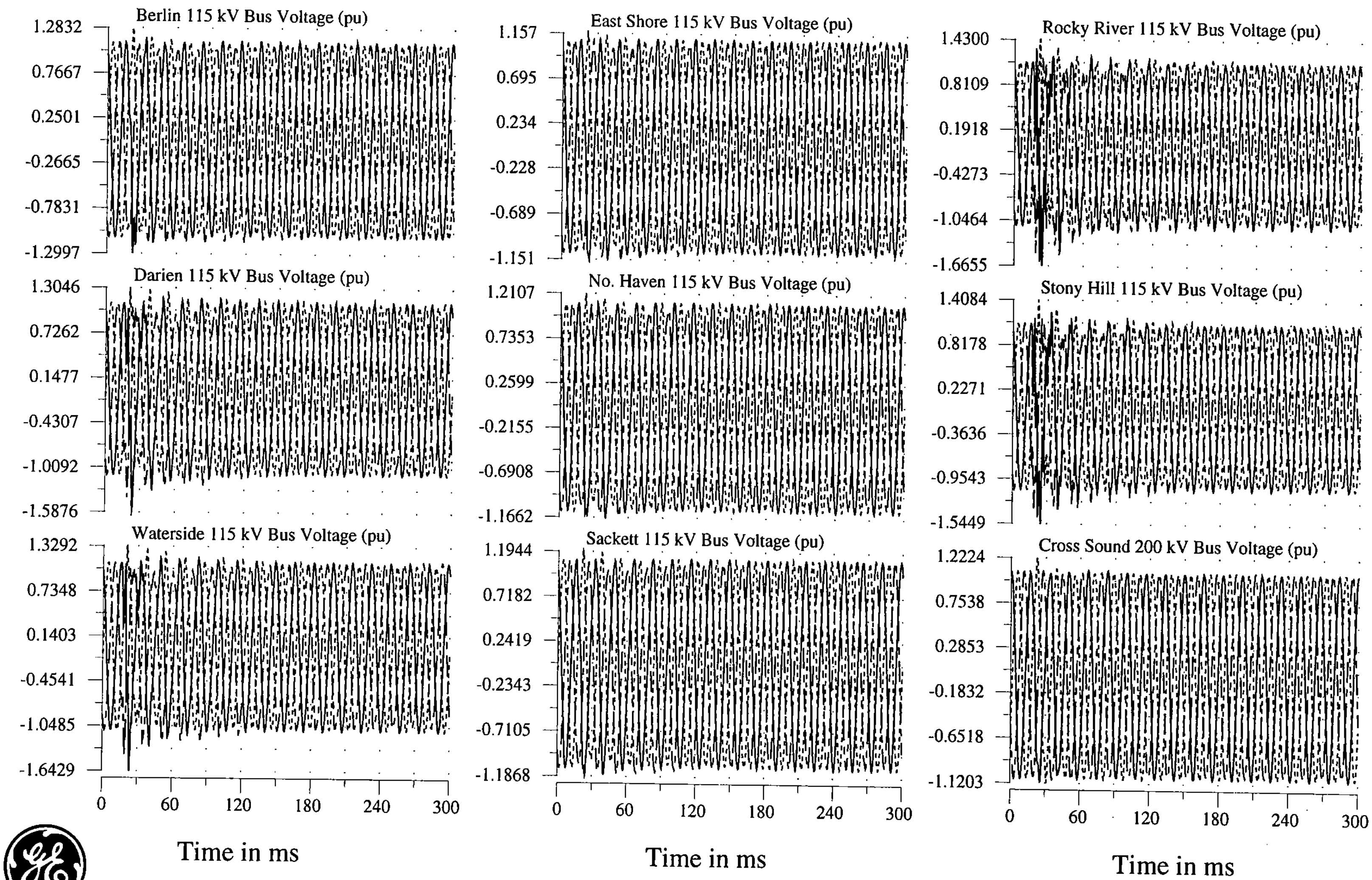


03-Nov-03 17:28:06 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Z1_03

115 kV Bus Voltages and Capacitor Bank Locations

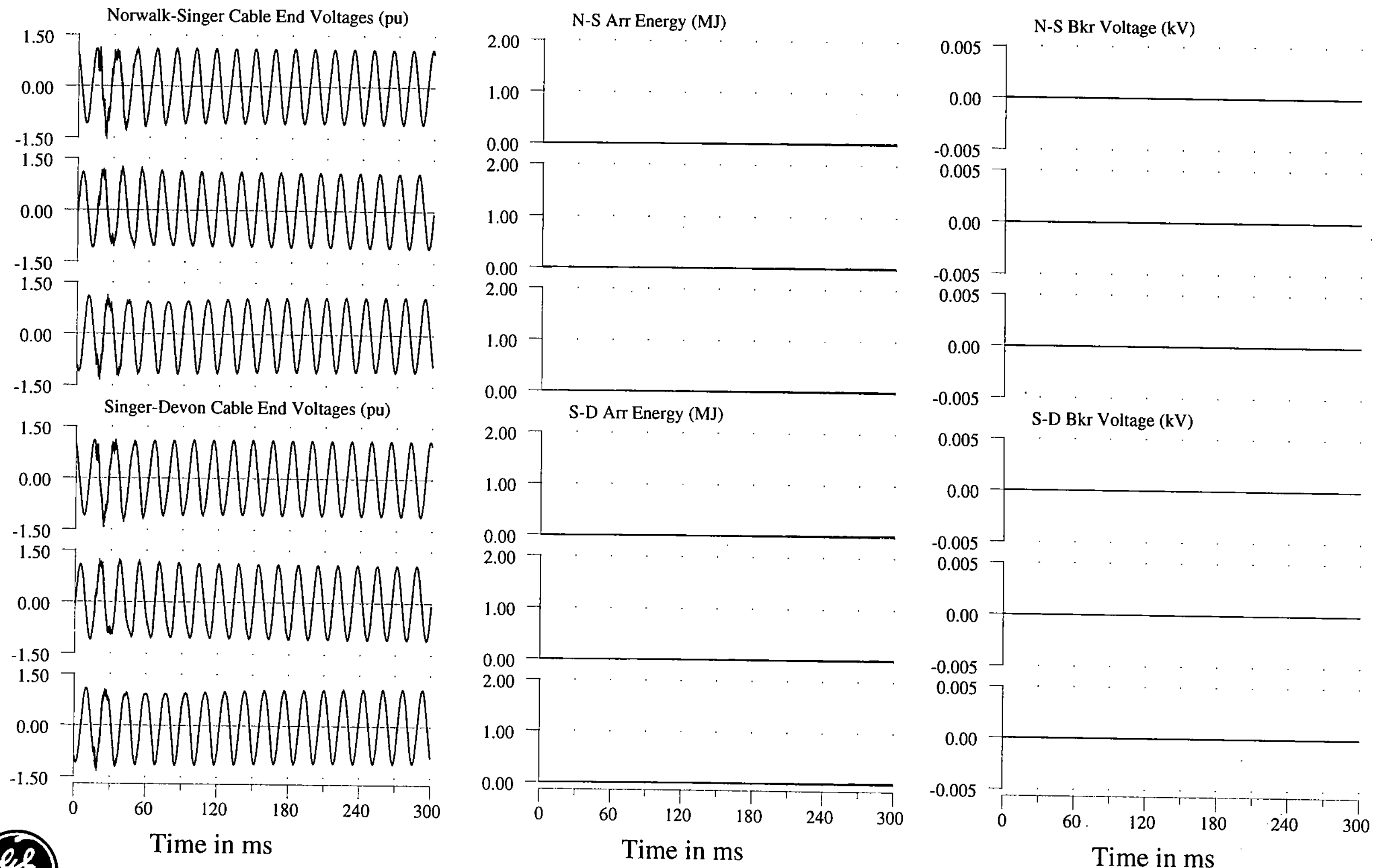


03-Nov-03 17:28:06 C:\Projects\atp\NU_phase2p\ps\PH2P_Z1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

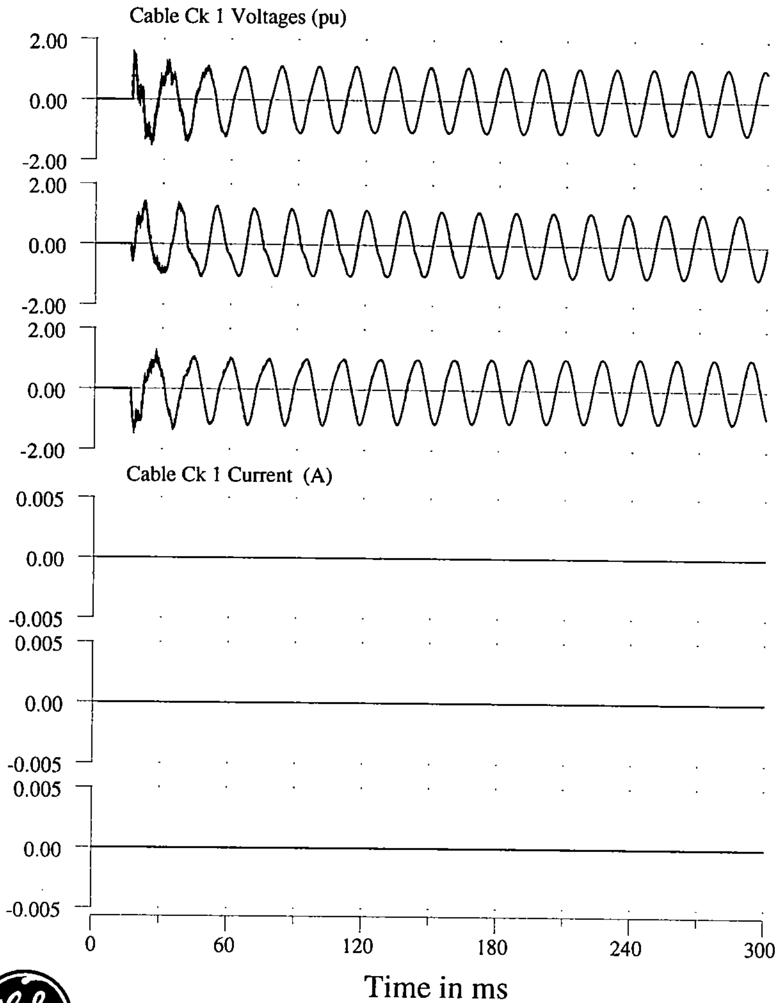


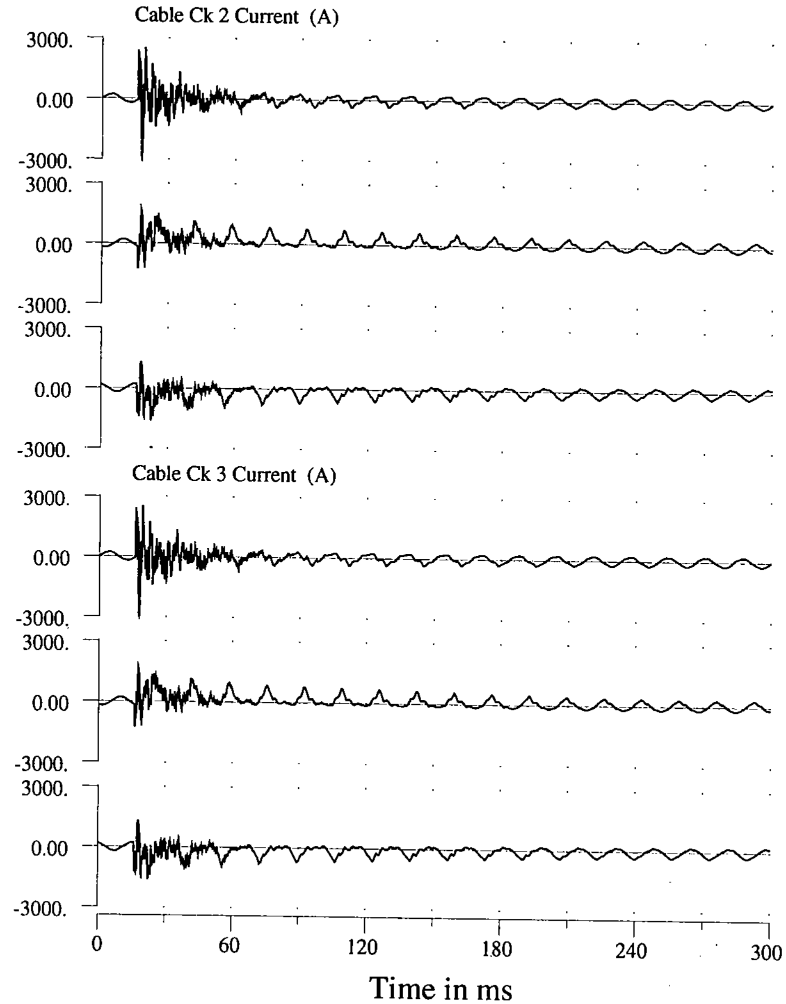
03-Nov-03 17:31:06 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_01

Devon-Beseck 345 kV Cables



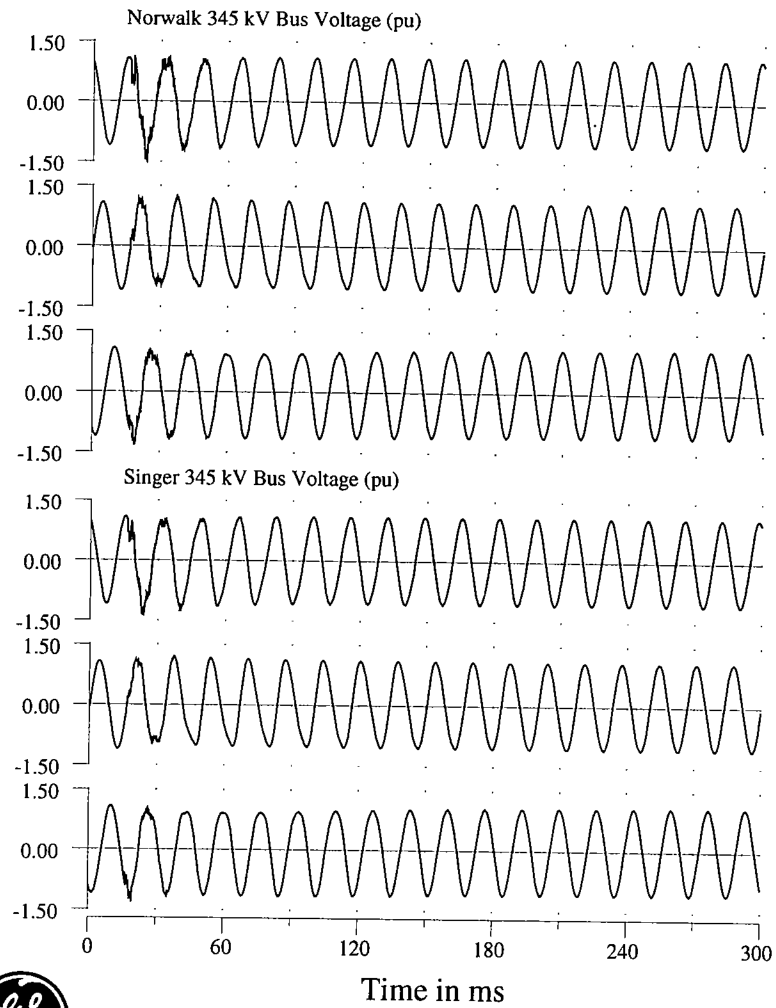


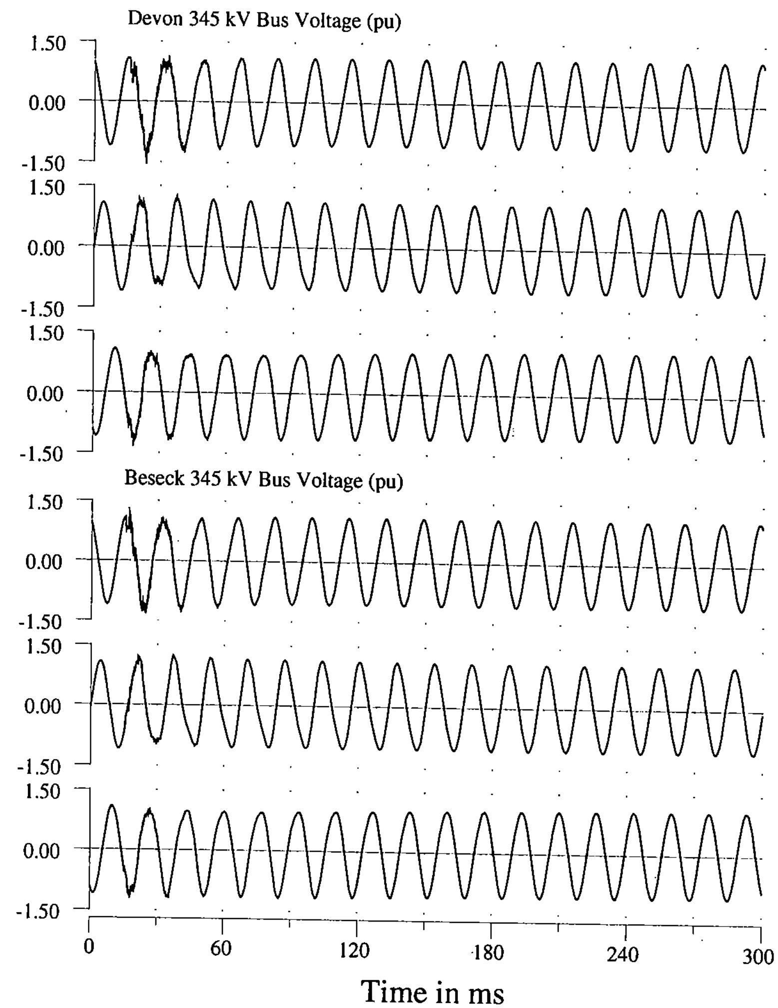
03-Nov-03 17:31:06 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_01

345 kV Bus Voltages



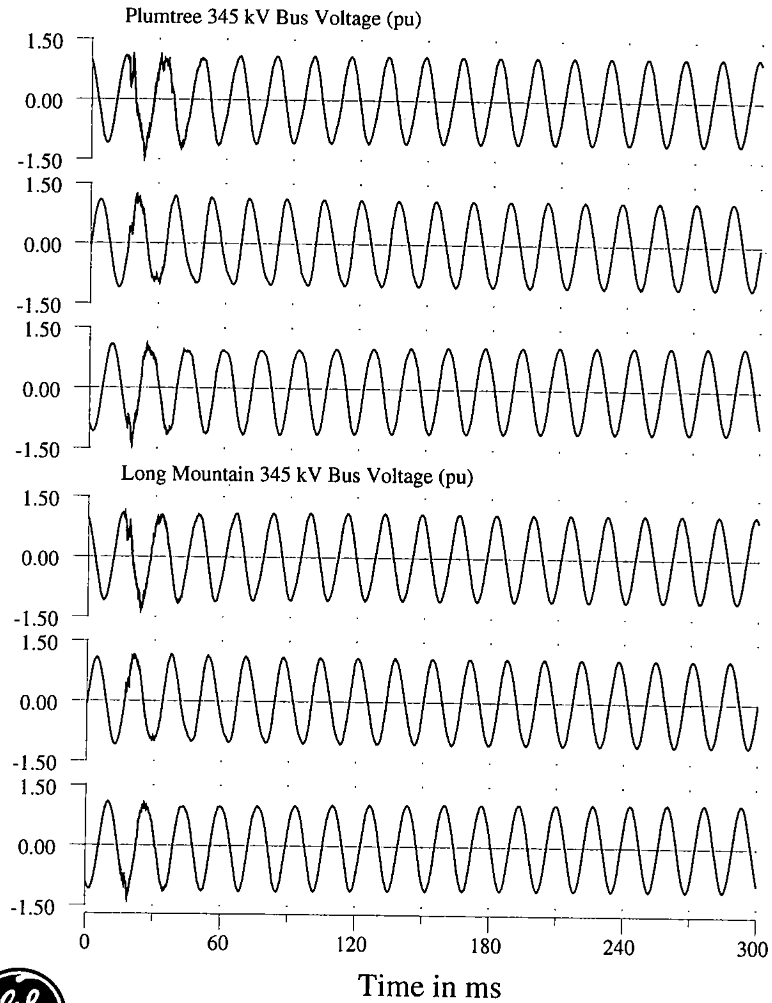


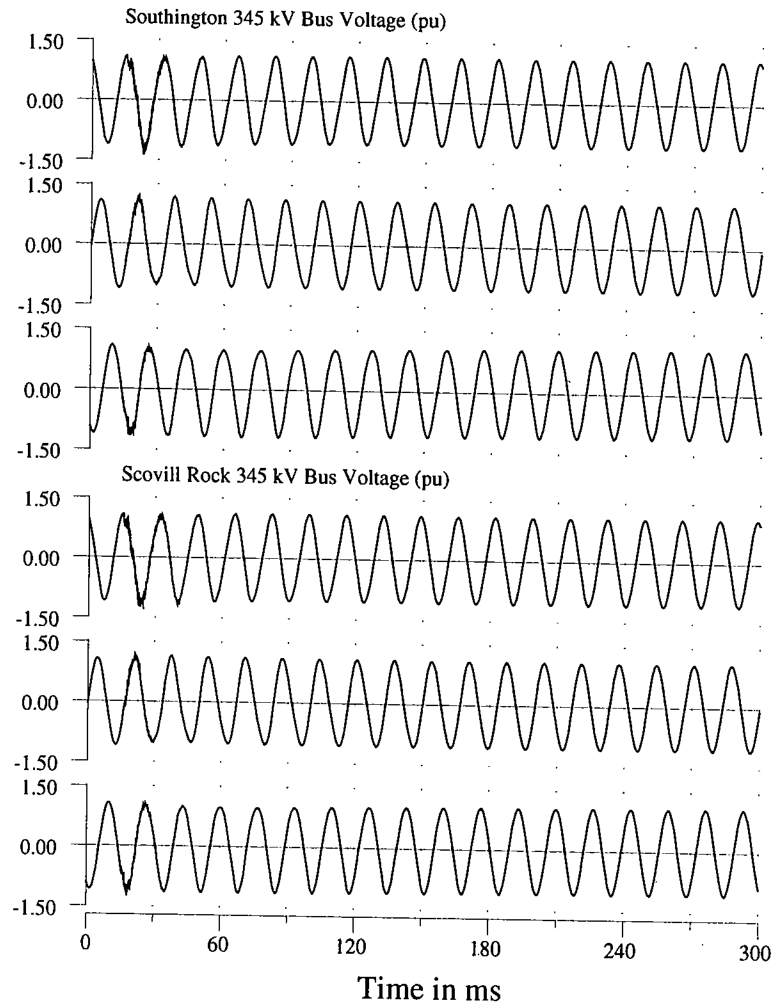
03-Nov-03 17:31:06 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_01

345 kV Bus Voltages



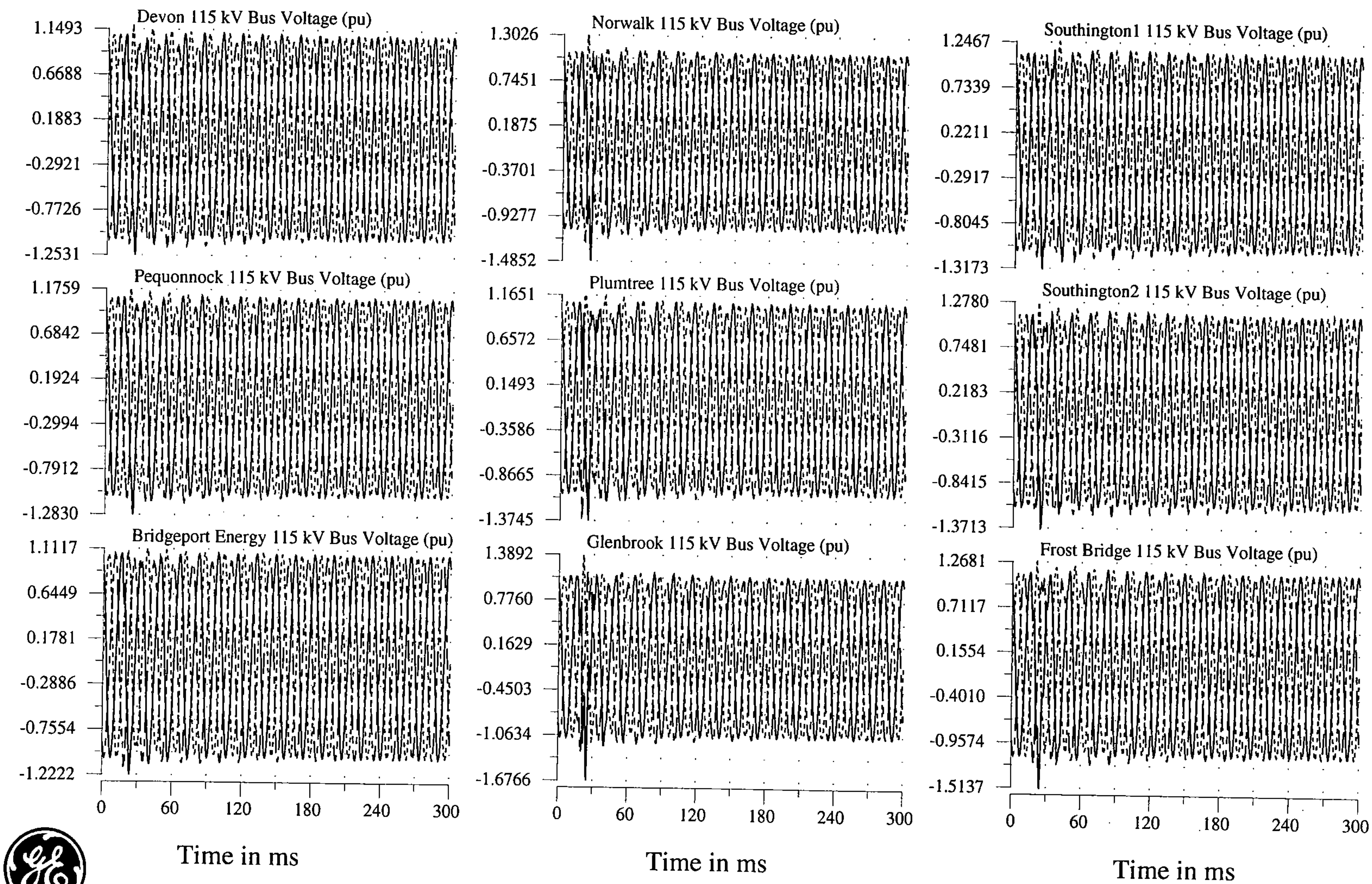


03-Nov-03 17:31:06 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_01

115 kV Bus Voltages and Capacitor Bank Locations

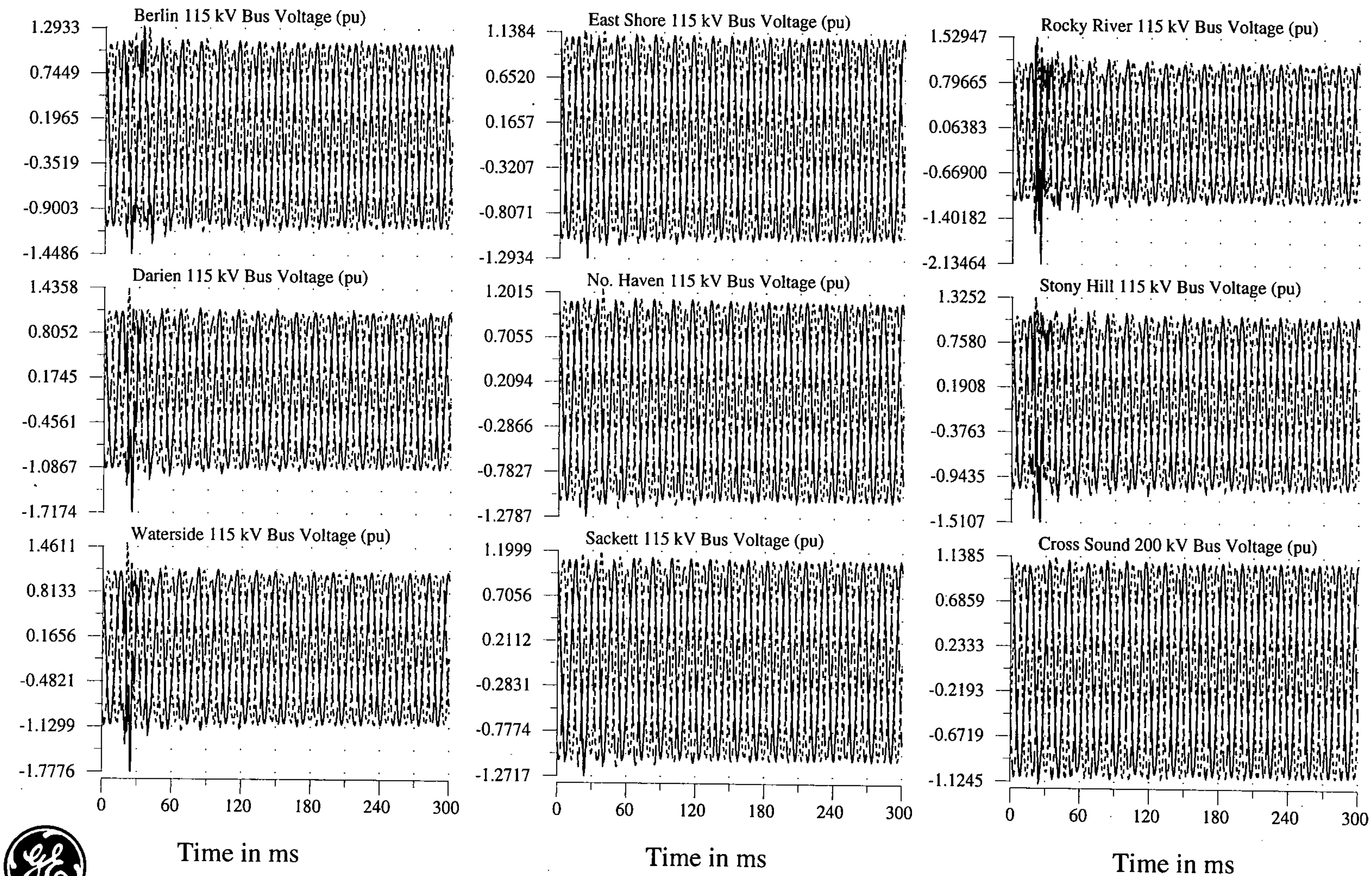


03-Nov-03 17:31:06 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_01

115 kV Bus Voltages and Capacitor Bank Locations

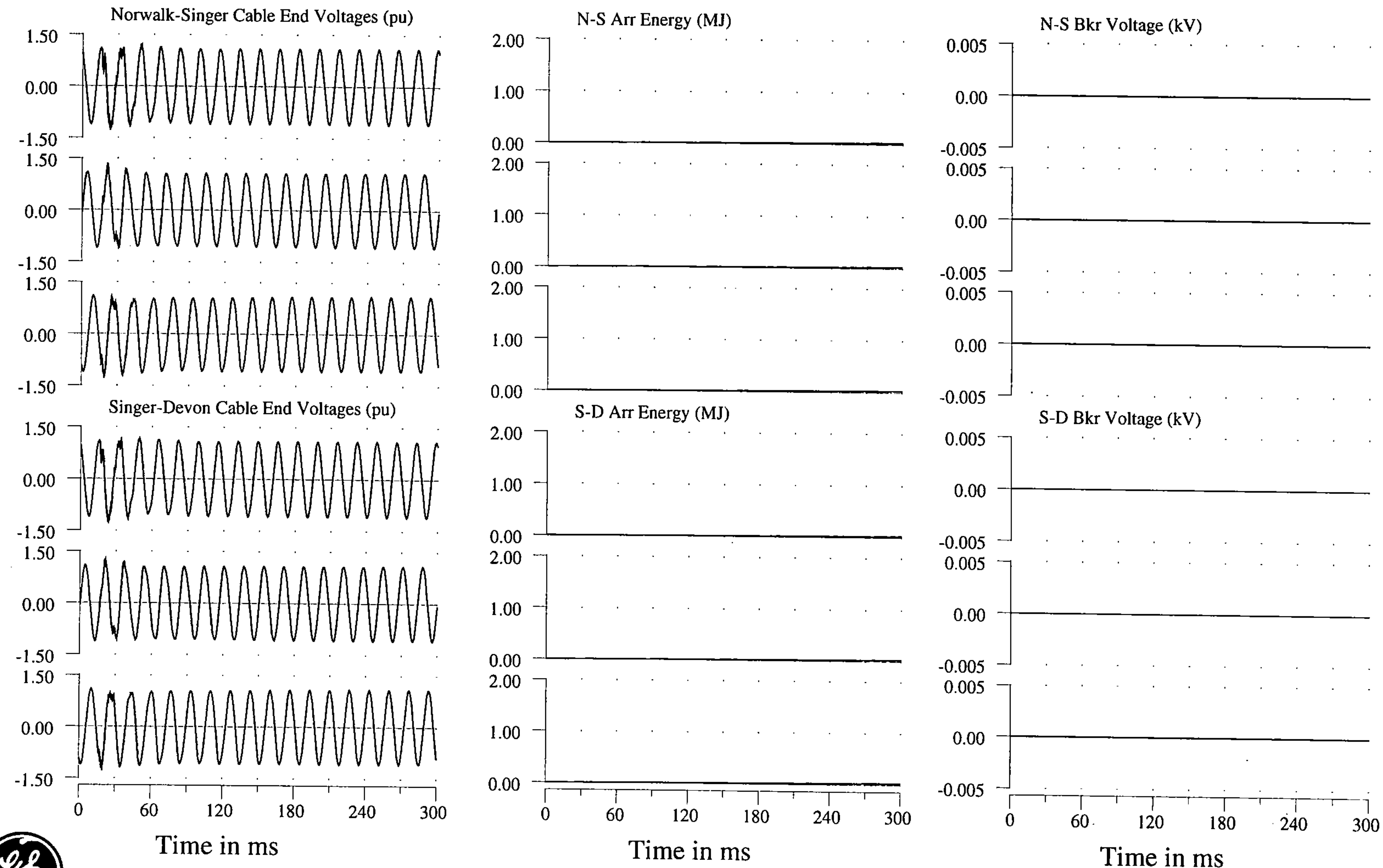


03-Nov-03 17:31:06 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_02

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

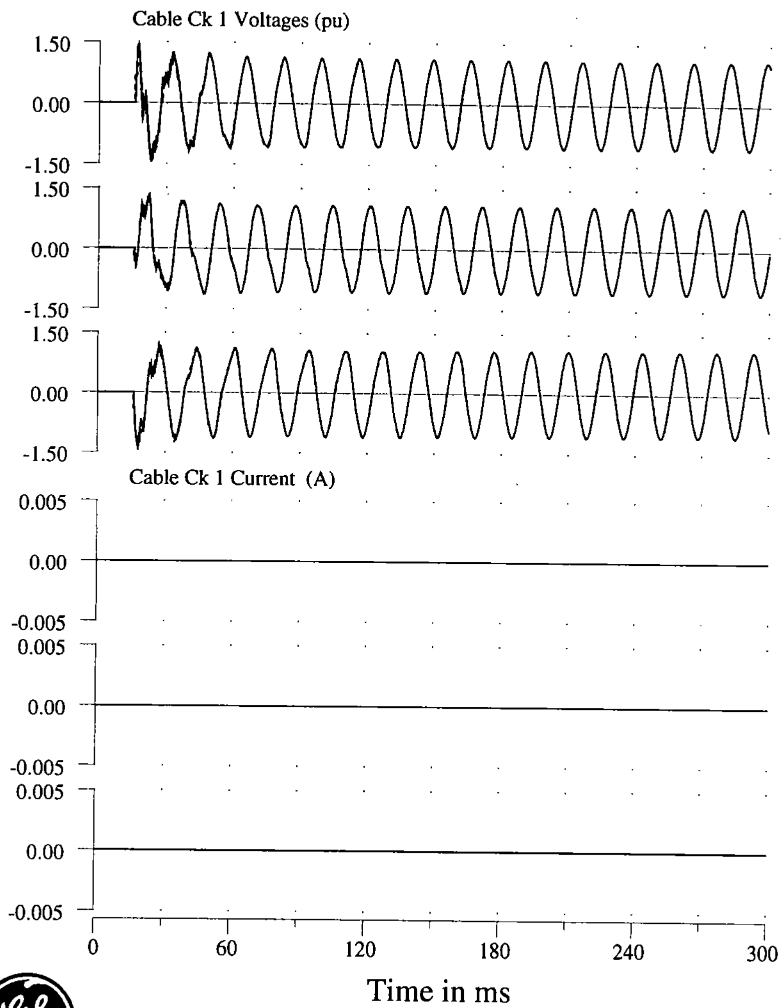


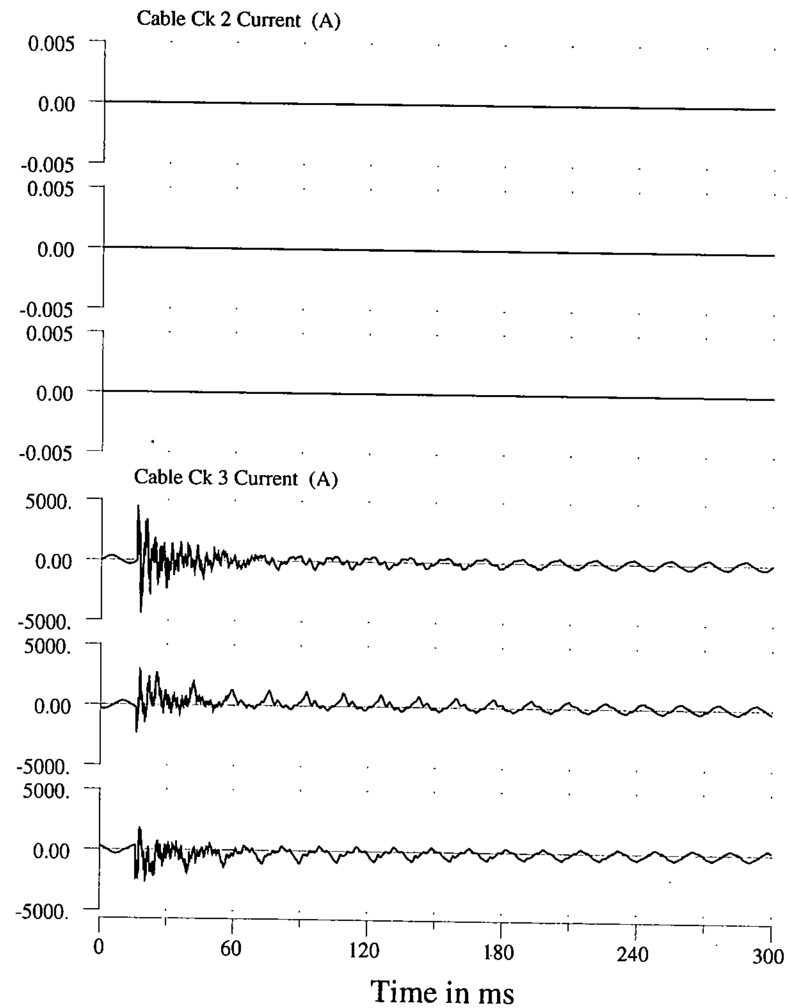
03-Nov-03 17:34:00 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_02

Devon-Beseck 345 kV Cables



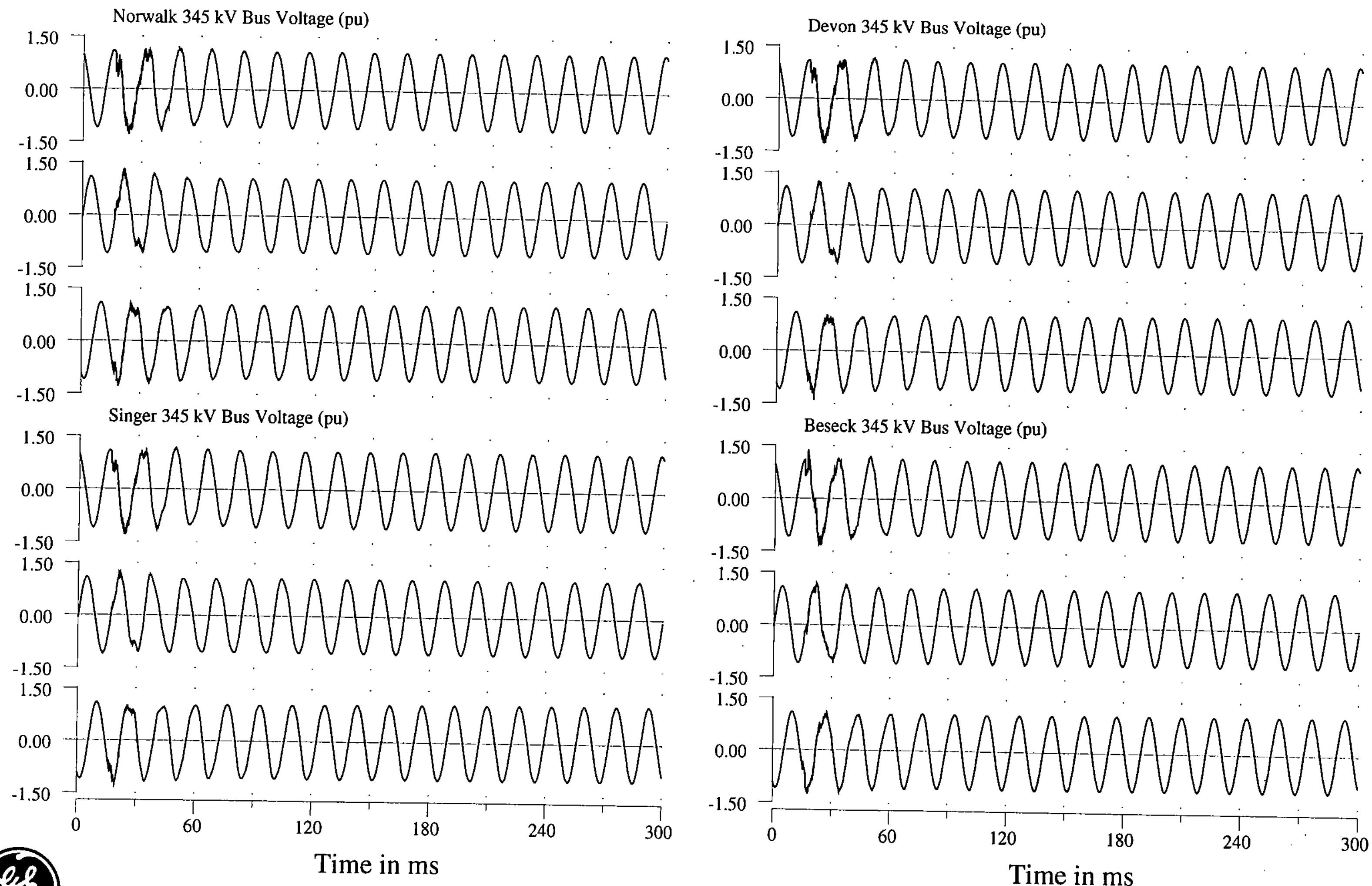


03-Nov-03 17:34:00 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_02

345 kV Bus Voltages

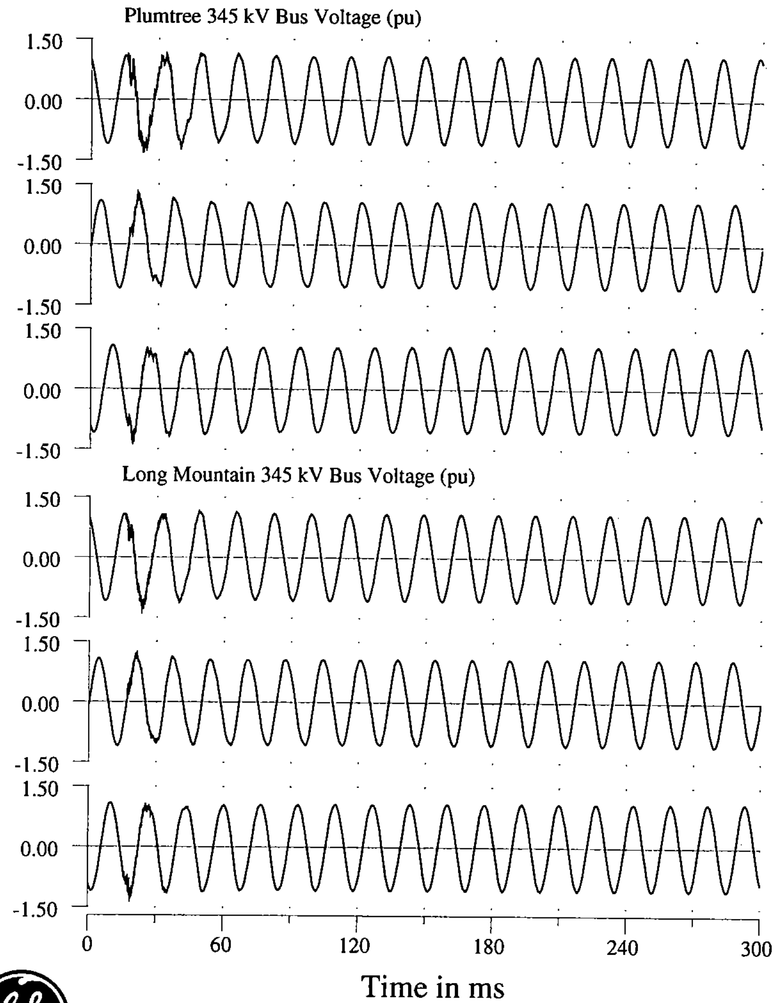


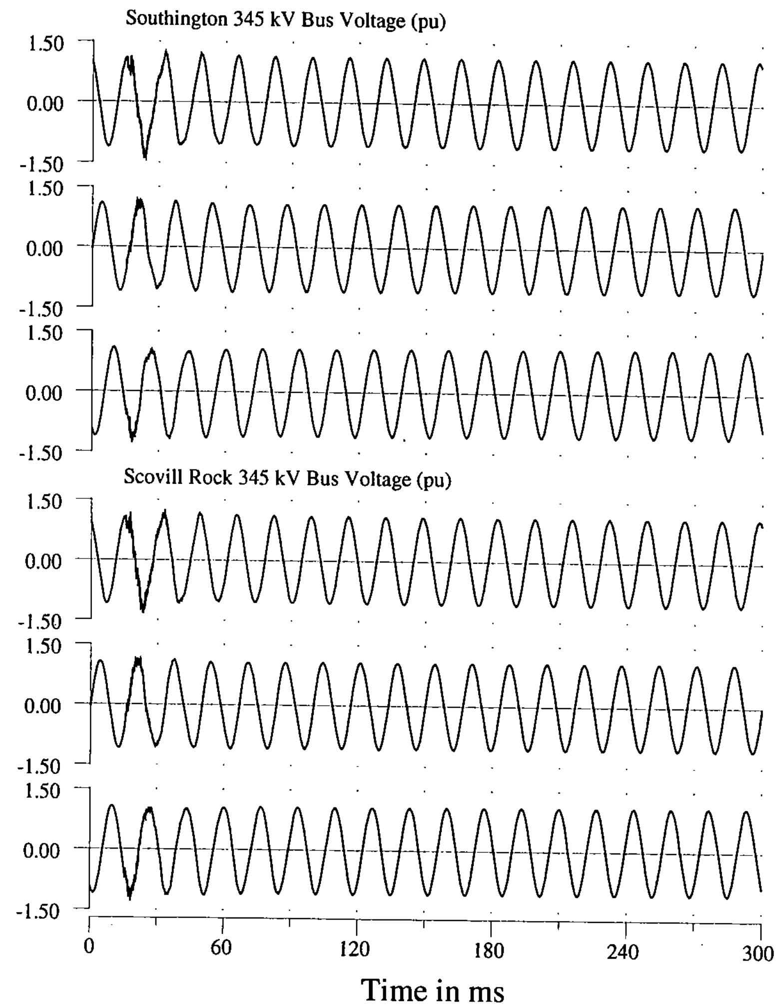
03-Nov-03 17:34:00 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_02

345 kV Bus Voltages



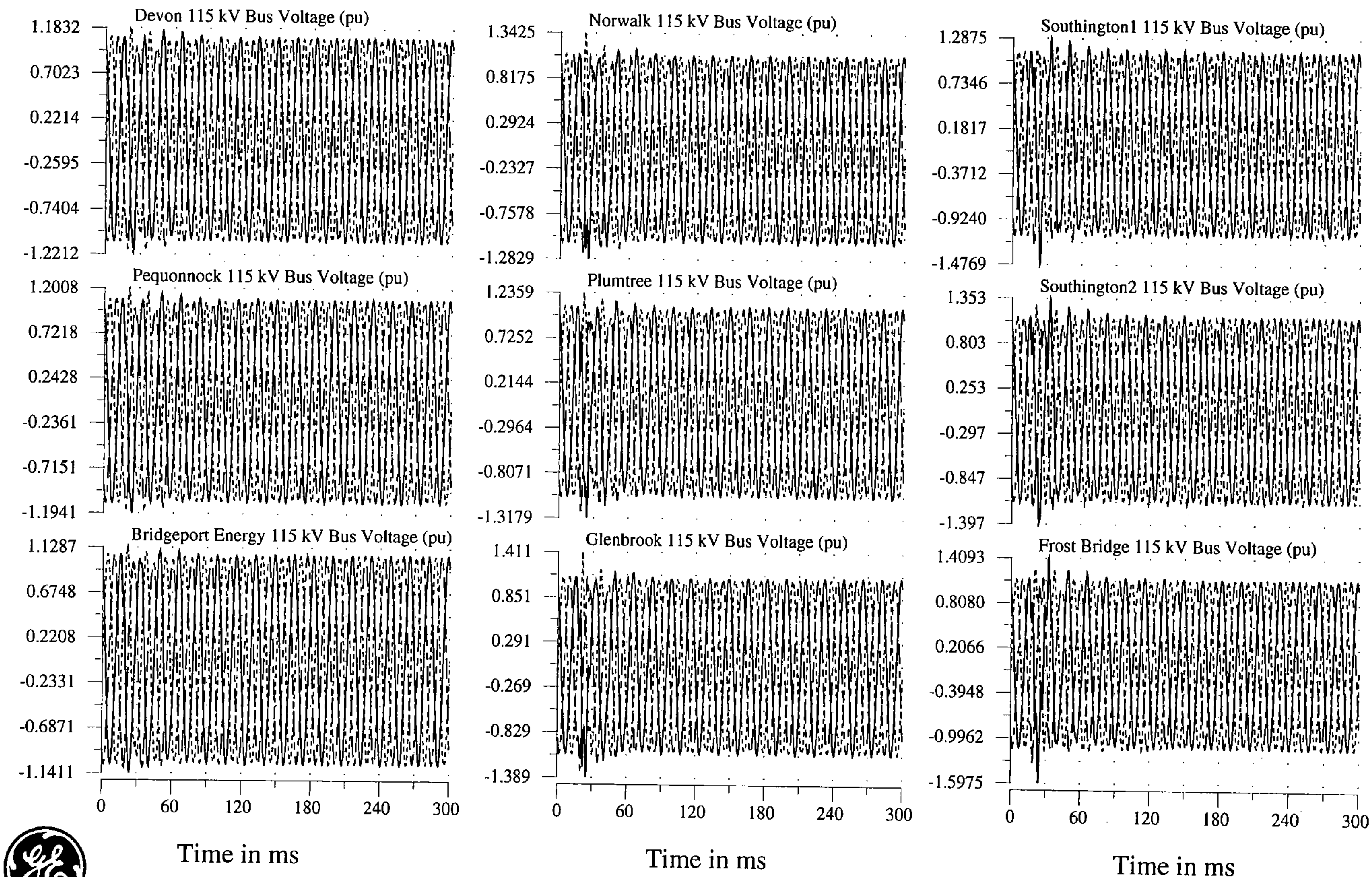


03-Nov-03 17:34:00 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_02

115 kV Bus Voltages and Capacitor Bank Locations

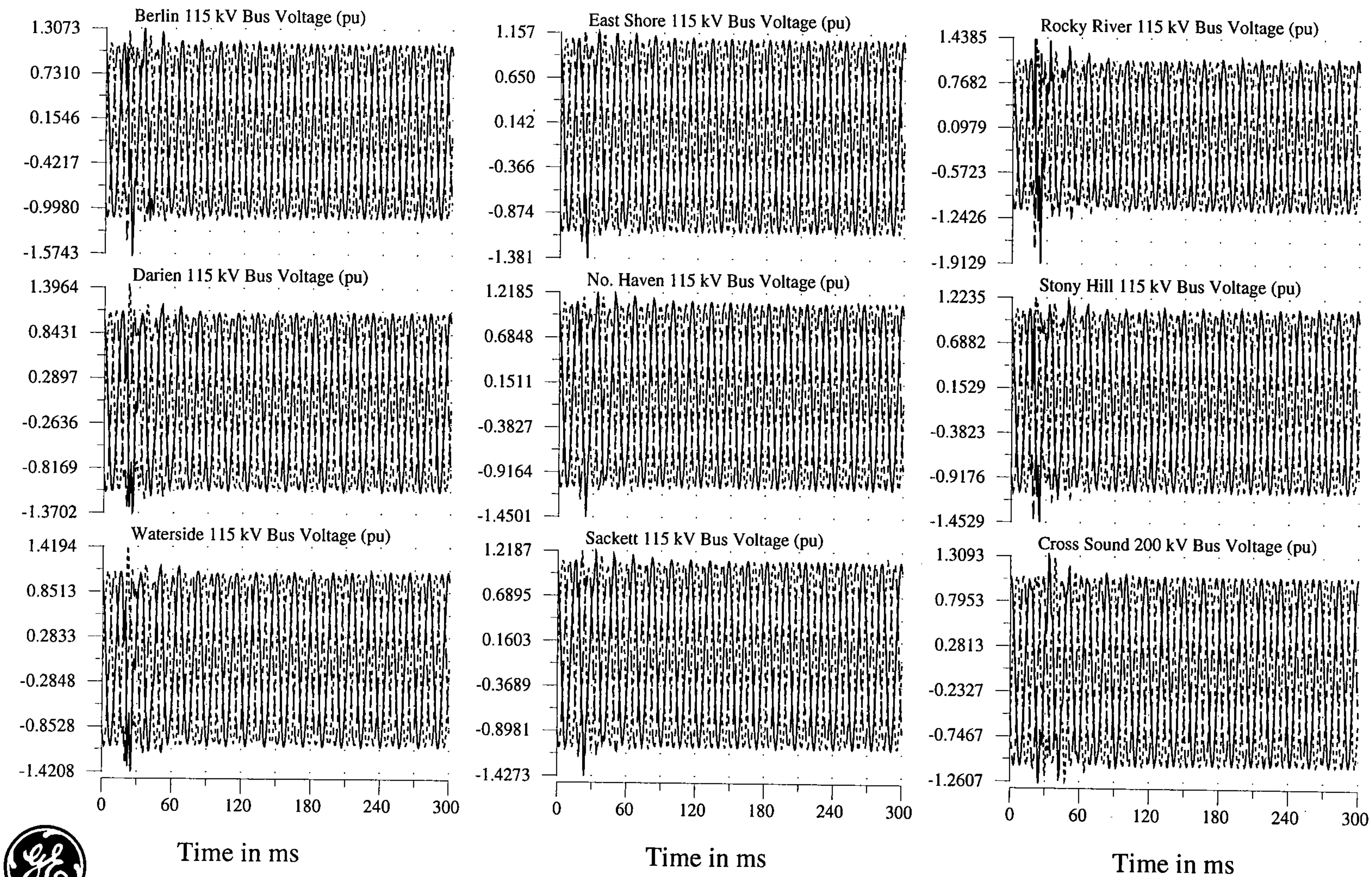


03-Nov-03 17:34:00 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_02

115 kV Bus Voltages and Capacitor Bank Locations

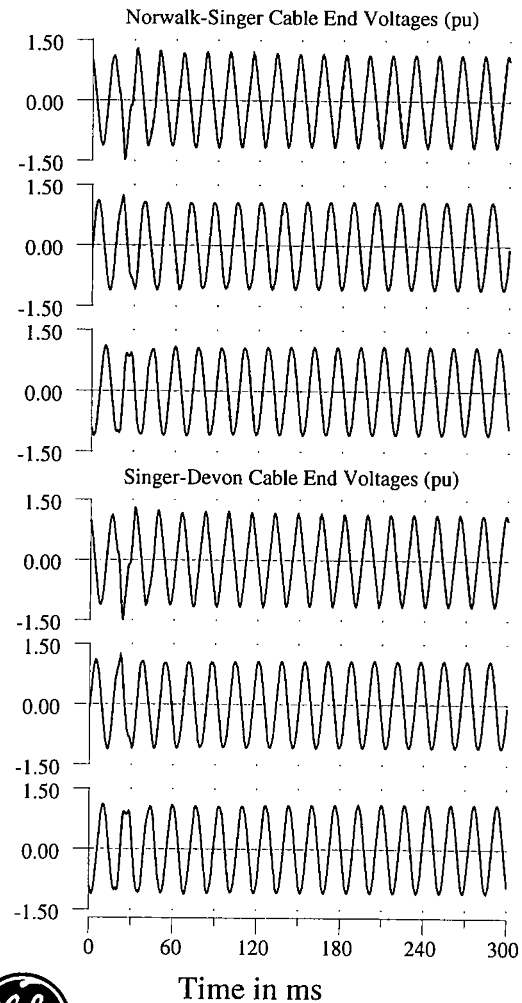


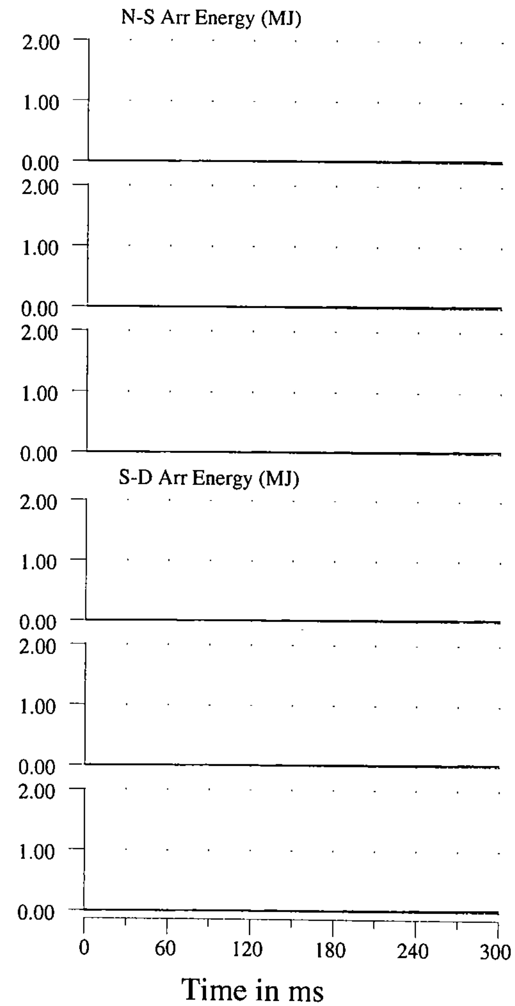
03-Nov-03 17:34:00 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_02.PL4

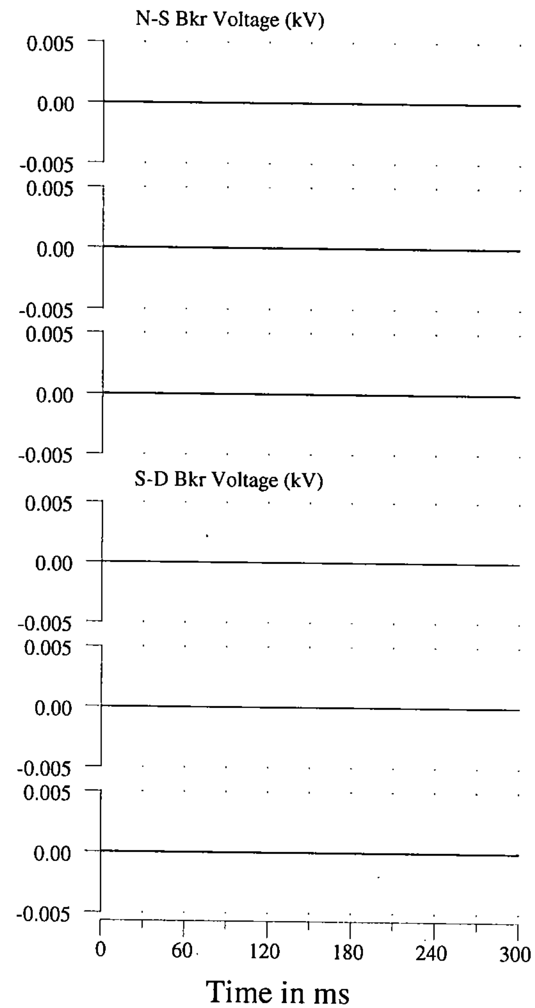
Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_03

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)





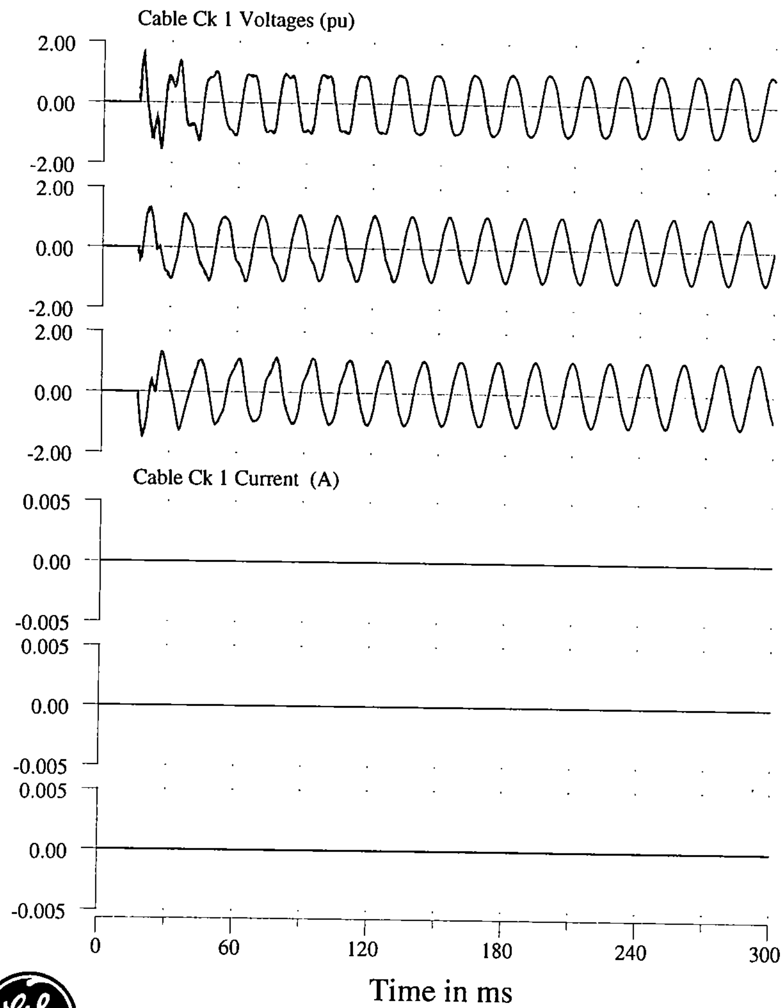


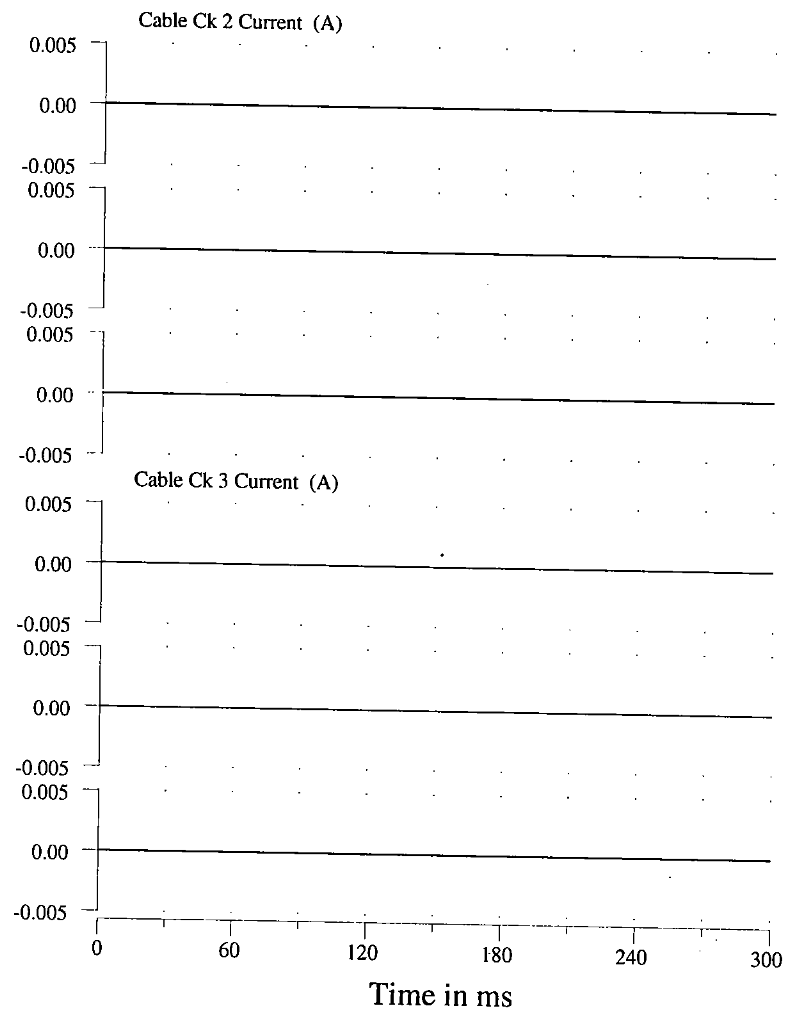
03-Nov-03 17:36:57 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_03

Devon-Beseck 345 kV Cables



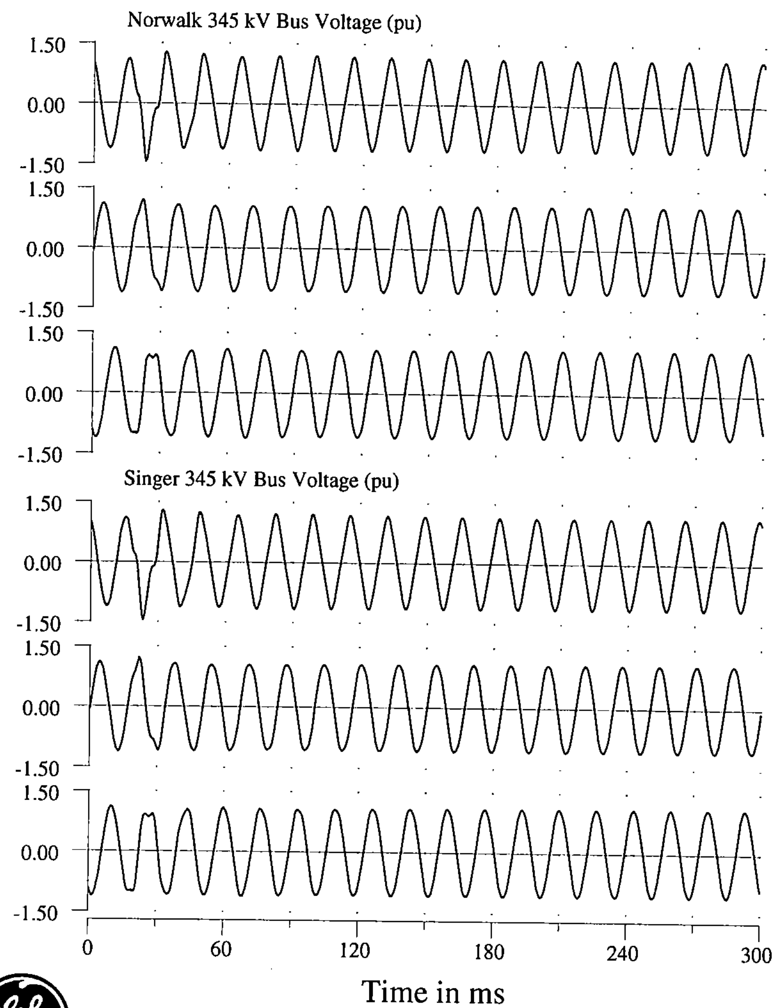


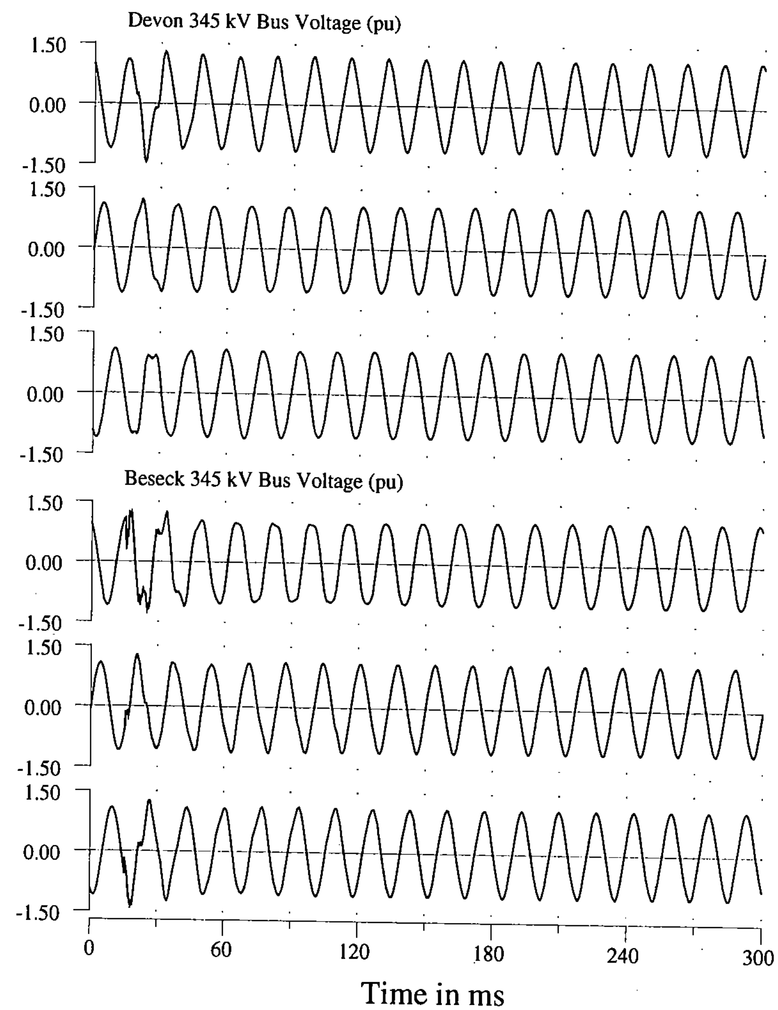
03-Nov-03 17:36:57 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_03

345 kV Bus Voltages



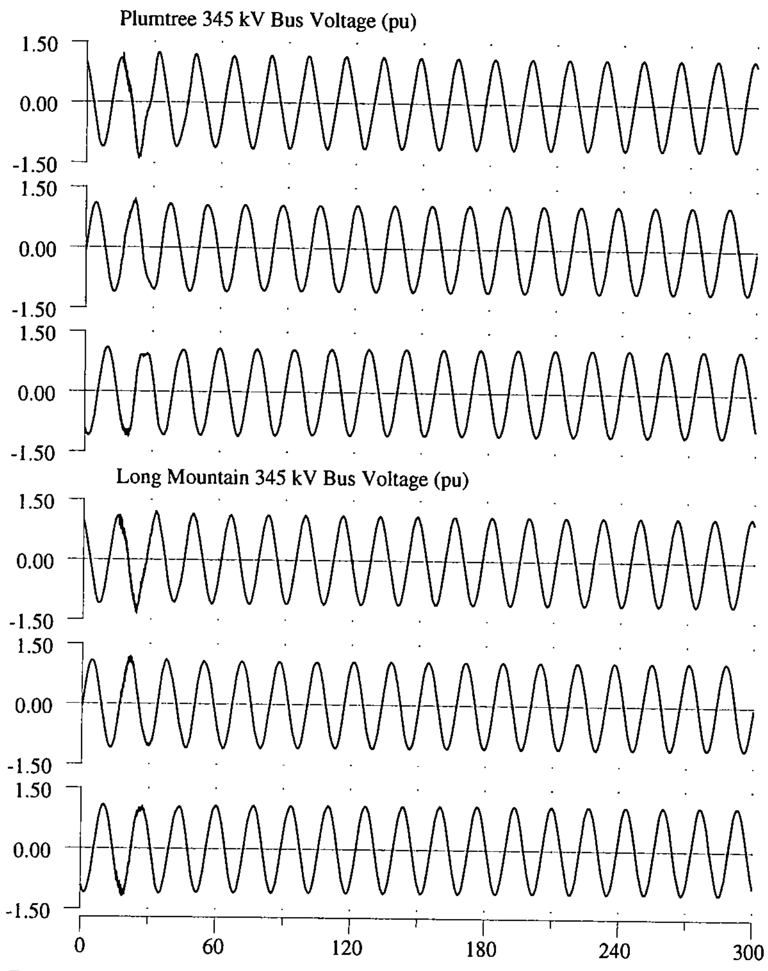


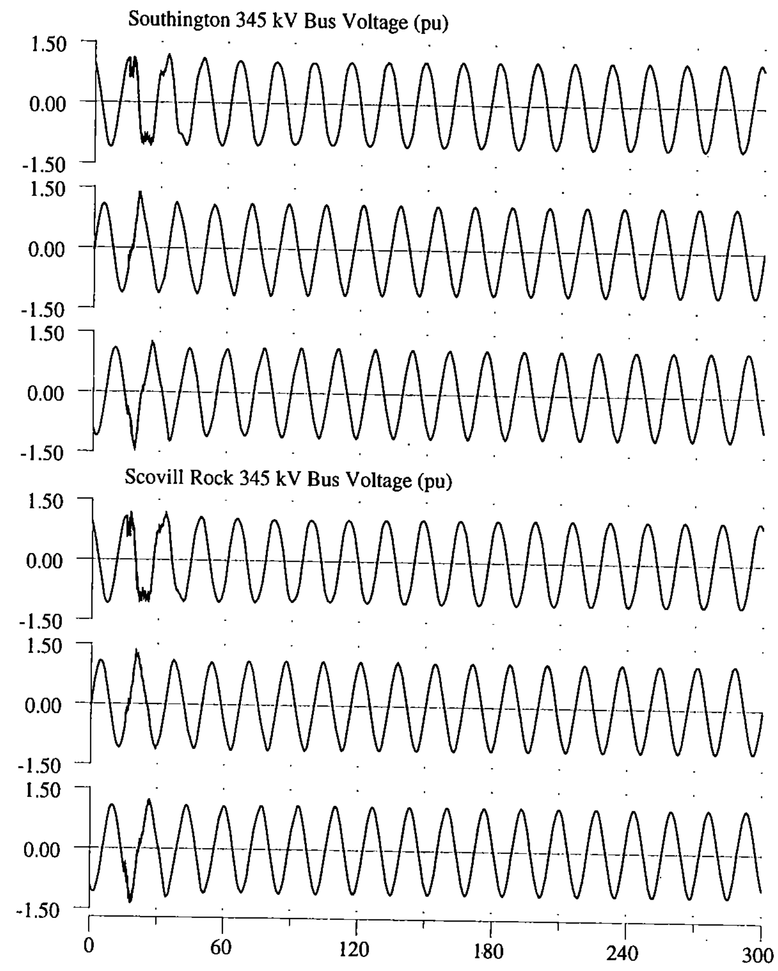
03-Nov-03 17:36:57 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_03

345 kV Bus Voltages



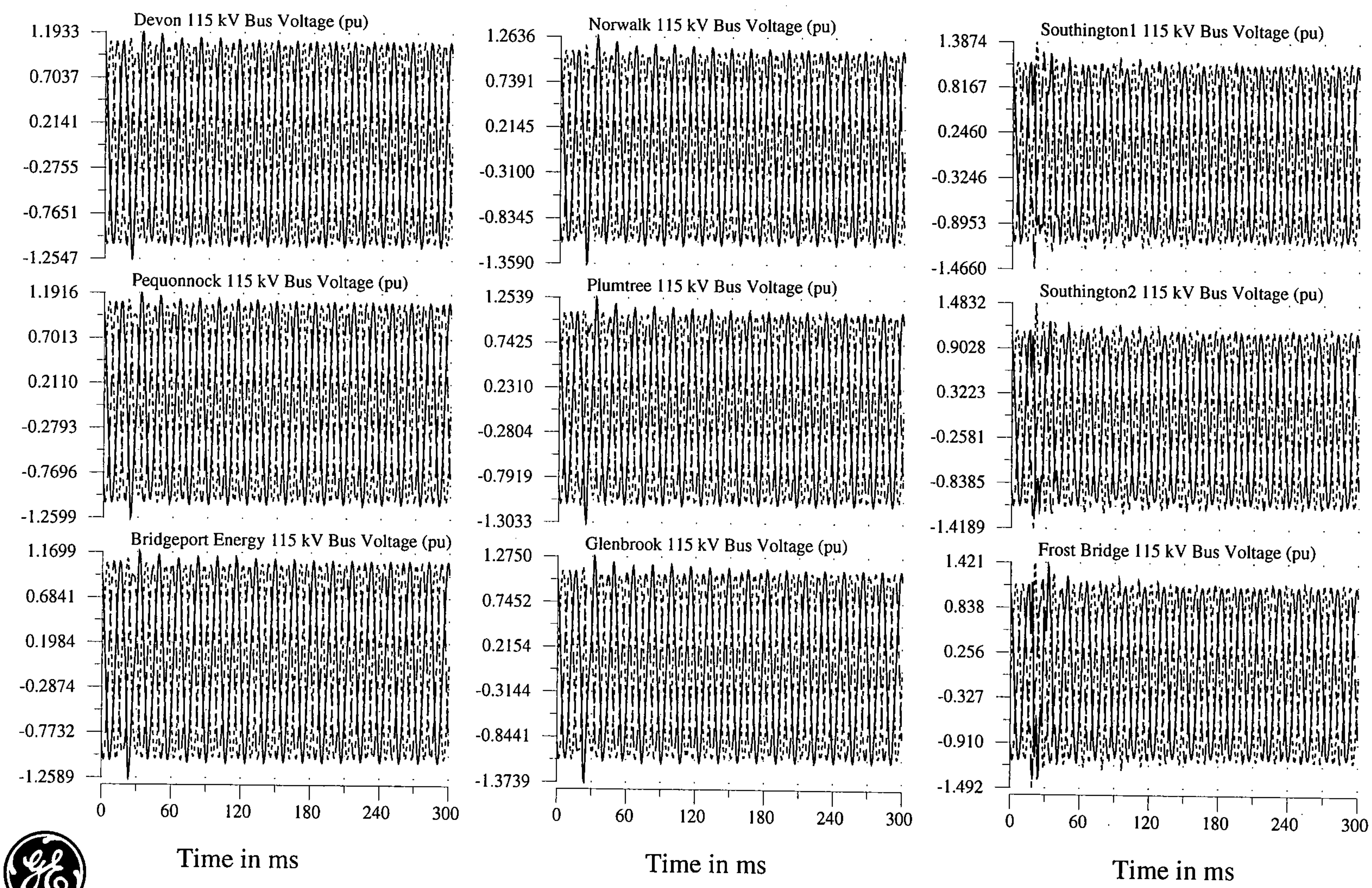


03-Nov-03 17:36:57 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_03

115 kV Bus Voltages and Capacitor Bank Locations

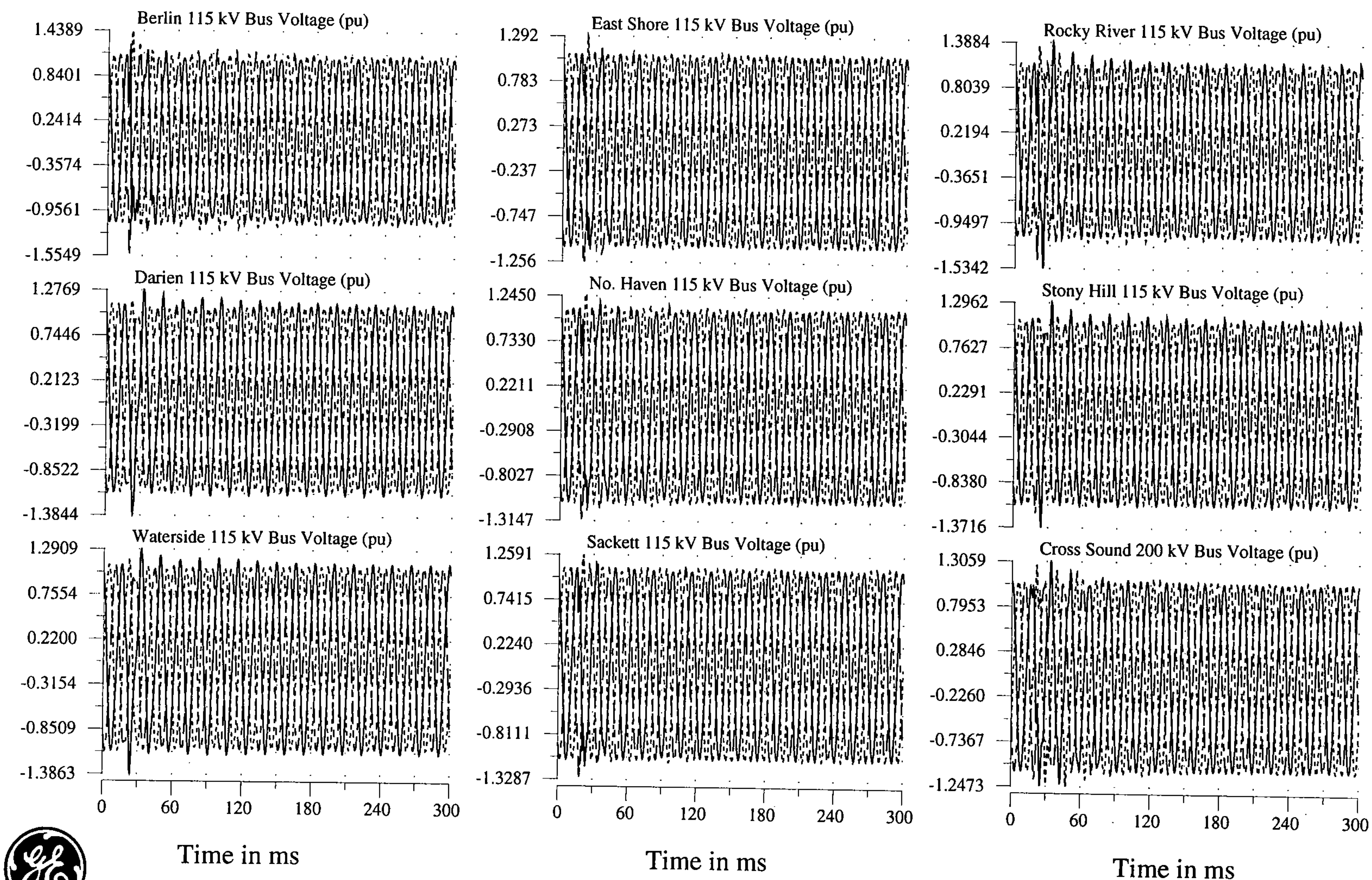


03-Nov-03 17:36:57 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_B1_03

115 kV Bus Voltages and Capacitor Bank Locations

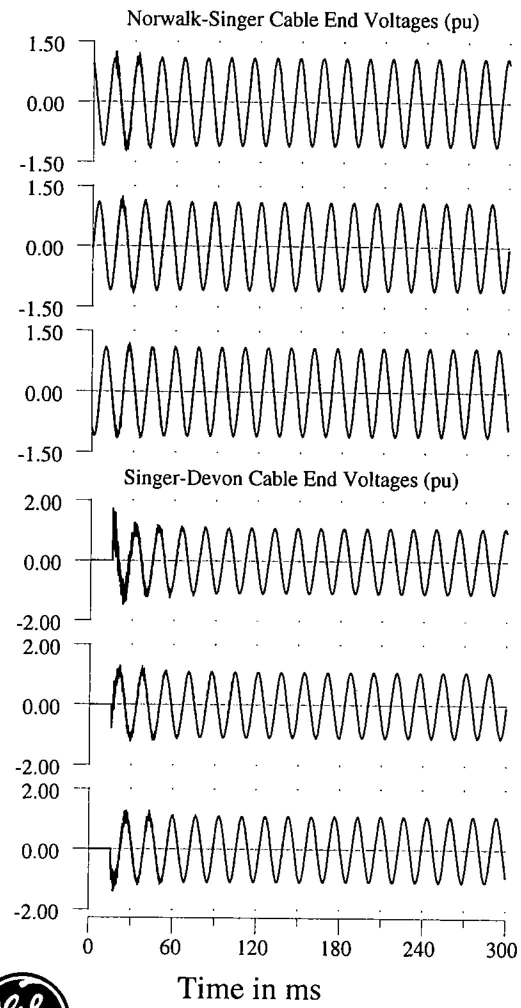


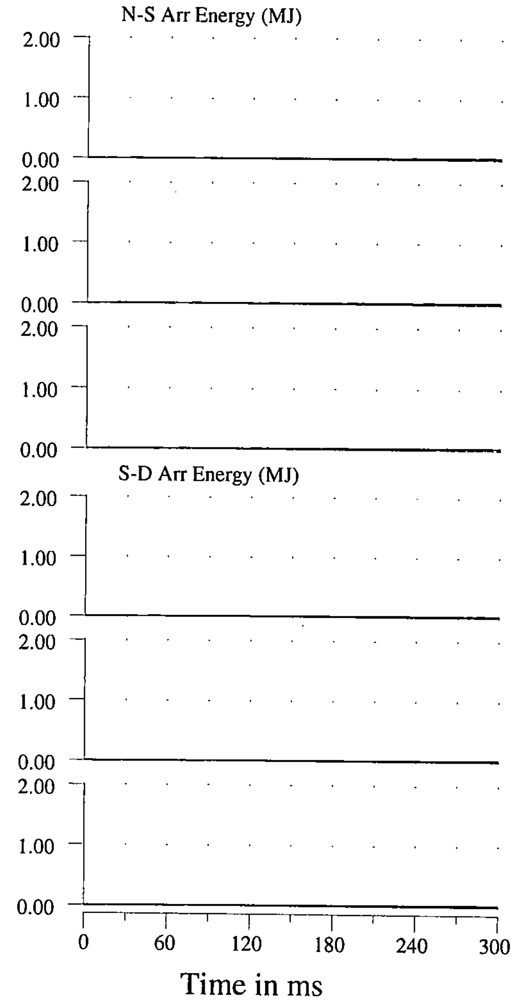
03-Nov-03 17:36:57 C:\Projects\atp\NU_phase2p\ps\PH2P_B1_03.PL4

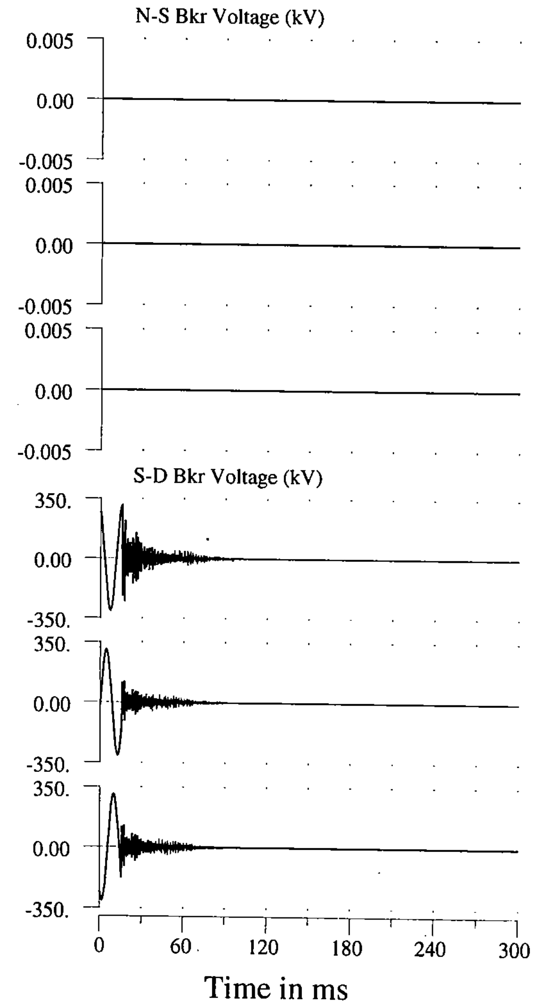
Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Y1_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)



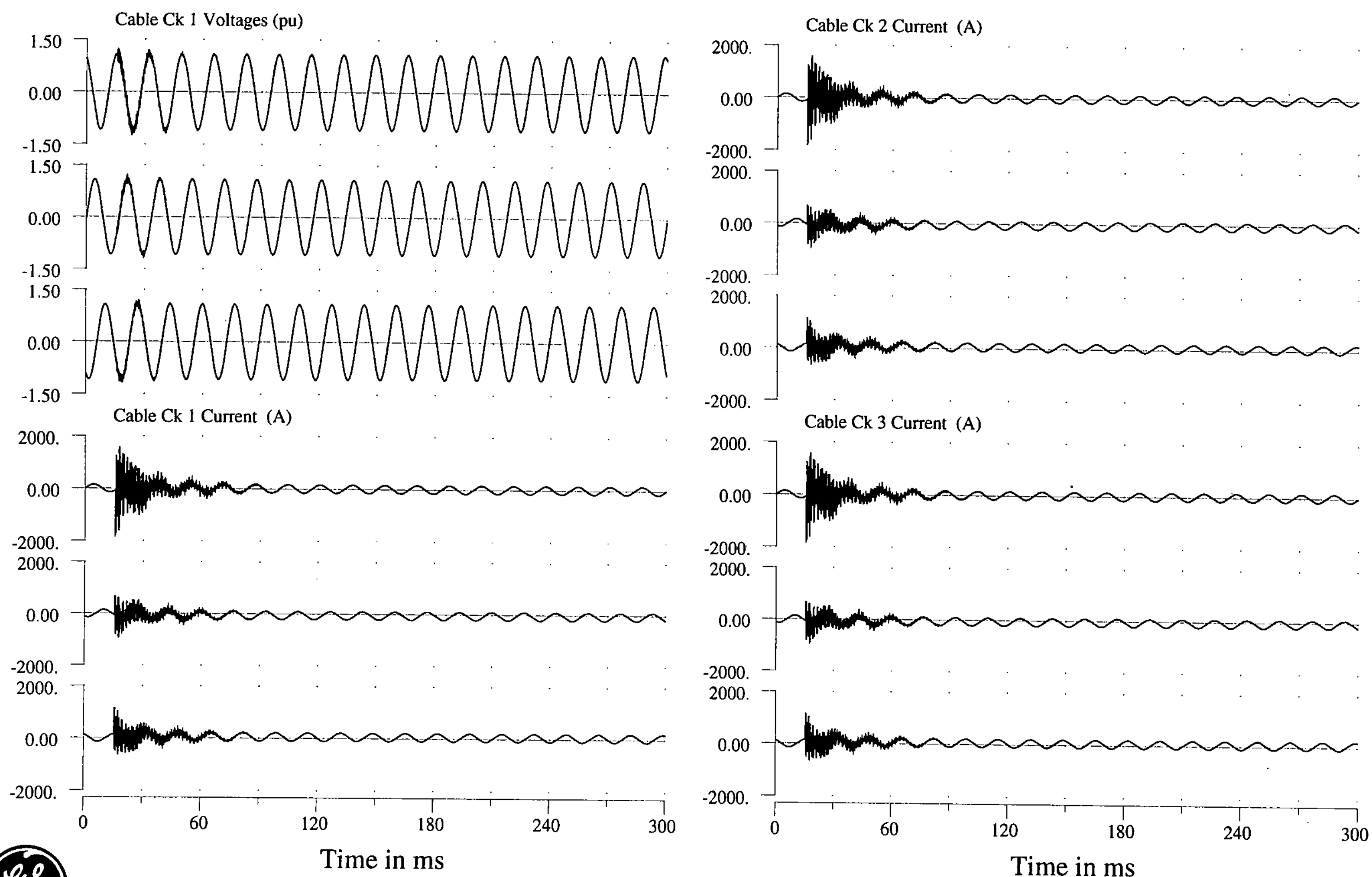




Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Y1_01

Devon-Beseck 345 kV Cables

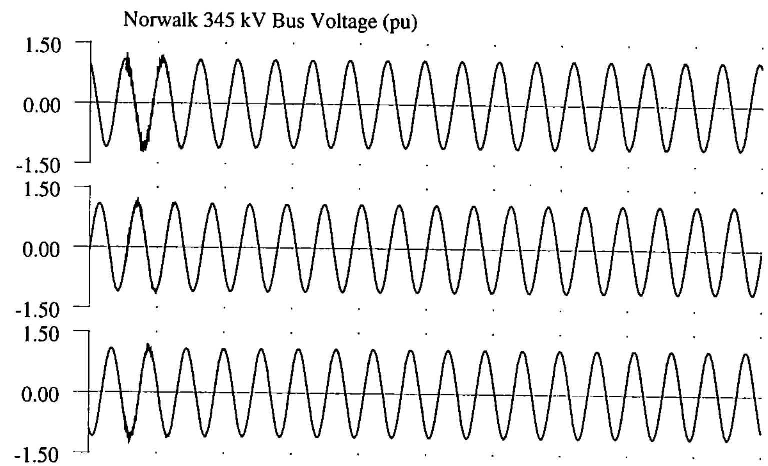


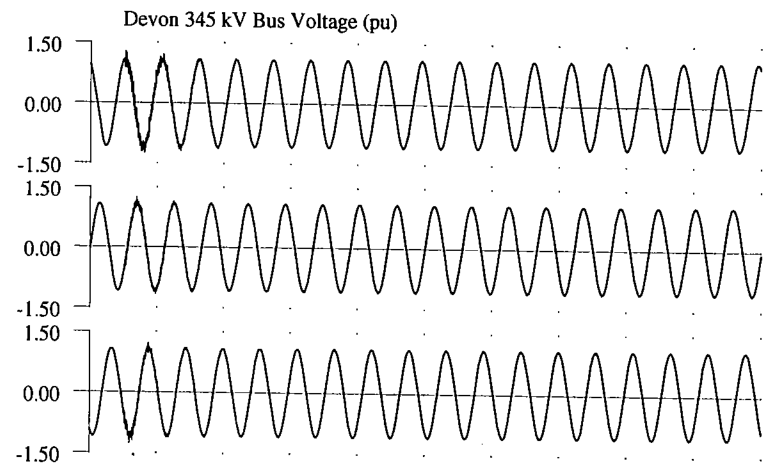
03-Nov-03 17:40:00 C:\Projects\atp\NU_phase2p\ps\PH2P_Y1_01.PL4

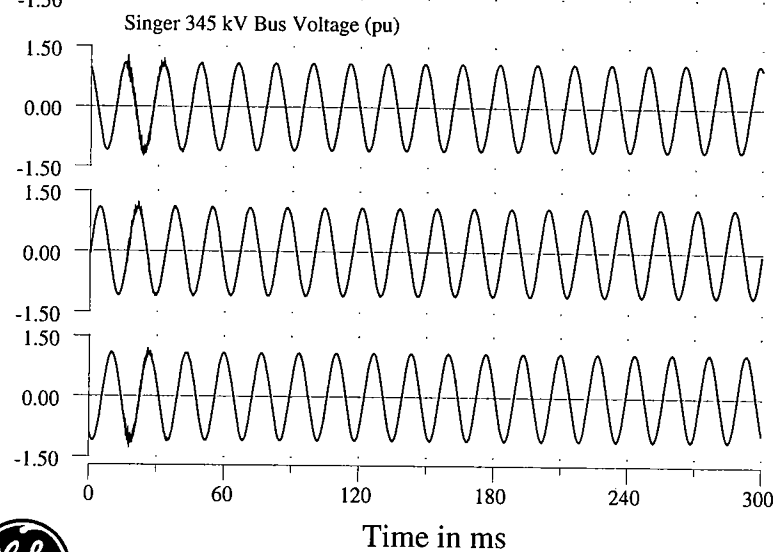
Northeast Utilities: Phase 2 Cable Transient Study

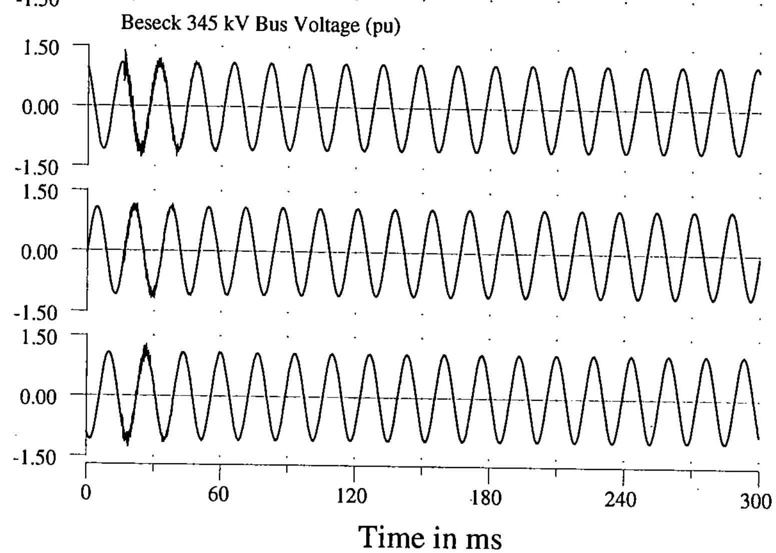
PH2P_Y1_01

345 kV Bus Voltages







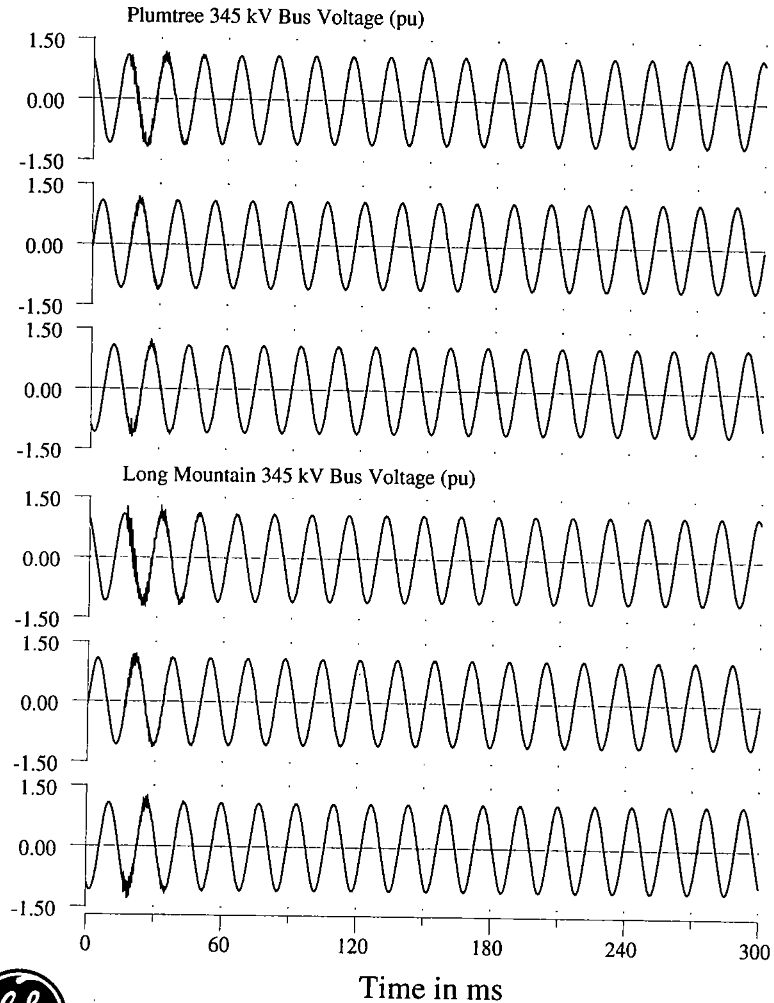


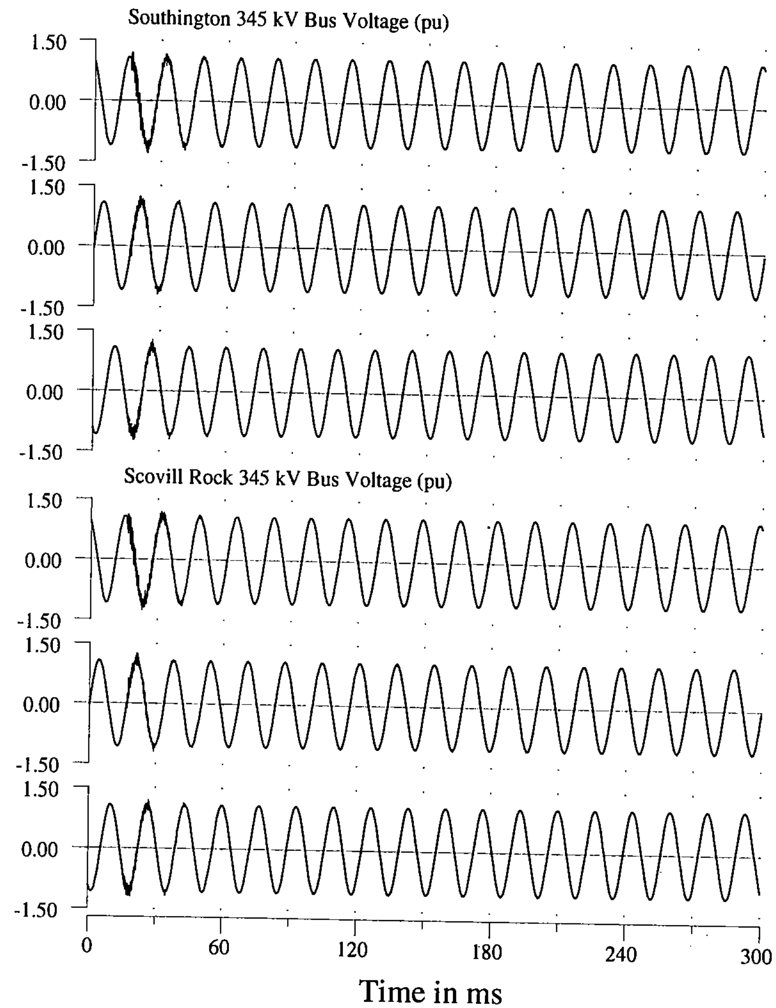
03-Nov-03 17:40:00 C:\Projects\atp\NU_phase2p\ps\PH2P_Y1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Y1_01

345 kV Bus Voltages



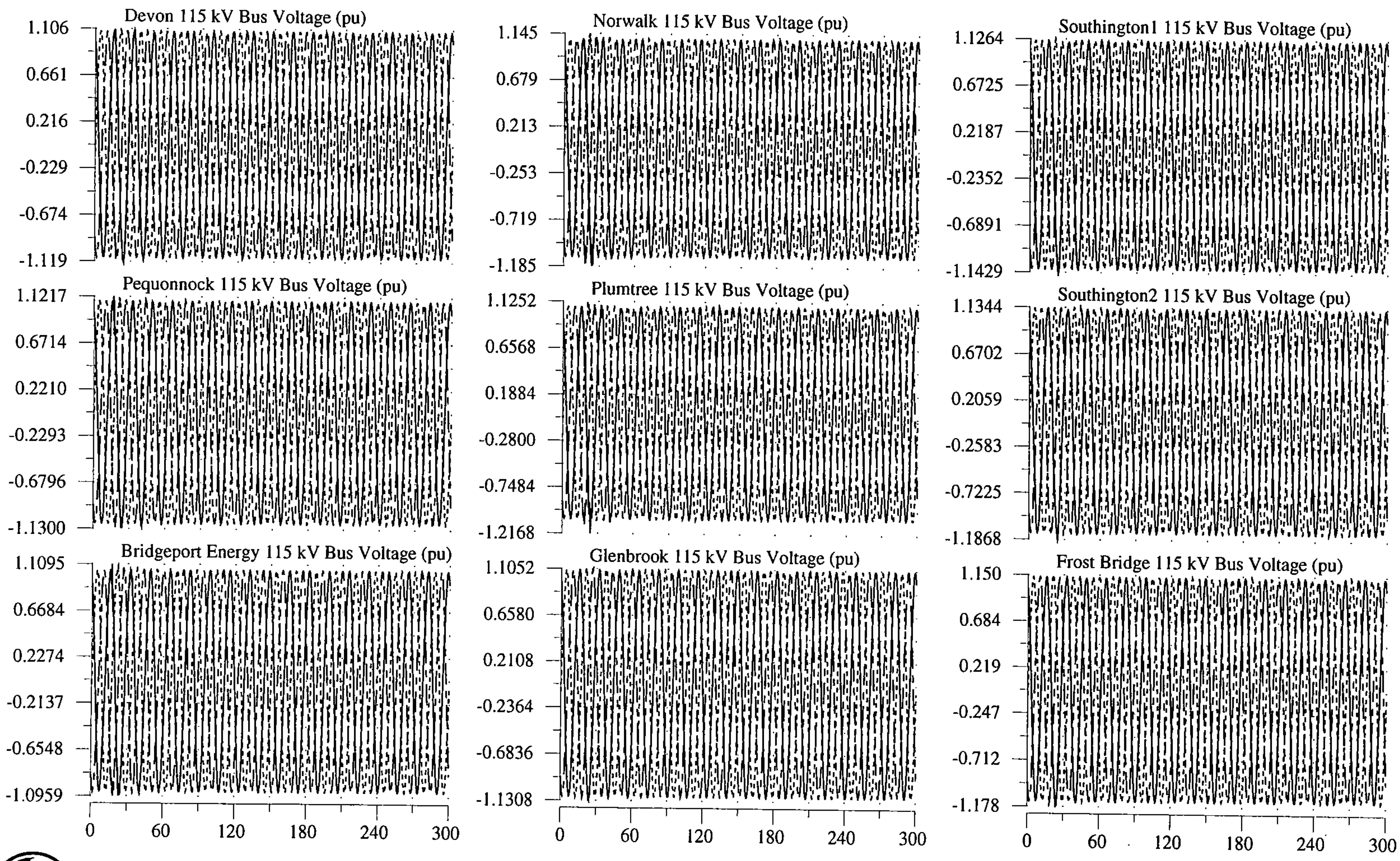


03-Nov-03 17:40:00 C:\Projects\atp\NU_phase2p\ps\PH2P_Y1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Y1_01

115 kV Bus Voltages and Capacitor Bank Locations

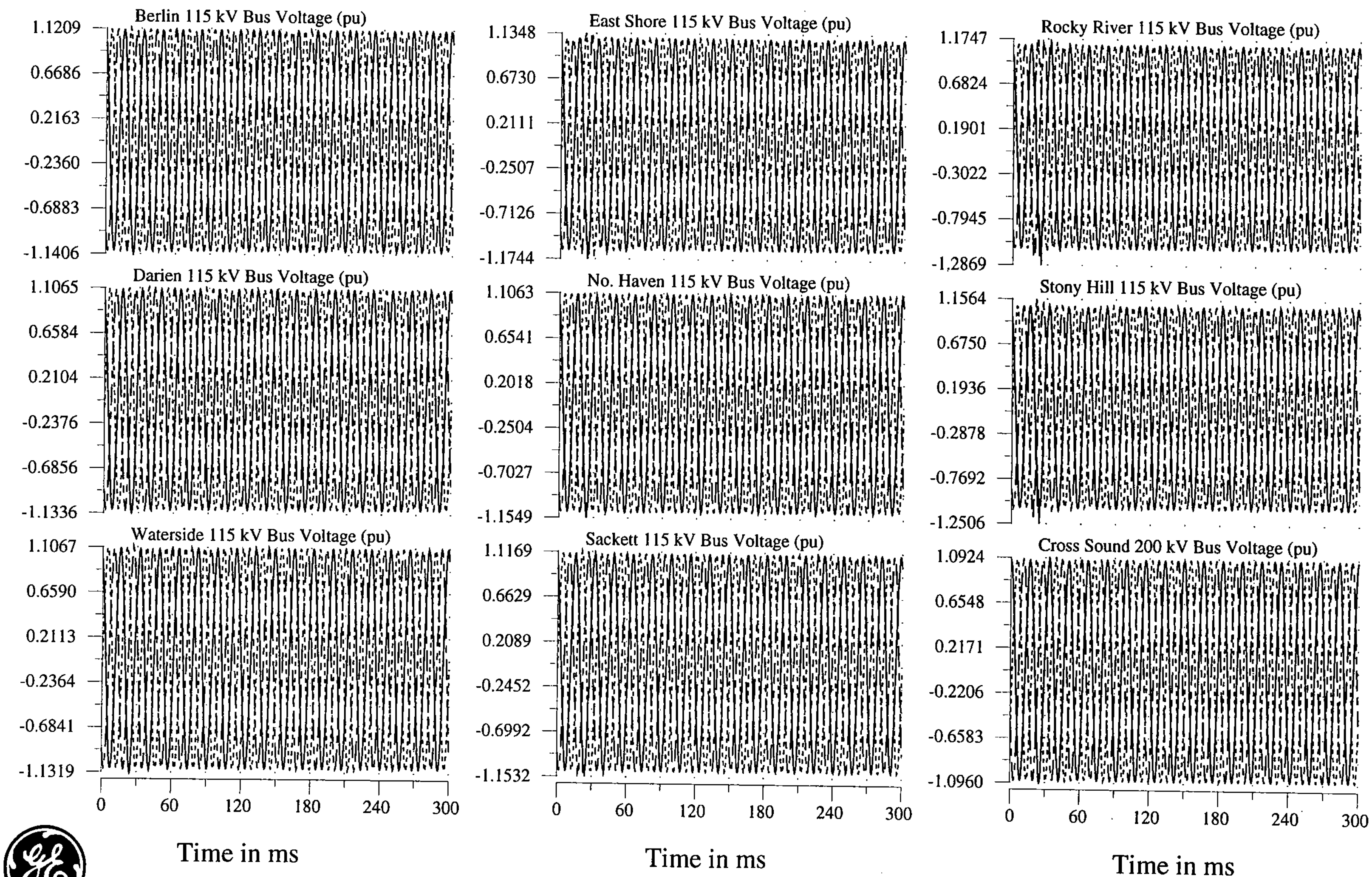


03-Nov-03 17:40:00 C:\Projects\atp\NU_phase2p\ps\PH2P_Y1_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_Y1_01

115 kV Bus Voltages and Capacitor Bank Locations

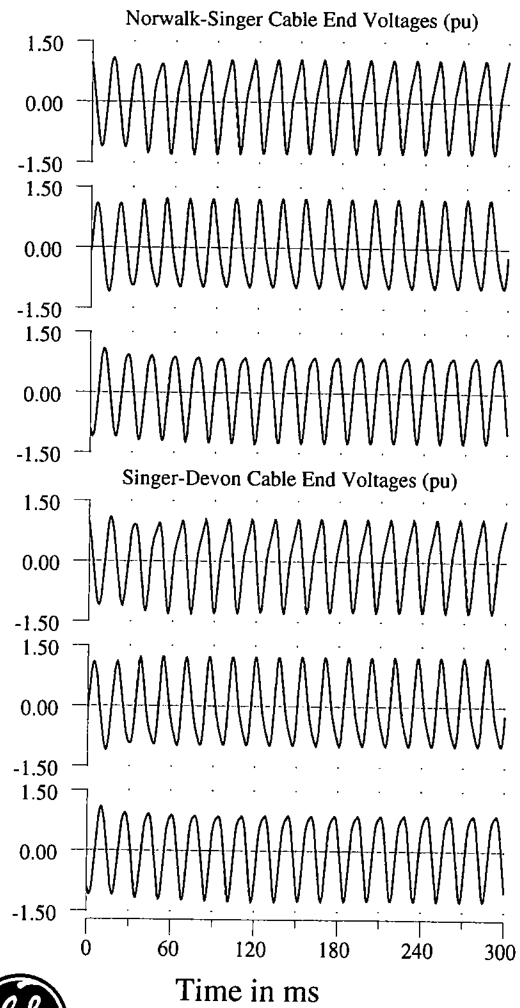


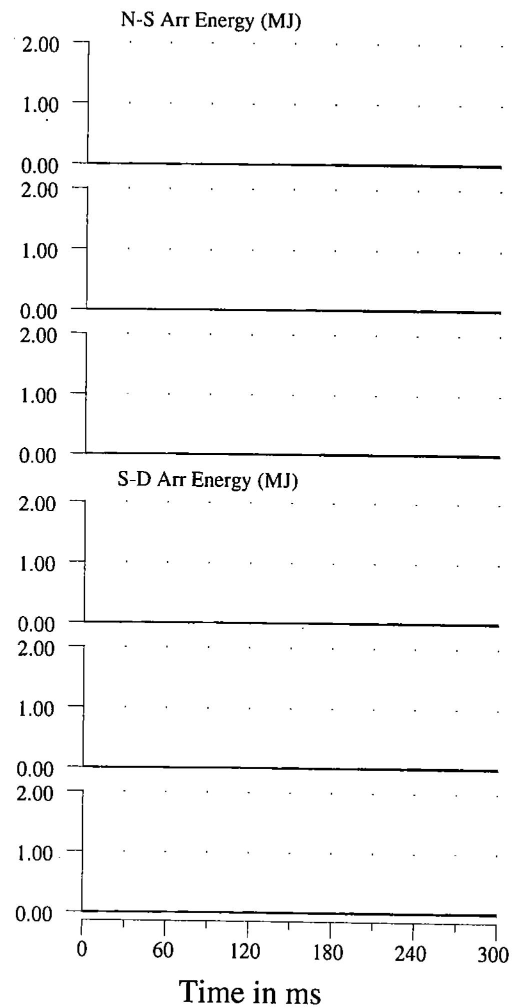
03-Nov-03 17:40:00 C:\Projects\atp\NU_phase2p\ps\PH2P_Y1_01.PL4

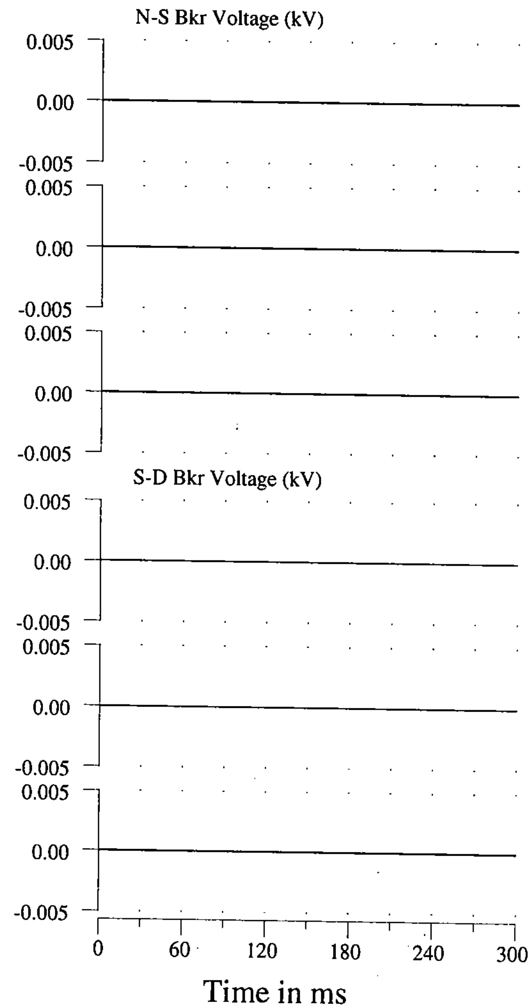
Northeast Utilities: Phase 2 Cable Transient Study

PH2P_6_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)





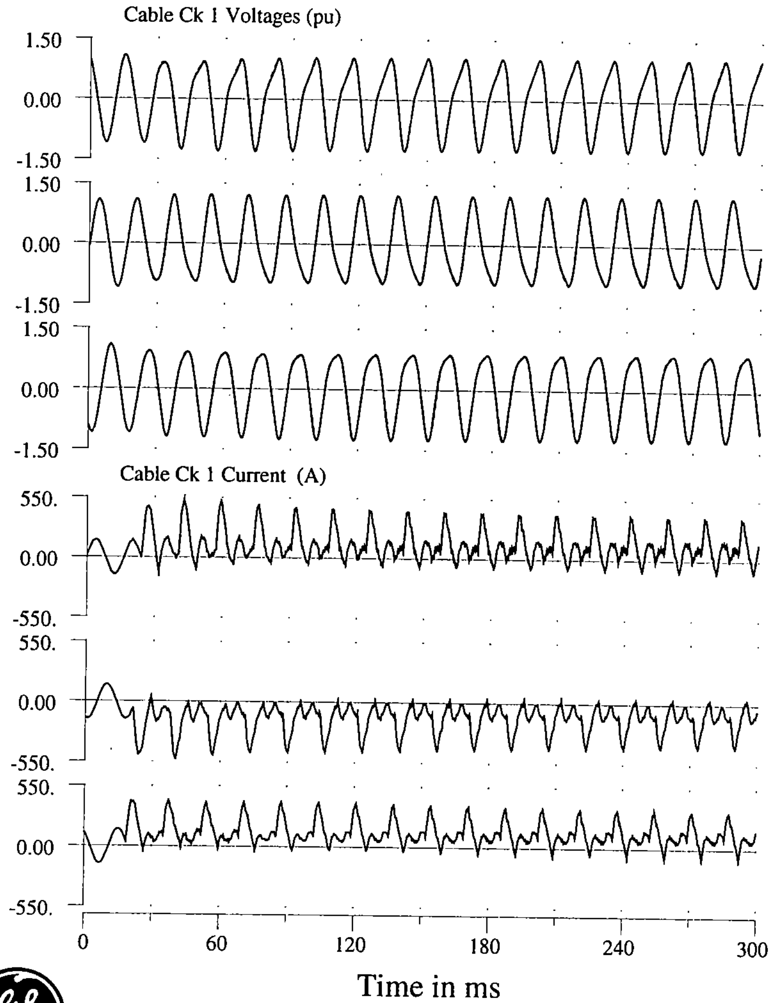


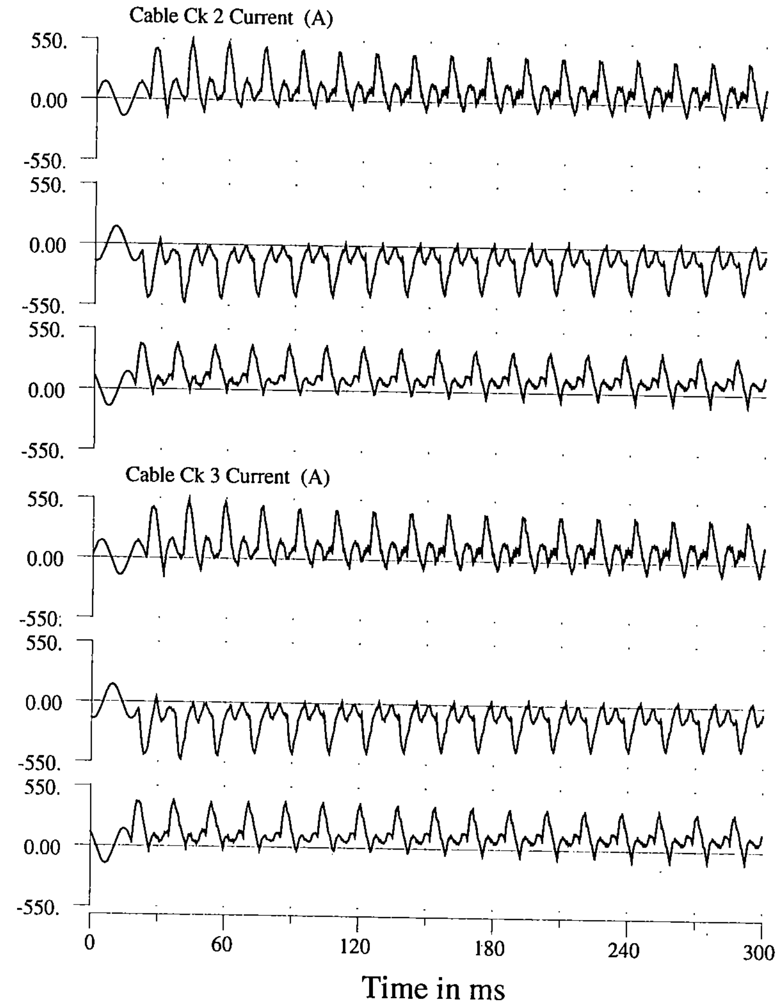
03-Nov-03 17:42:54 C:\Projects\atp\NU_phase2p\ps\PH2P_6_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_6_01

Devon-Beseck 345 kV Cables



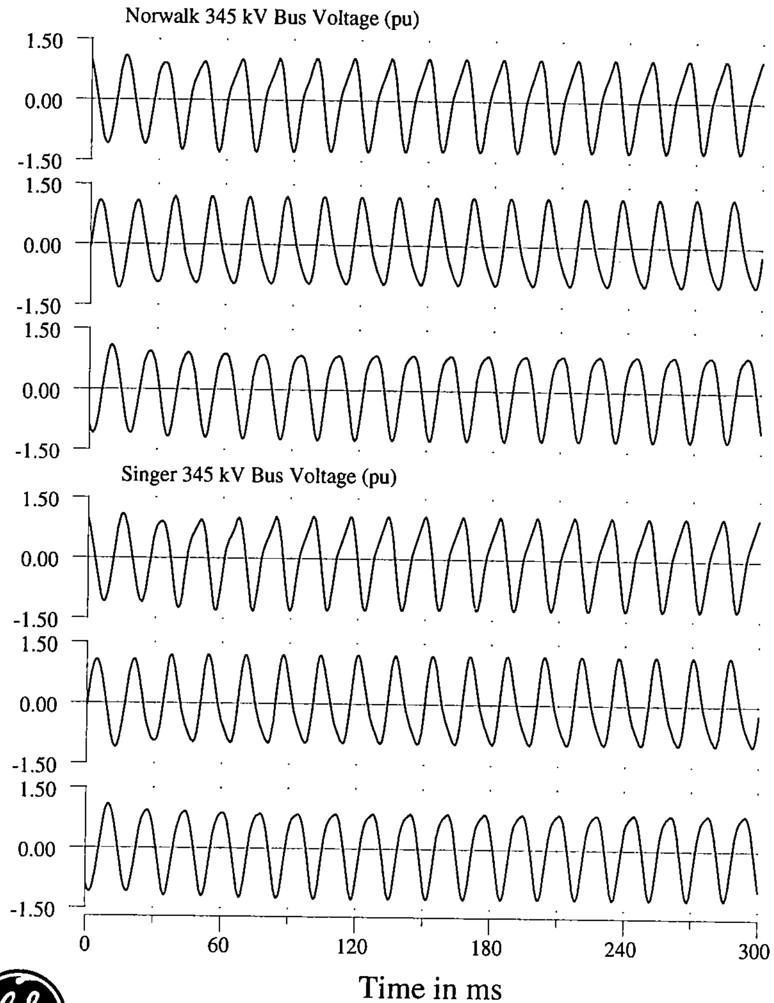


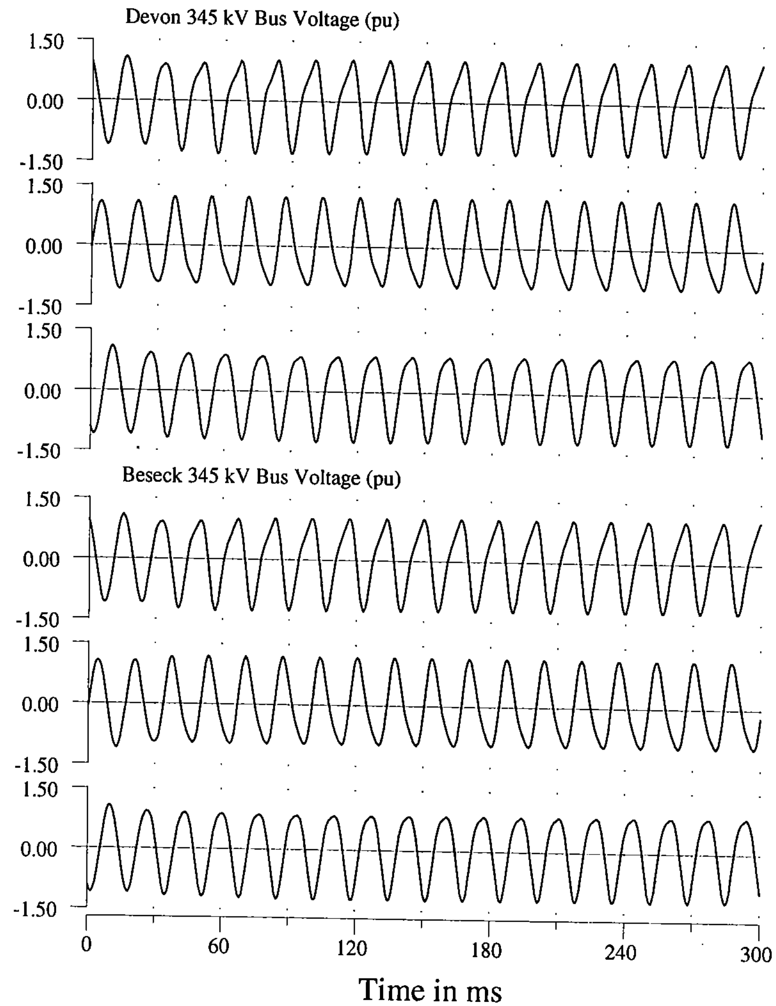
03-Nov-03 17:42:54 C:\Projects\atp\NU_phase2p\ps\PH2P_6_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_6_01

345 kV Bus Voltages



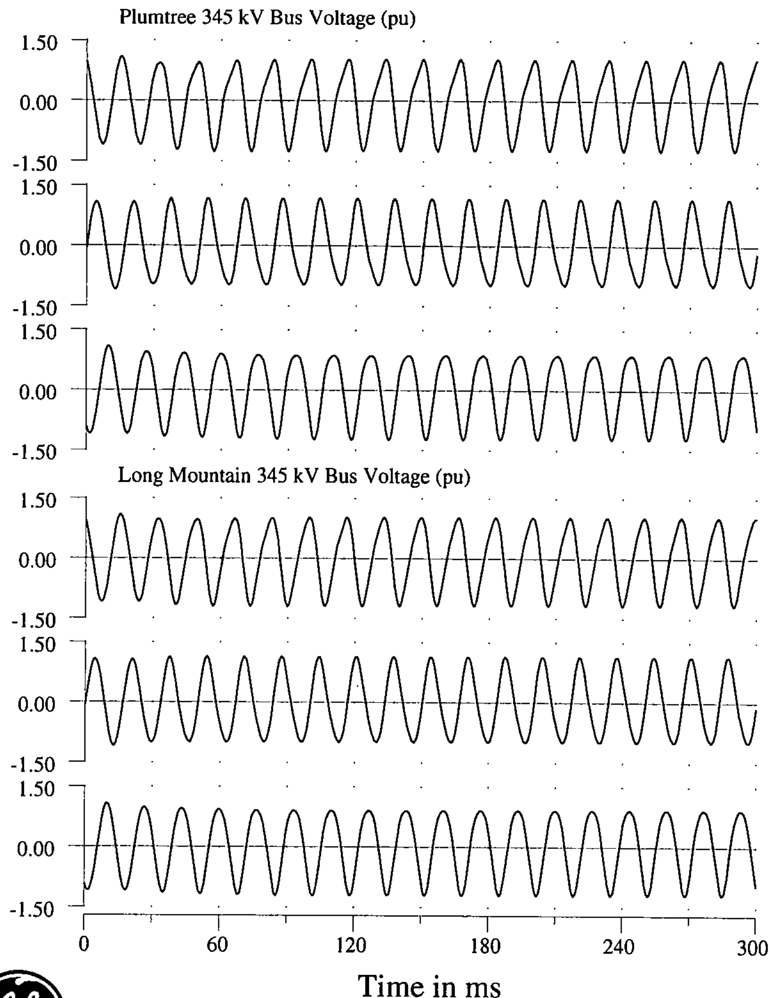


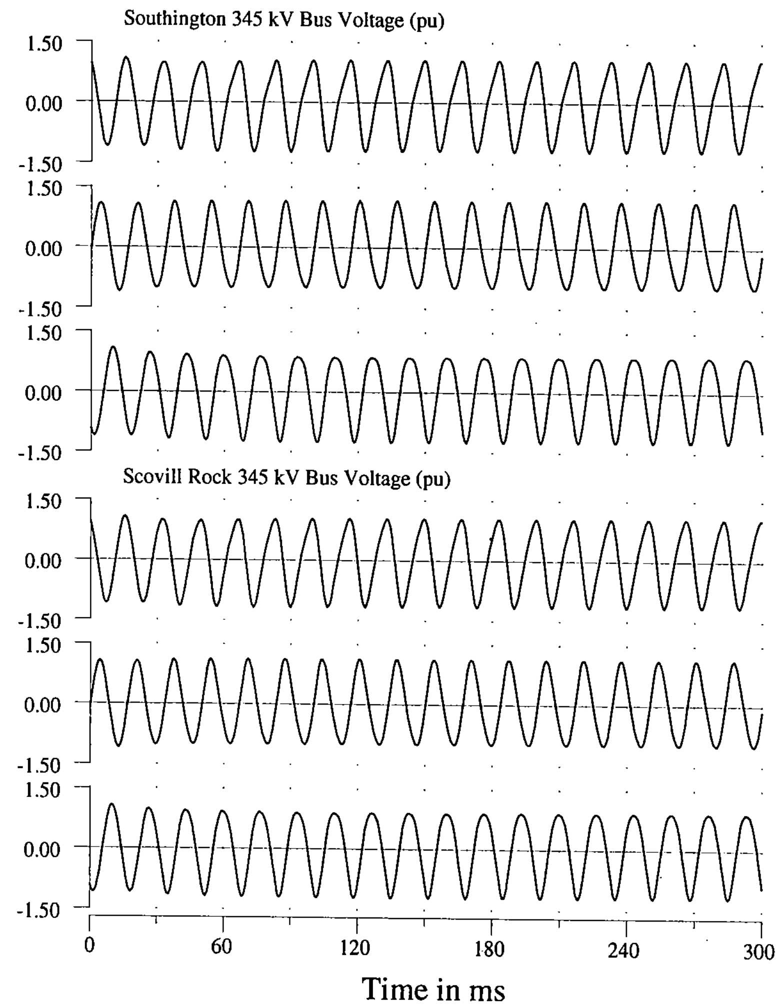
03-Nov-03 17:42:54 C:\Projects\atp\NU_phase2p\ps\PH2P_6_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_6_01

345 kV Bus Voltages



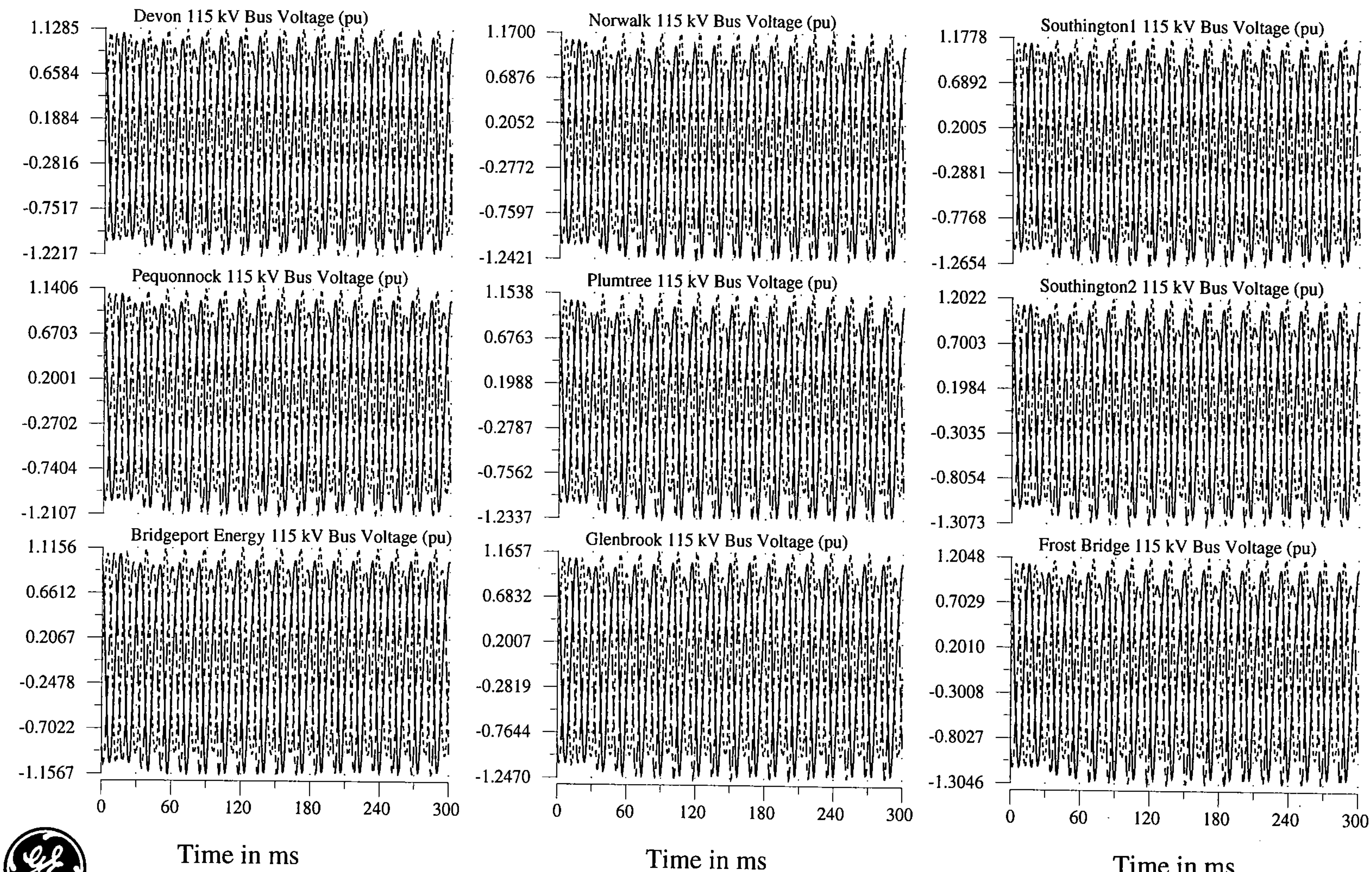


03-Nov-03 17:42:54 C:\Projects\atp\NU_phase2p\ps\PH2P_6_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

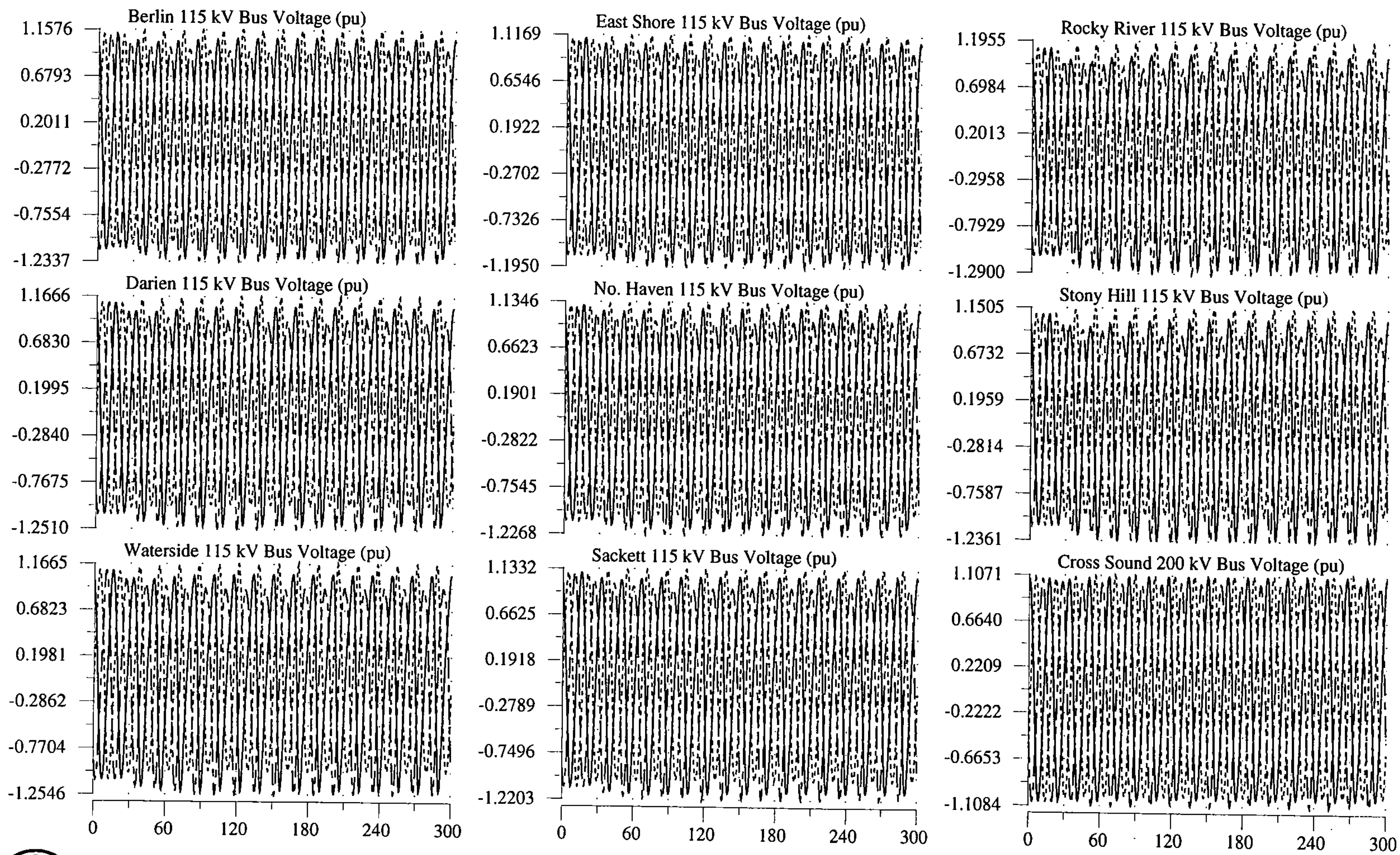
PH2P_6_01

115 kV Bus Voltages and Capacitor Bank Locations



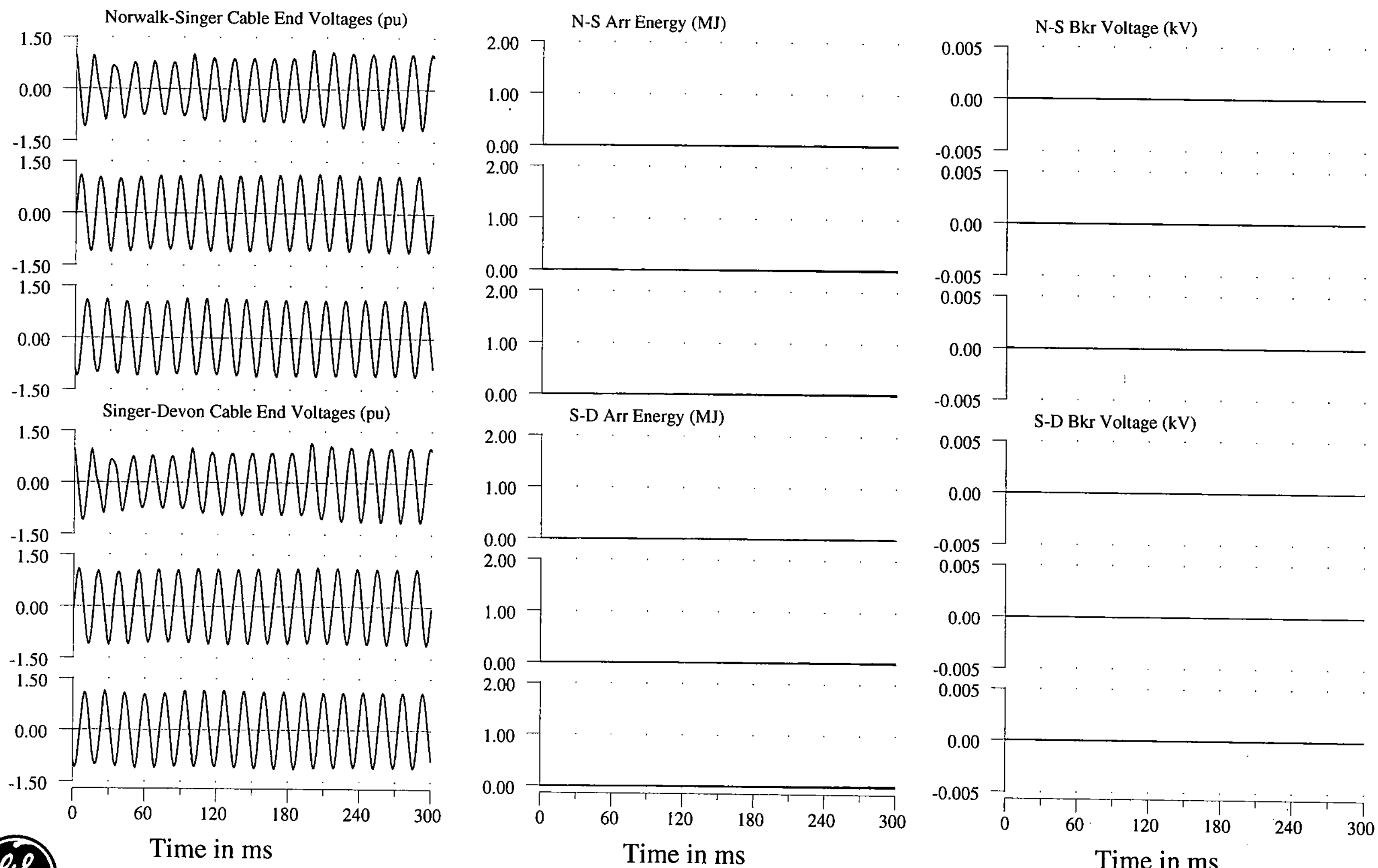
03-Nov-03 17:42:54 C:\Projects\atp\NU_phase2p\ps\PH2P_6_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_6_01
115 kV Bus Voltages and Capacitor Bank Locations



03-Nov-03 17:42:54 C:\Projects\atp\NU_phase2p\ps\PH2P_6_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_DTF_01
Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

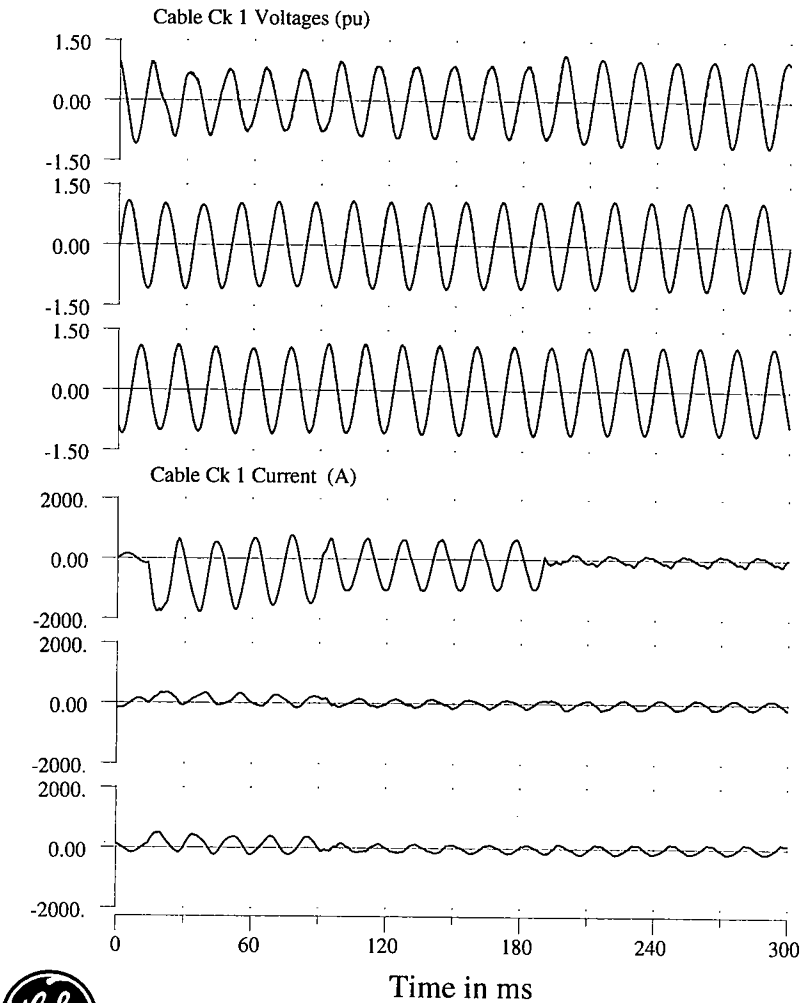


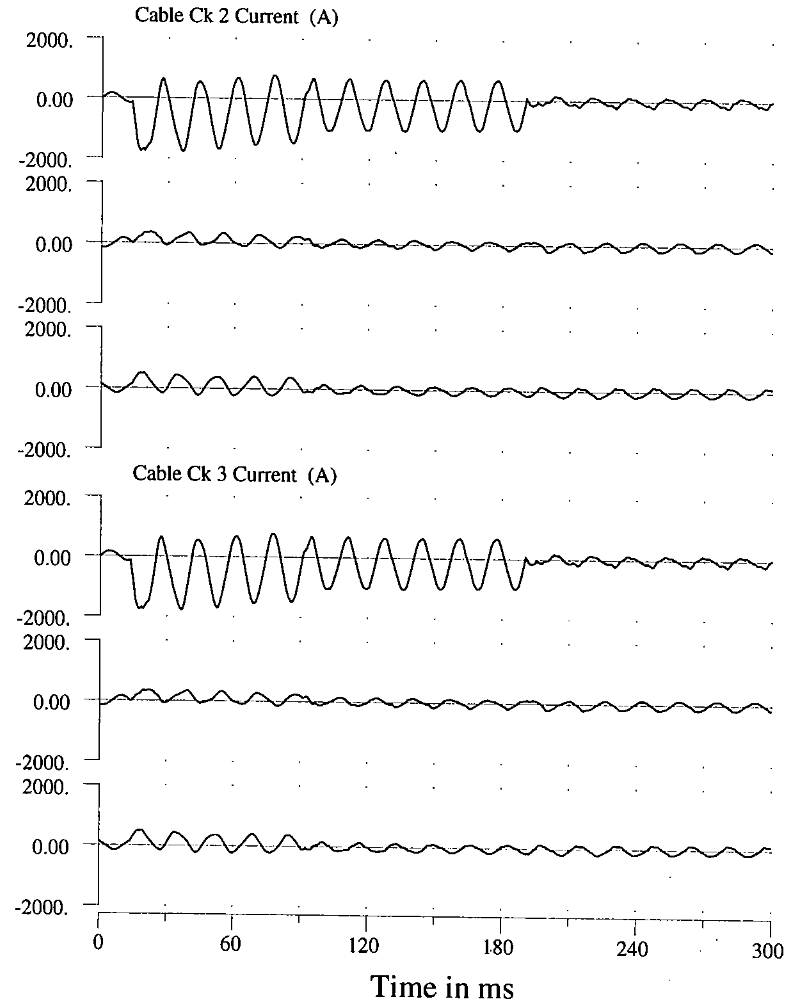
03-Nov-03 17:45:35 C:\Projects\atp\NU_phase2p\ps\PH2P_DTF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_DTF_01

Devon-Beseck 345 kV Cables



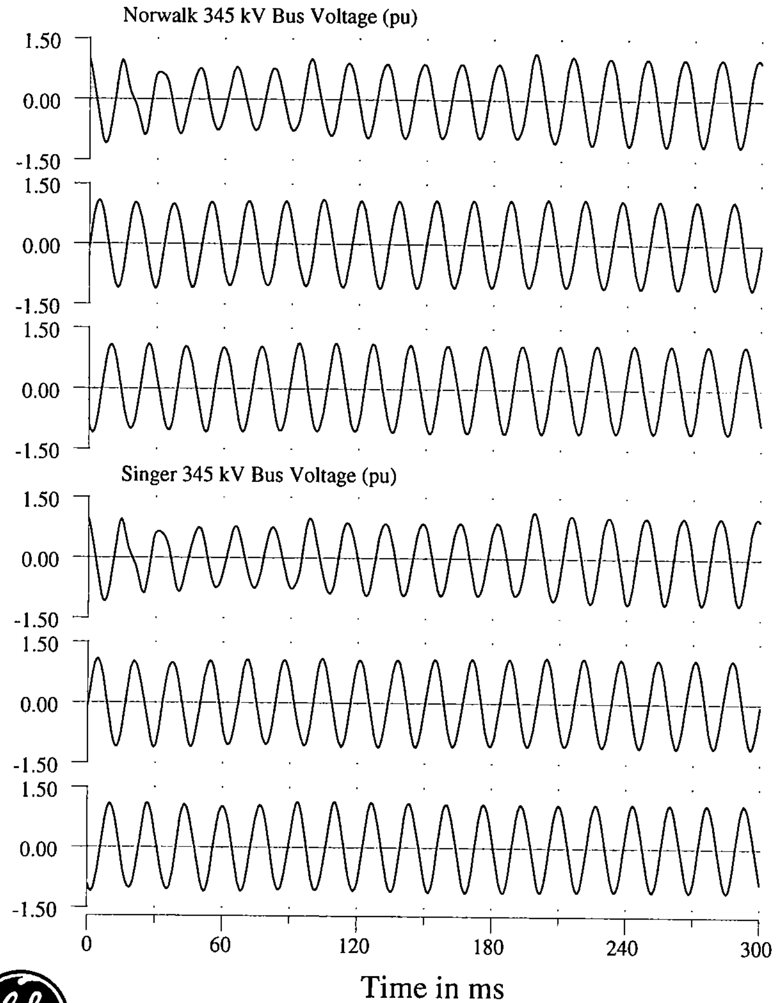


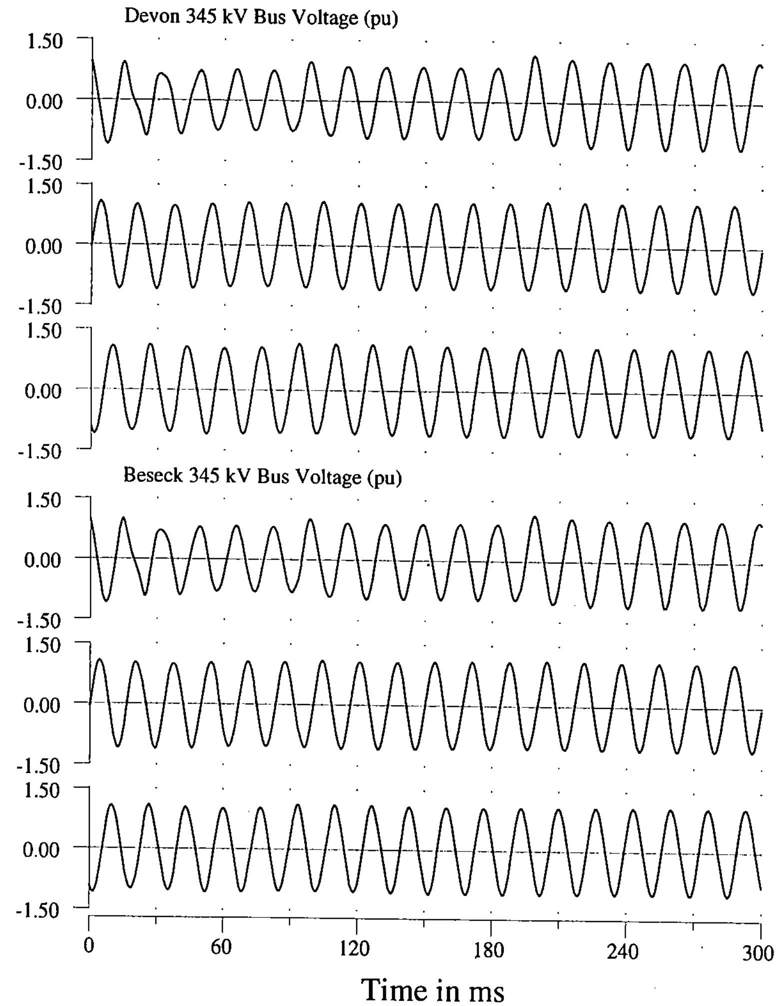
03-Nov-03 17:45:35 C:\Projects\atp\NU_phase2p\ps\PH2P_DTF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_DTF_01

345 kV Bus Voltages



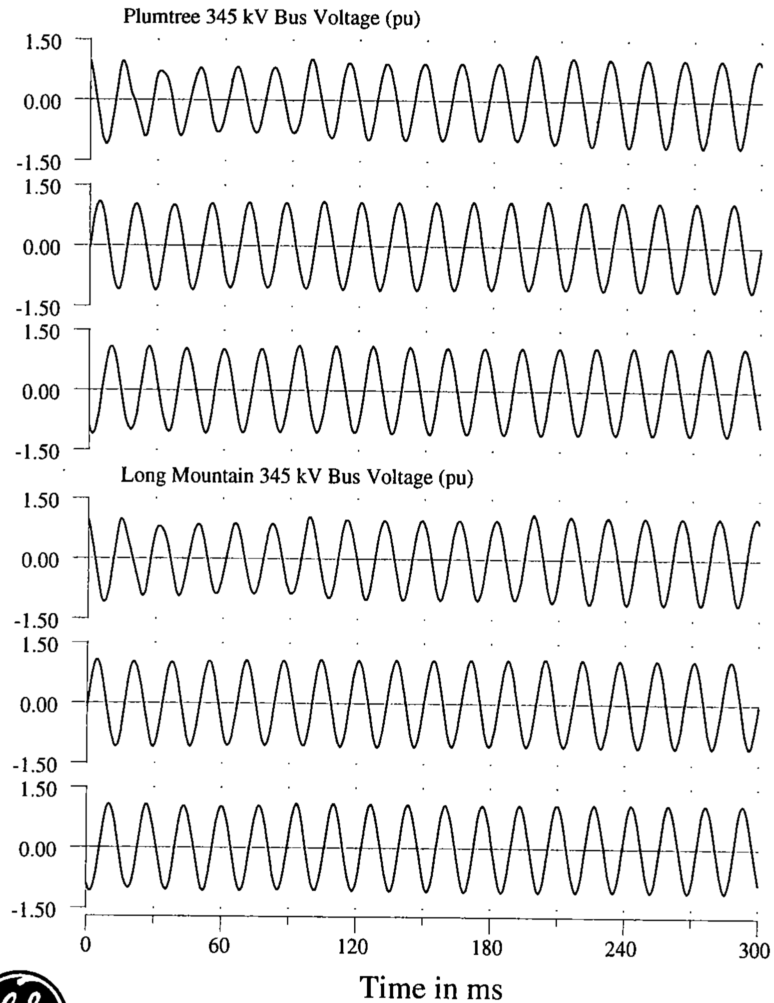


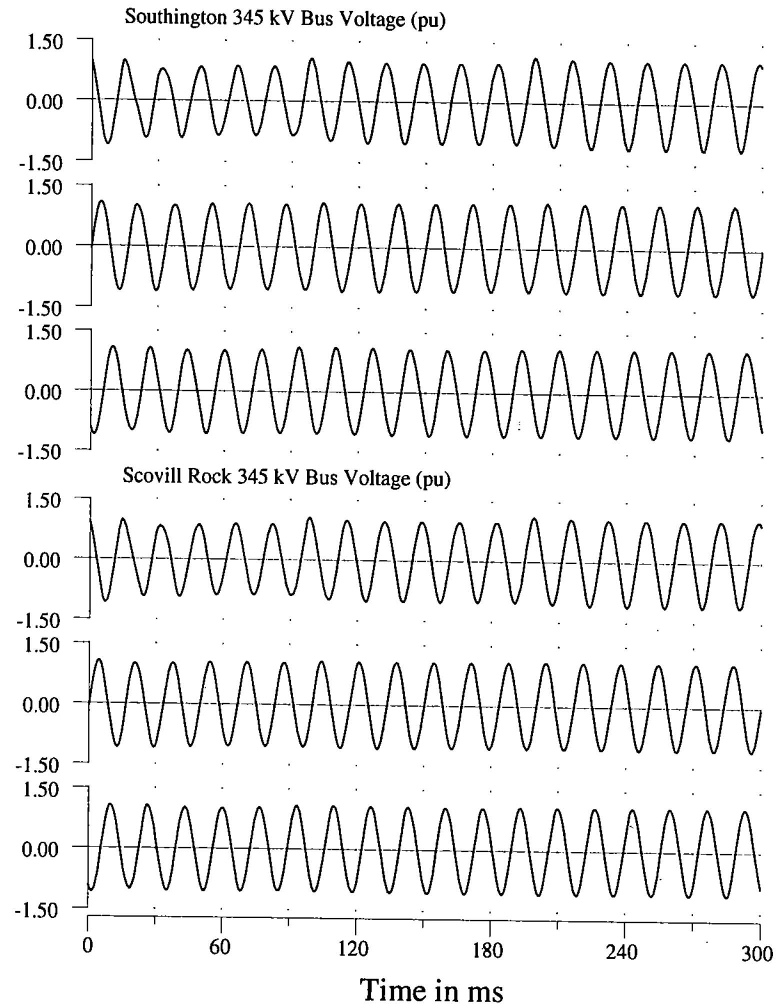
03-Nov-03 17:45:35 C:\Projects\atp\NU_phase2p\ps\PH2P_DTF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_DTF_01

345 kV Bus Voltages



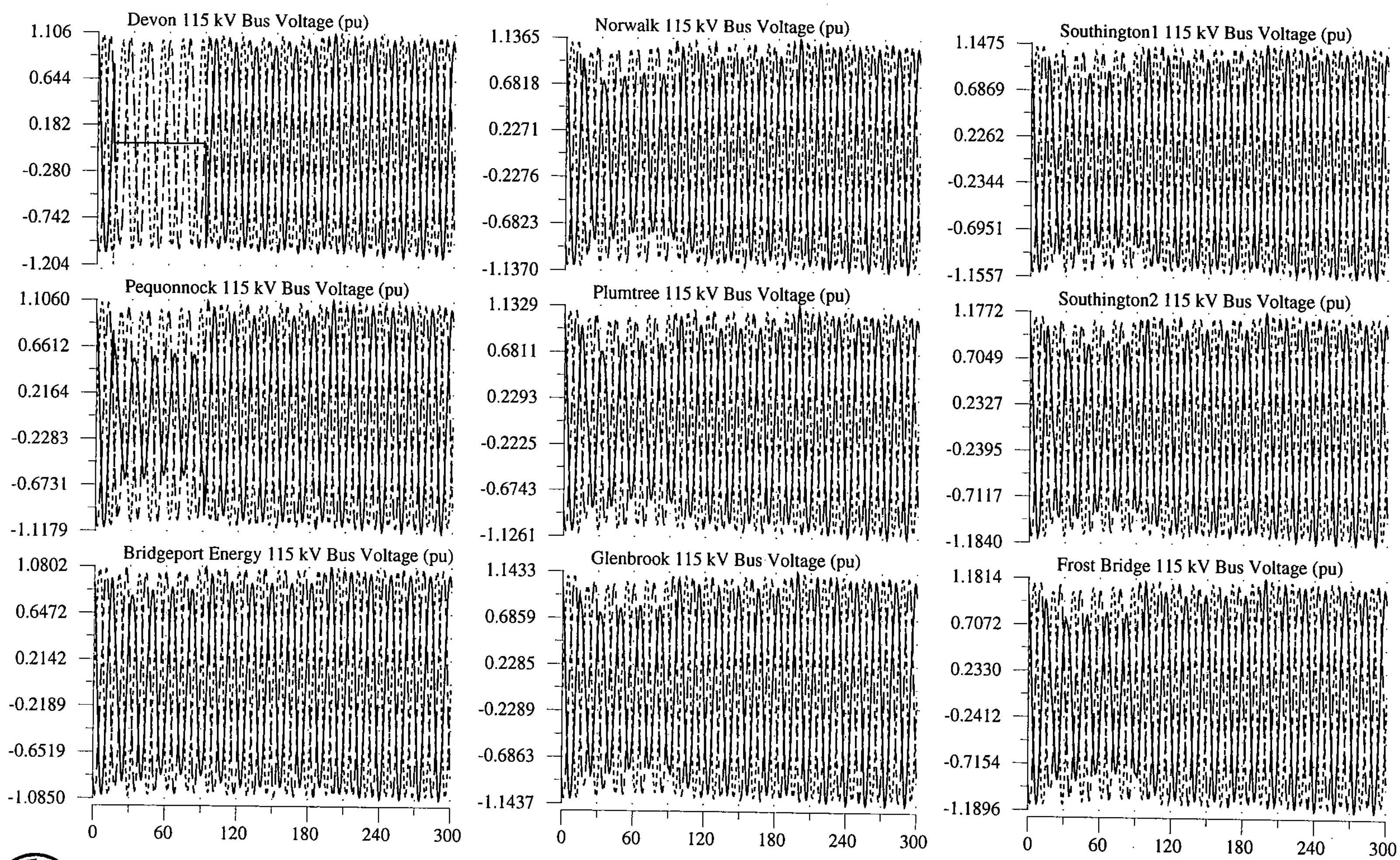


03-Nov-03 17:45:35 C:\Projects\atp\NU_phase2p\ps\PH2P_DTF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_DTF_01

115 kV Bus Voltages and Capacitor Bank Locations

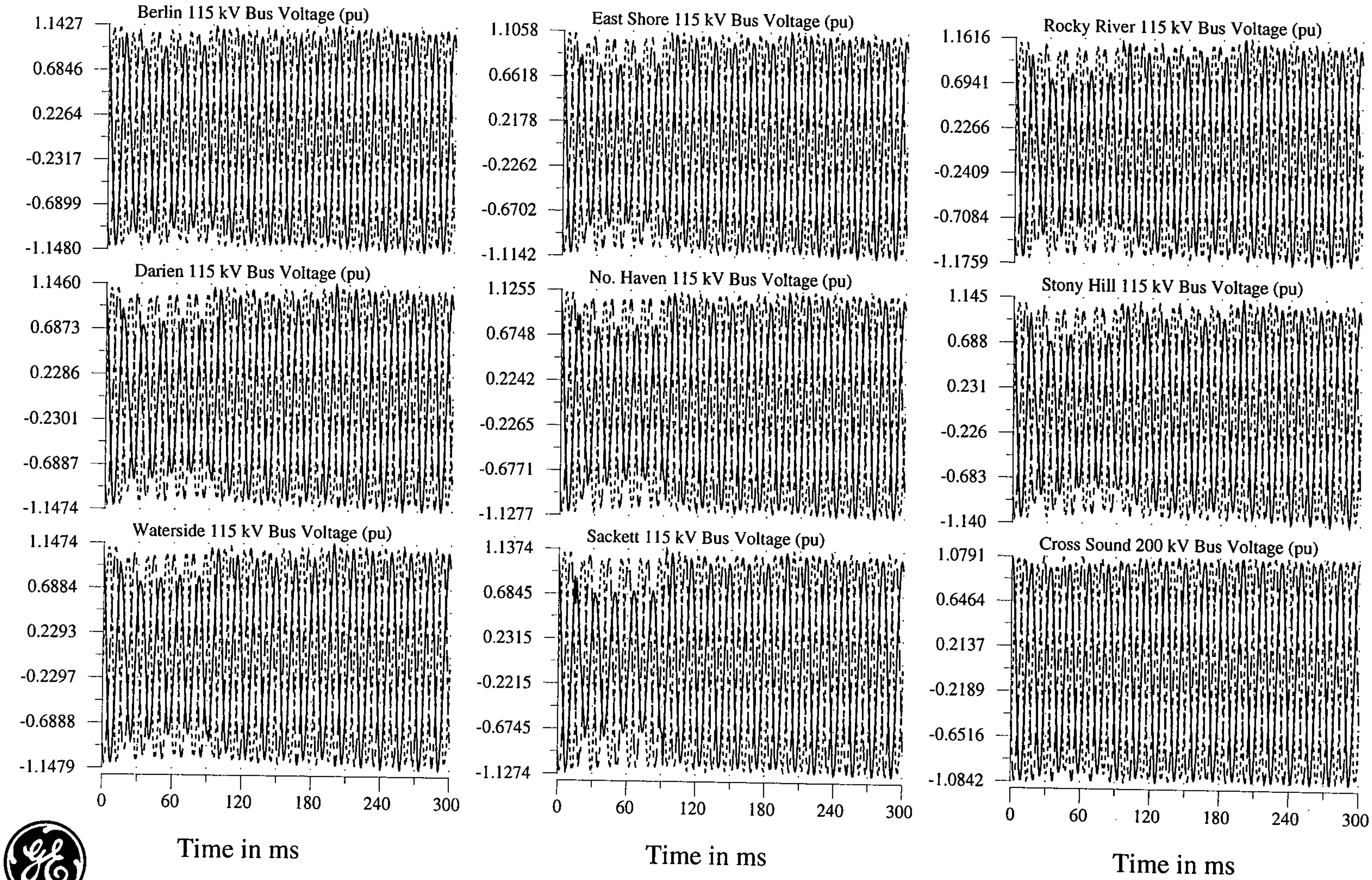


03-Nov-03 17:45:35 C:\Projects\atp\NU_phase2p\ps\PH2P_DTF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_DTF_01

115 kV Bus Voltages and Capacitor Bank Locations

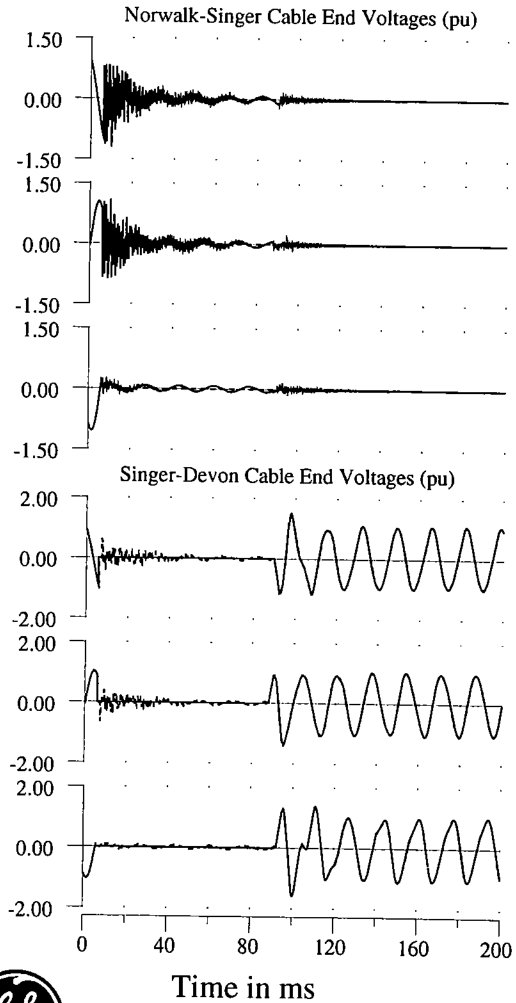


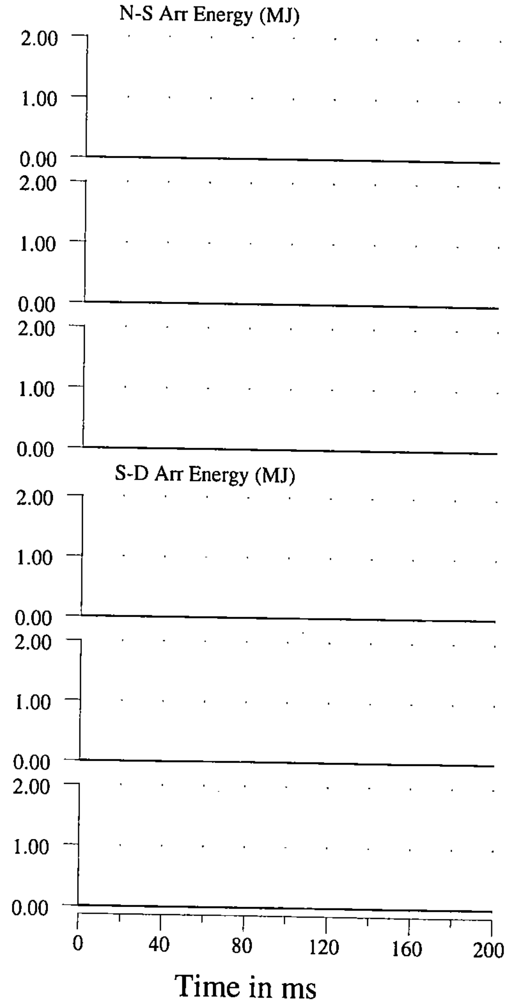
03-Nov-03 17:45:35 C:\Projects\atp\NU_phase2p\ps\PH2P_DTF_01.PL4

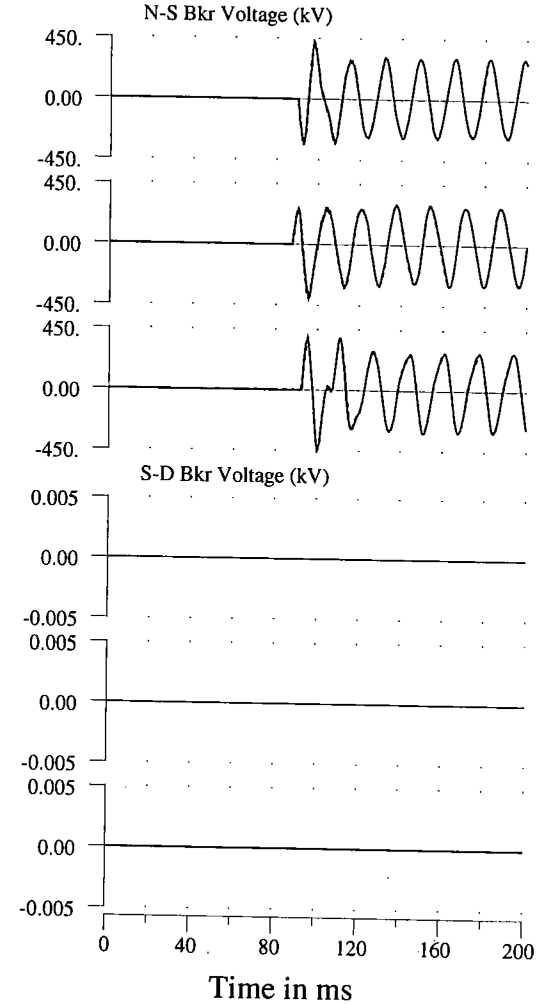
Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)





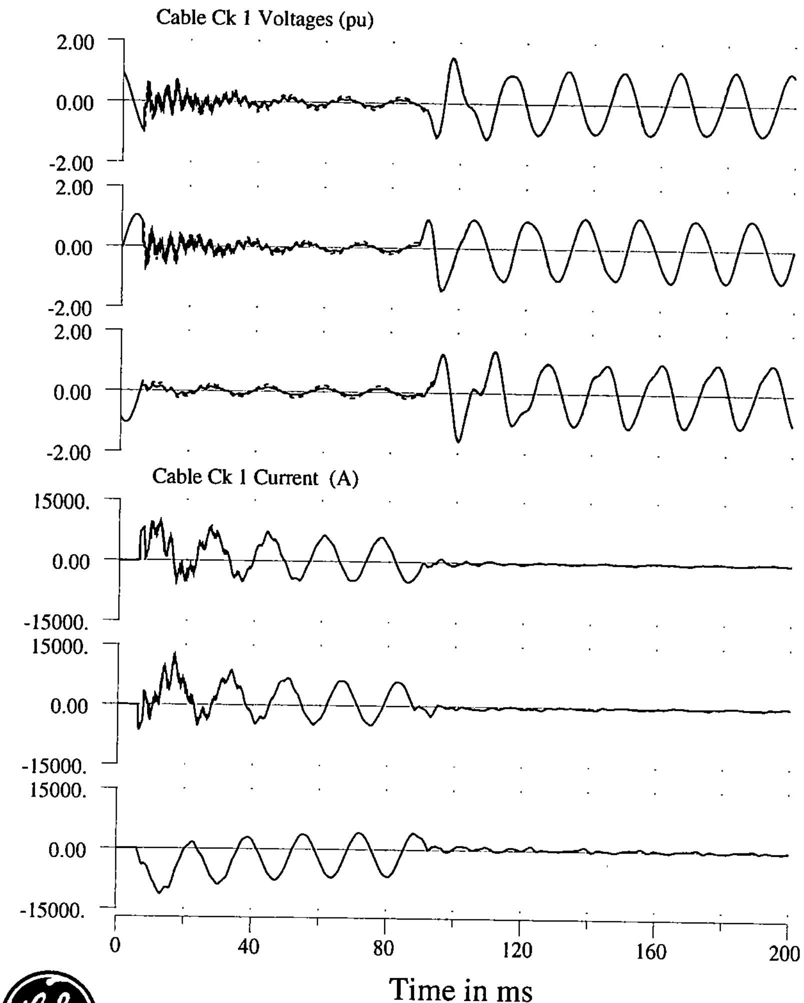


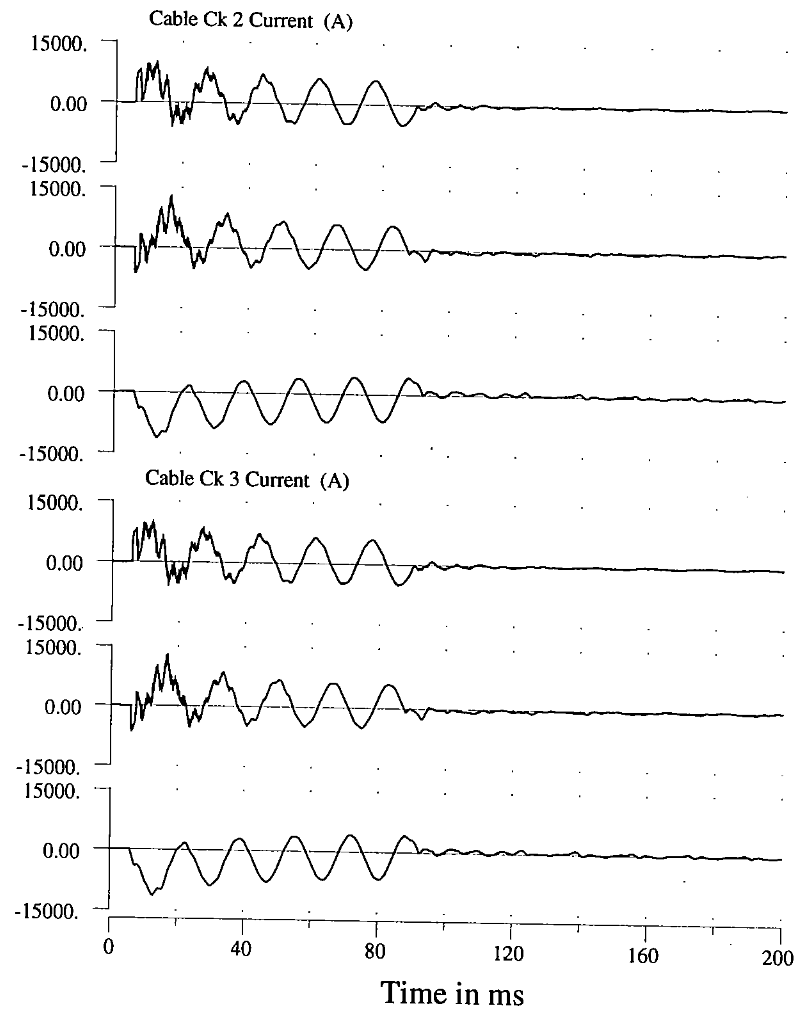
07-Nov-03 09:29:47 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_01

Devon-Beseck 345 kV Cables



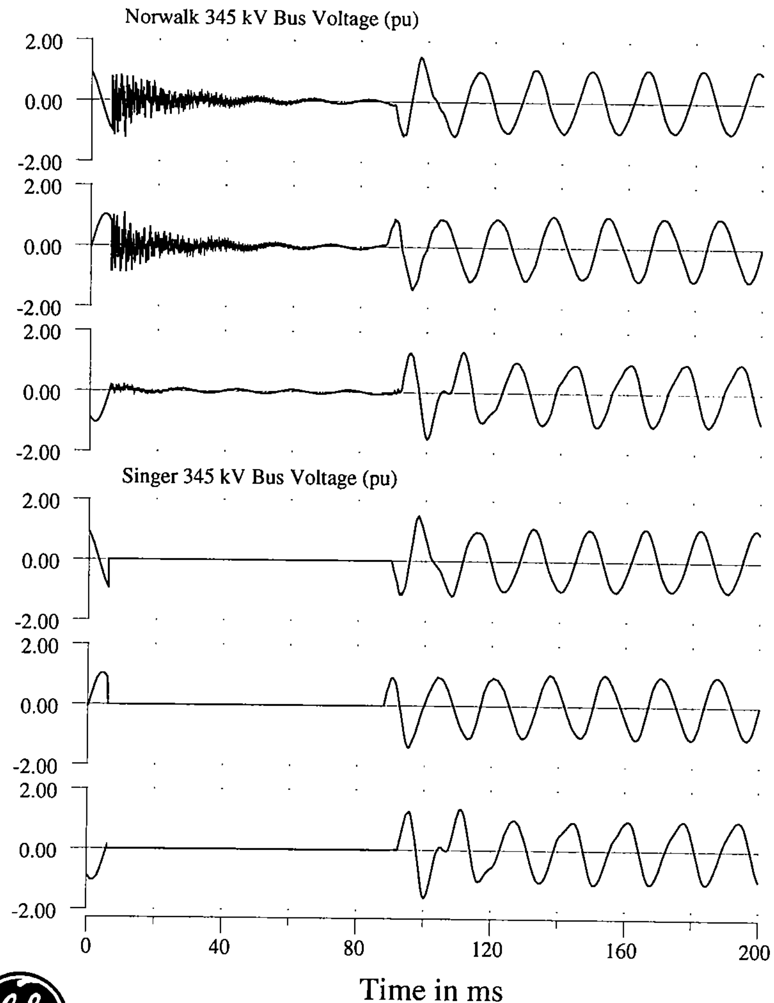


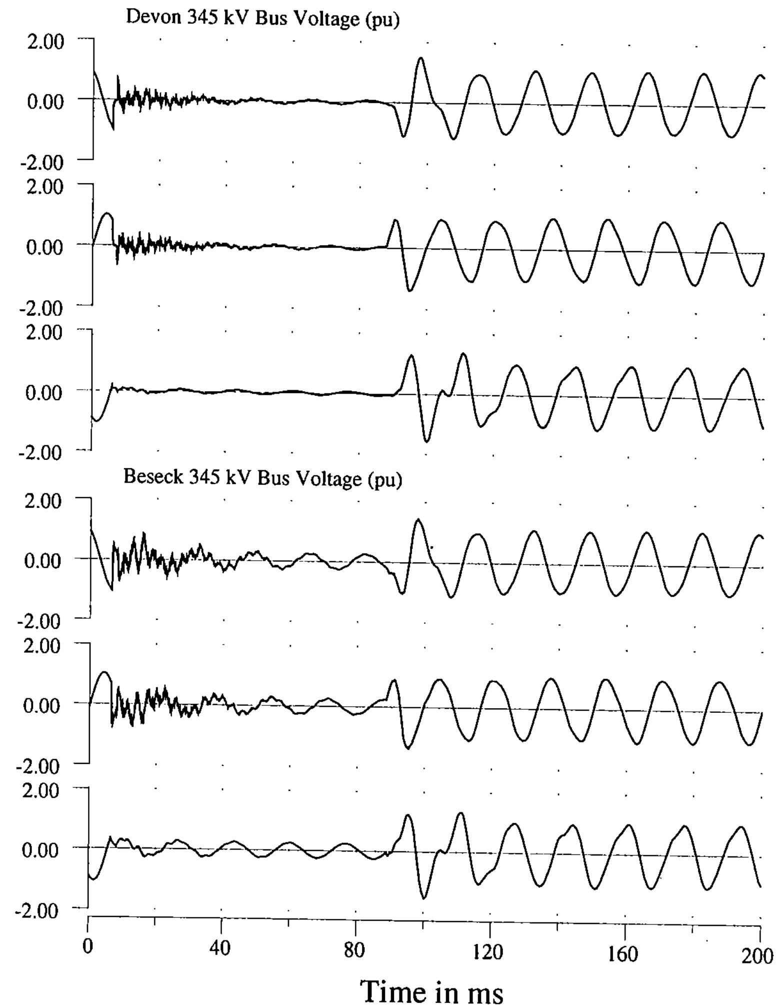
07-Nov-03 09:29:47 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_01

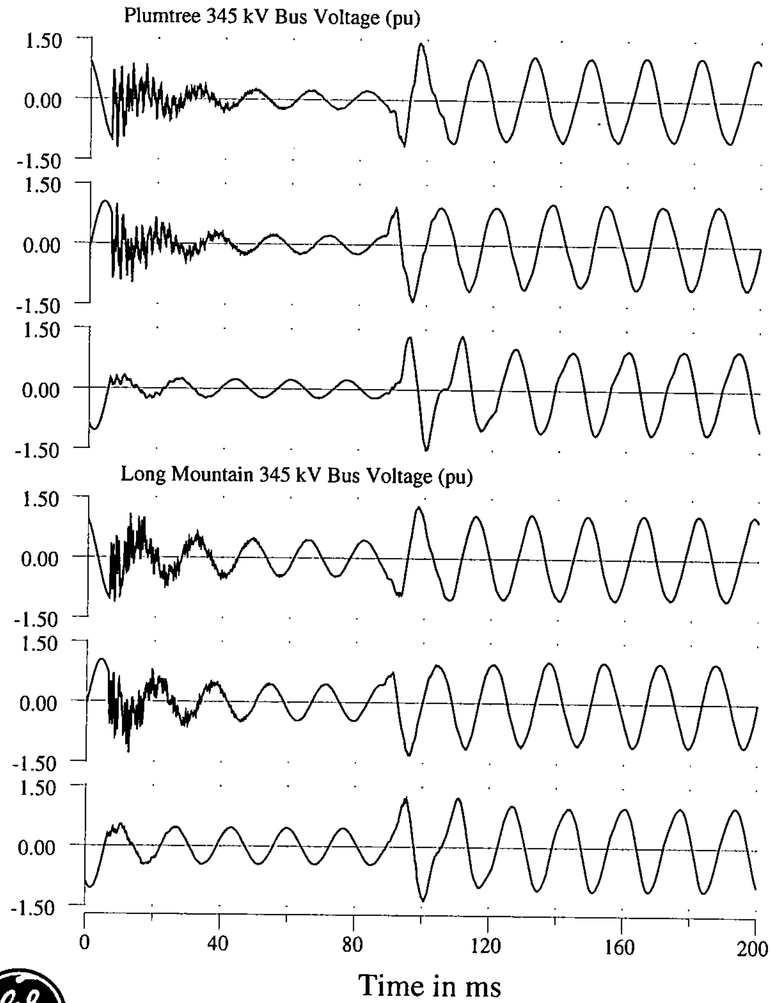
345 kV Bus Voltages

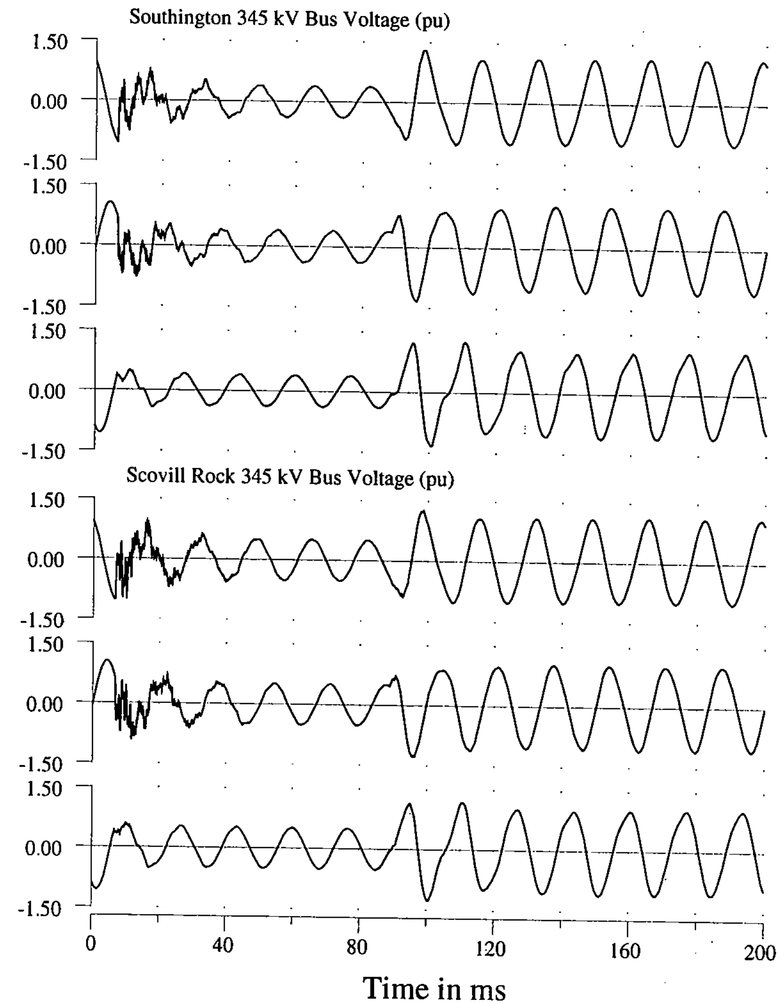




07-Nov-03 09:29:47 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_01
345 kV Bus Voltages



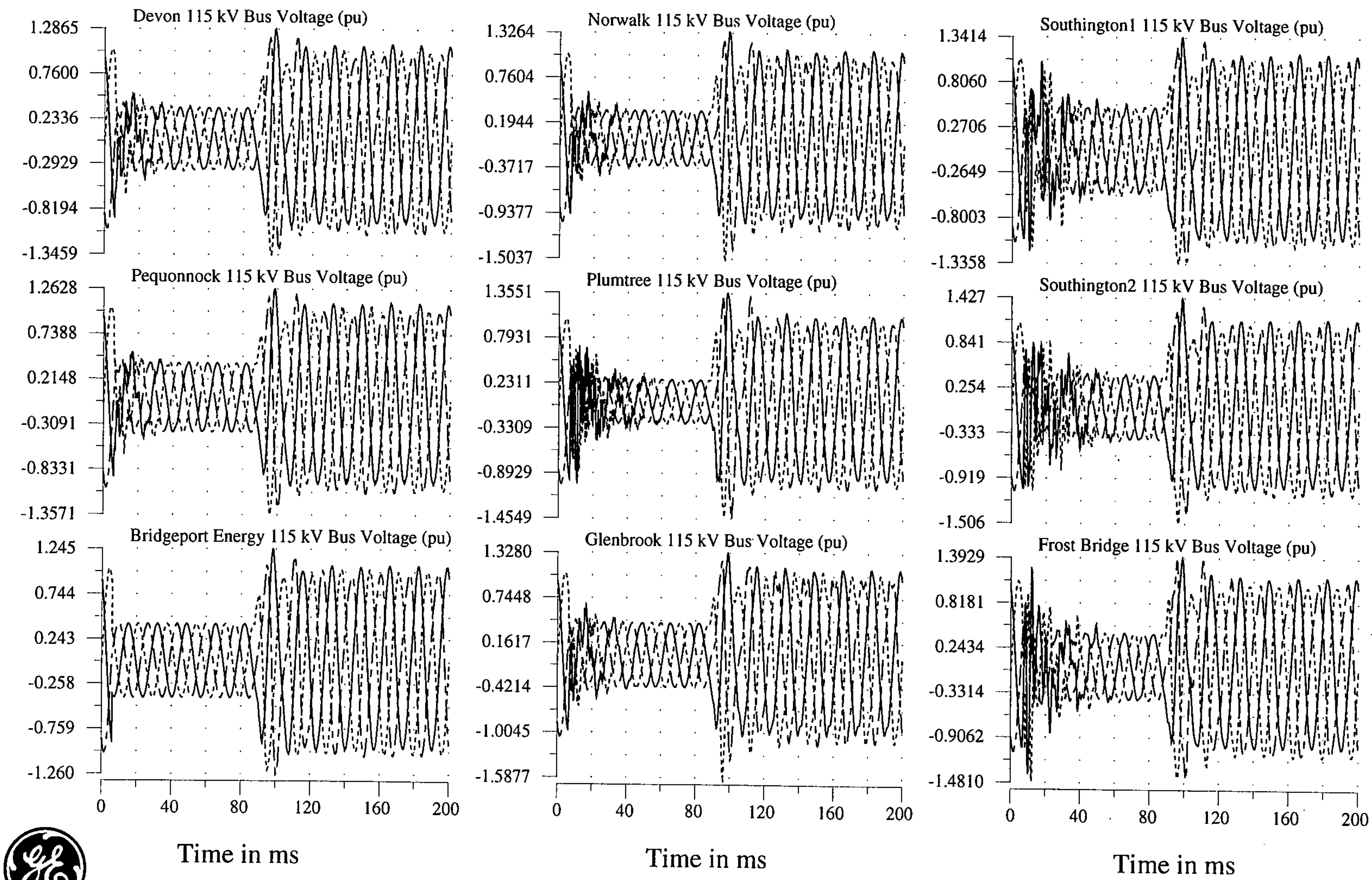


07-Nov-03 09:29:47 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_01

115 kV Bus Voltages and Capacitor Bank Locations

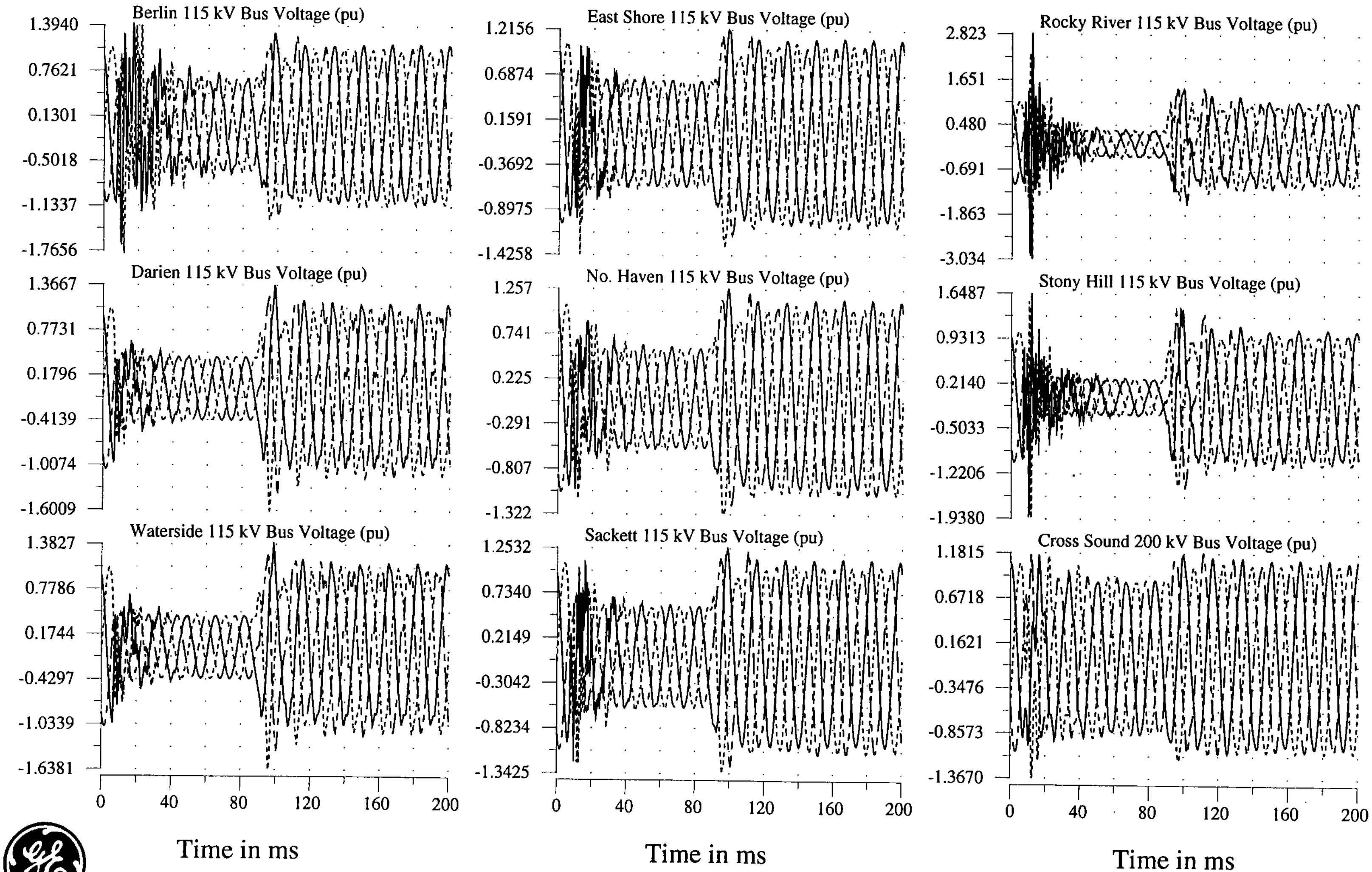


07-Nov-03 09:29:47 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_01

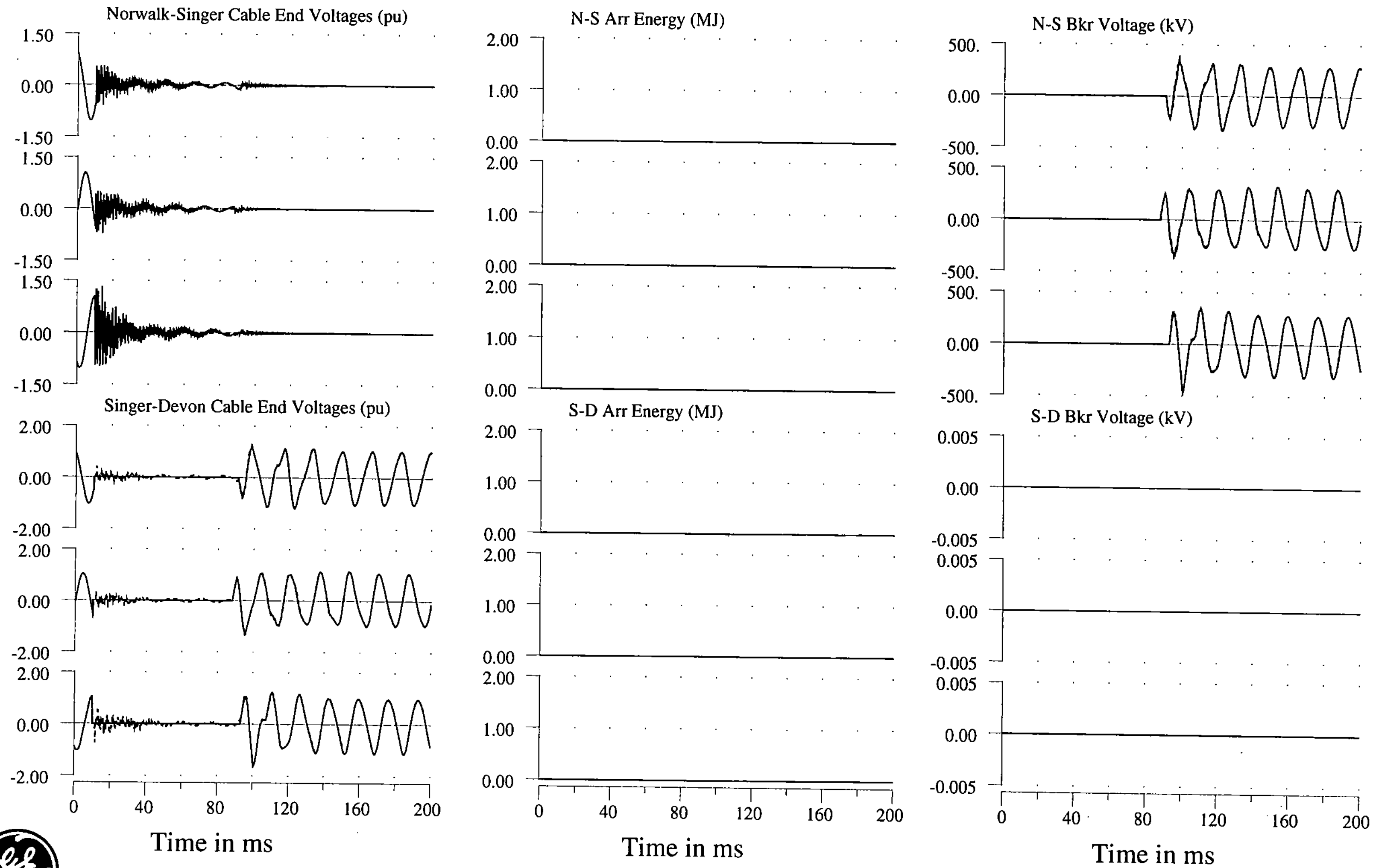
115 kV Bus Voltages and Capacitor Bank Locations



Northeast Utilities: Phase 2 Cable Transient Study

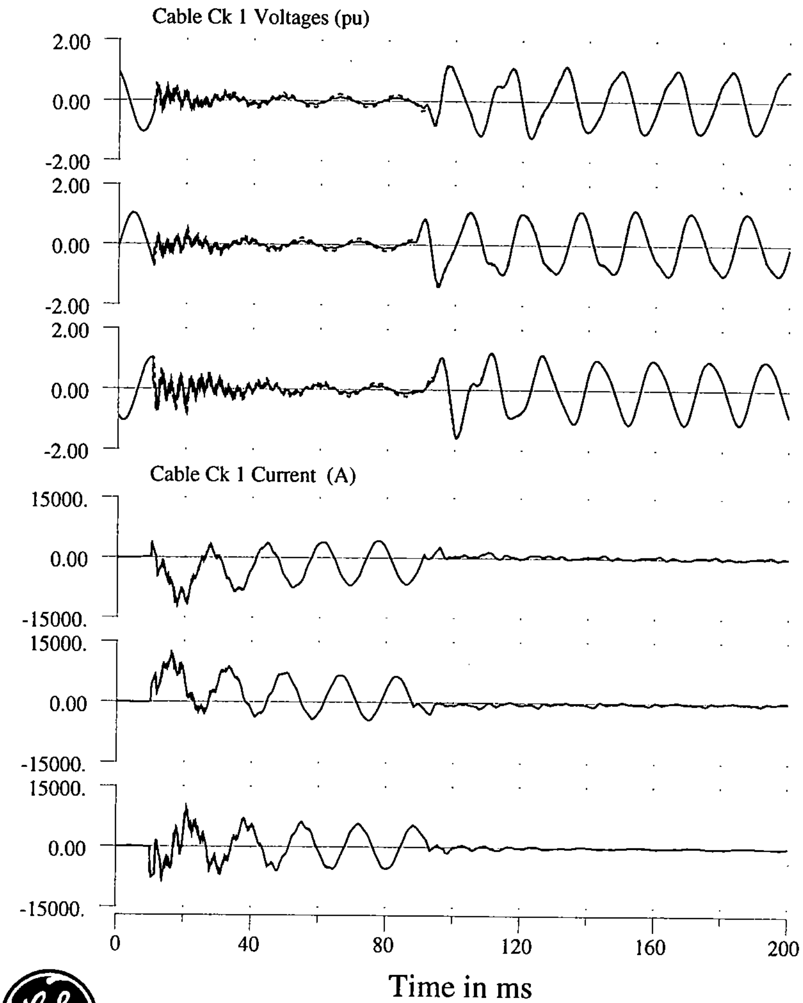
PH2P_NSF_01_90

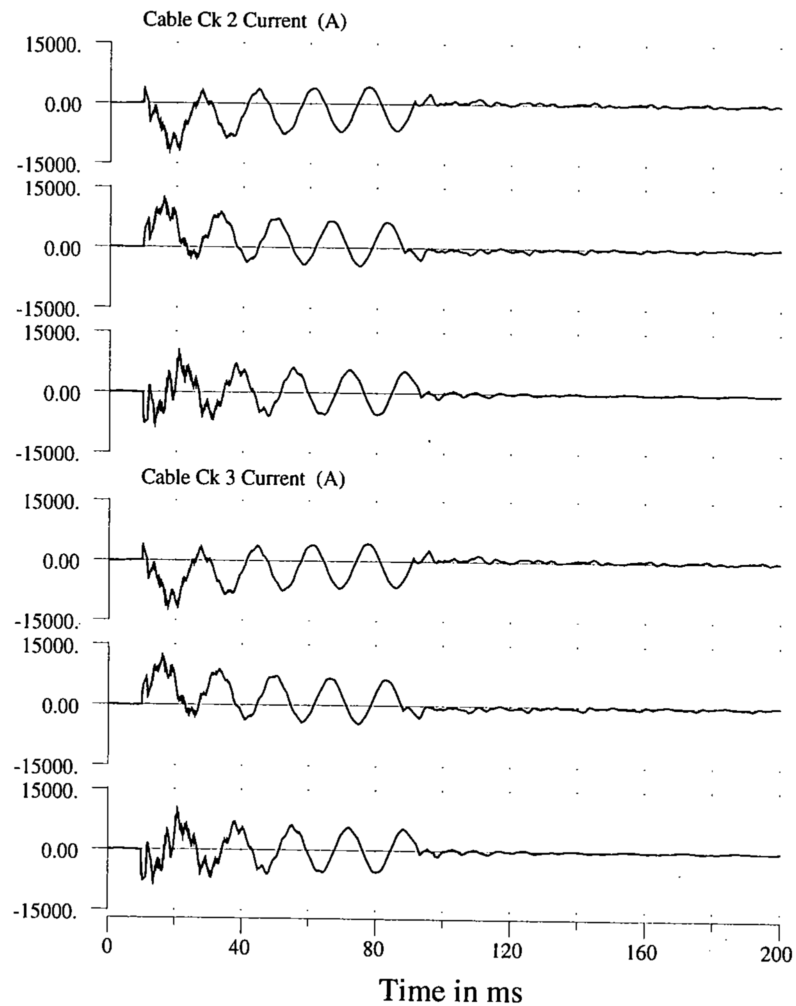
Case Summary Plots for Phase 2 345 kV Cables (Ck 1)



07-Nov-03 09:35:22 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01_90.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_01_90
Devon-Beseck 345 kV Cables

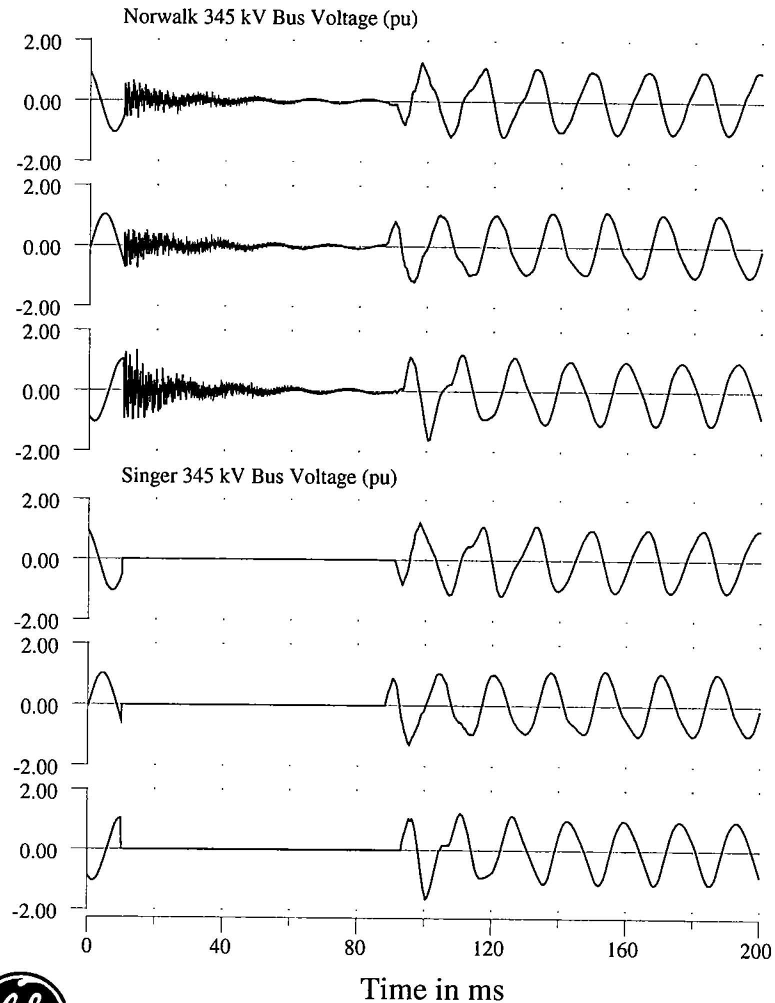


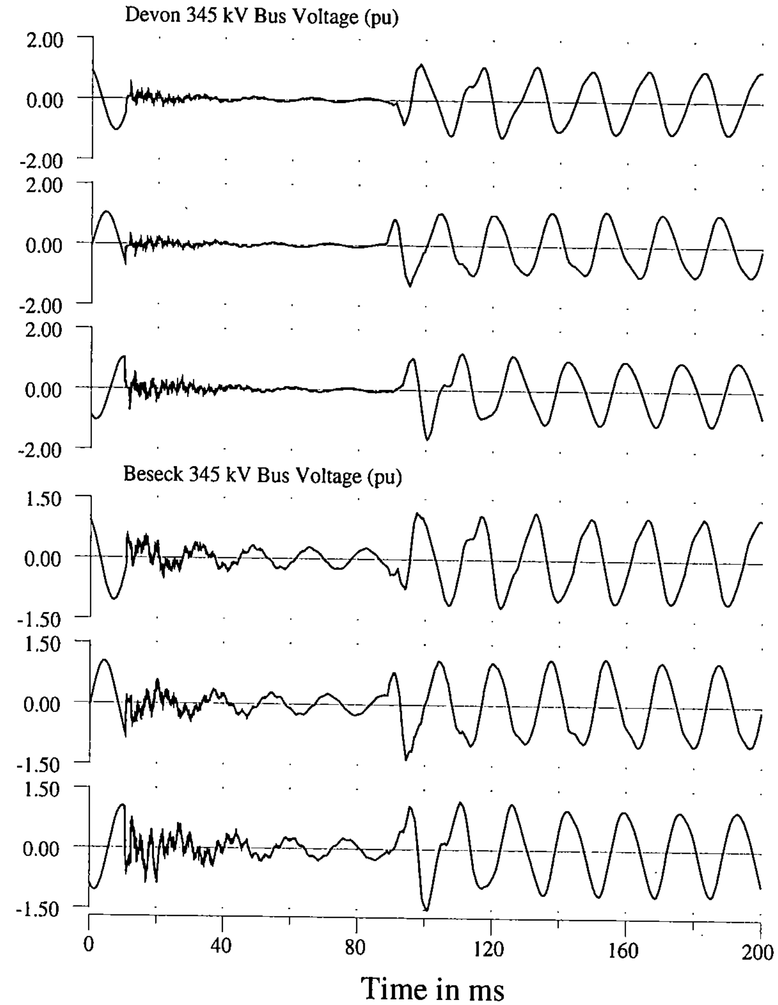


Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_01_90

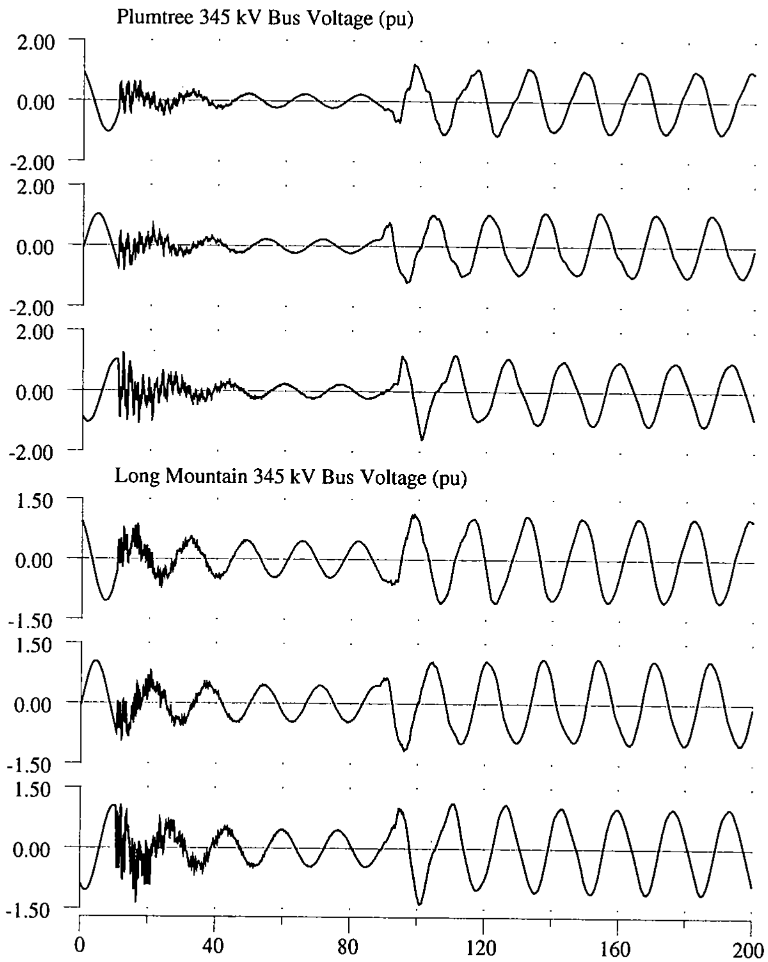
345 kV Bus Voltages

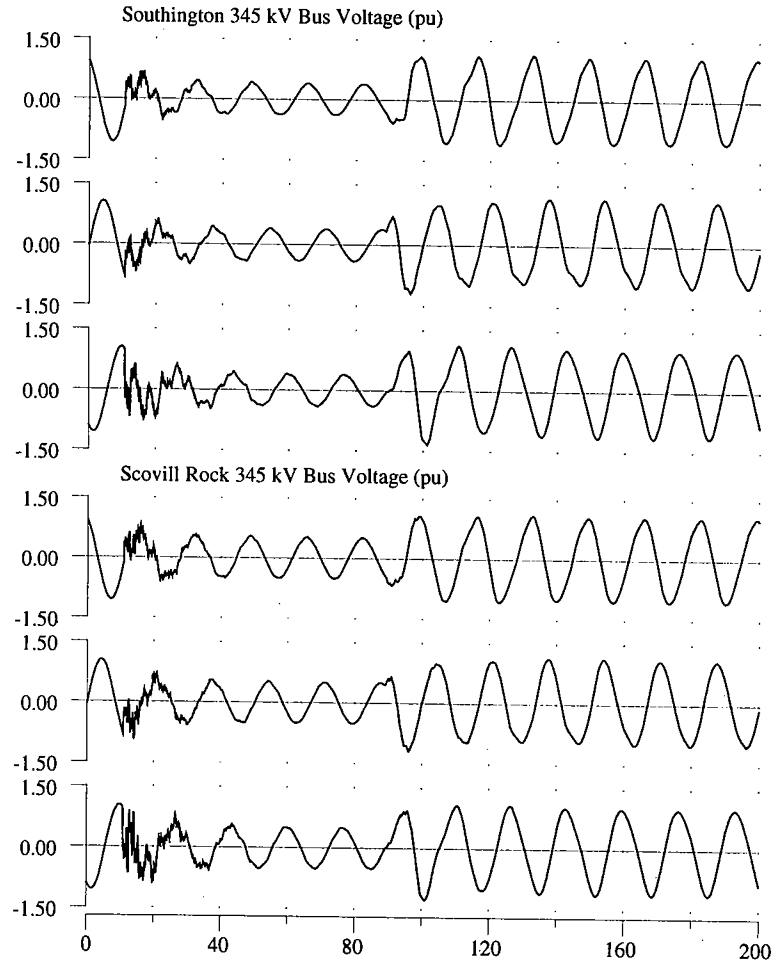




07-Nov-03 09:35:22 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01_90.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_01_90
345 kV Bus Voltages



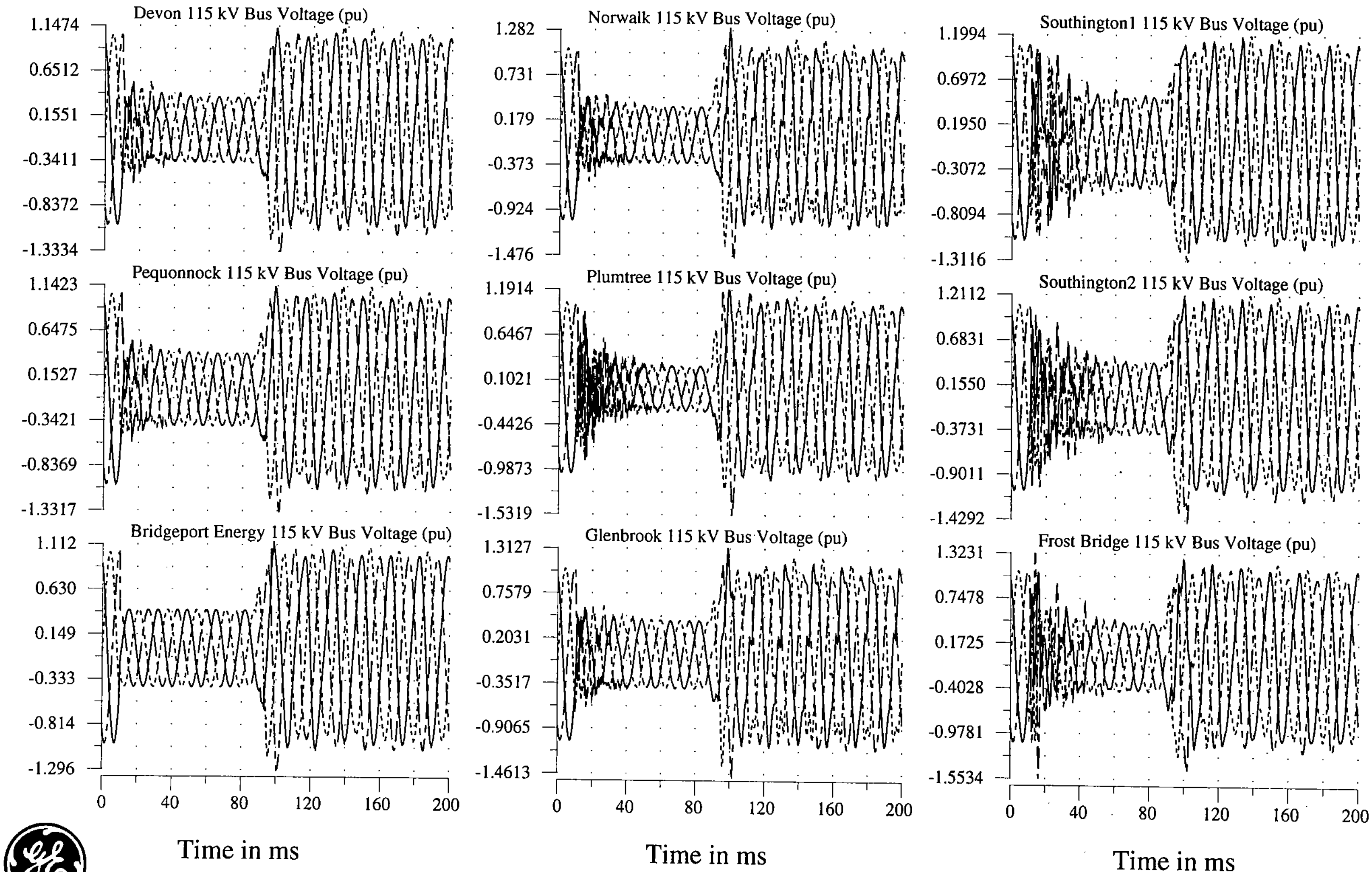


07-Nov-03 09:35:22 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01_90.PL4

Northeast Utilities: Phase 2 Cable Transient Study

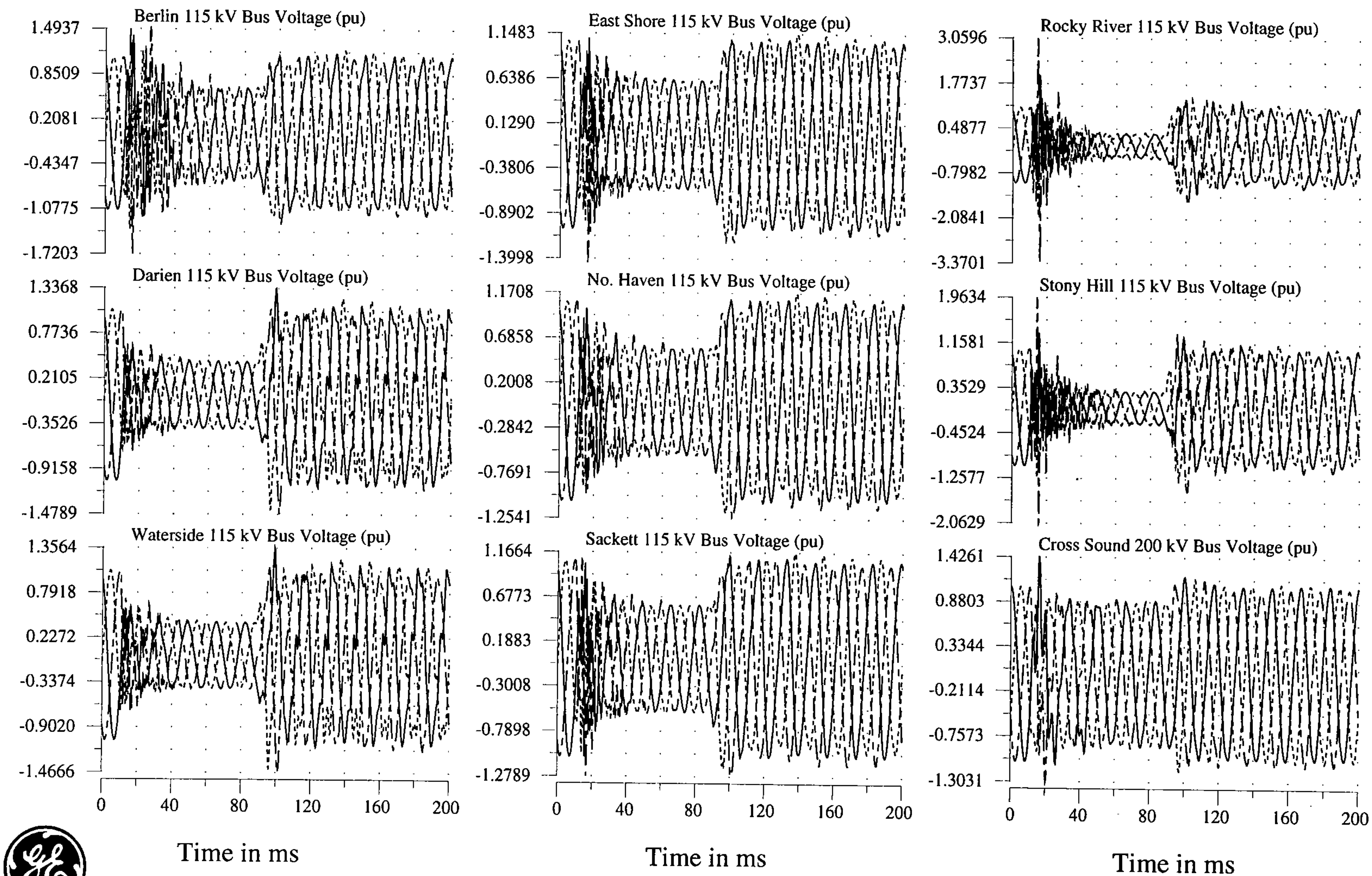
PH2P_NSF_01_90

115 kV Bus Voltages and Capacitor Bank Locations



07-Nov-03 09:35:22 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01_90.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_01_90
115 kV Bus Voltages and Capacitor Bank Locations

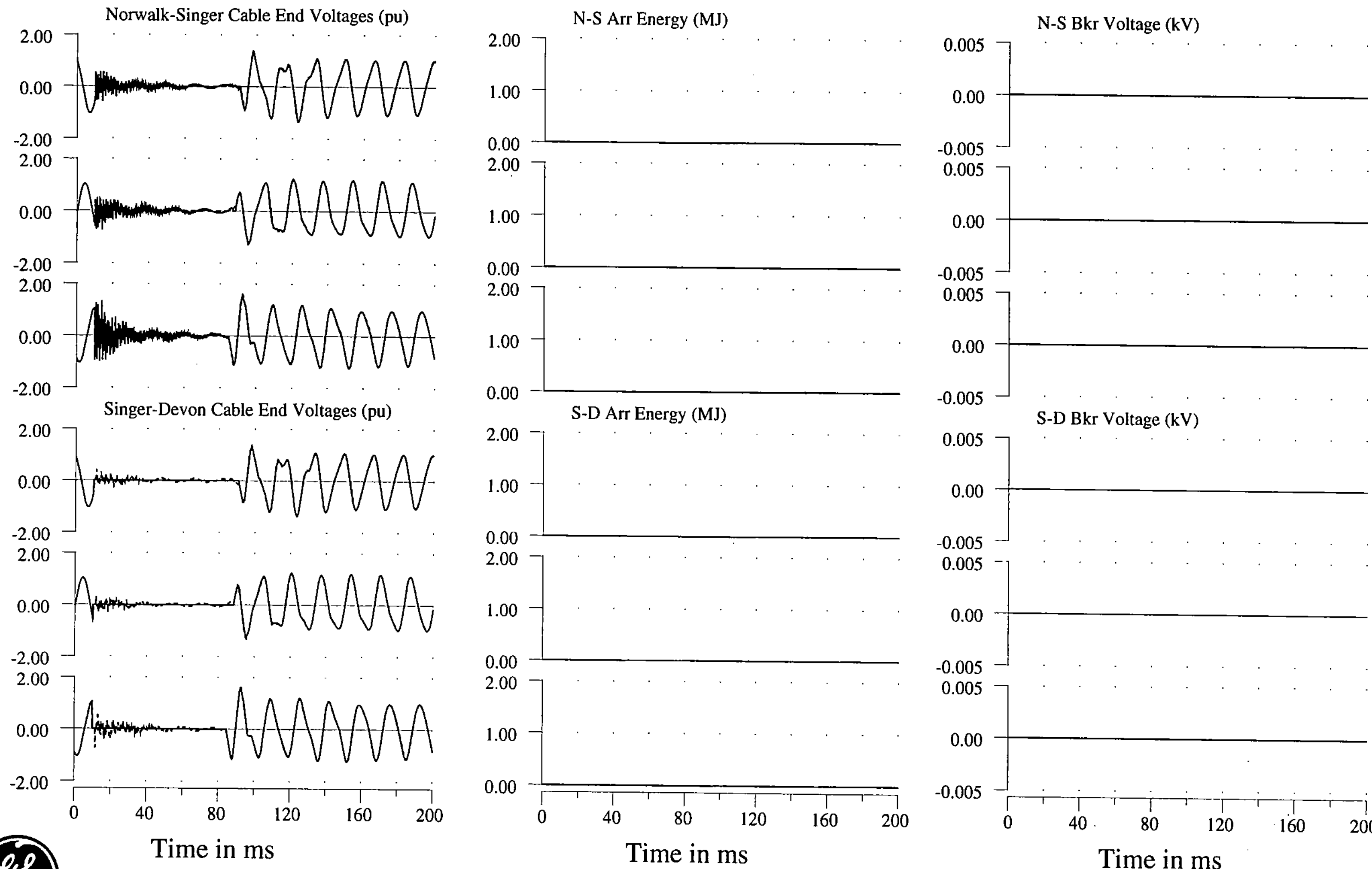


07-Nov-03 09:35:22 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_01_90.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_02

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

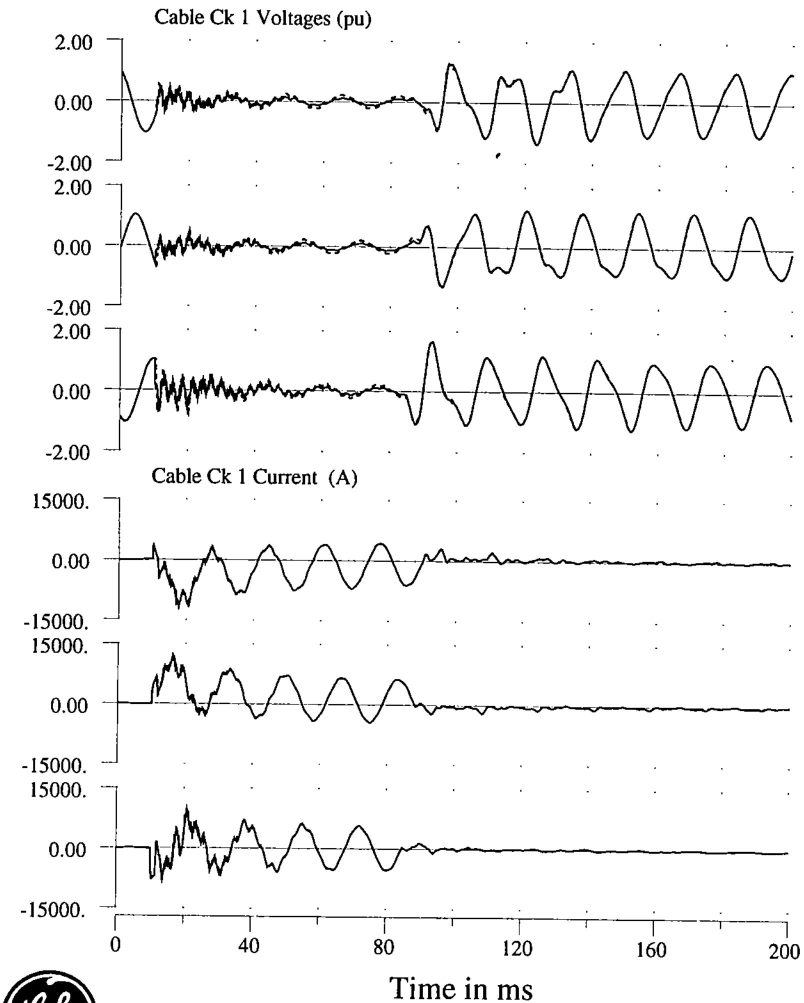


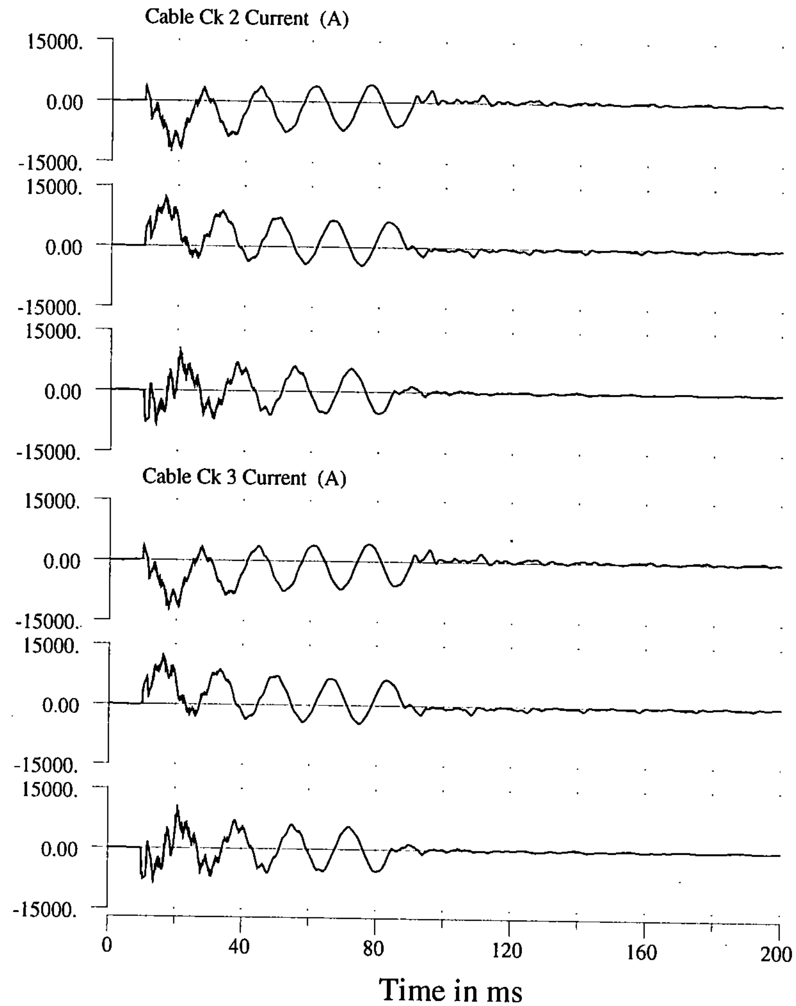
07-Nov-03 10:00:44 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_02

Devon-Beseck 345 kV Cables



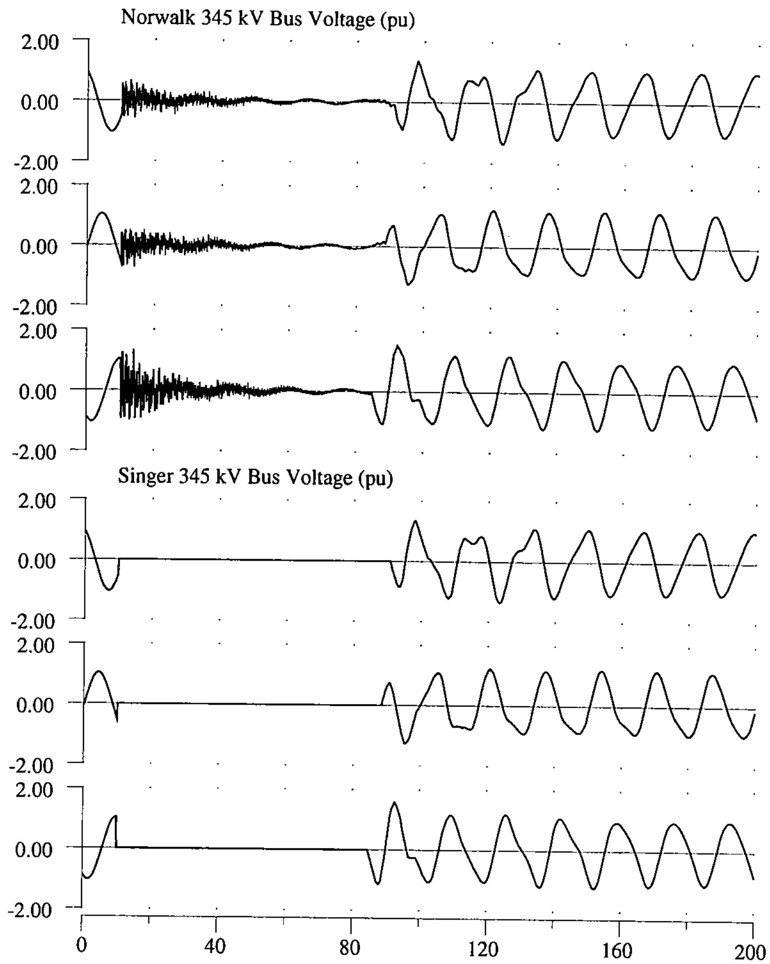


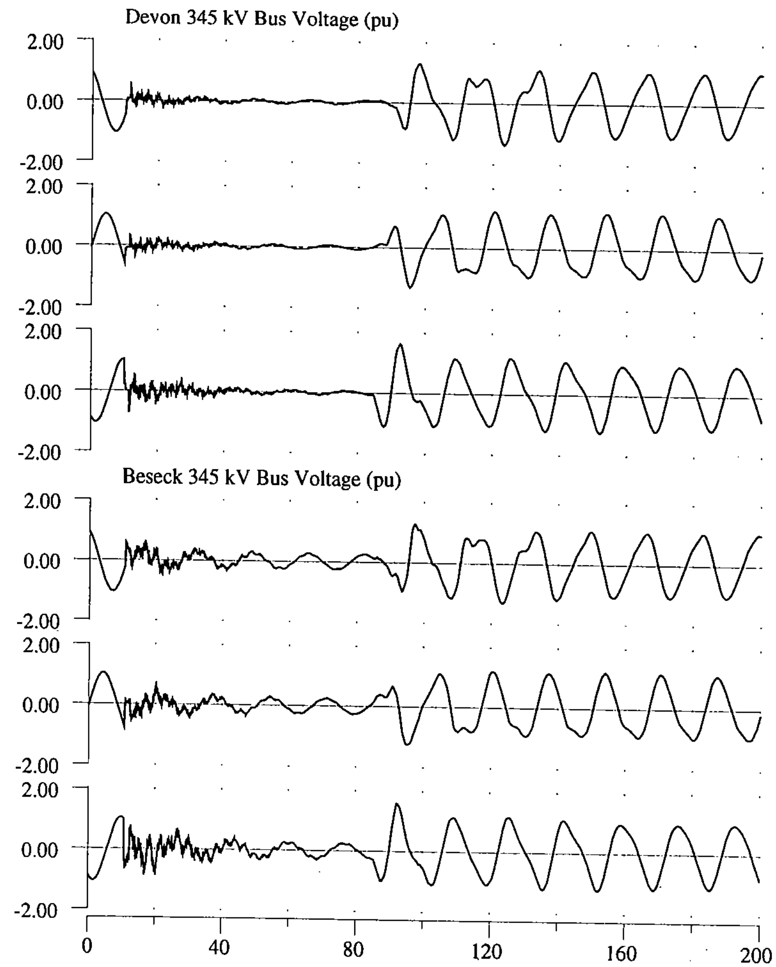
07-Nov-03 10:00:44 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

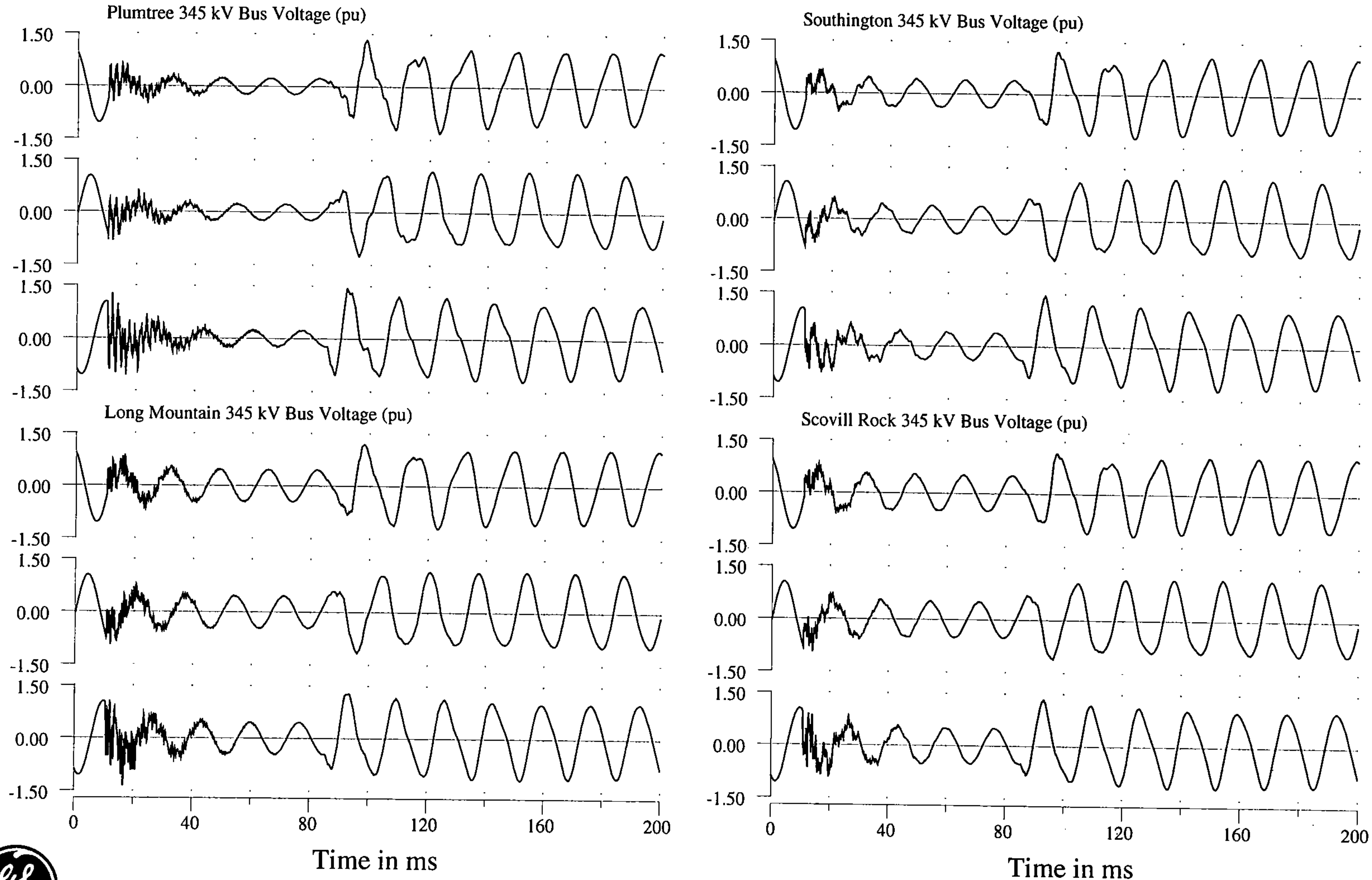
PH2P_NSF_02

345 kV Bus Voltages





Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_02
345 kV Bus Voltages

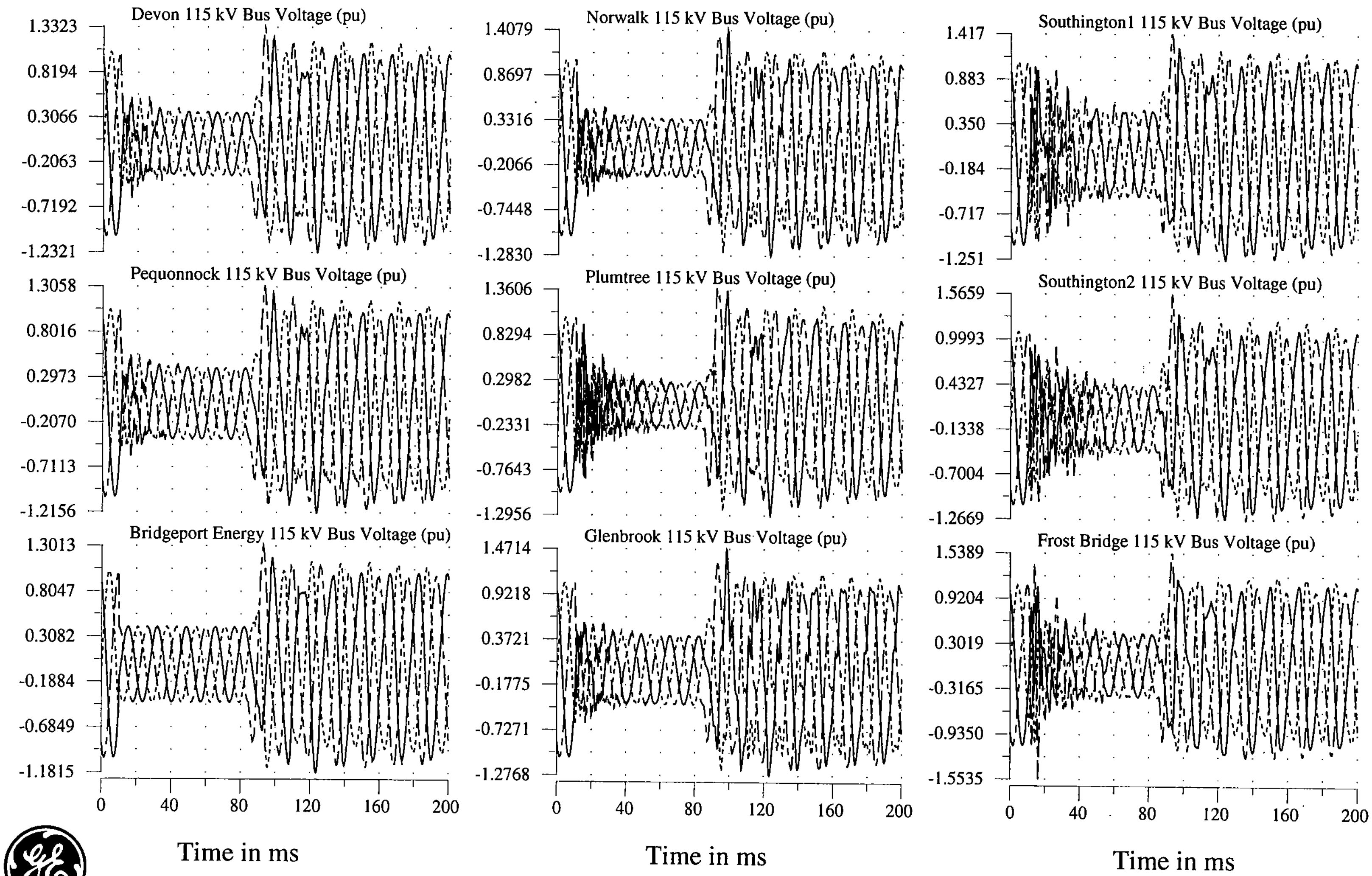


07-Nov-03 10:00:44 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_02

115 kV Bus Voltages and Capacitor Bank Locations

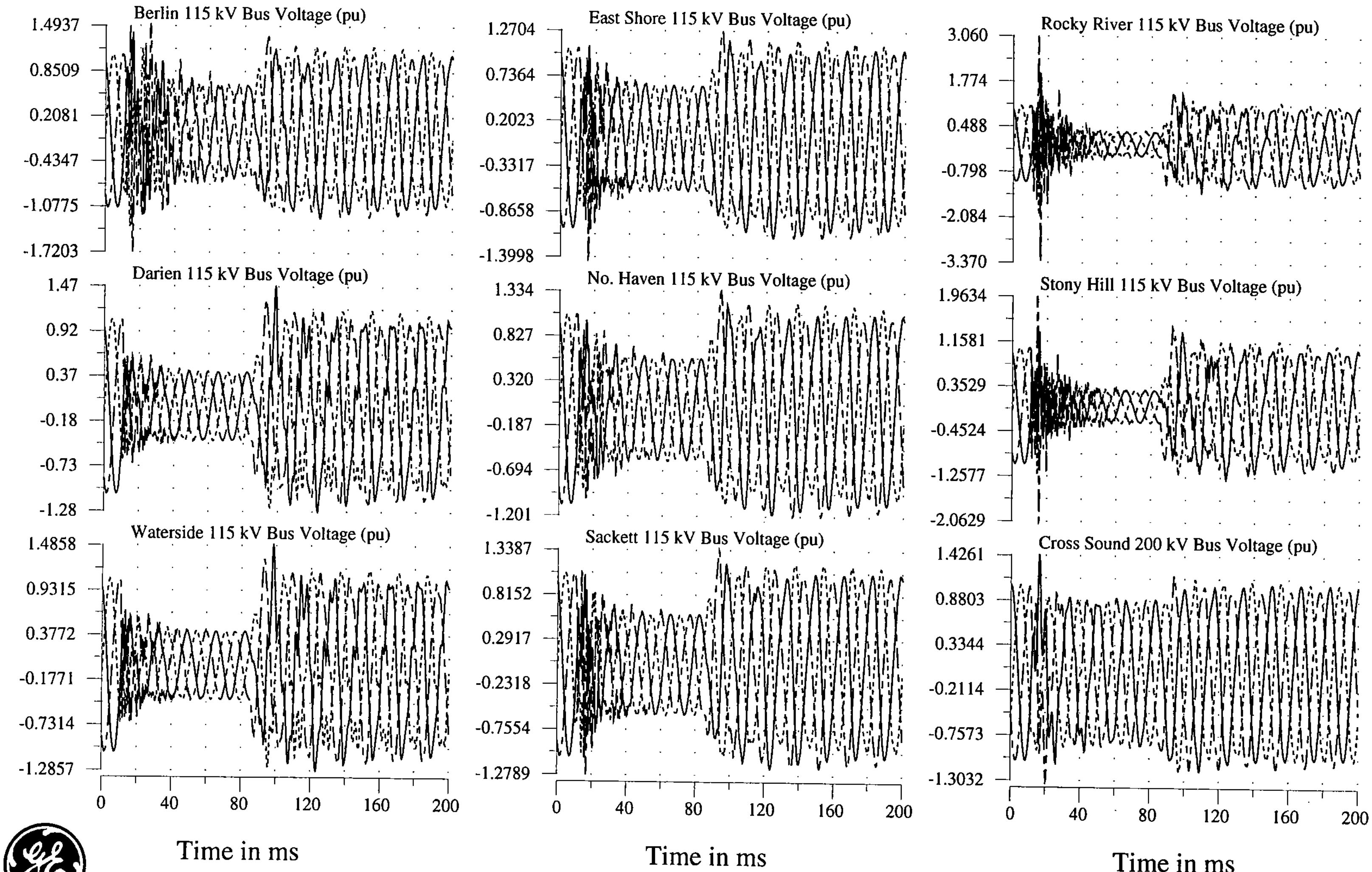


07-Nov-03 10:00:44 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

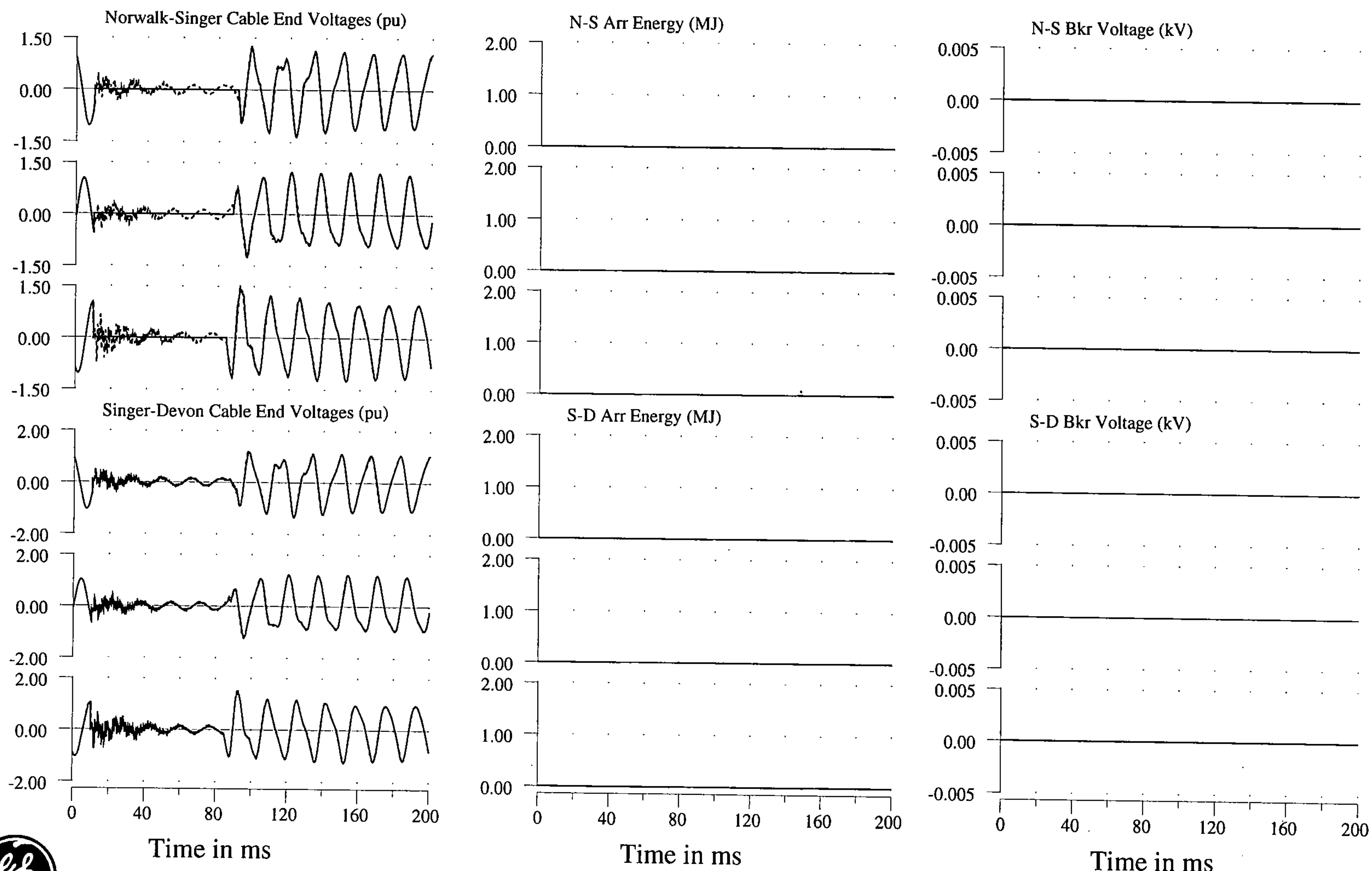
PH2P_NSF_02

115 kV Bus Voltages and Capacitor Bank Locations



07-Nov-03 10:00:44 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_03
Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

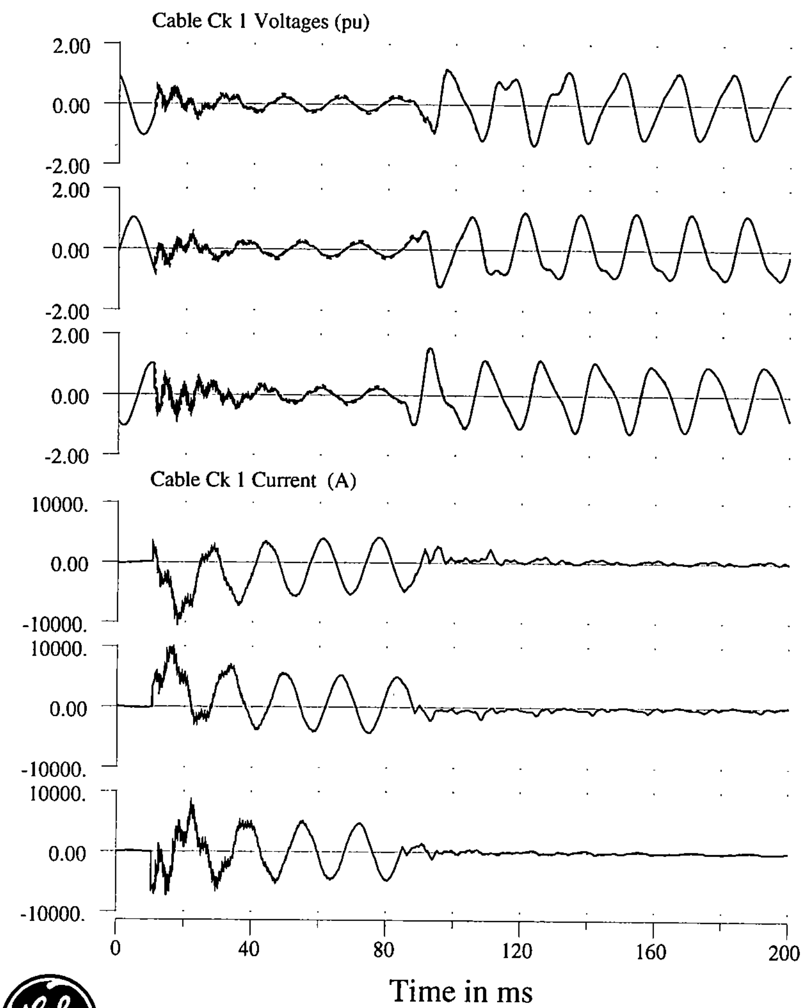


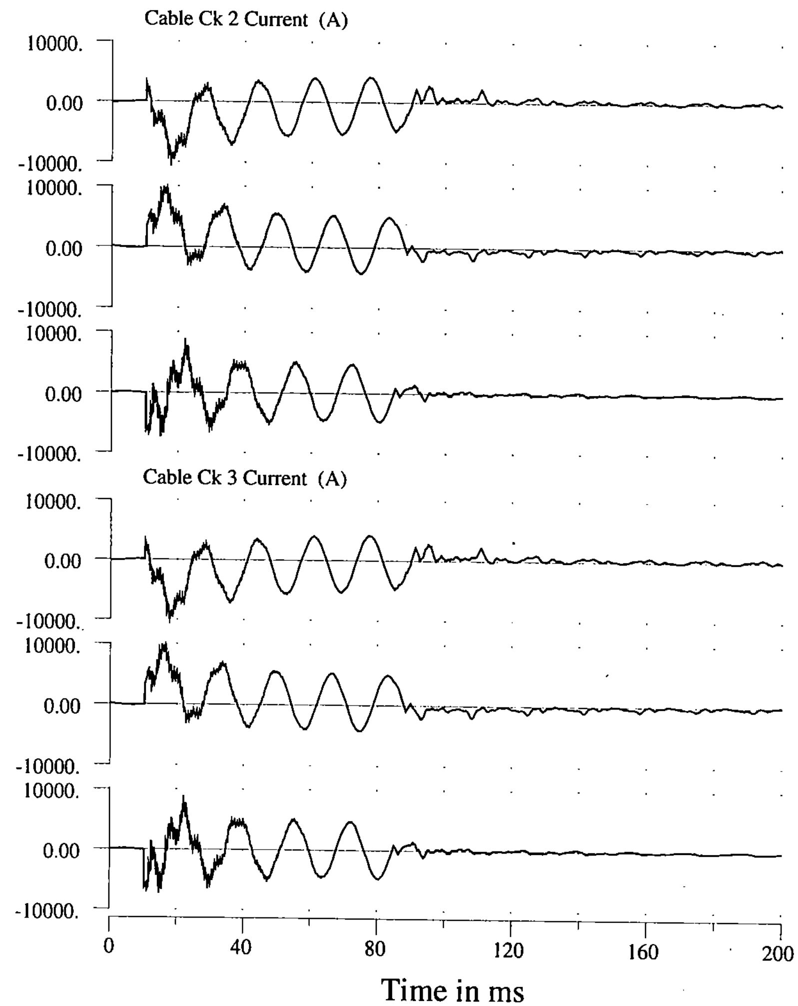
07-Nov-03 10:05:15 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03

Devon-Beseck 345 kV Cables



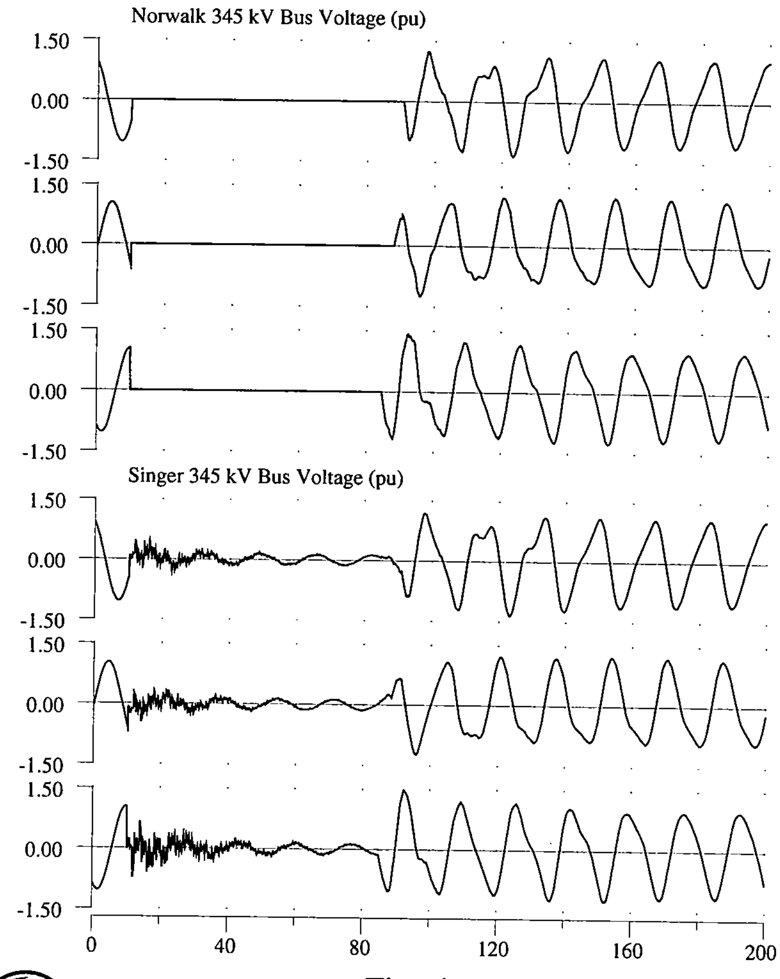


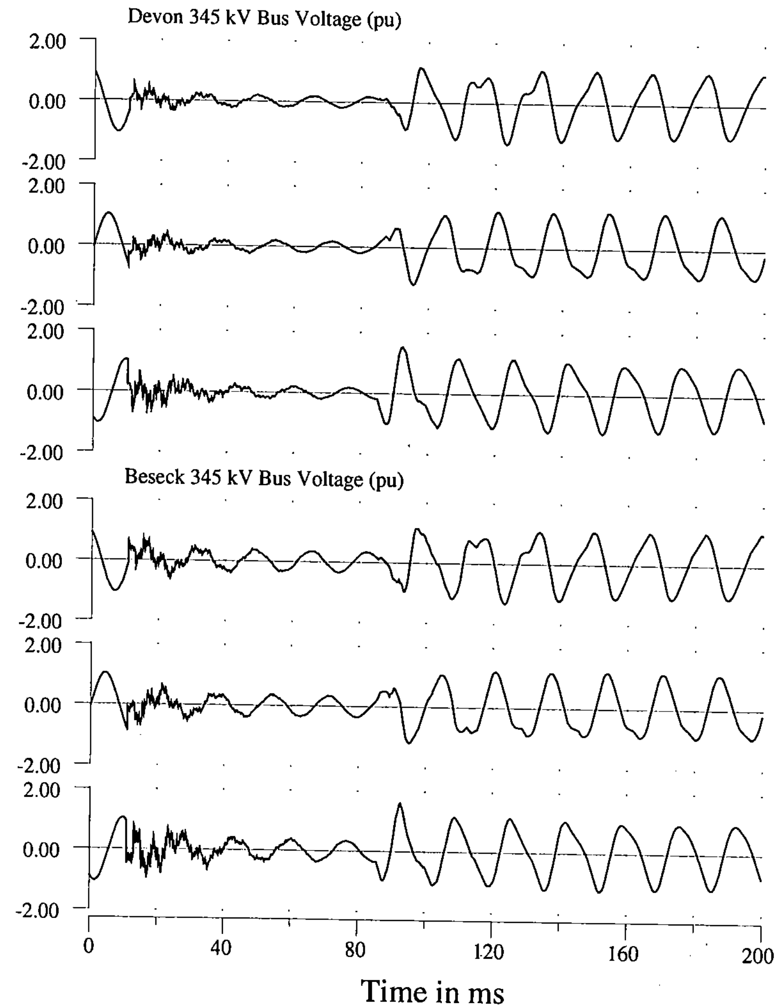
07-Nov-03 10:05:15 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03

345 kV Bus Voltages



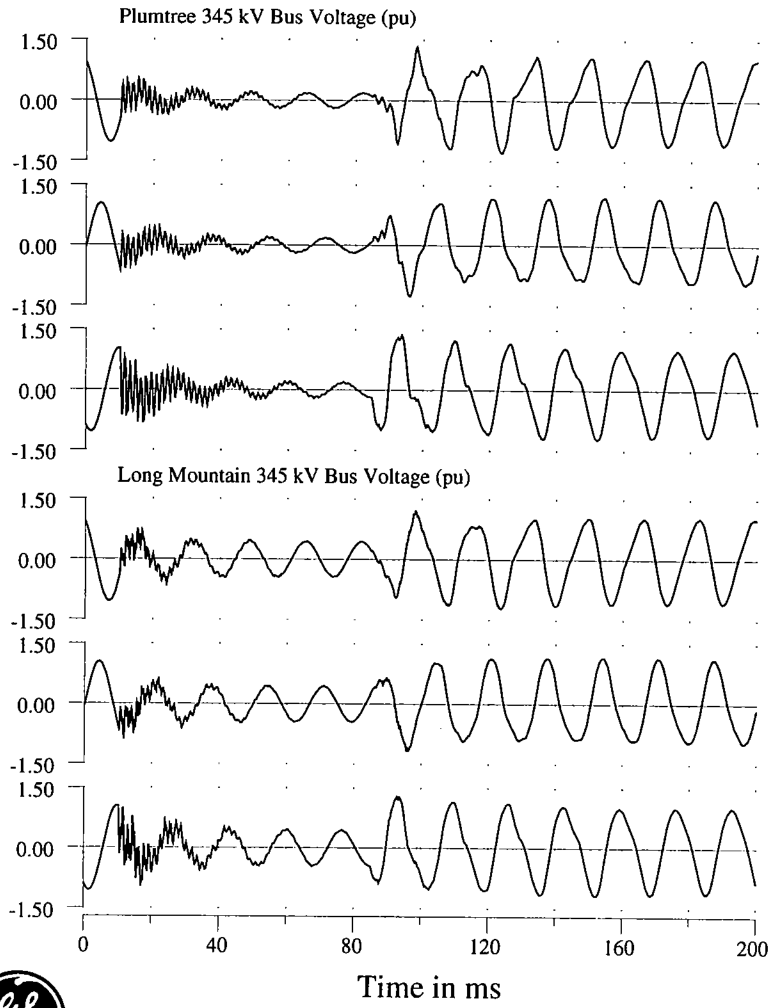


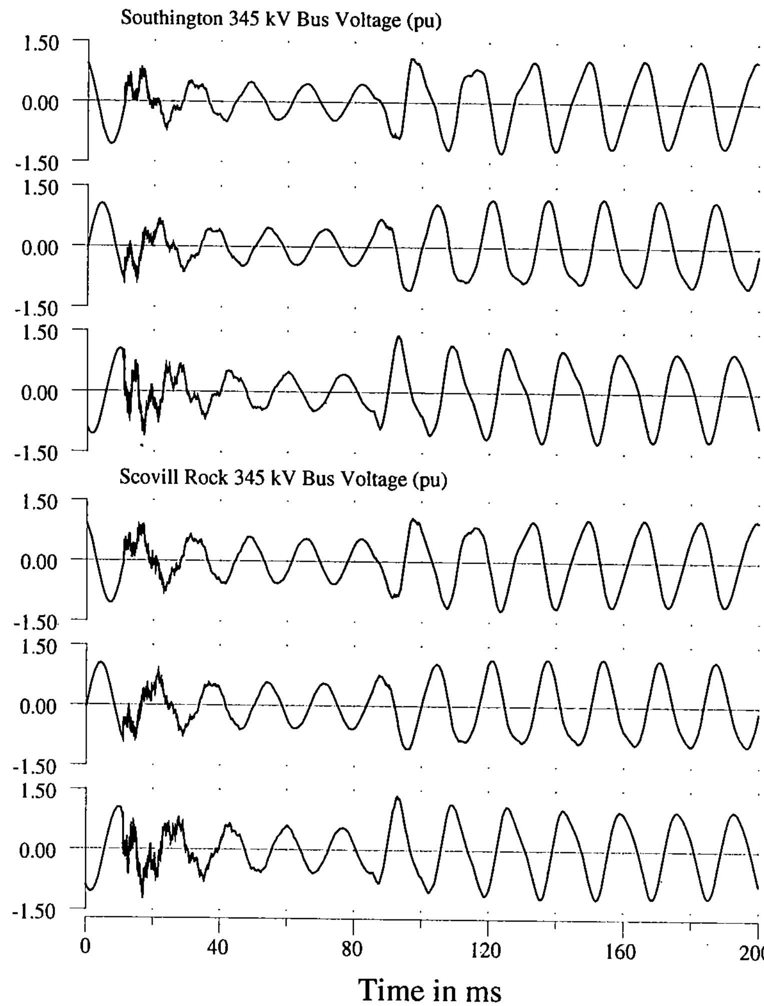
07-Nov-03 10:05:15 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03

345 kV Bus Voltages

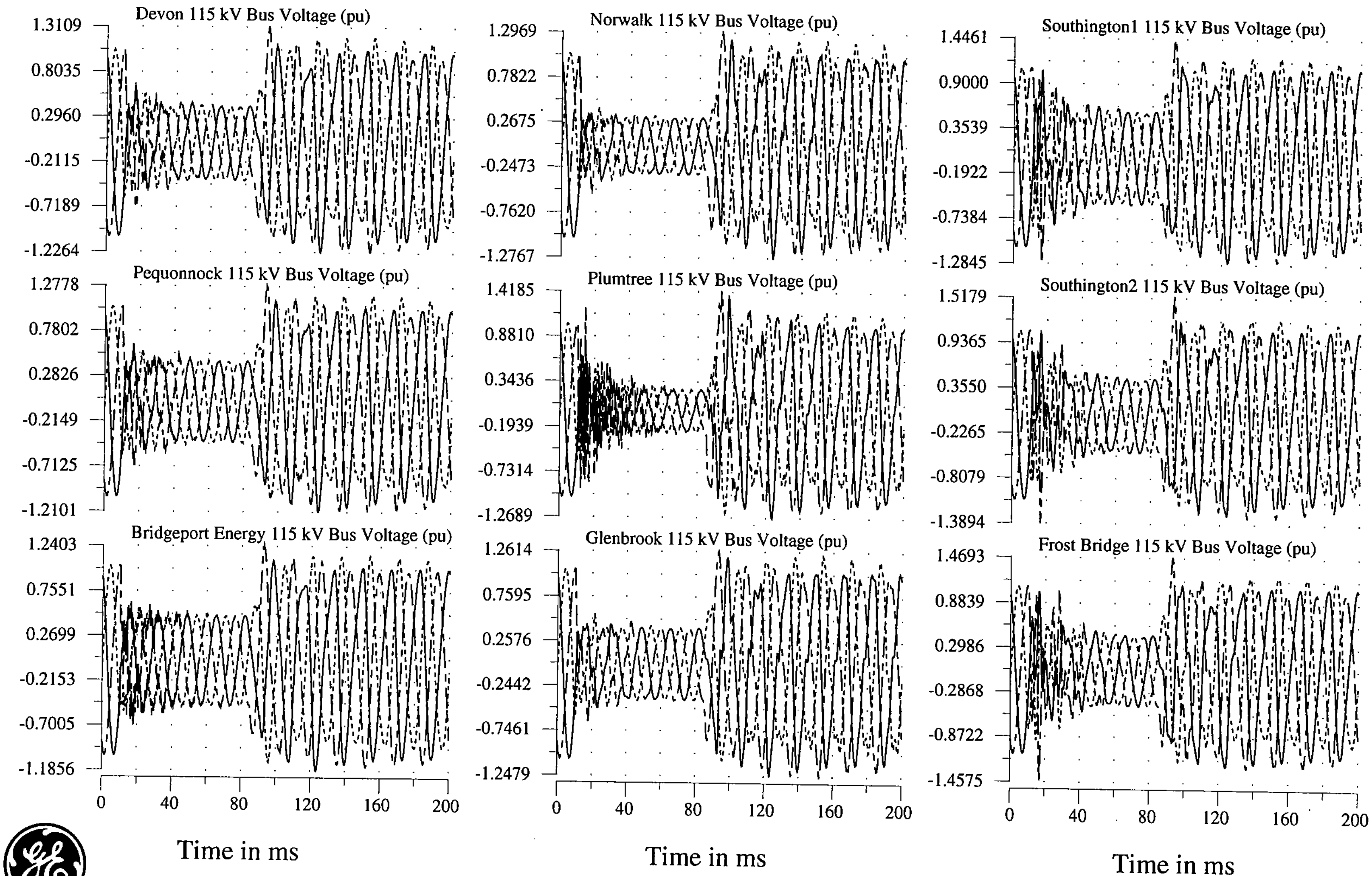




Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03

115 kV Bus Voltages and Capacitor Bank Locations

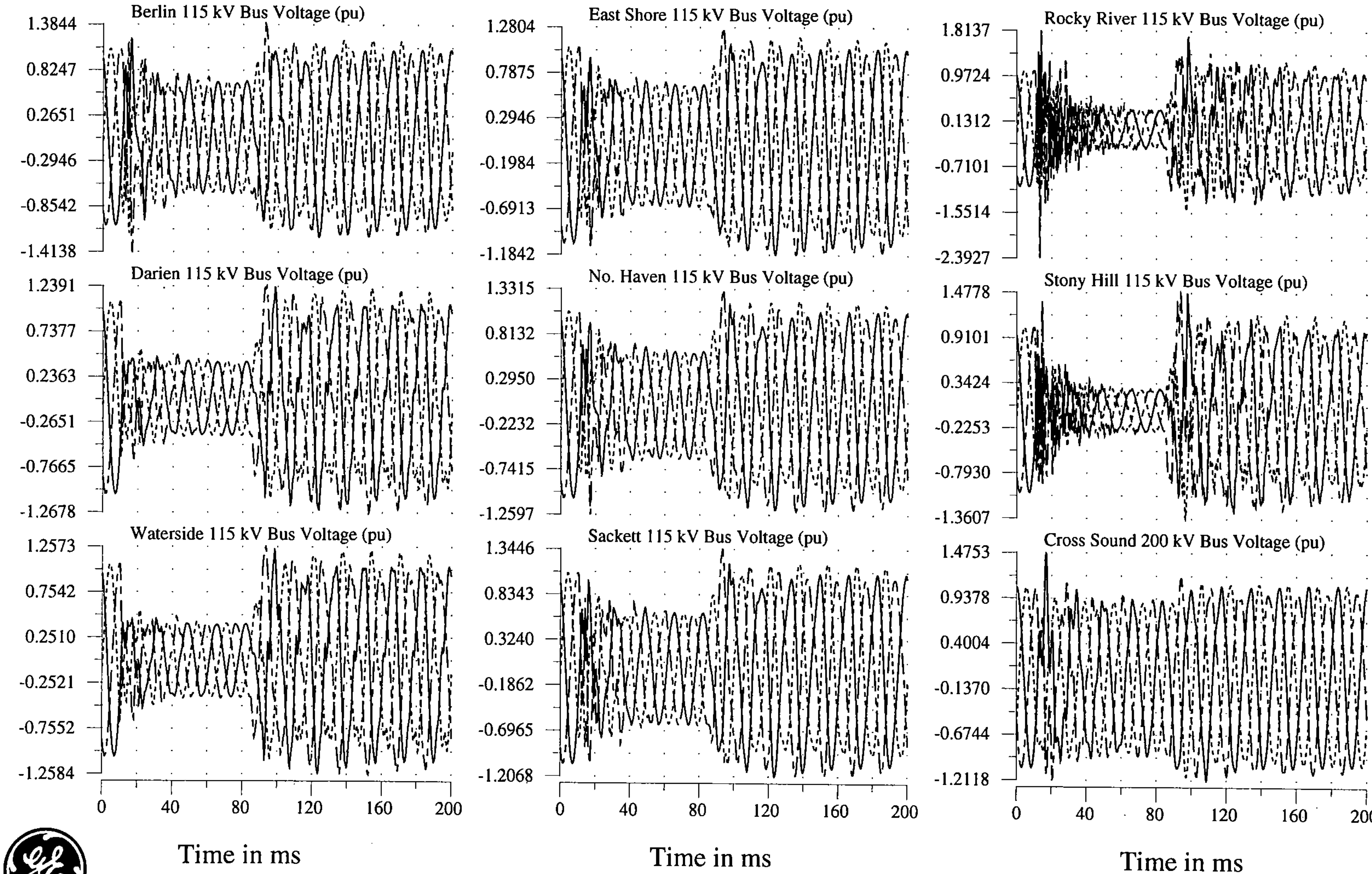


07-Nov-03 10:05:15 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03

115 kV Bus Voltages and Capacitor Bank Locations

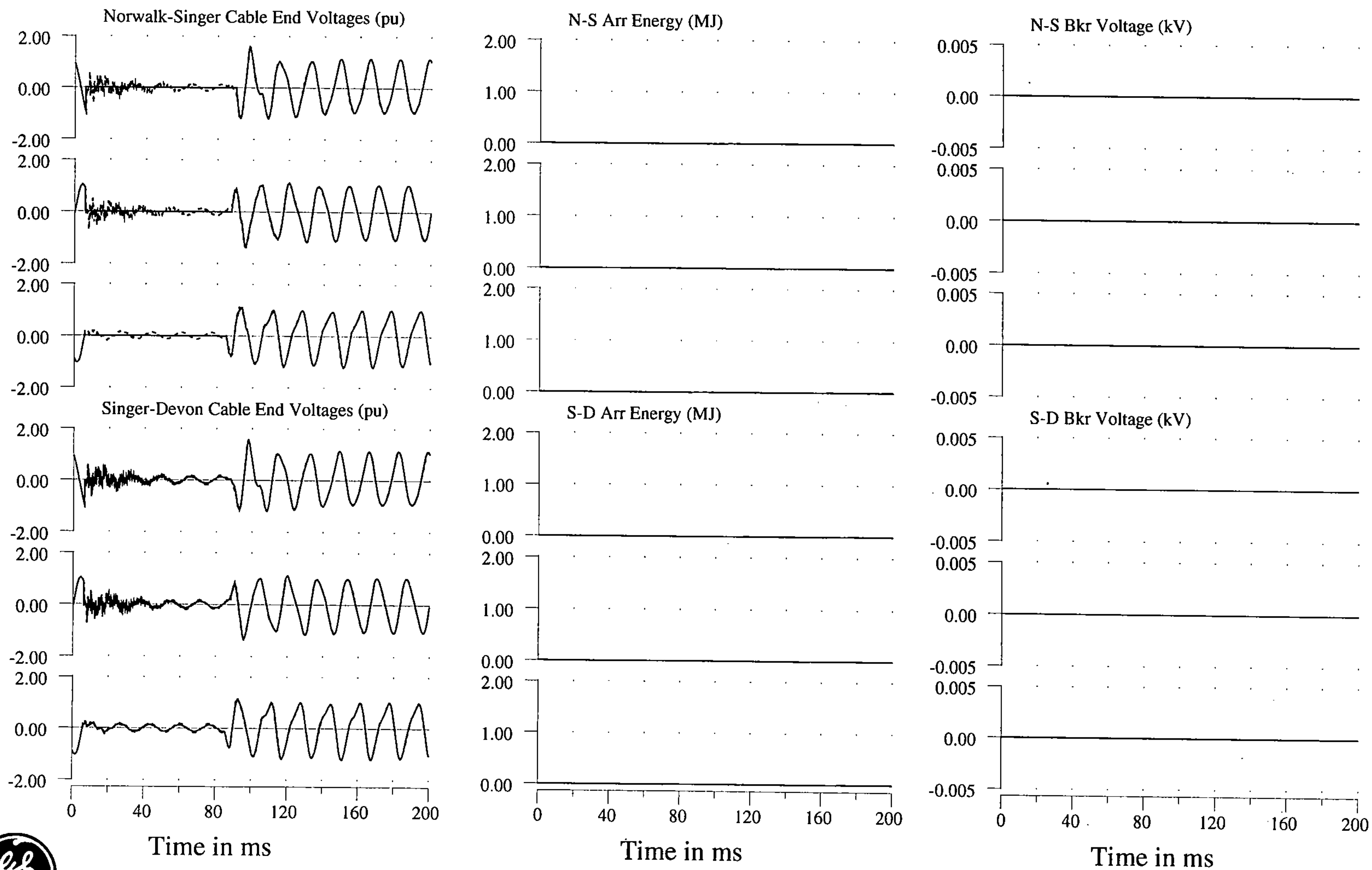


07-Nov-03 10:05:15 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03_0

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

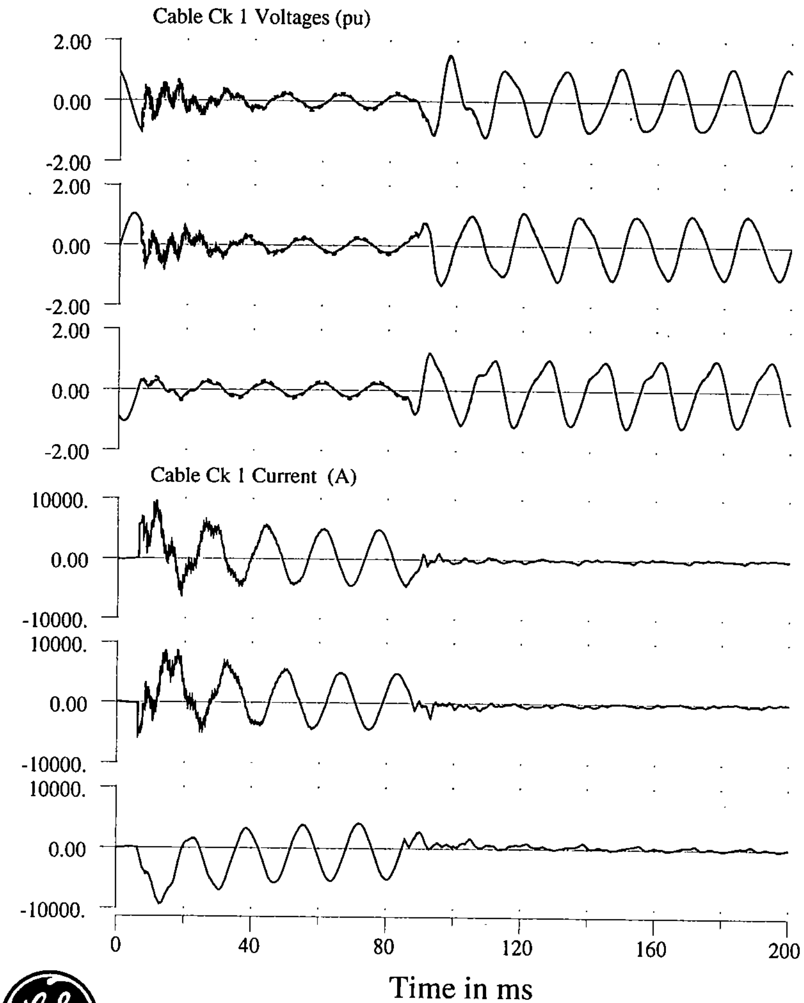


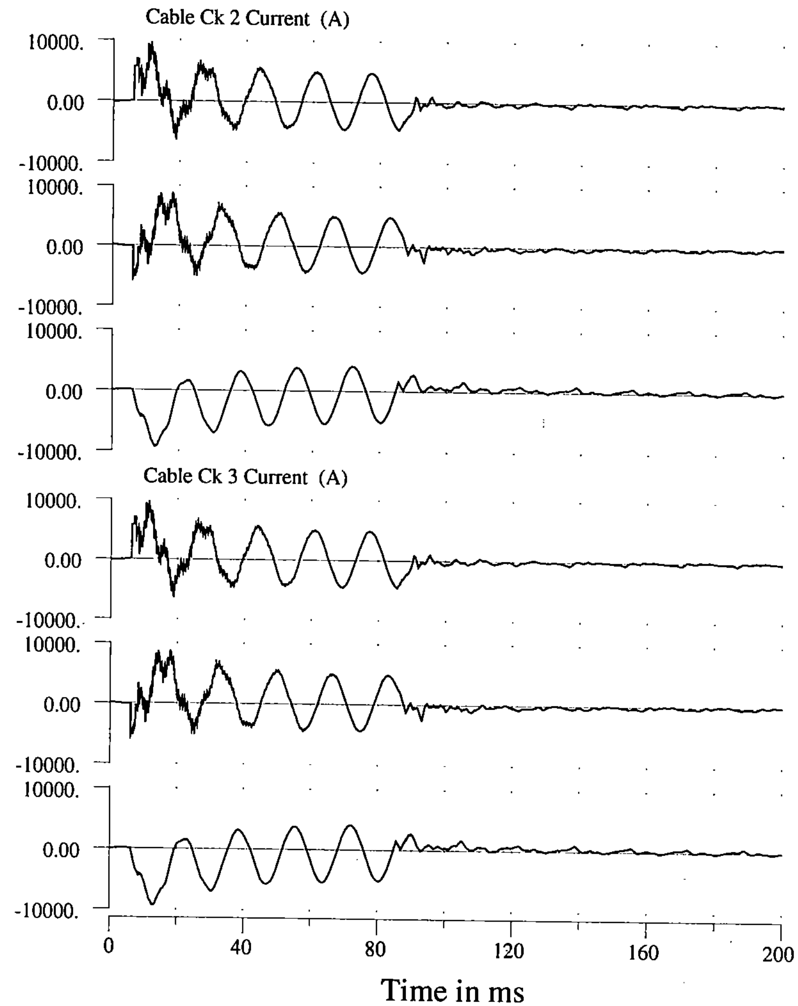
07-Nov-03 10:07:03 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03_0.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03_0

Devon-Beseck 345 kV Cables



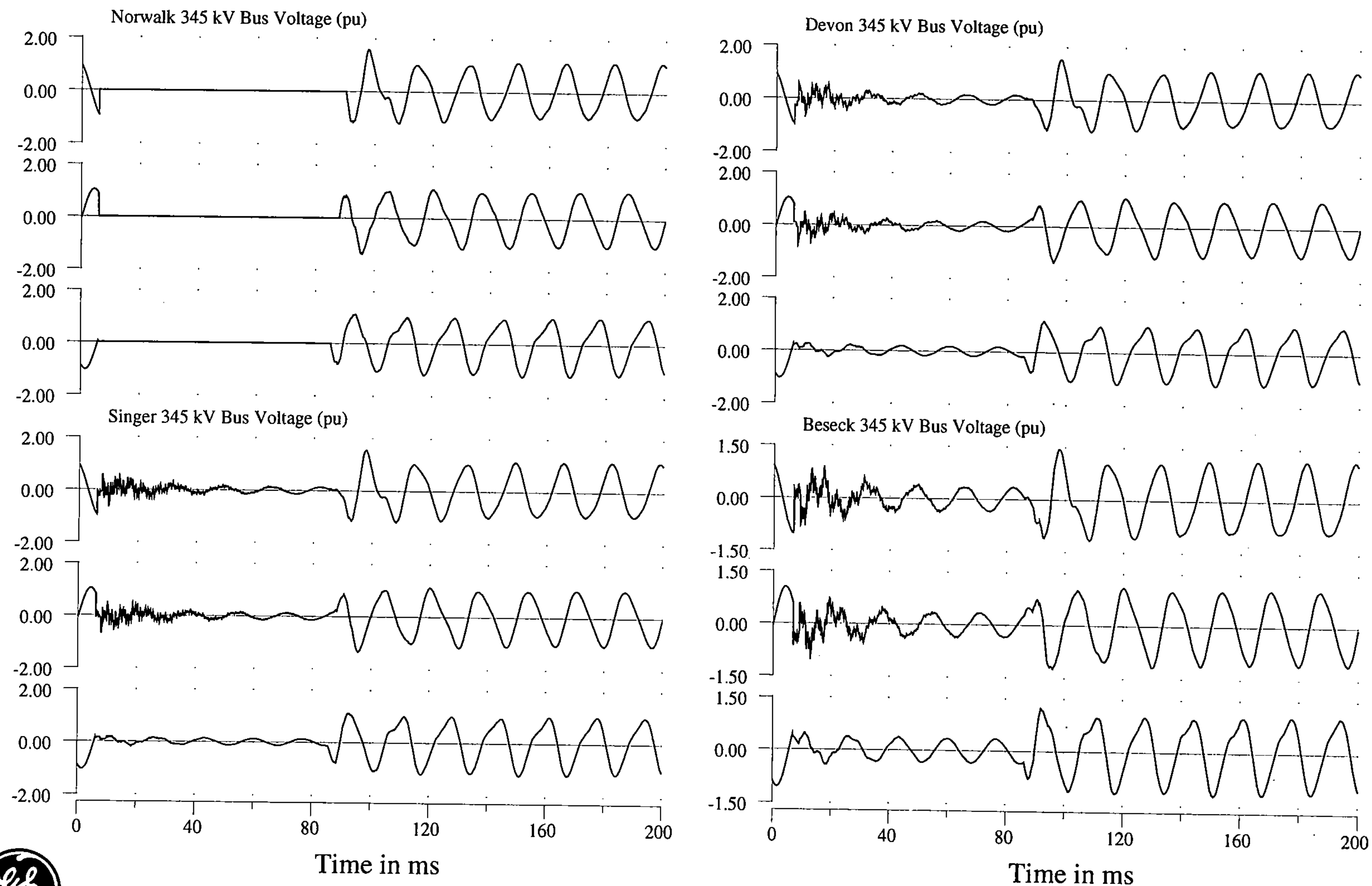


07-Nov-03 10:07:03 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03_0.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03_0

345 kV Bus Voltages

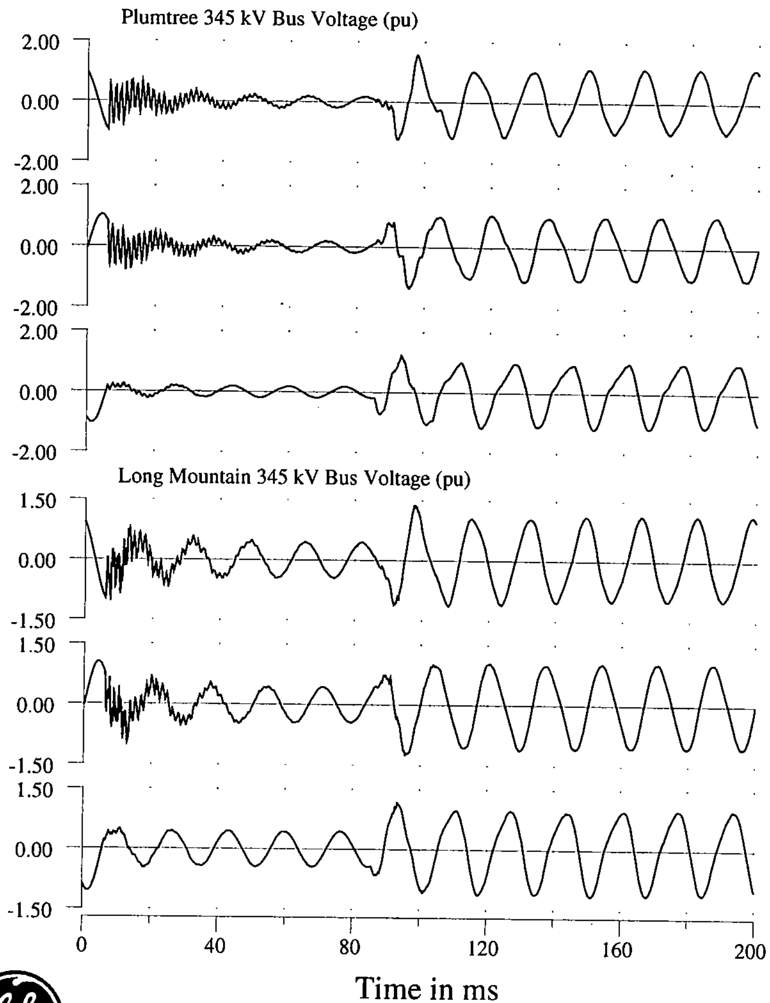


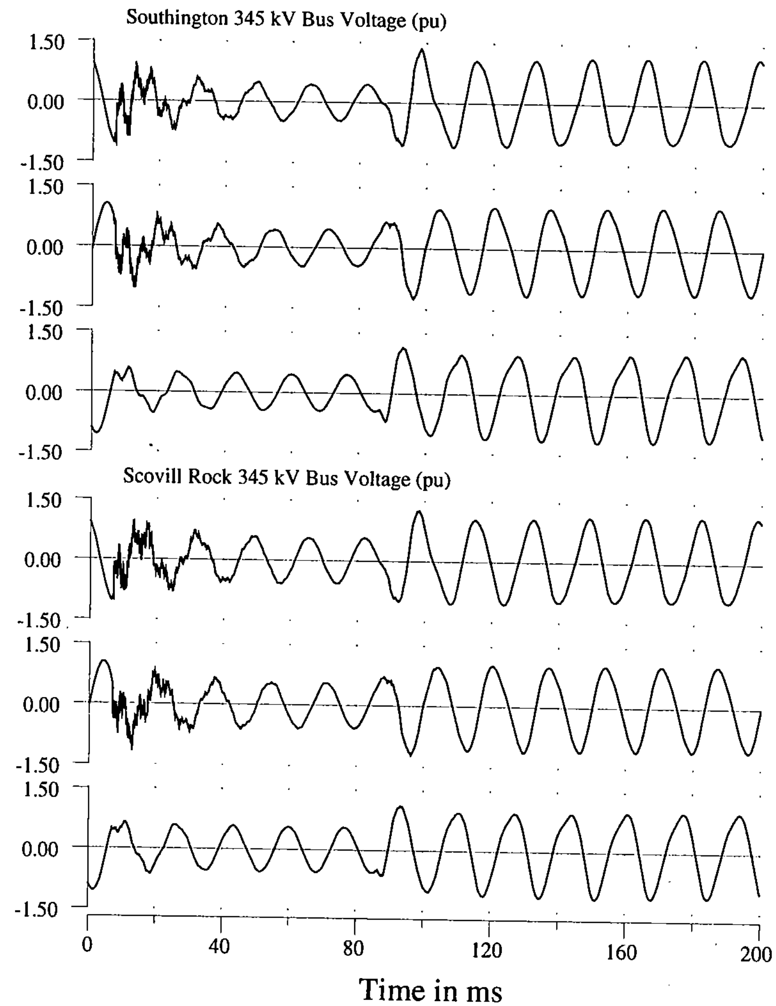
07-Nov-03 10:07:03 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03_0.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03_0

345 kV Bus Voltages



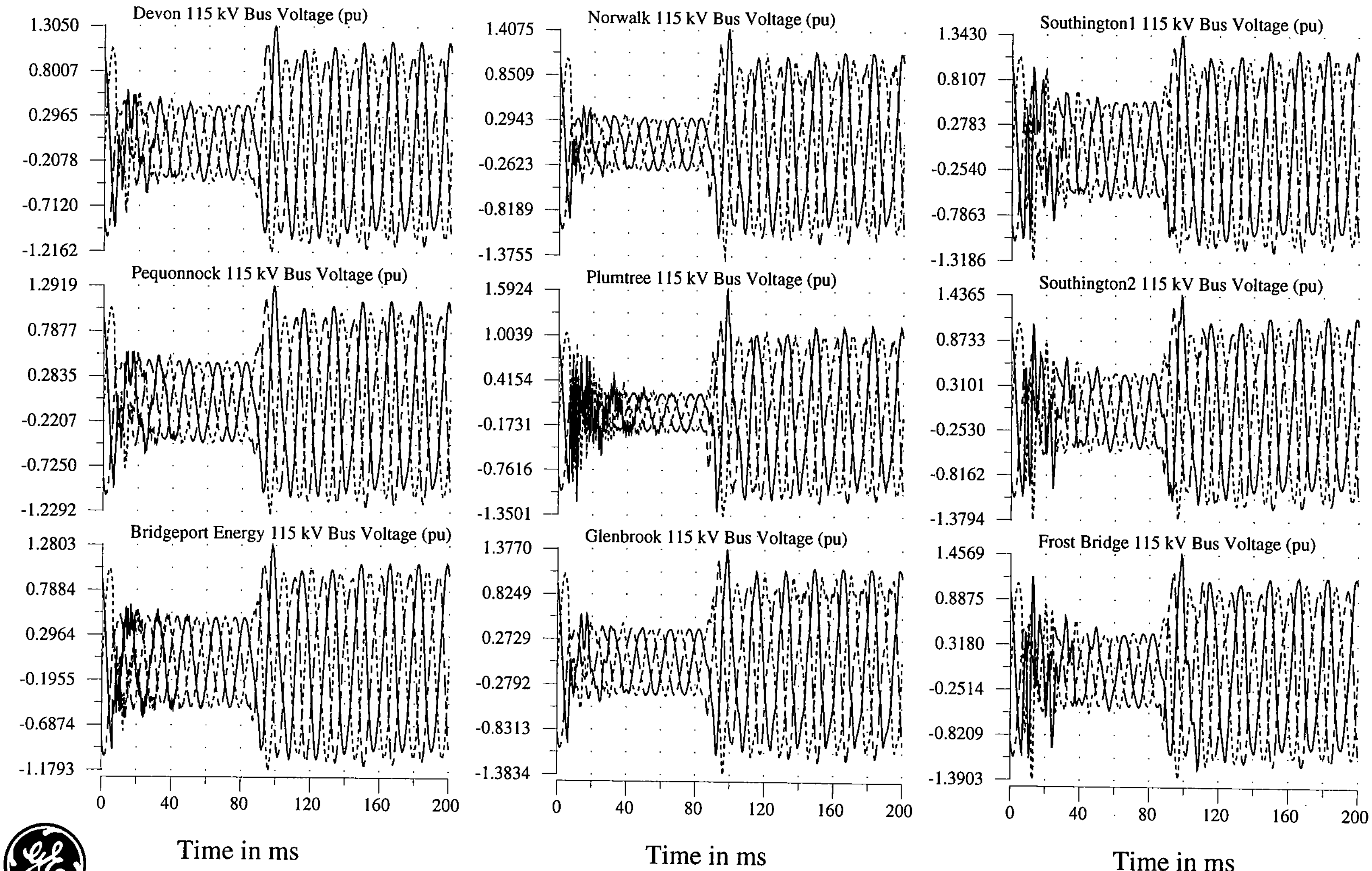


07-Nov-03 10:07:03 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03_0.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03_0

115 kV Bus Voltages and Capacitor Bank Locations

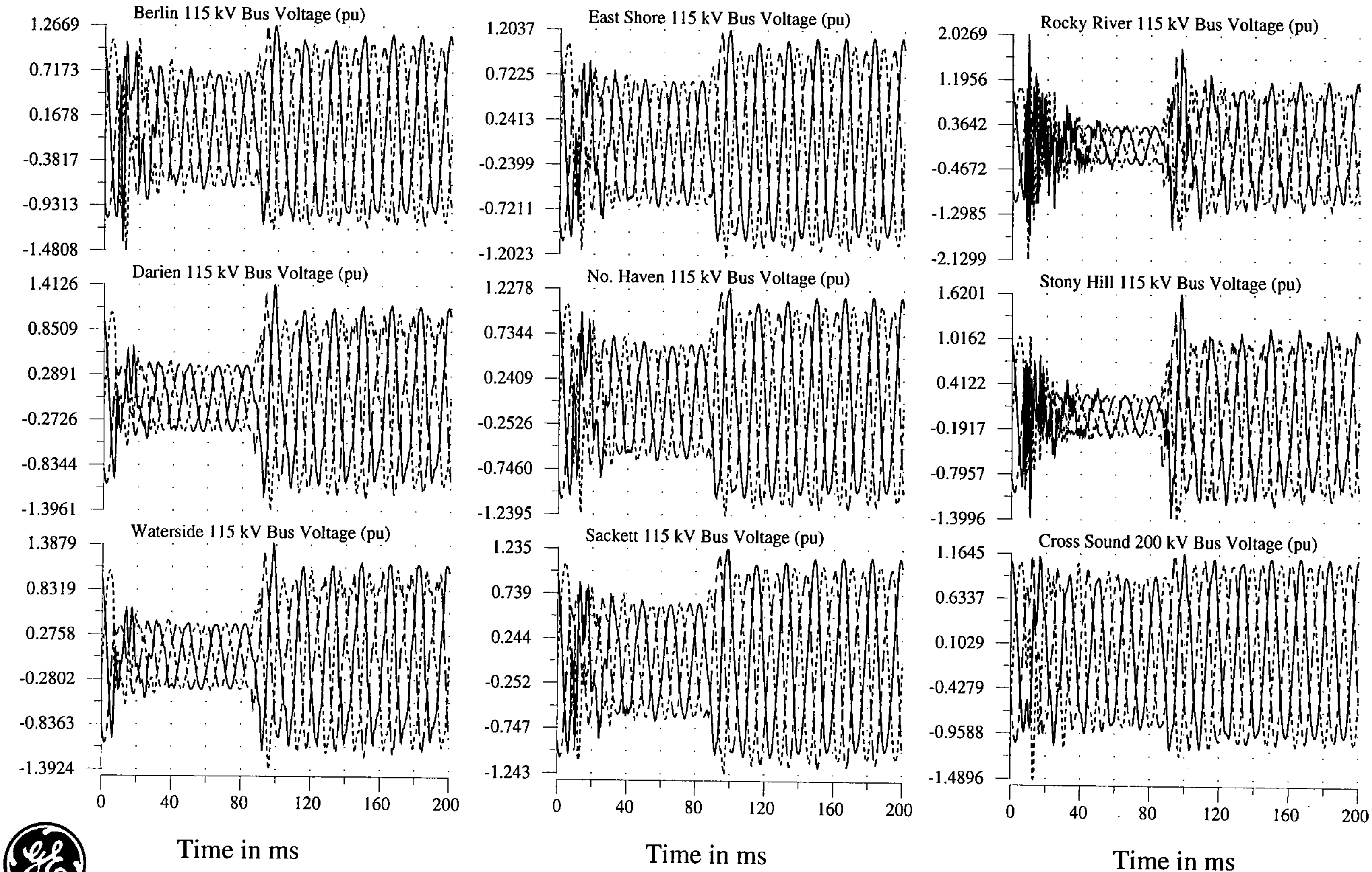


07-Nov-03 10:07:03 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03_0.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_03_0

115 kV Bus Voltages and Capacitor Bank Locations

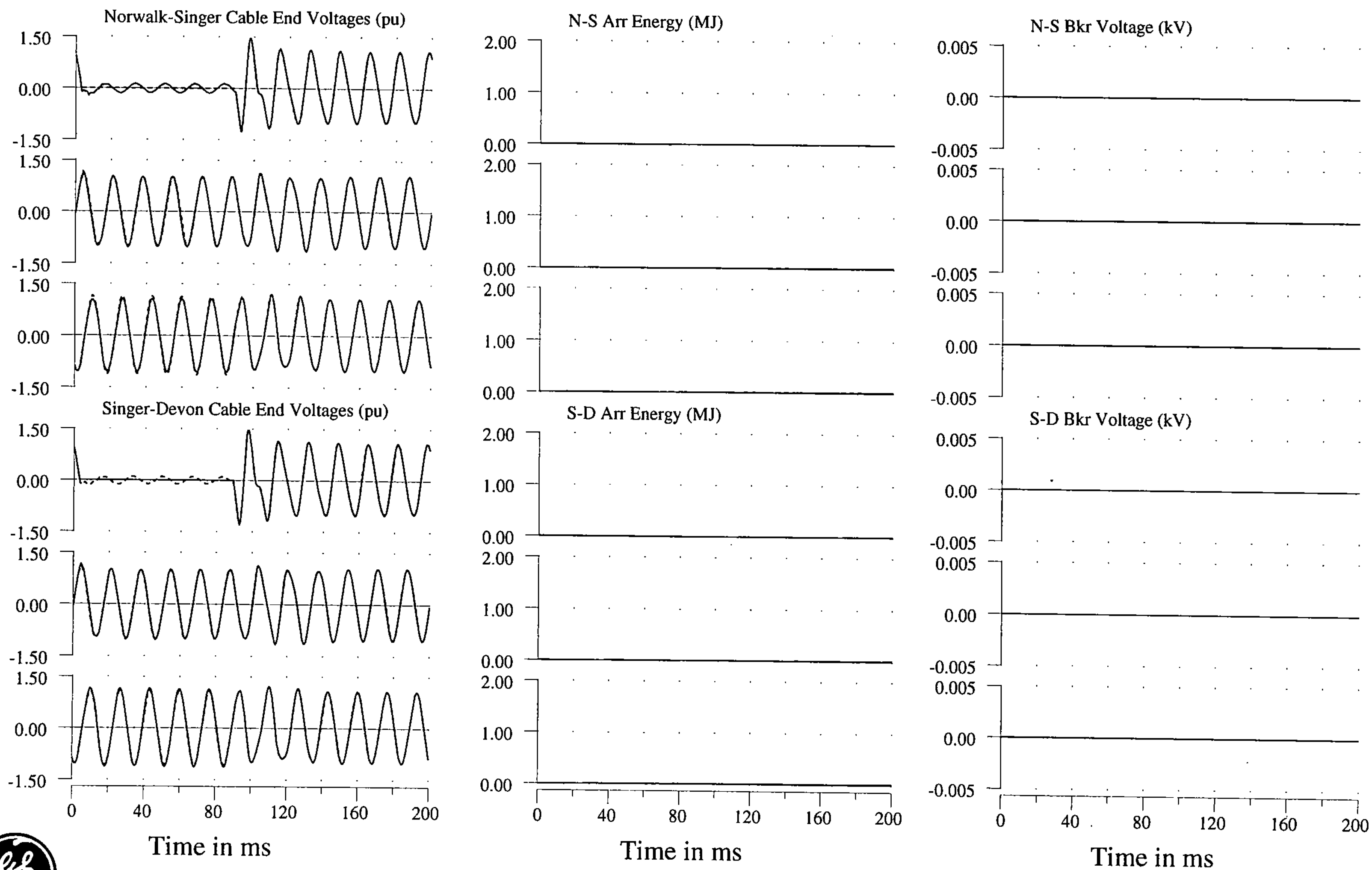


07-Nov-03 10:07:03 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_03_0.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_04

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

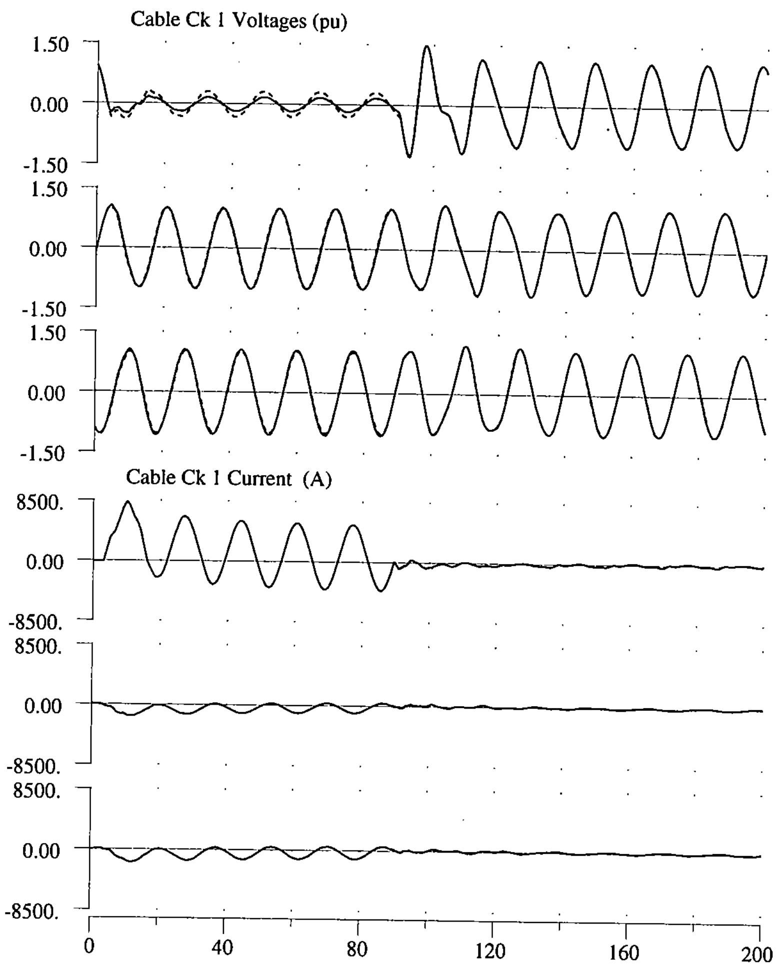


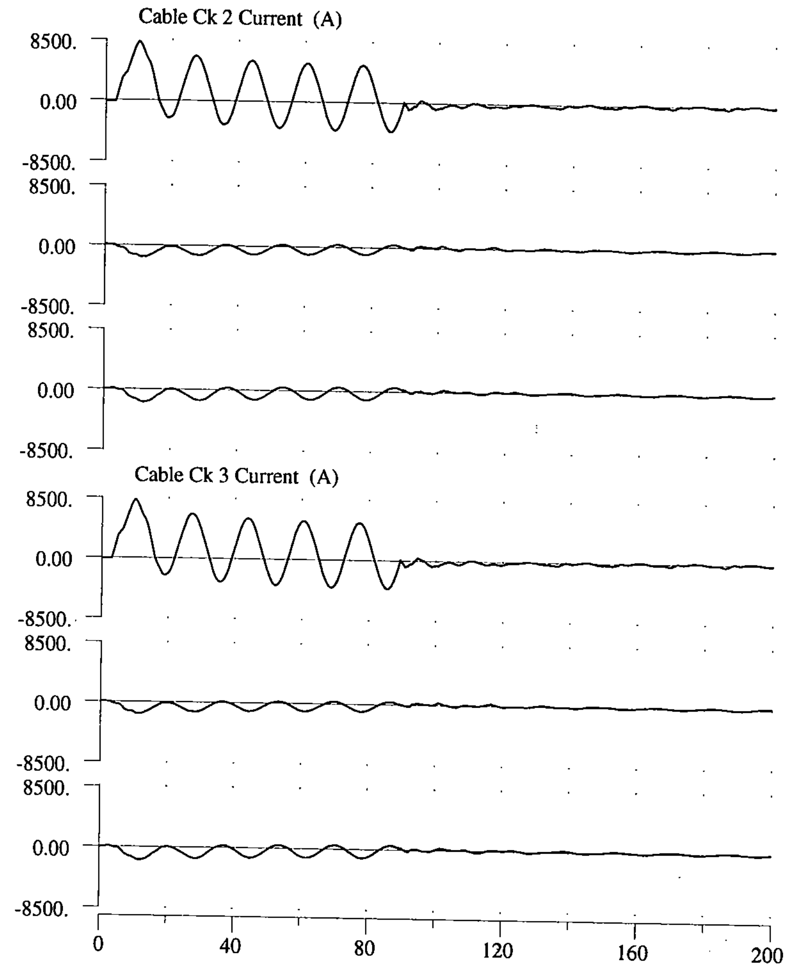
07-Nov-03 17:09:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_04.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_04

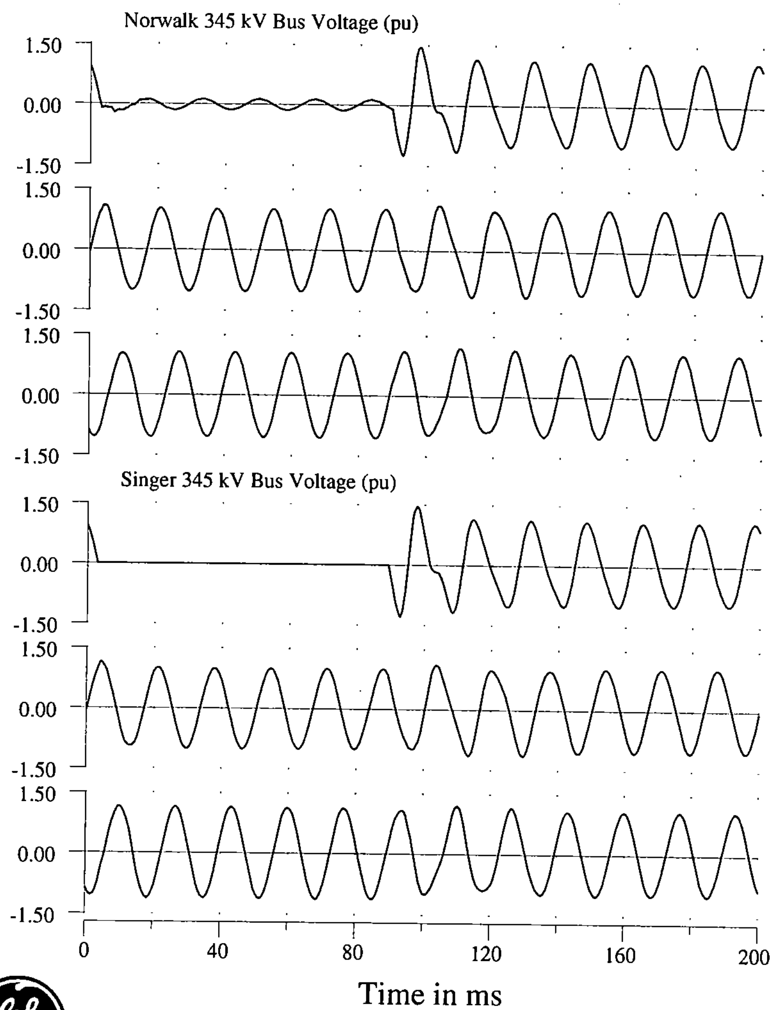
Devon-Beseck 345 kV Cables

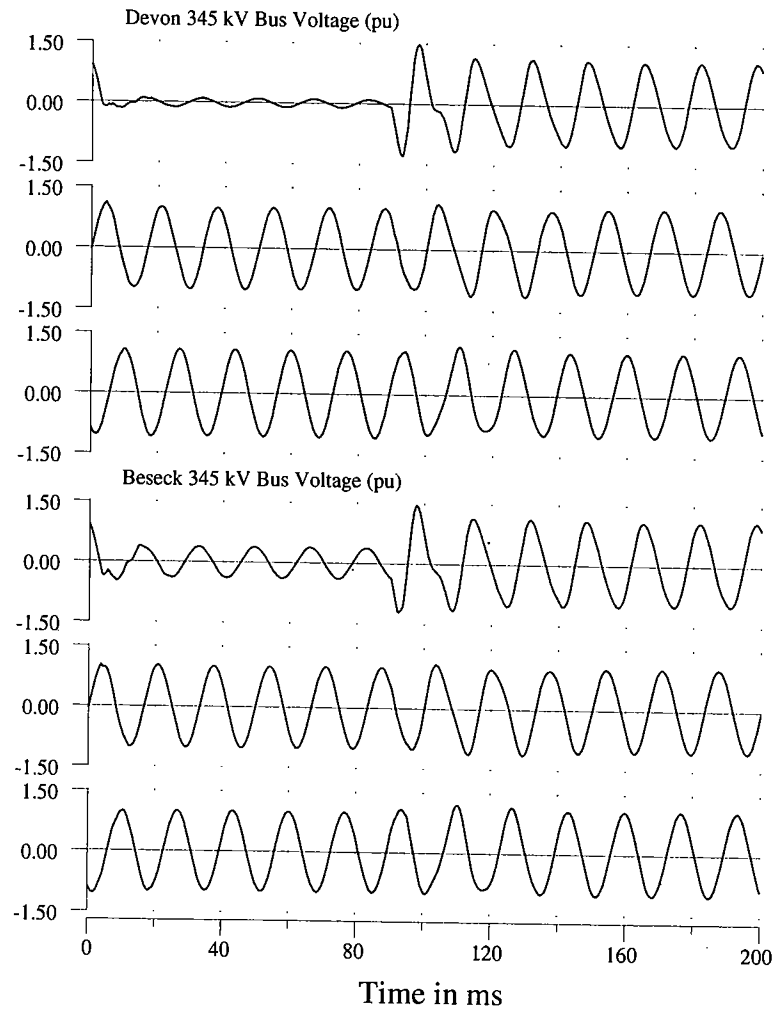




07-Nov-03 17:09:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_04.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_04
345 kV Bus Voltages



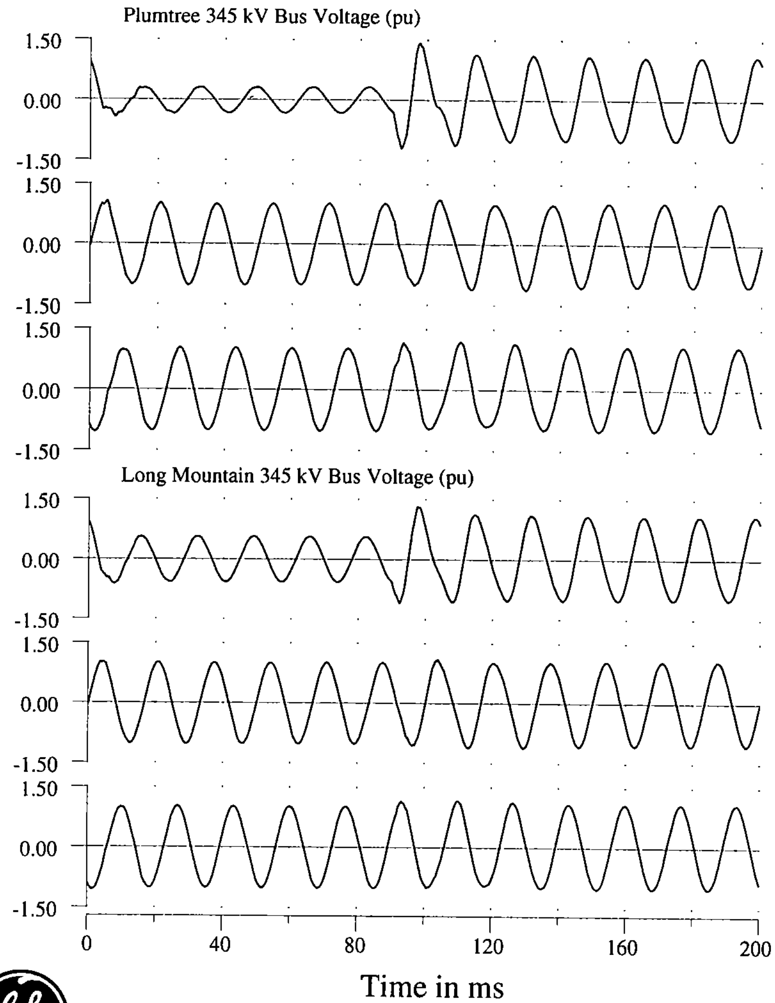


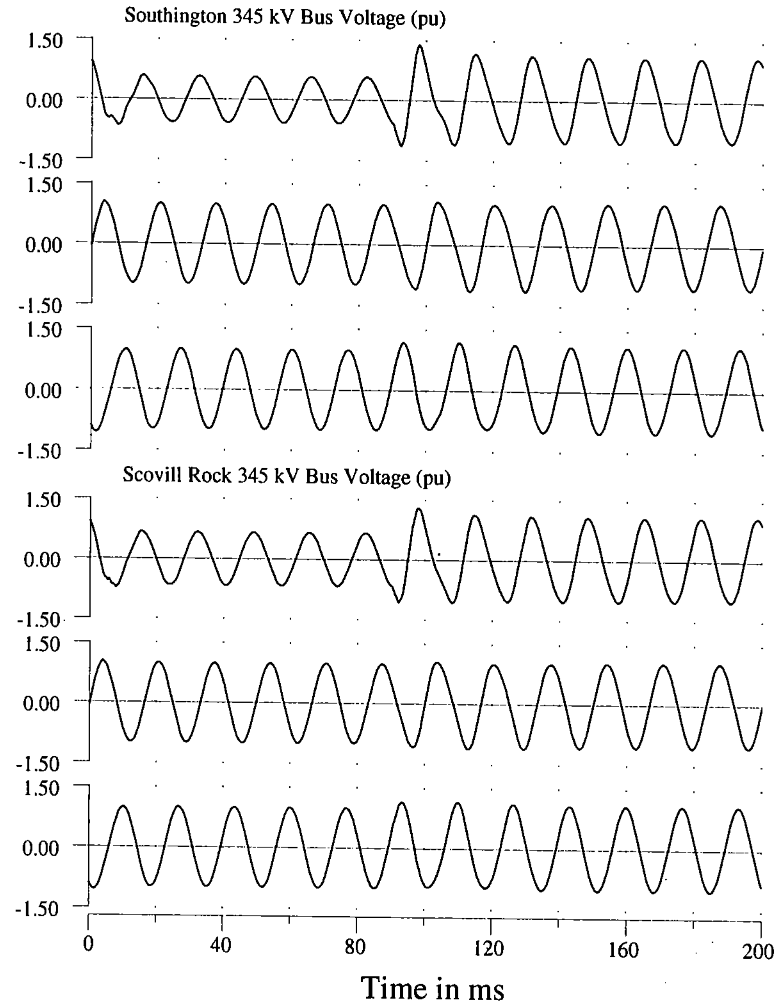
07-Nov-03 17:09:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_04.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_04

345 kV Bus Voltages

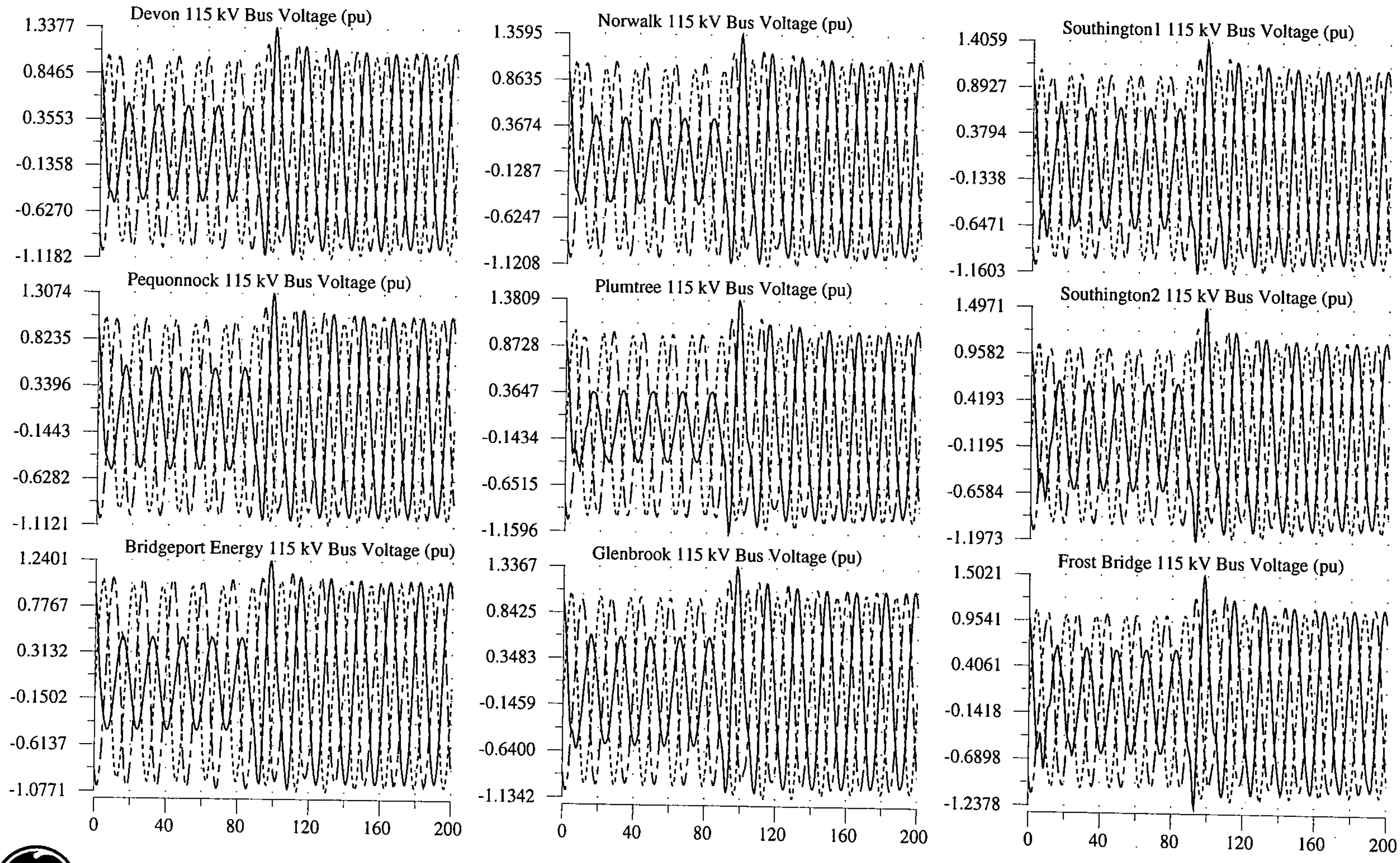




Northeast Utilities: Phase 2 Cable Transient Study

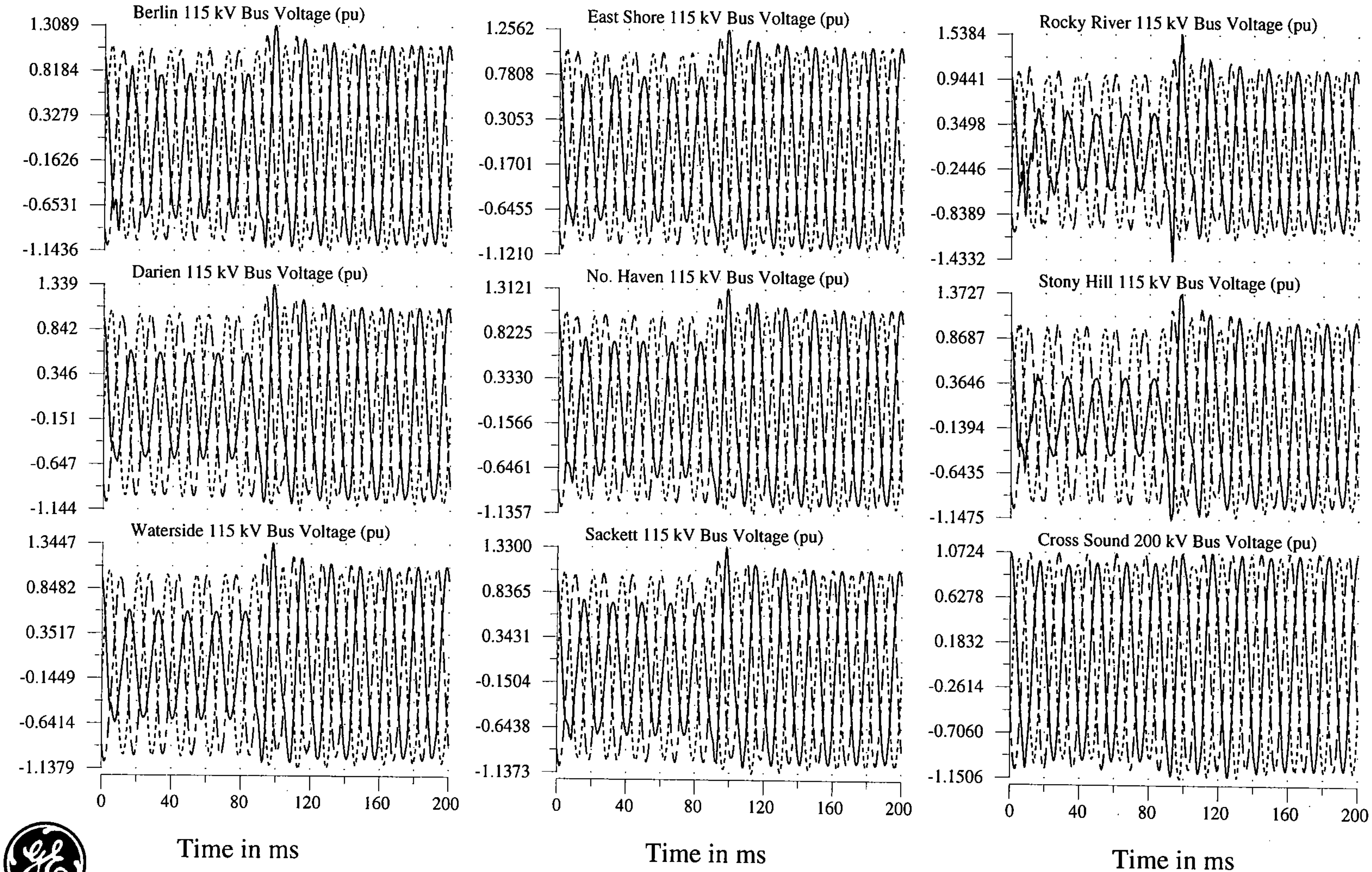
PH2P_NSF_04

115 kV Bus Voltages and Capacitor Bank Locations



07-Nov-03 17:09:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_04.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_NSF_04
115 kV Bus Voltages and Capacitor Bank Locations

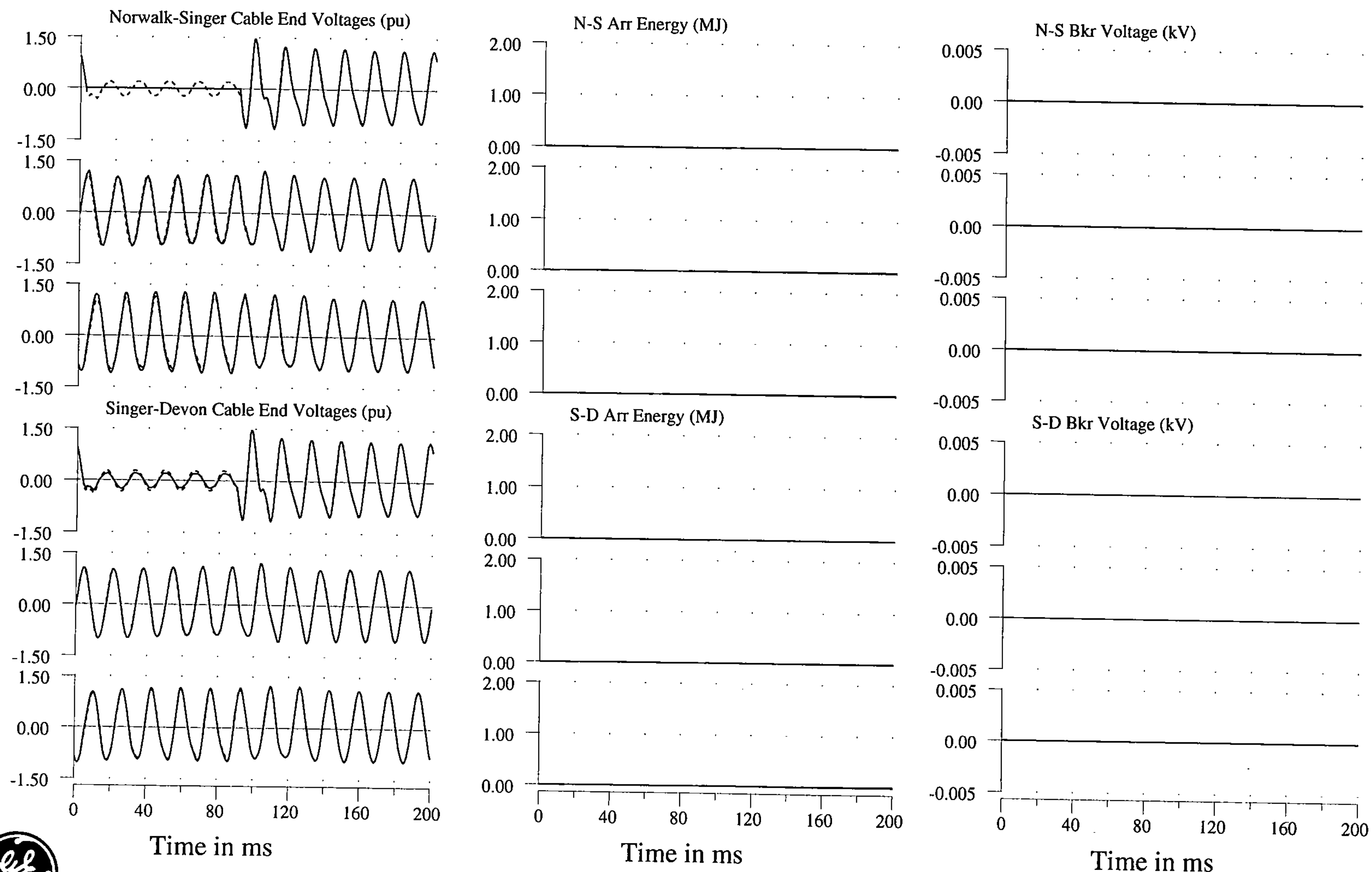


07-Nov-03 17:09:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_04.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_05

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

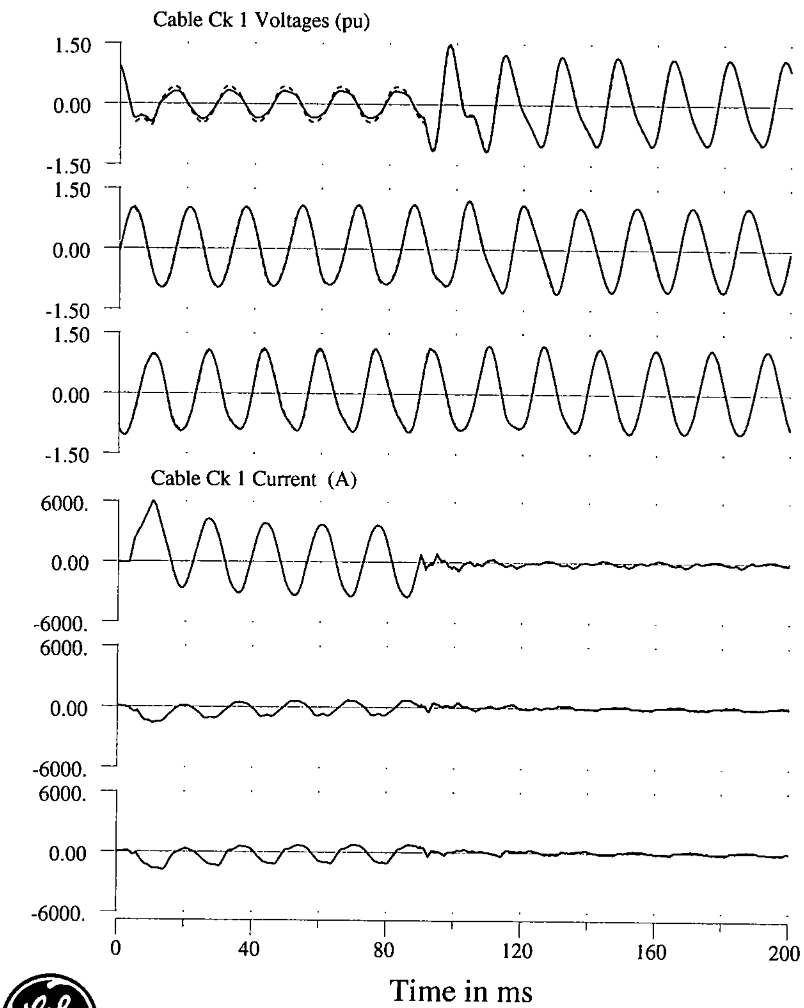


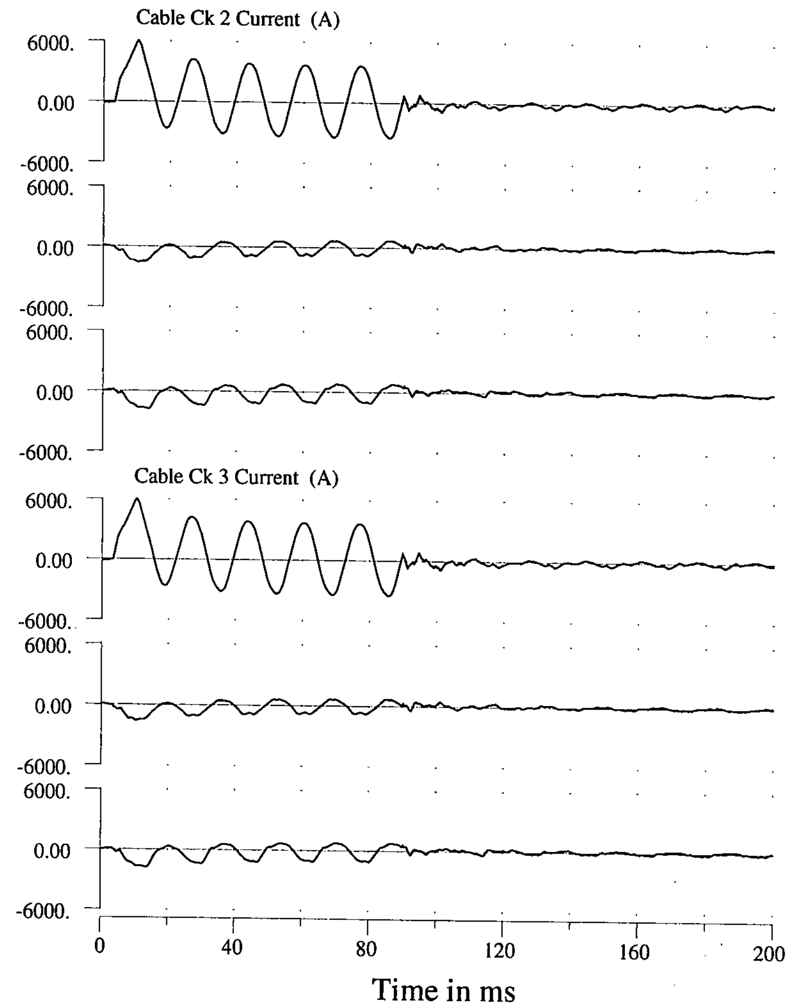
07-Nov-03 17:07:25 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_05.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_05

Devon-Beseck 345 kV Cables

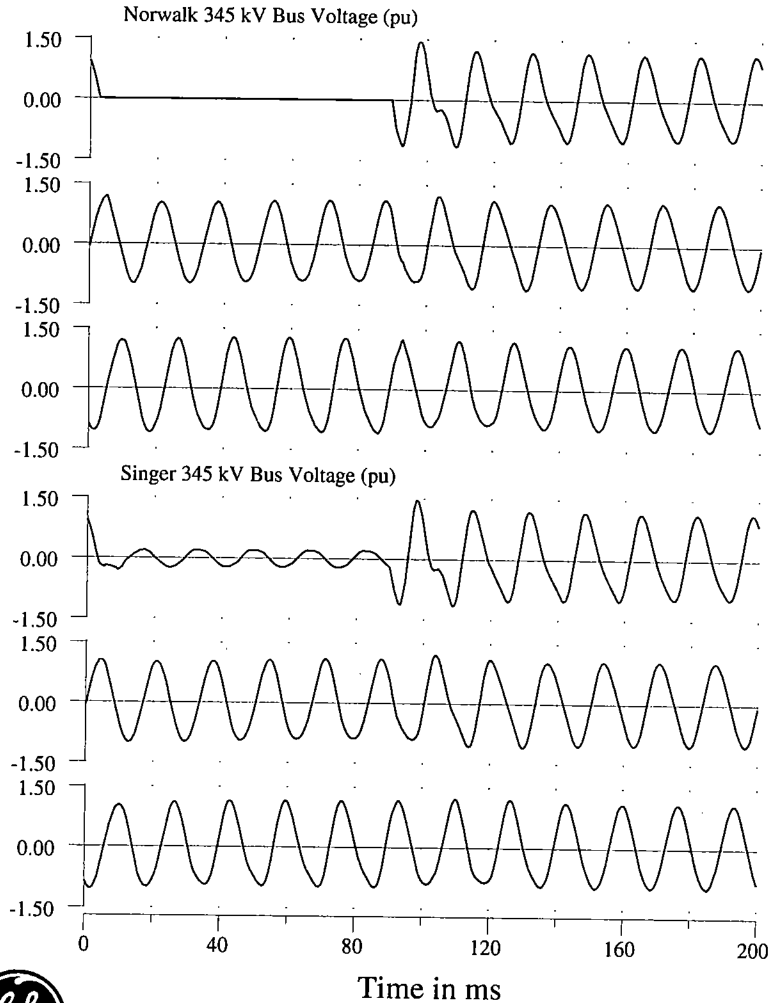


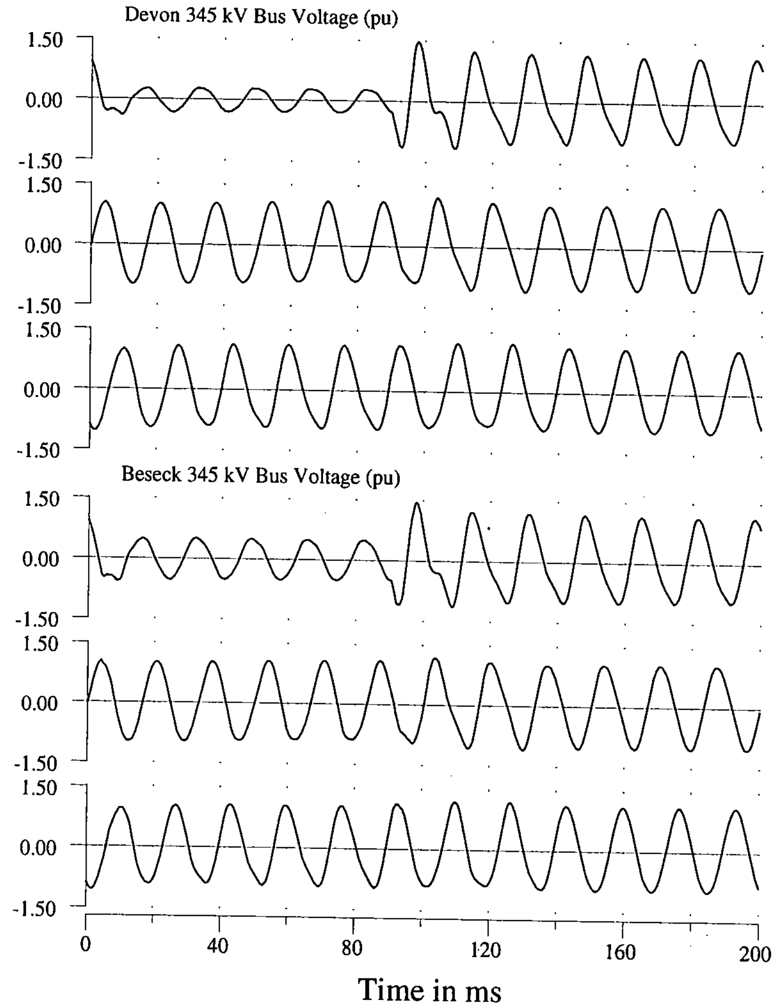


Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_05

345 kV Bus Voltages



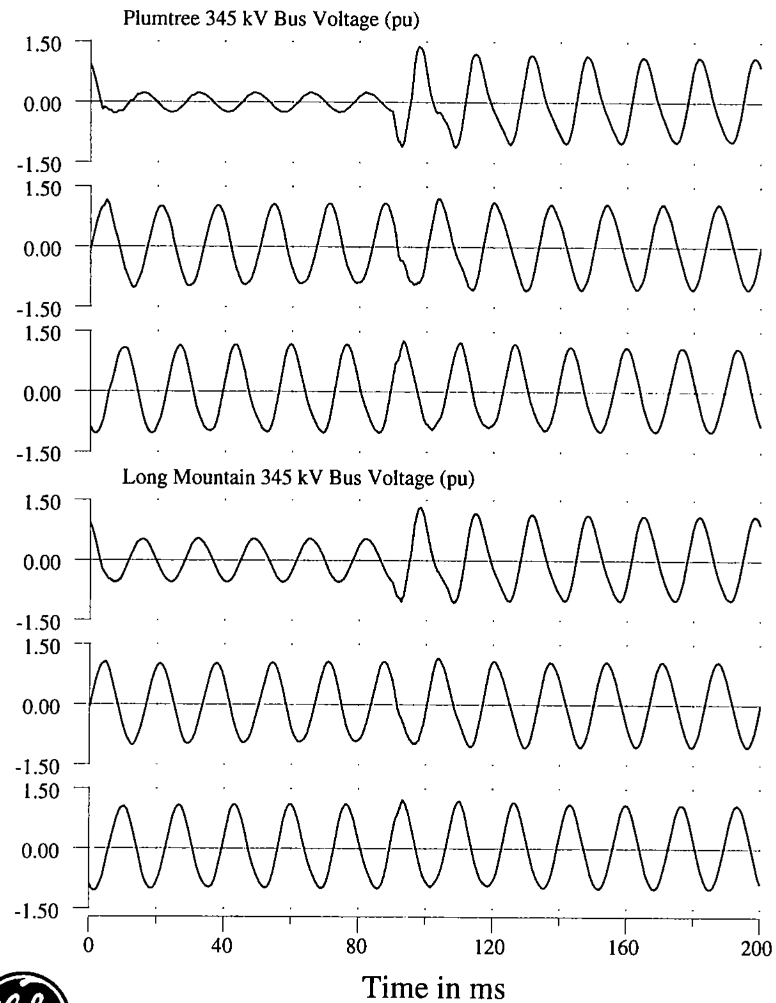


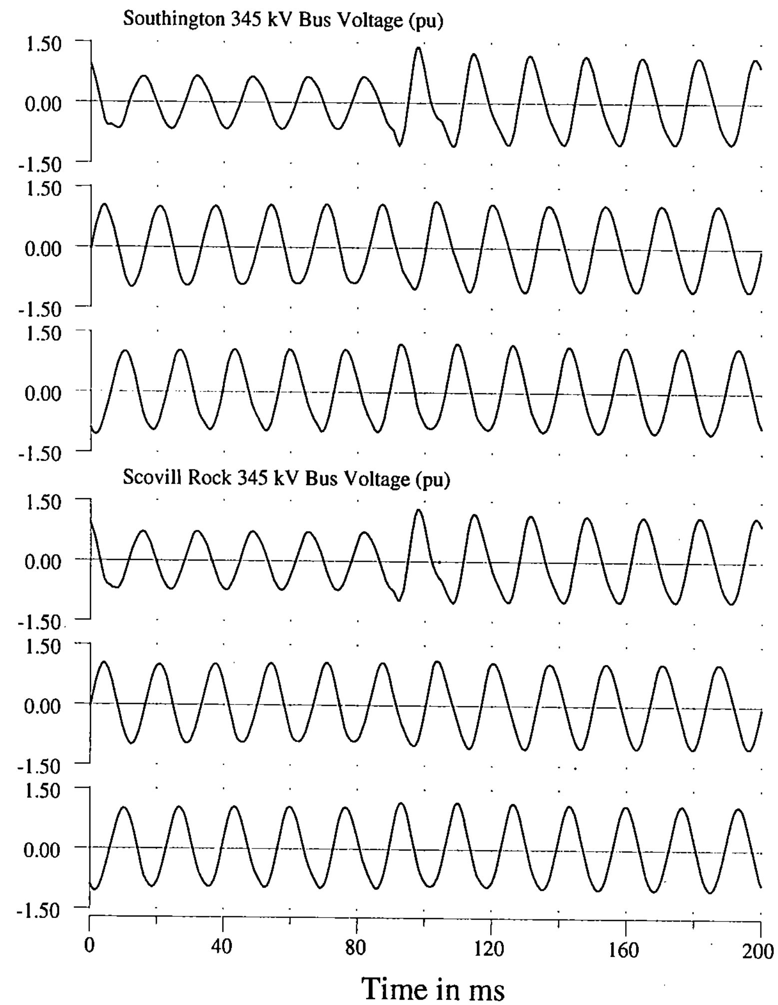
07-Nov-03 17:07:25 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_05.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_05

345 kV Bus Voltages



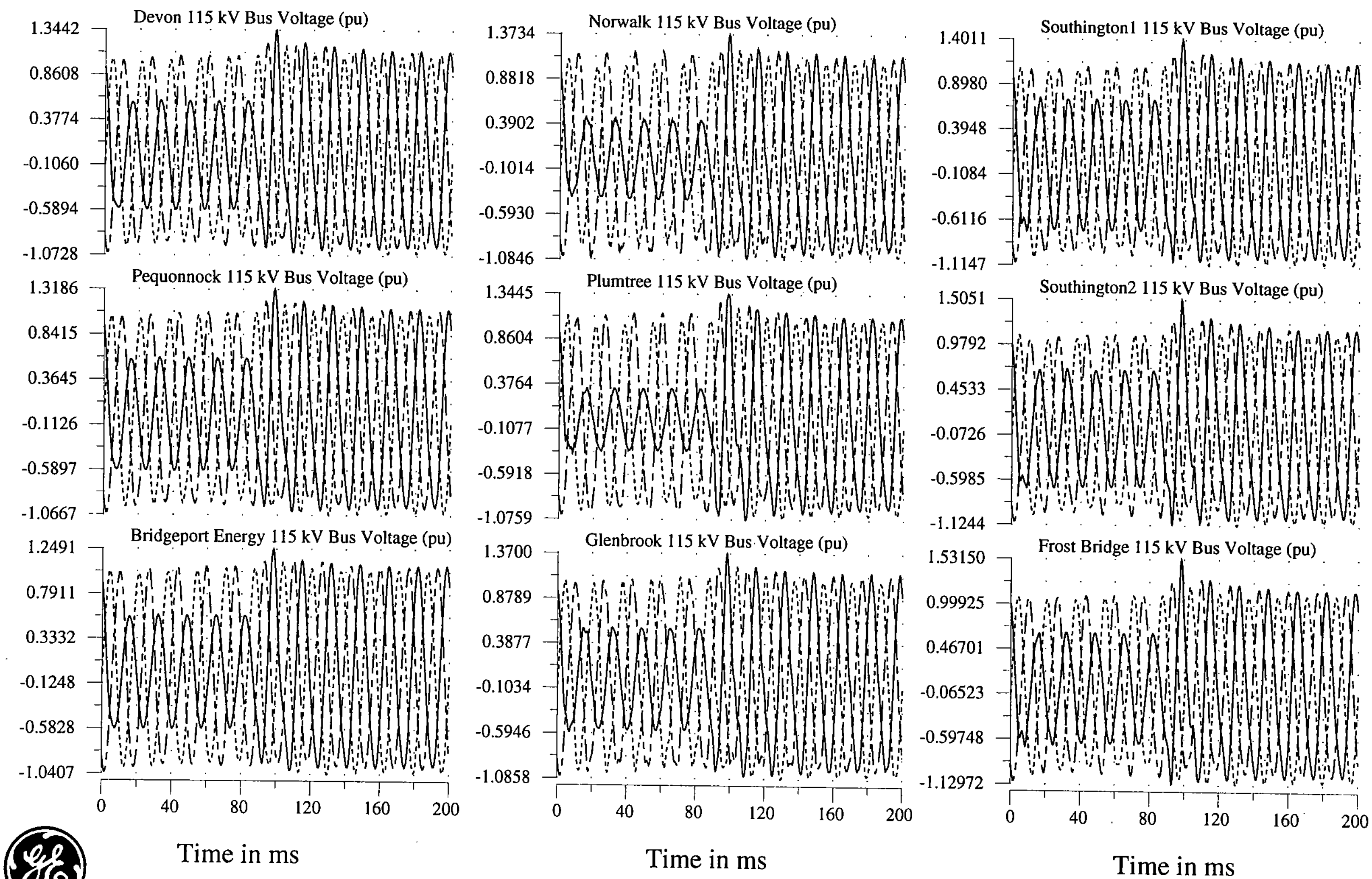


07-Nov-03 17:07:25 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_05.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_05

115 kV Bus Voltages and Capacitor Bank Locations

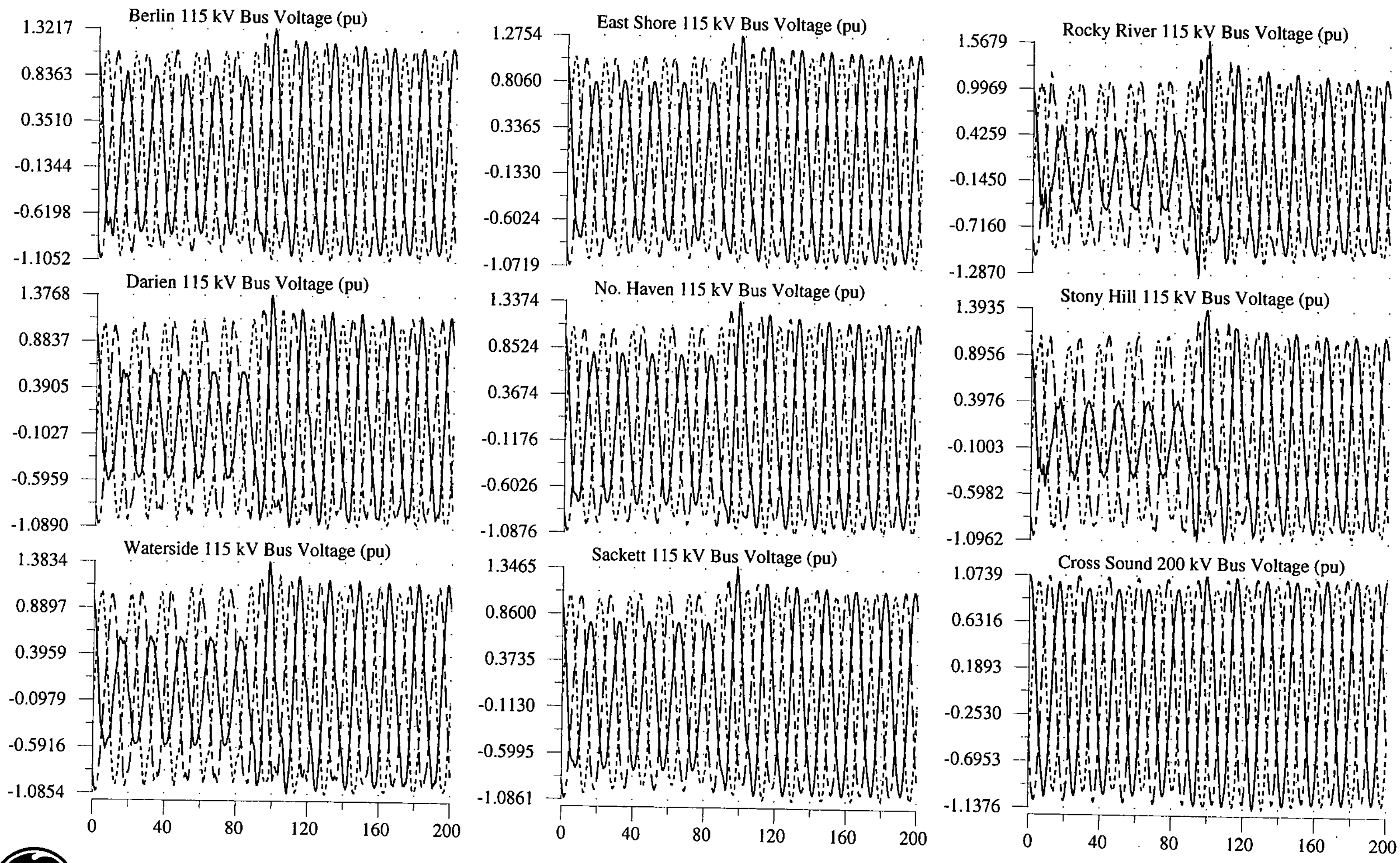


07-Nov-03 17:07:25 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_05.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_NSF_05

115 kV Bus Voltages and Capacitor Bank Locations

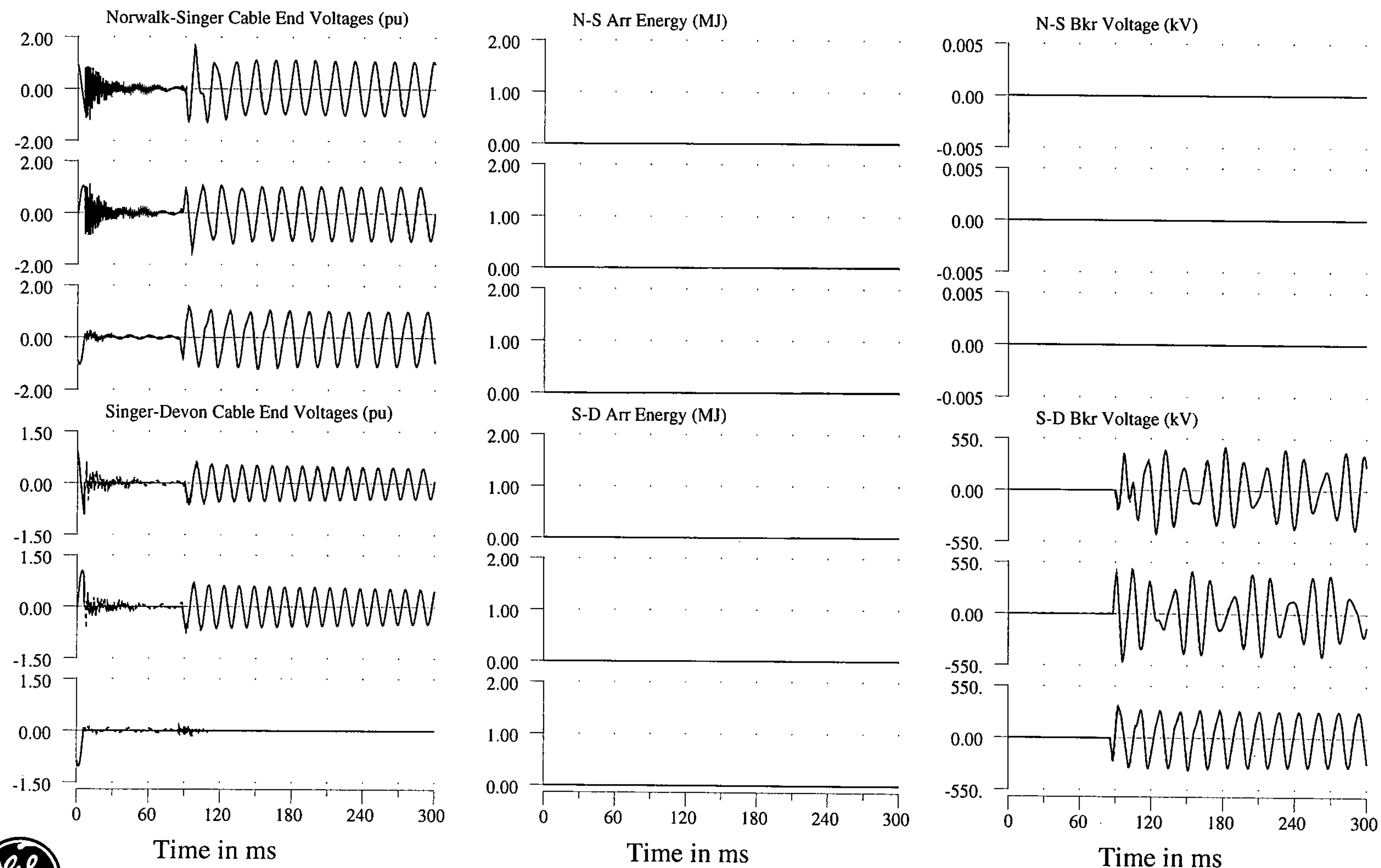


07-Nov-03 17:07:25 C:\Projects\atp\NU_PHASE2P\ps\PH2P_NSF_05.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_SDF_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

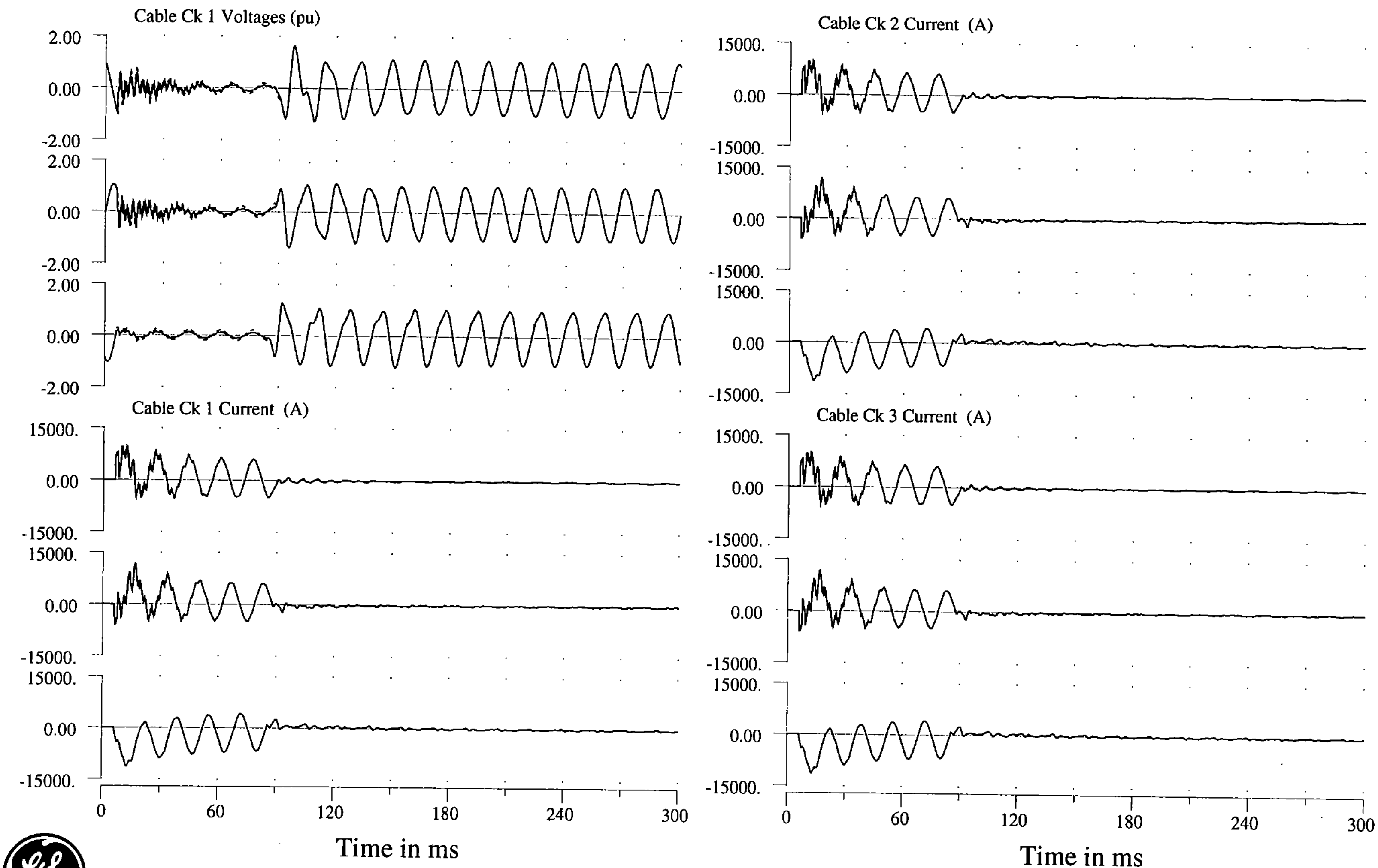


07-Nov-03 10:28:20 C:\Projects\atp\NU_PHASE2P\ps\PH2P_SDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_SDF_01

Devon-Beseck 345 kV Cables

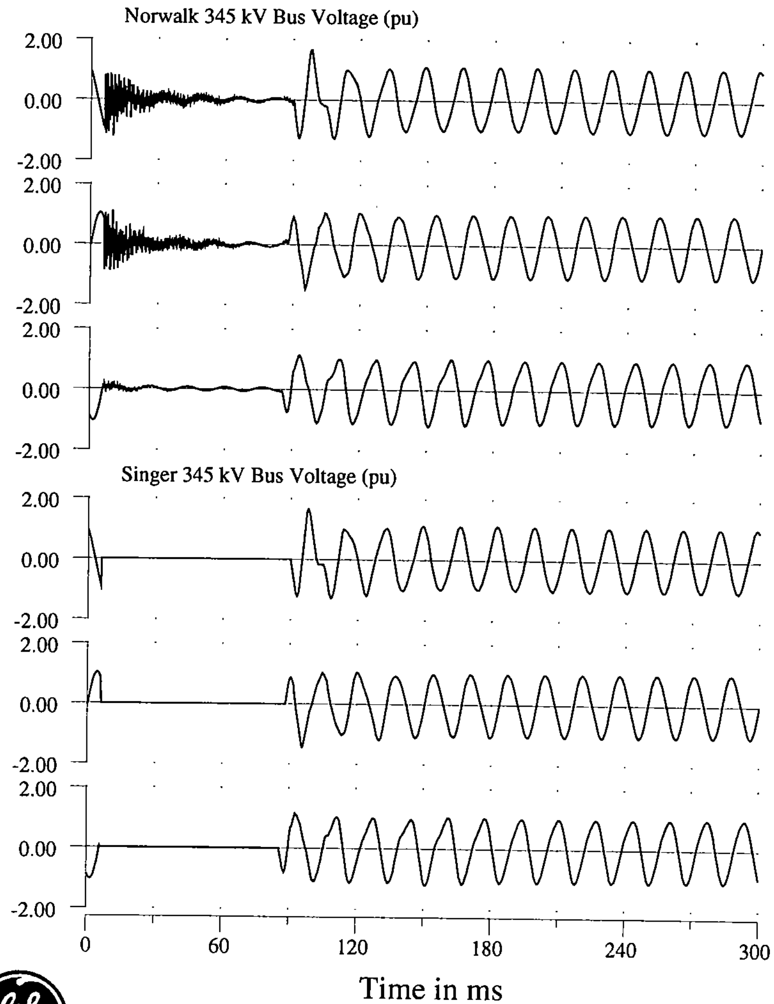


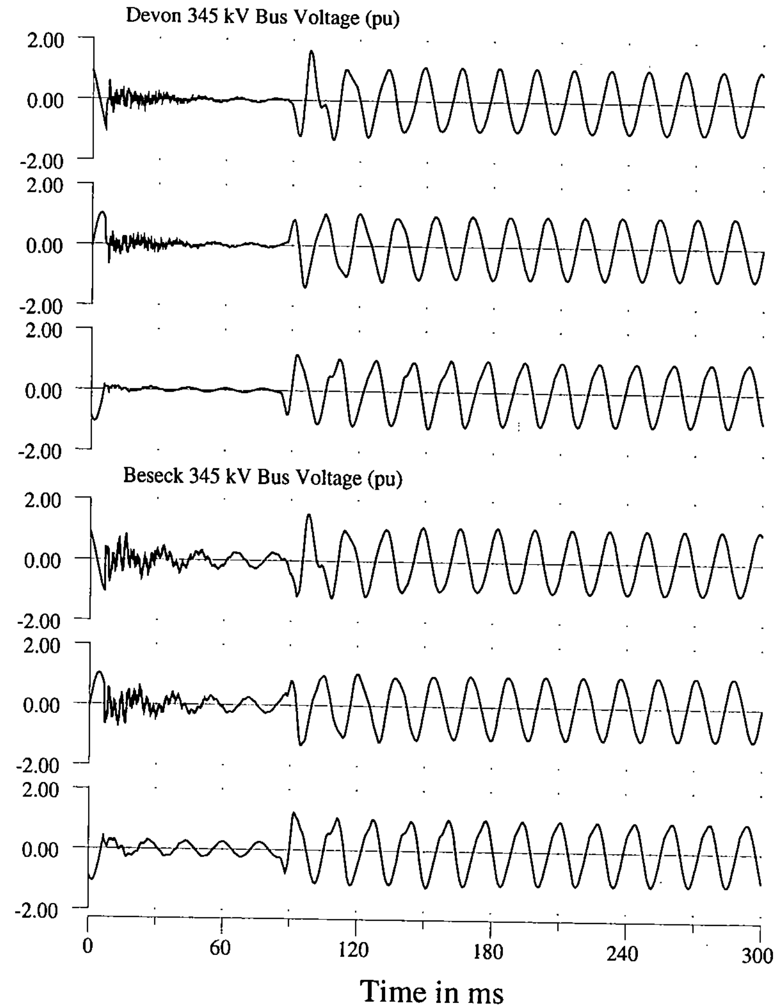
07-Nov-03 10:28:20 C:\Projects\atp\NU_PHASE2P\ps\PH2P_SDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_SDF_01

345 kV Bus Voltages



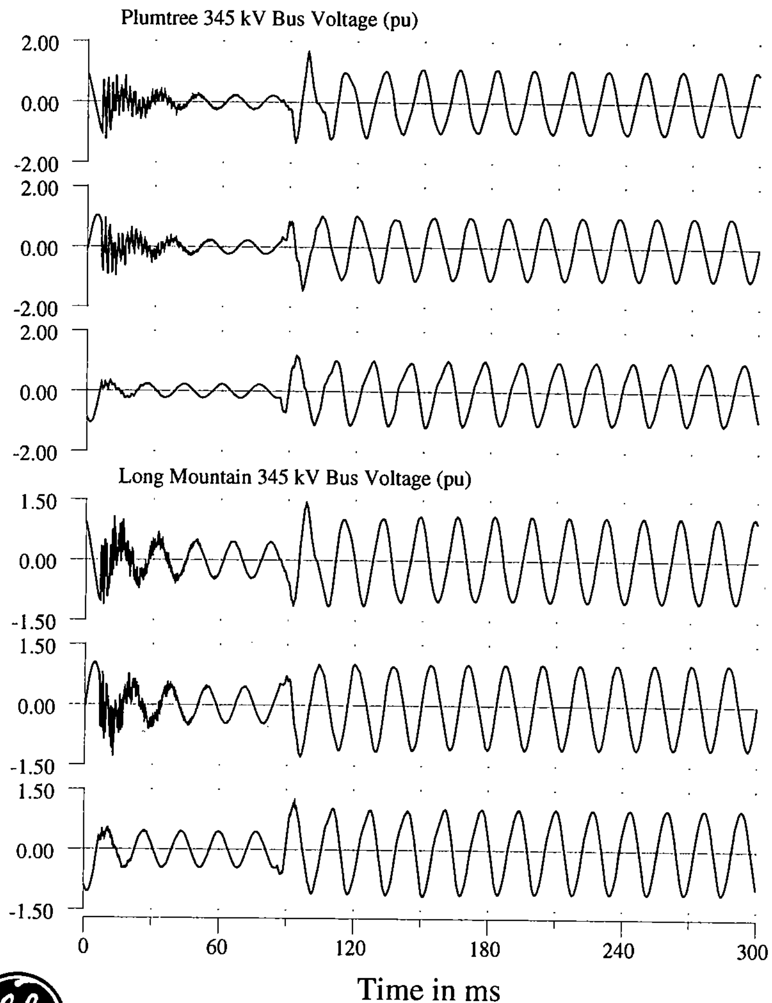


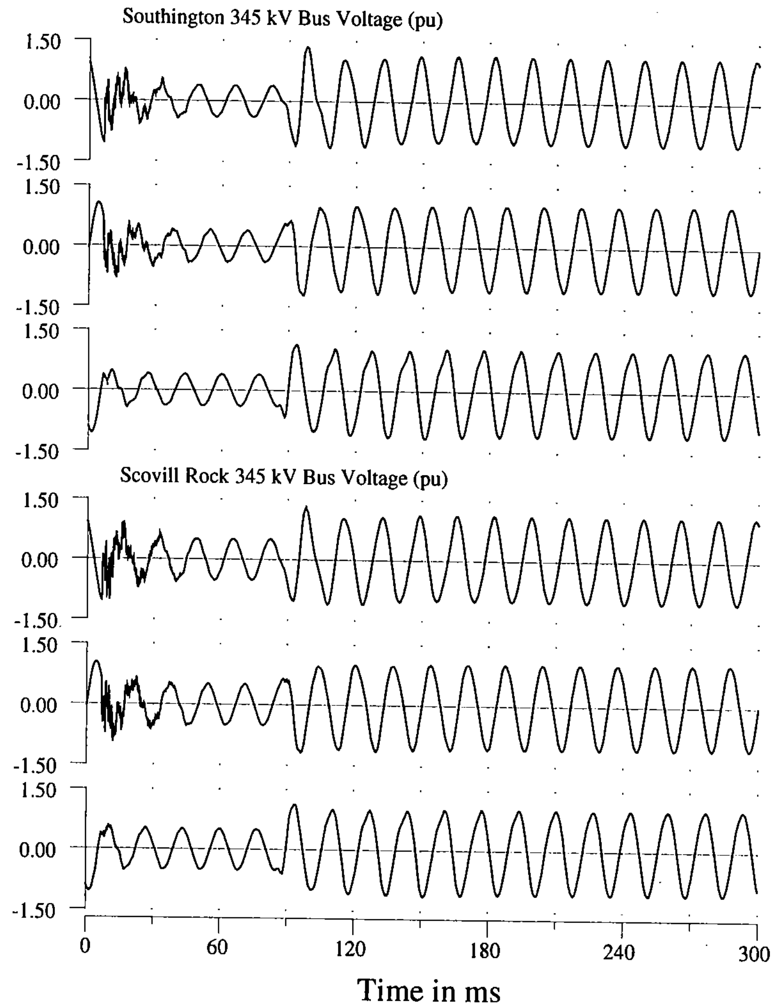
07-Nov-03 10:28:20 C:\Projects\atp\NU_PHASE2P\ps\PH2P_SDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_SDF_01

345 kV Bus Voltages

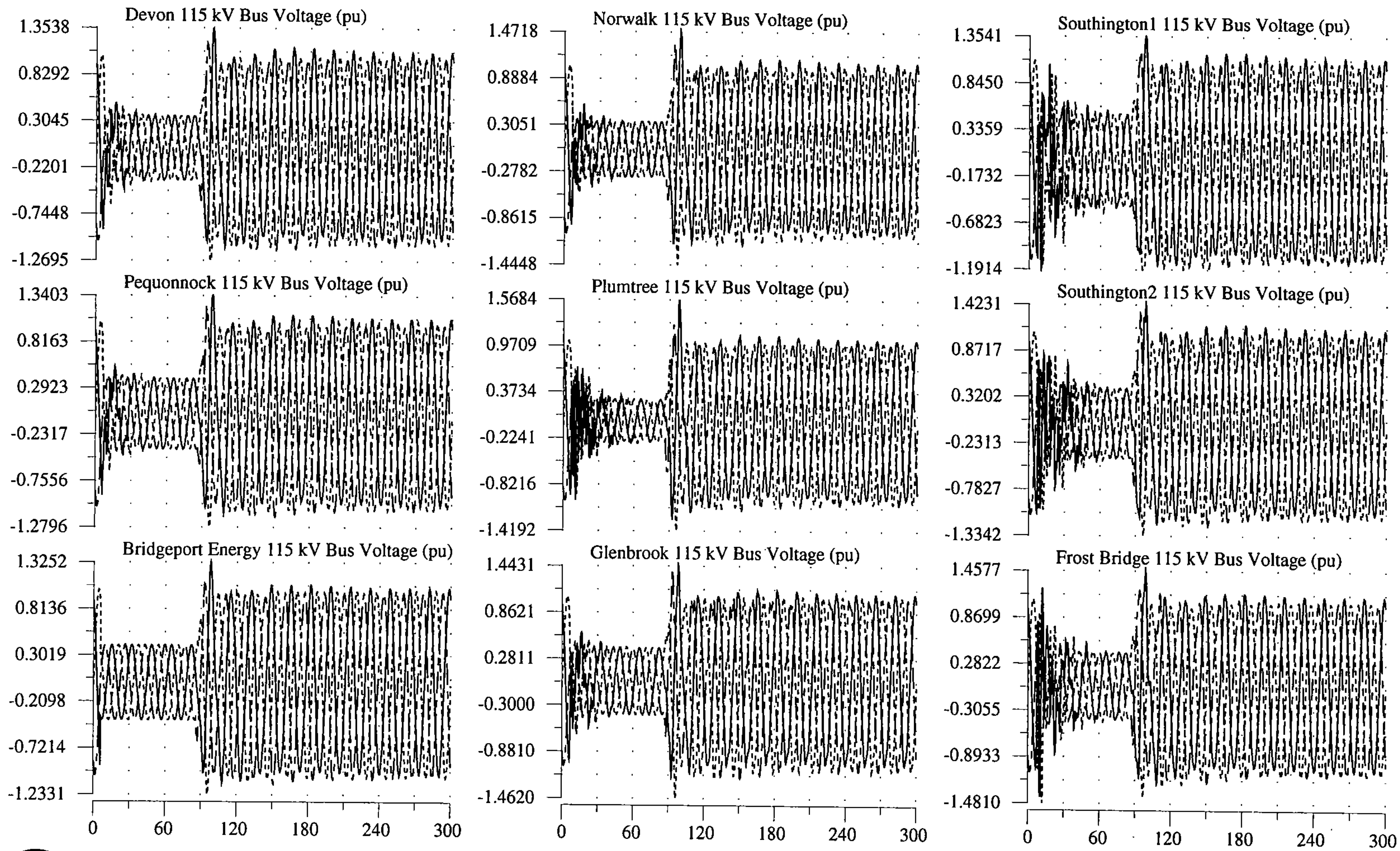




Northeast Utilities: Phase 2 Cable Transient Study

PH2P_SDF_01

115 kV Bus Voltages and Capacitor Bank Locations

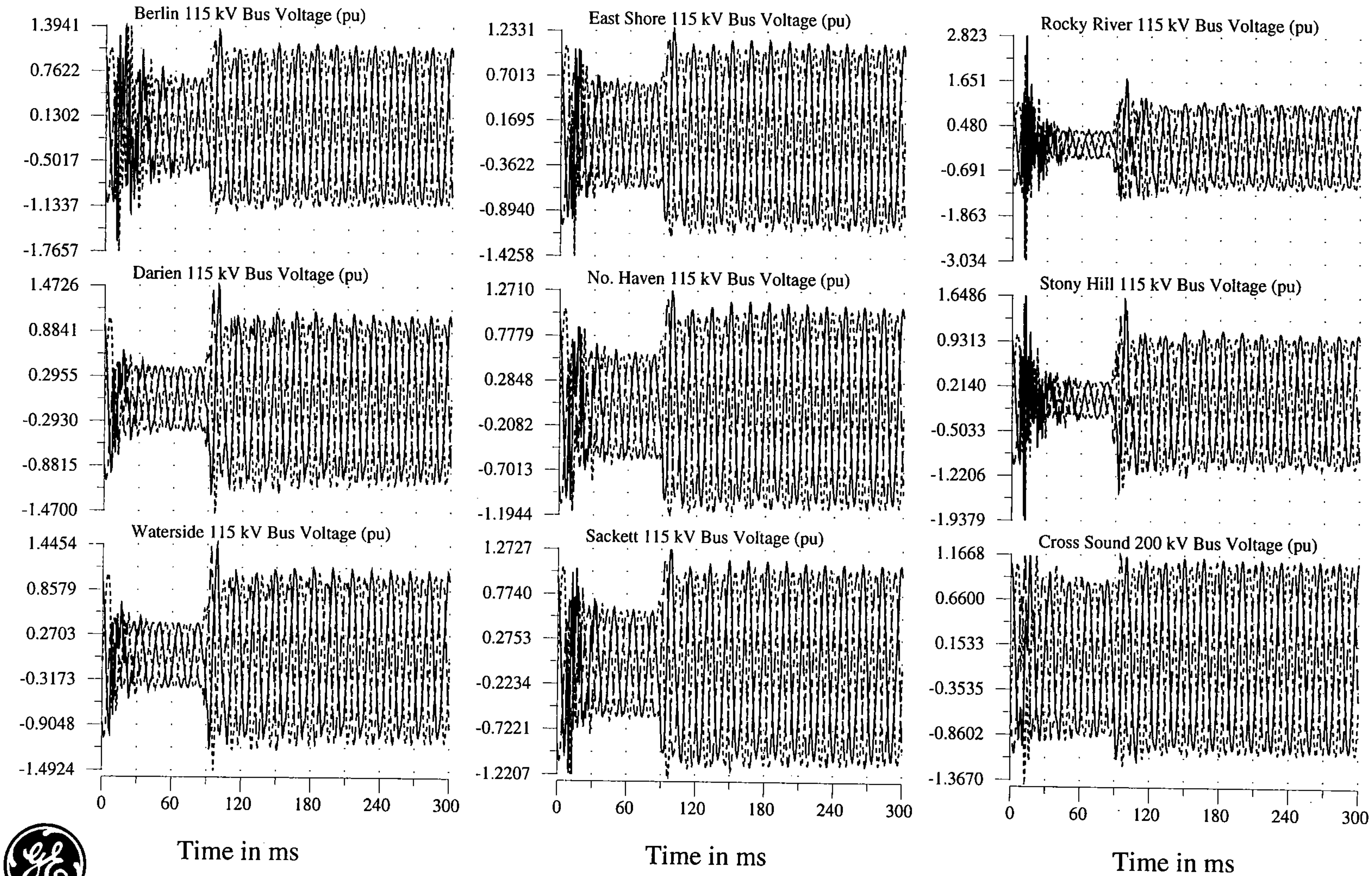


07-Nov-03 10:28:20 C:\Projects\atp\NU_PHASE2P\ps\PH2P_SDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

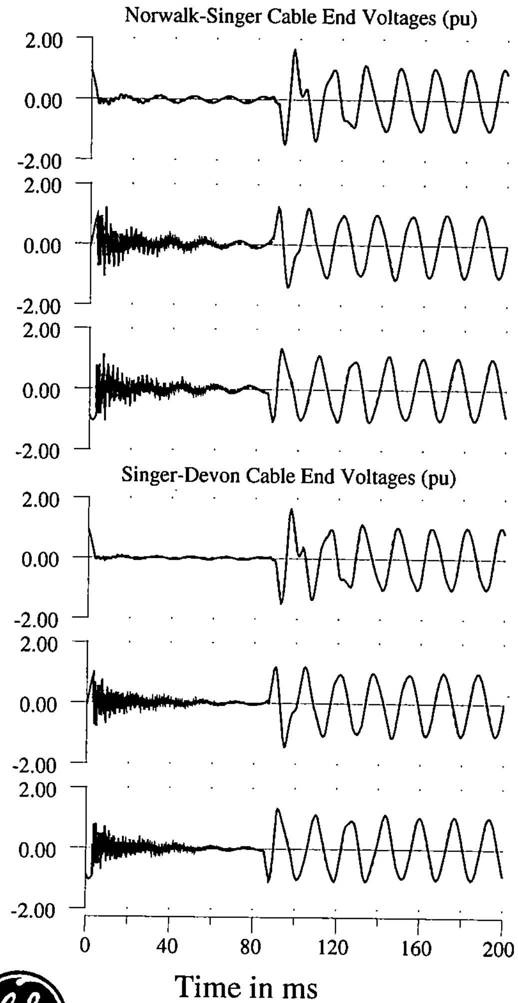
PH2P_SDF_01

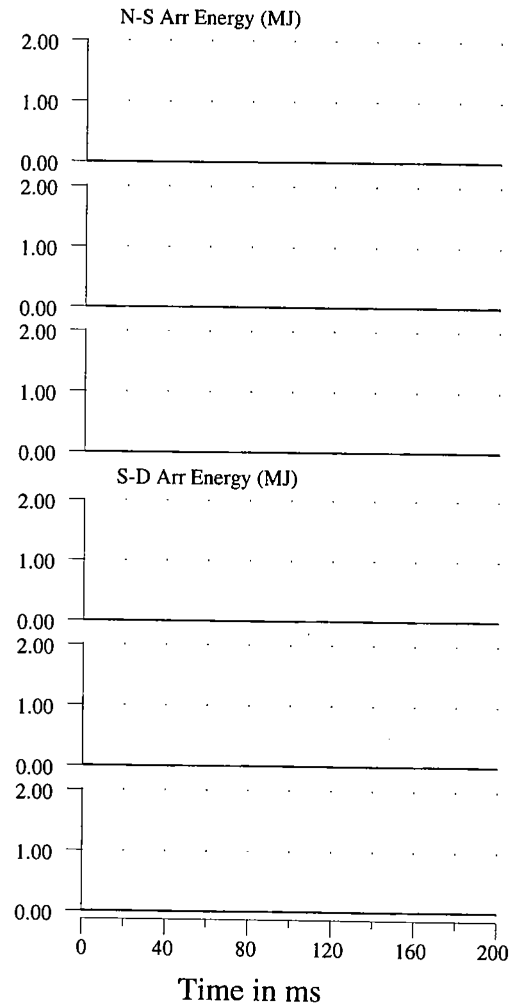
115 kV Bus Voltages and Capacitor Bank Locations

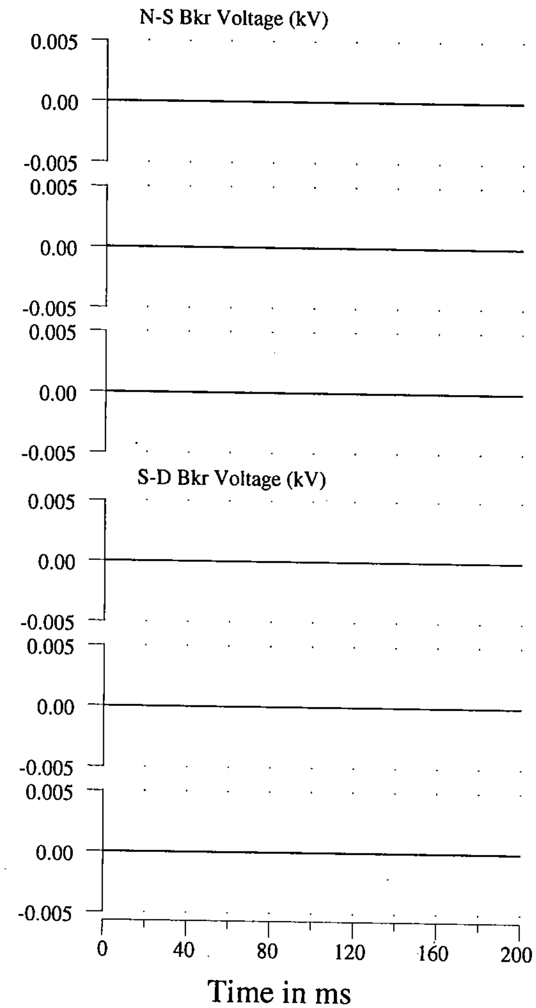


07-Nov-03 10:28:20 C:\Projects\atp\NU_PHASE2P\ps\PH2P_SDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_BDF_01
Case Summary Plots for Phase 2 345 kV Cables (Ck 1)





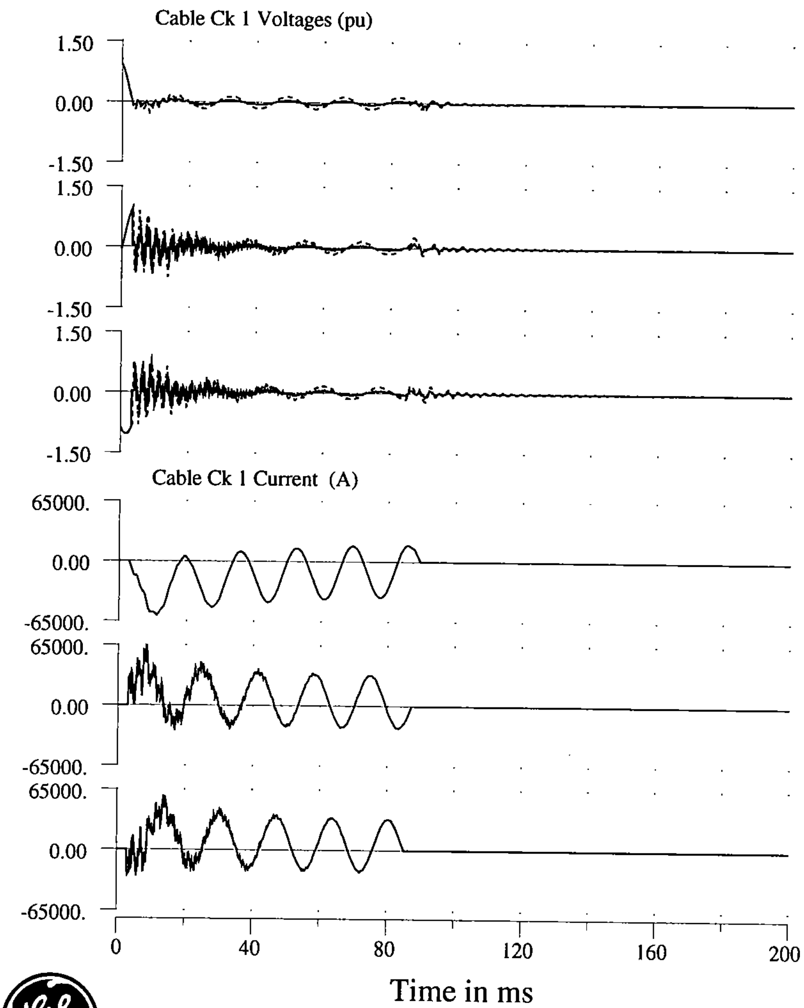


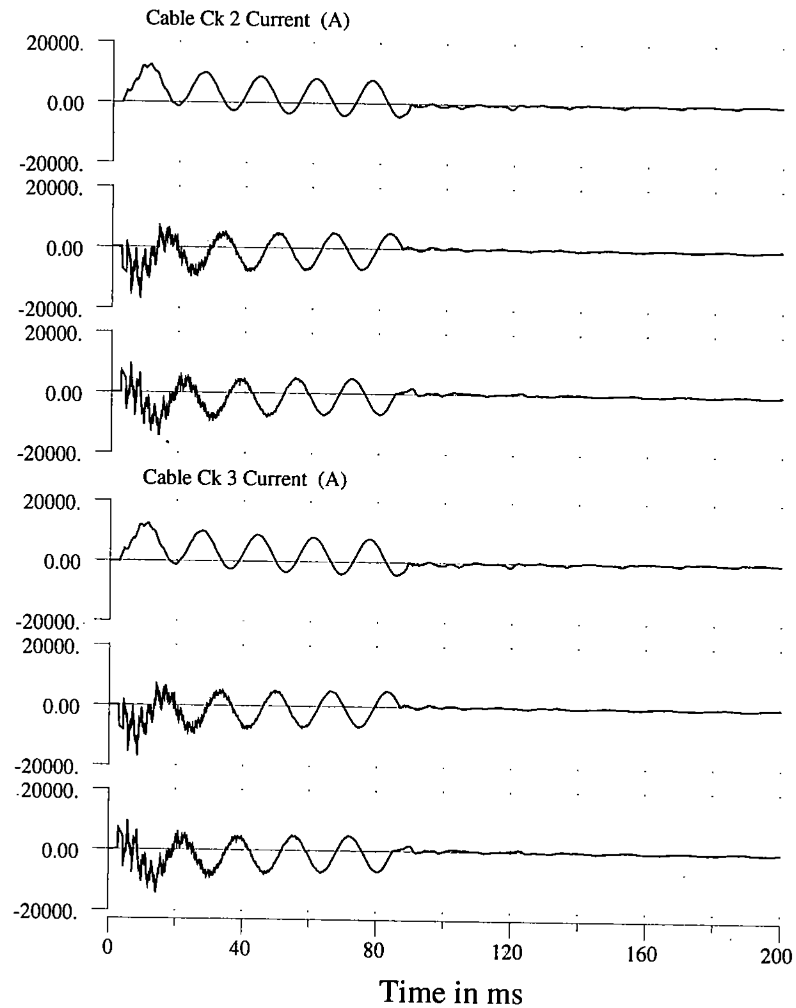
07-Nov-03 17:32:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_01

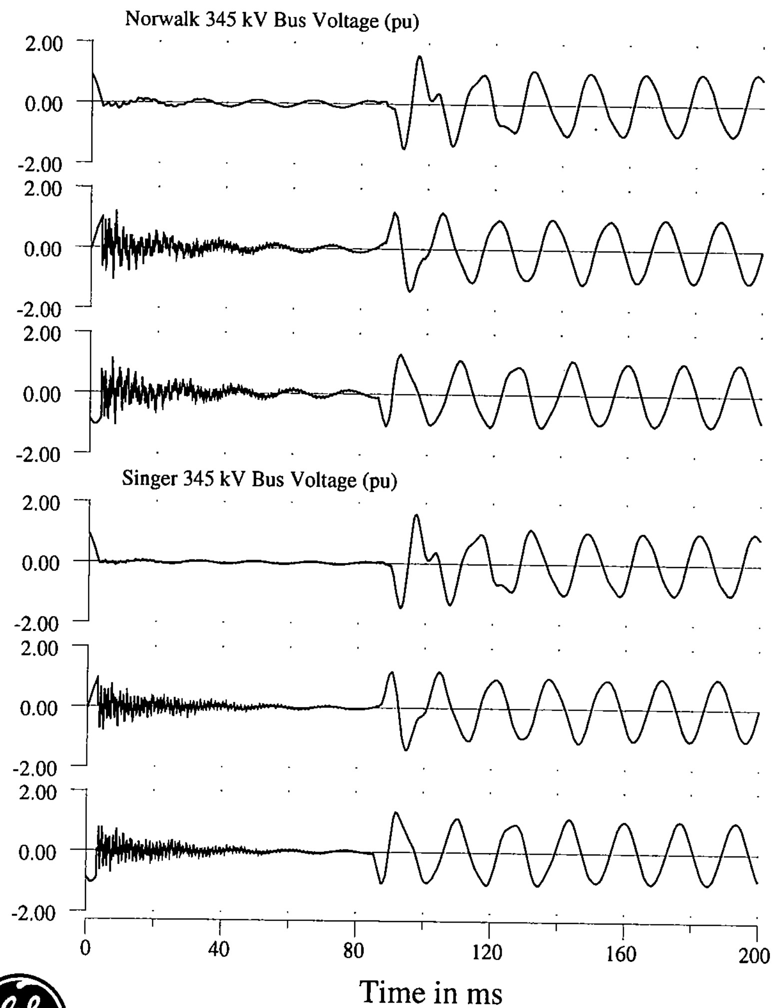
Devon-Beseck 345 kV Cables

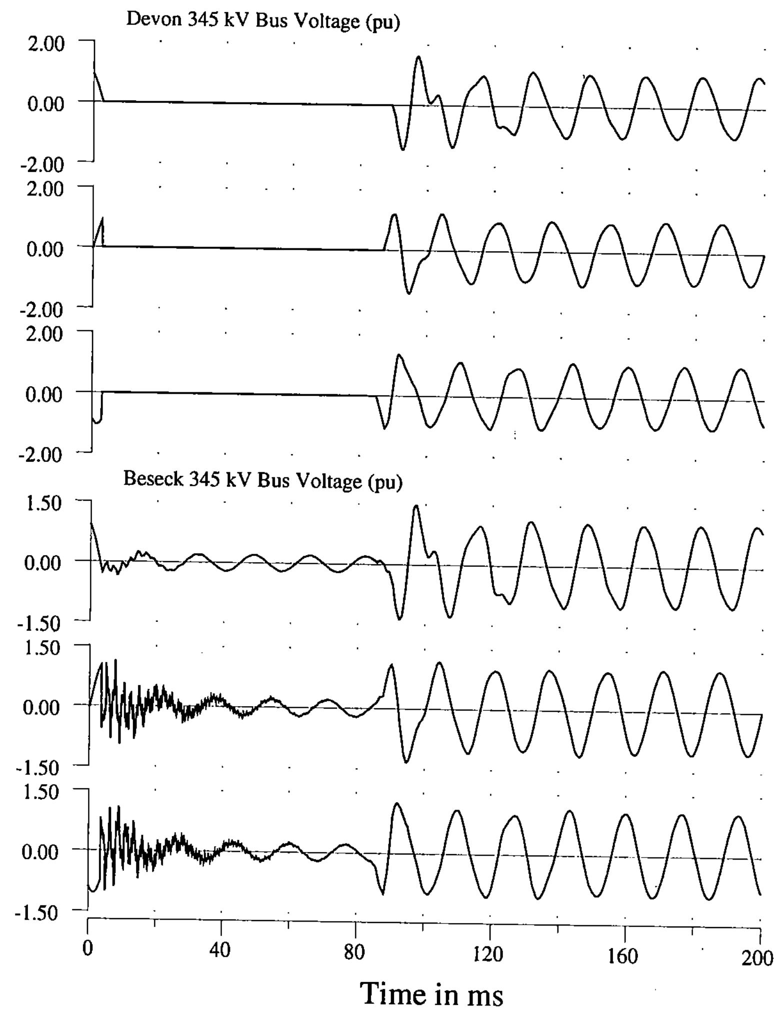




07-Nov-03 17:32:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_BDF_01
345 kV Bus Voltages





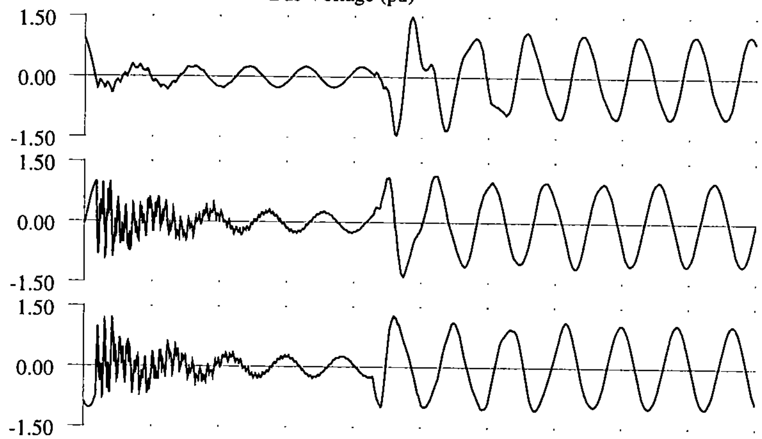
07-Nov-03 17:32:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

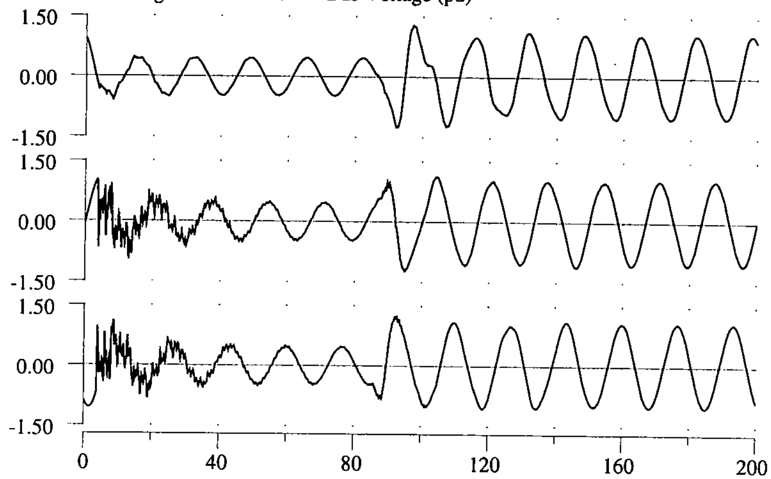
PH2P_BDF_01

345 kV Bus Voltages

Plumtree 345 kV Bus Voltage (pu)

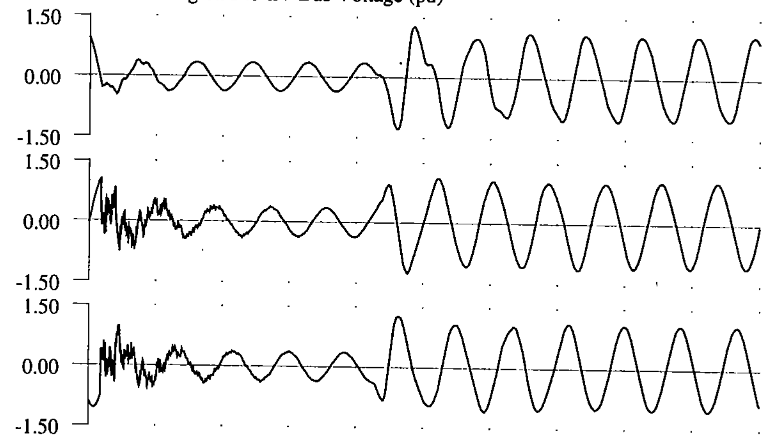


Long Mountain 345 kV Bus Voltage (pu)

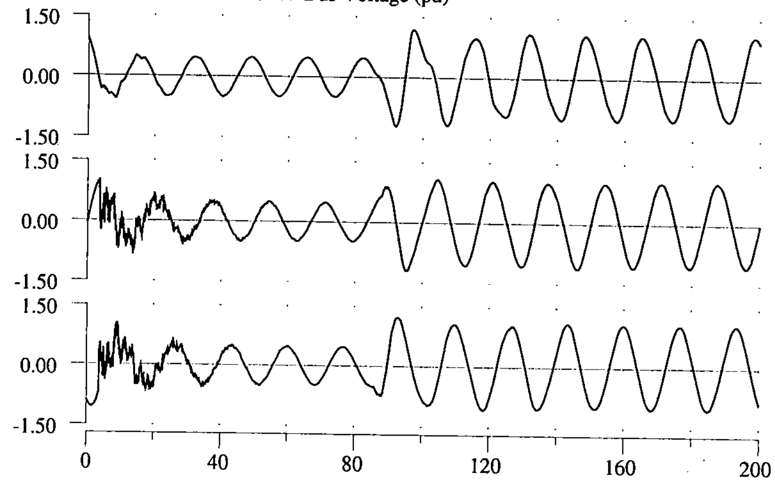


Time in ms

Southington 345 kV Bus Voltage (pu)



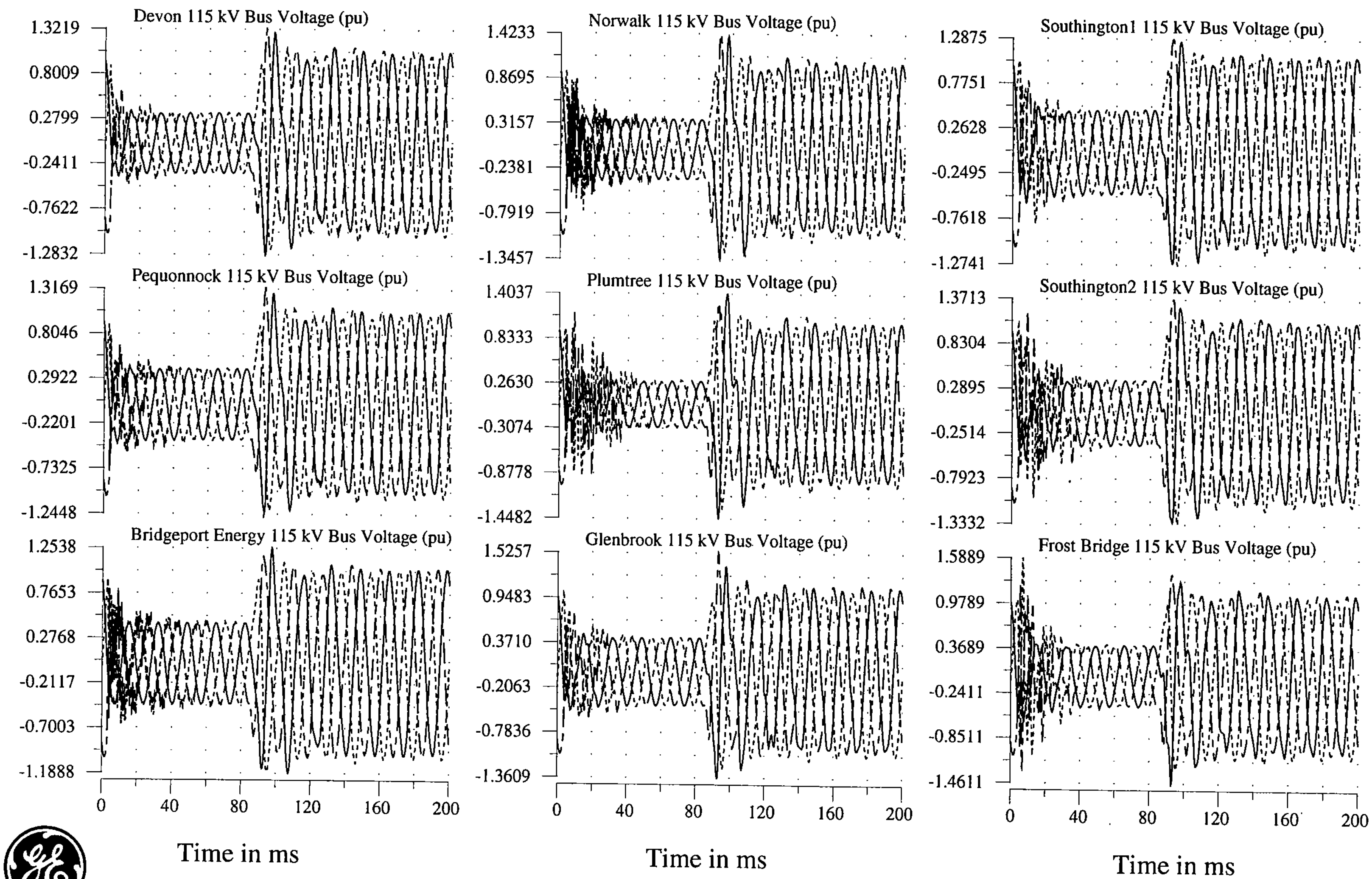
Scovill Rock 345 kV Bus Voltage (pu)



Time in ms

07-Nov-03 17:32:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_BDF_01
115 kV Bus Voltages and Capacitor Bank Locations

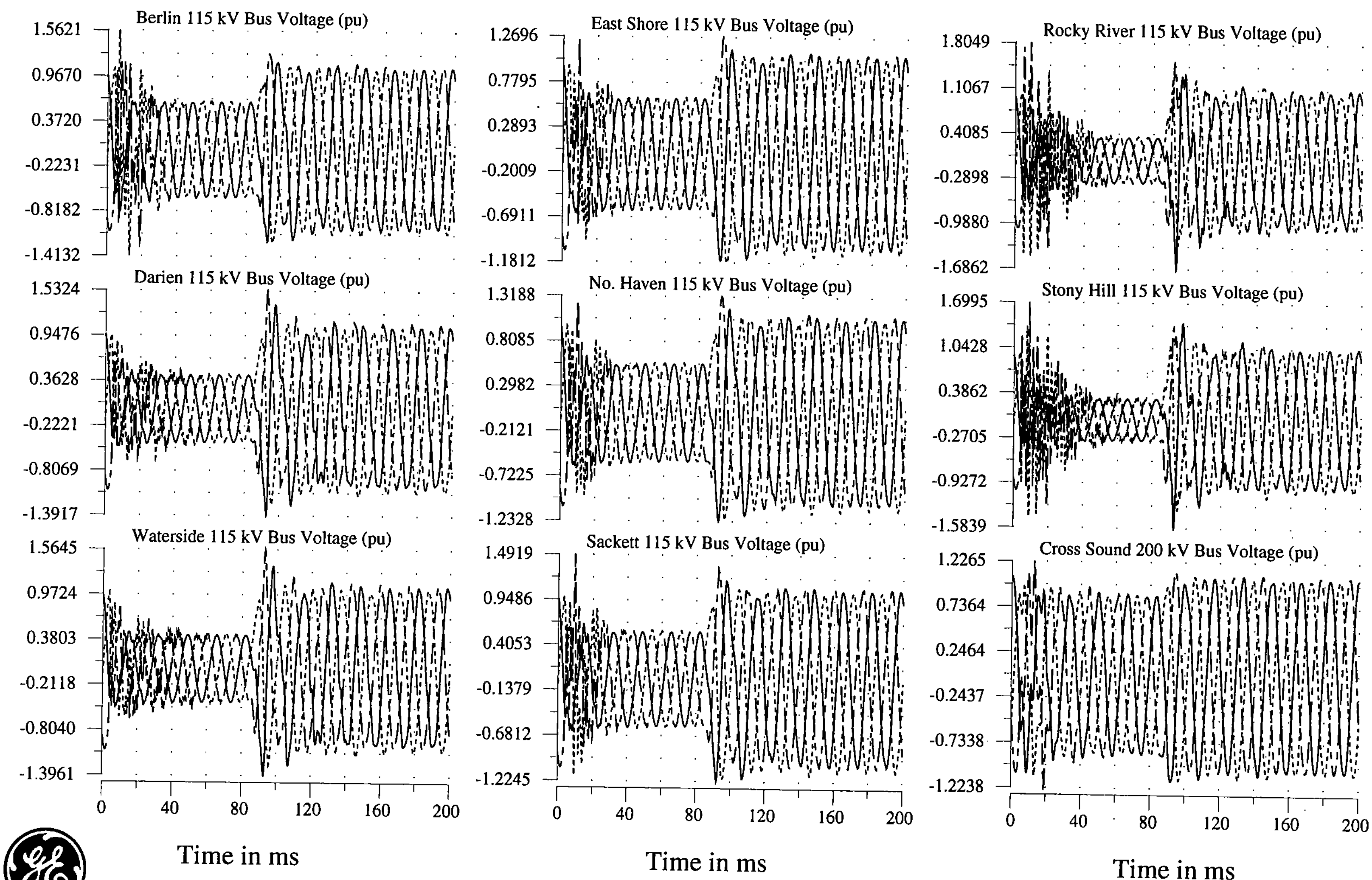


07-Nov-03 17:32:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_01

115 kV Bus Voltages and Capacitor Bank Locations

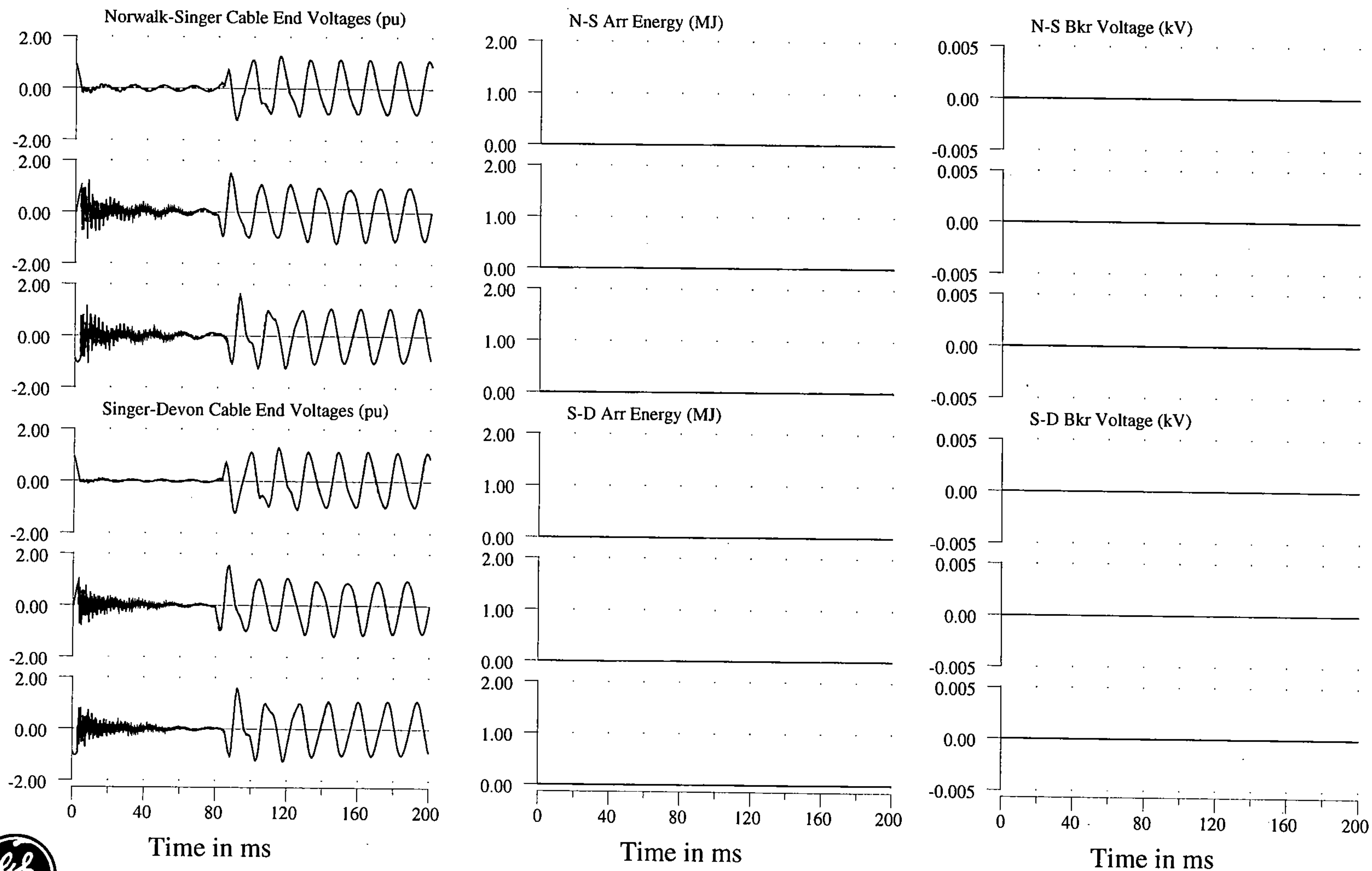


07-Nov-03 17:32:06 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_02

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

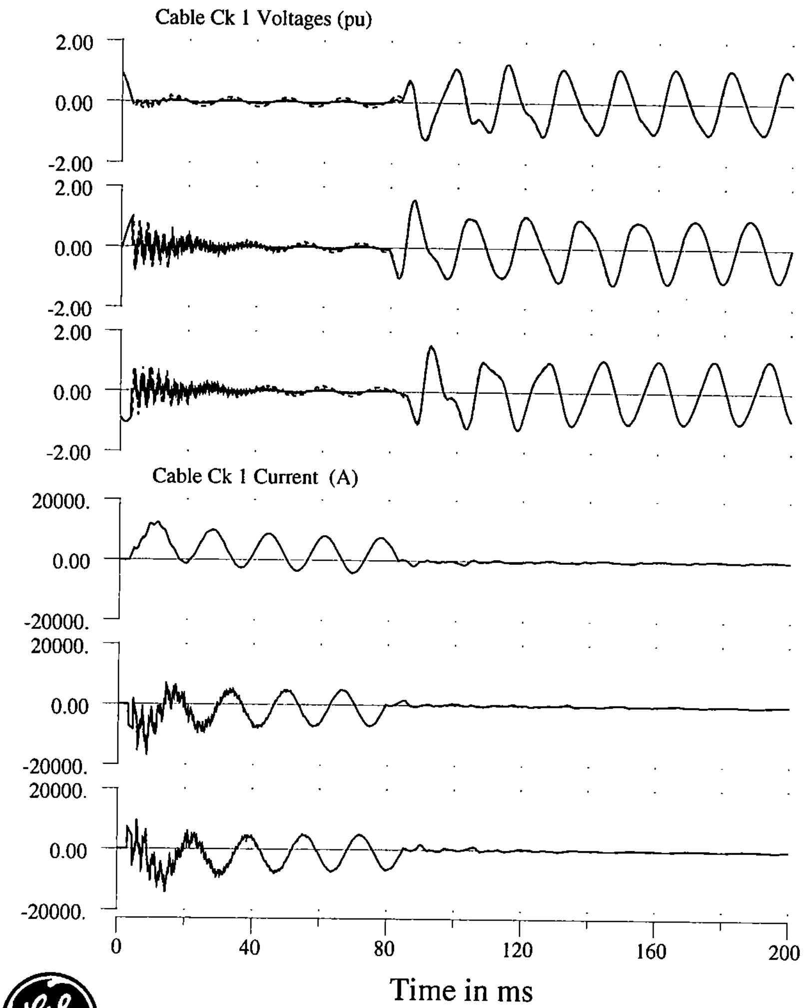


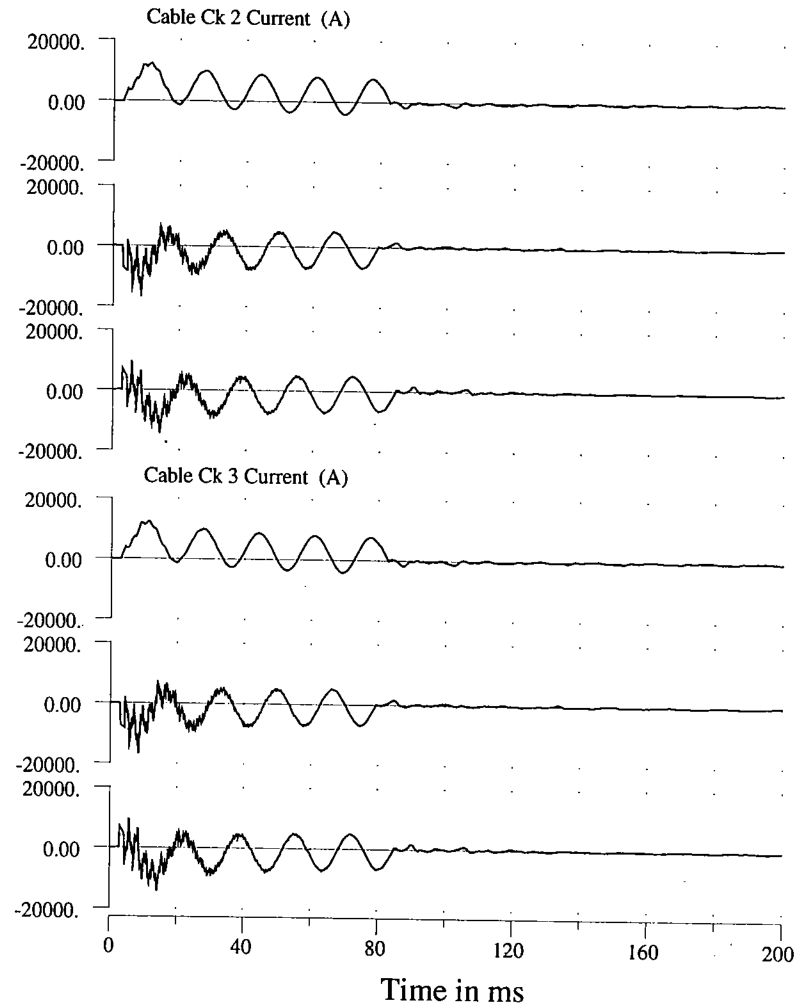
07-Nov-03 17:35:27 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_02

Devon-Beseck 345 kV Cables

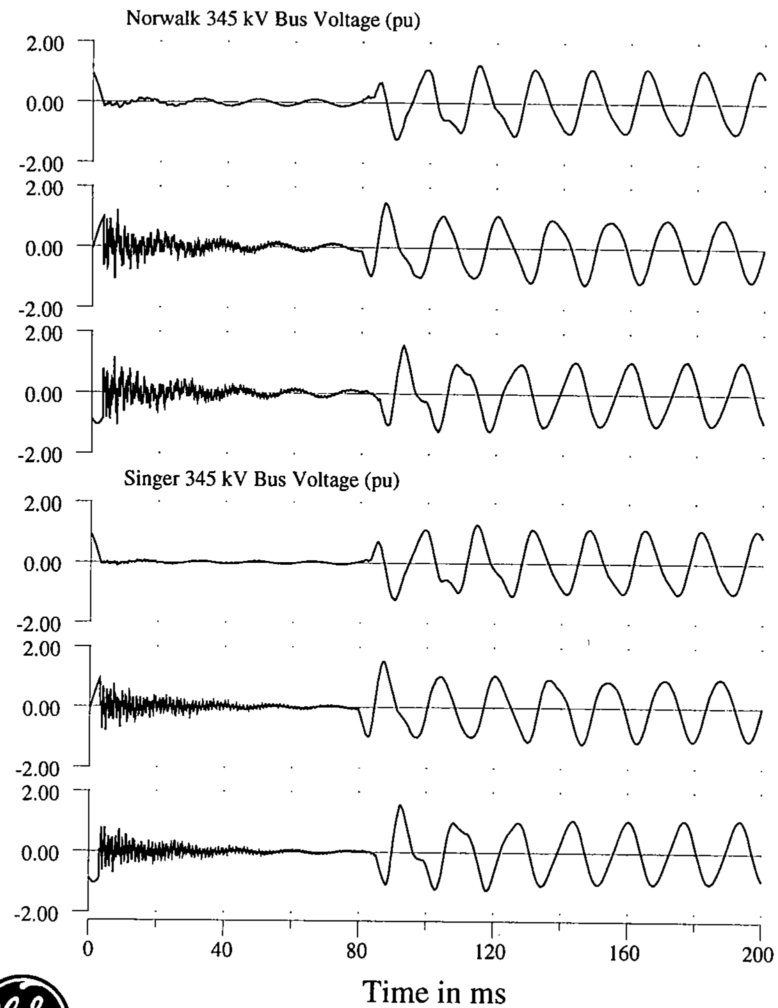


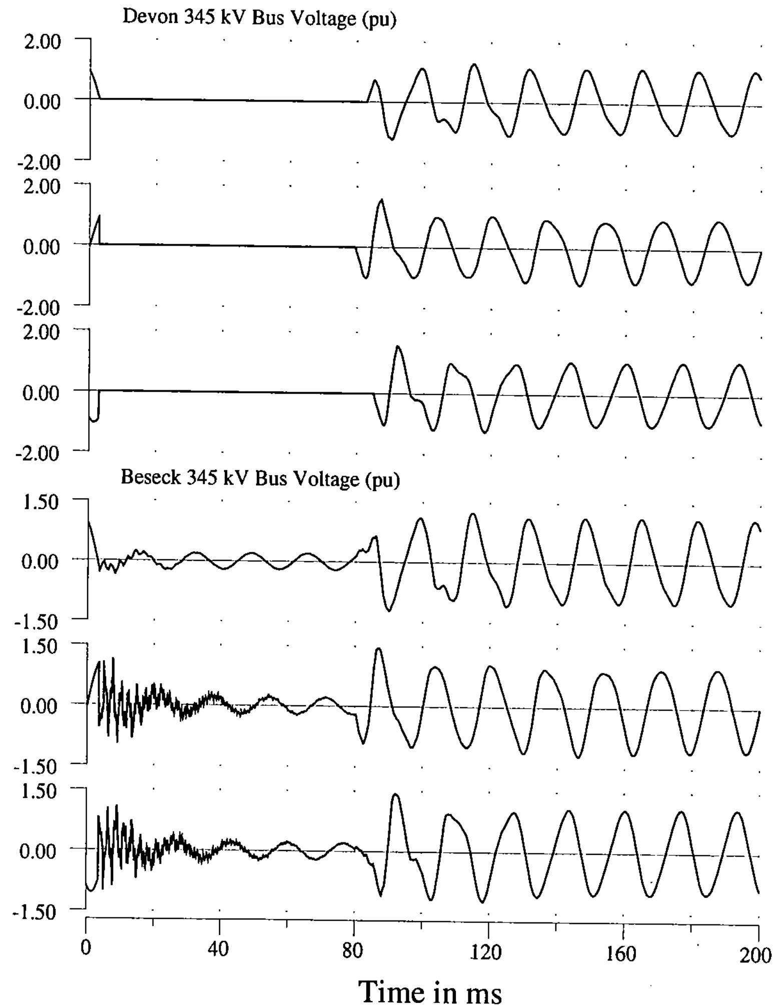


Northeast Utilities: Phase 2 Cable Transient Study

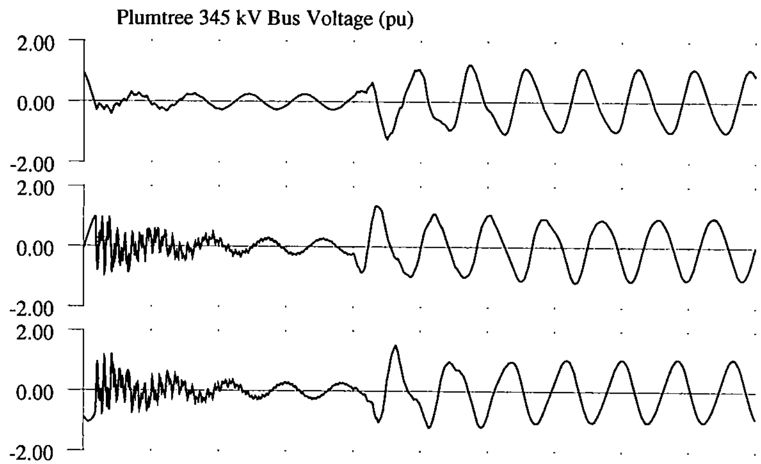
PH2P_BDF_02

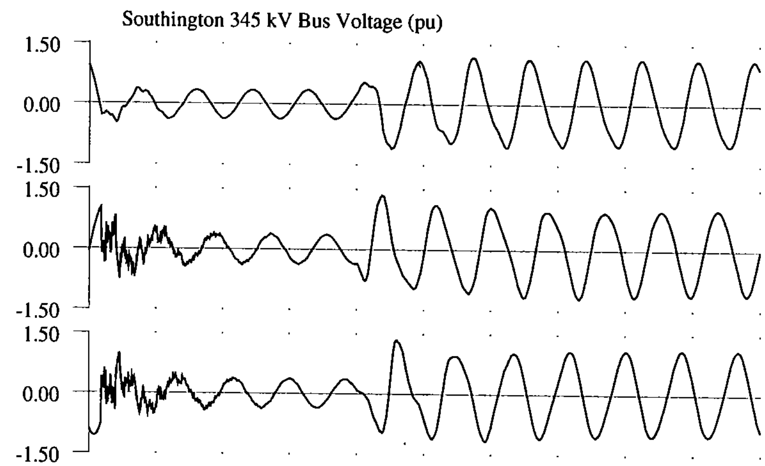
345 kV Bus Voltages

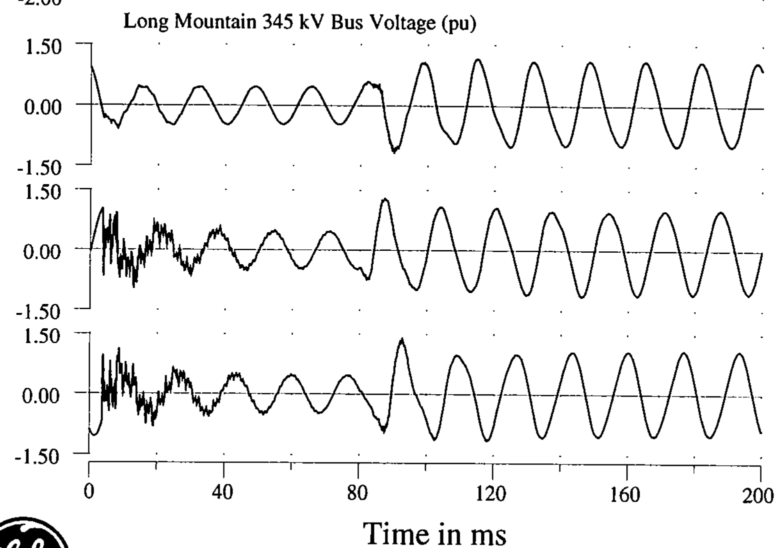


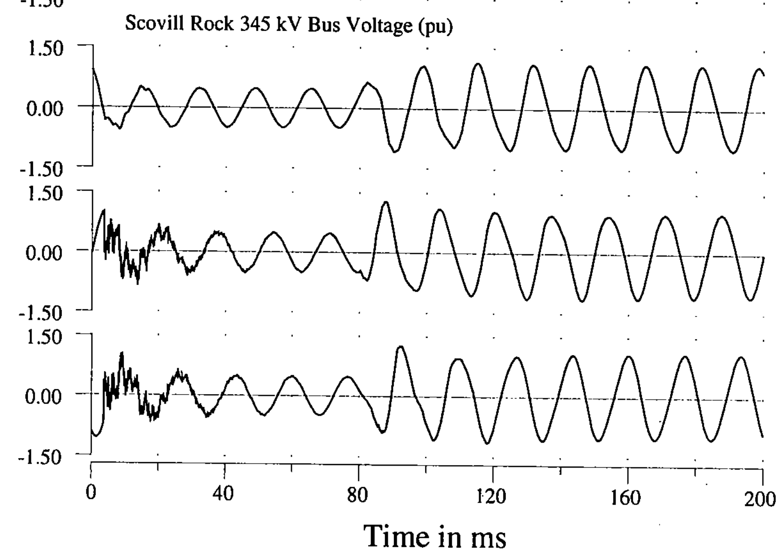


Northeast Utilities: Phase 2 Cable Transient Study
PH2P_BDF_02
345 kV Bus Voltages





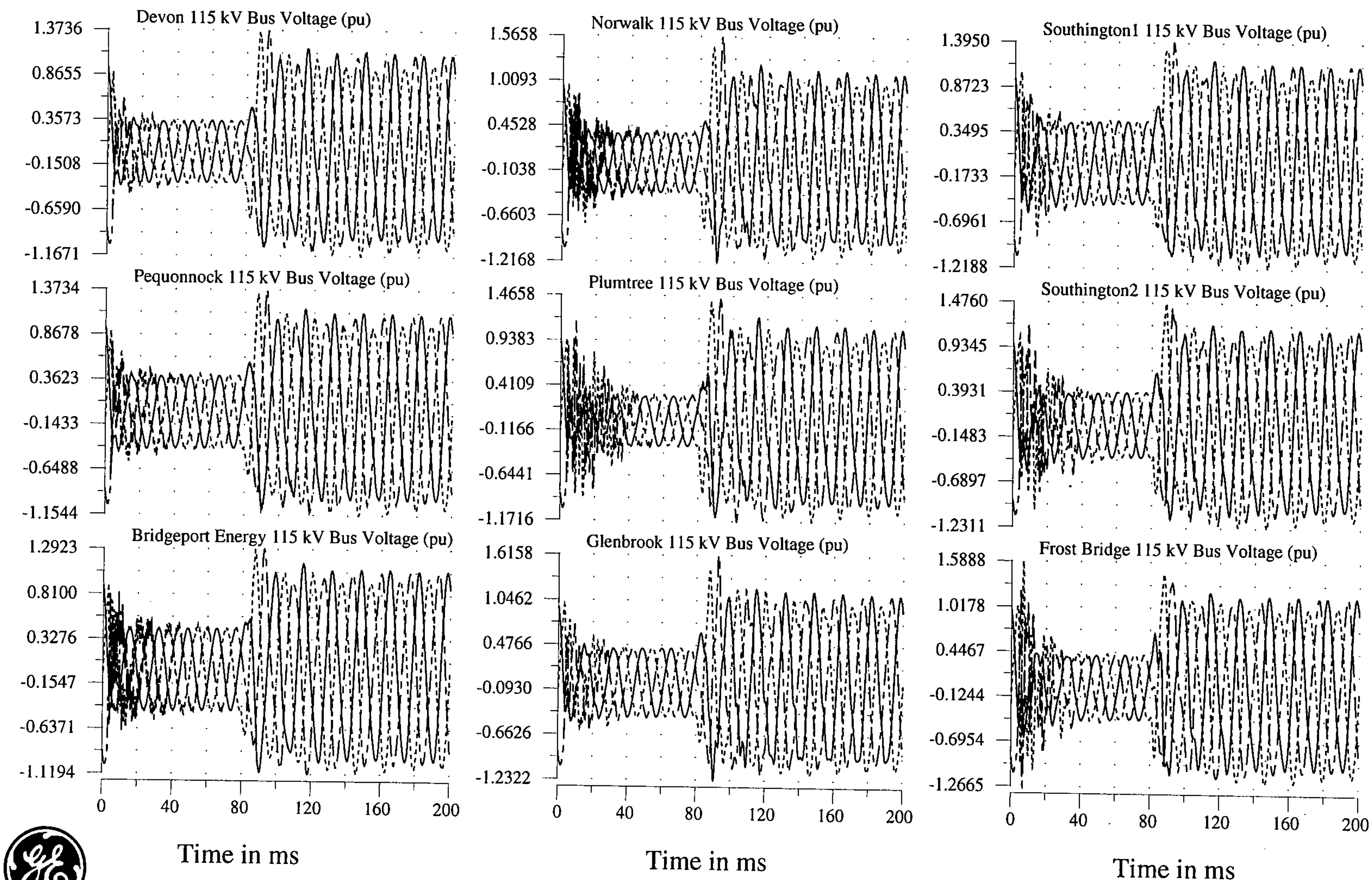




Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_02

115 kV Bus Voltages and Capacitor Bank Locations

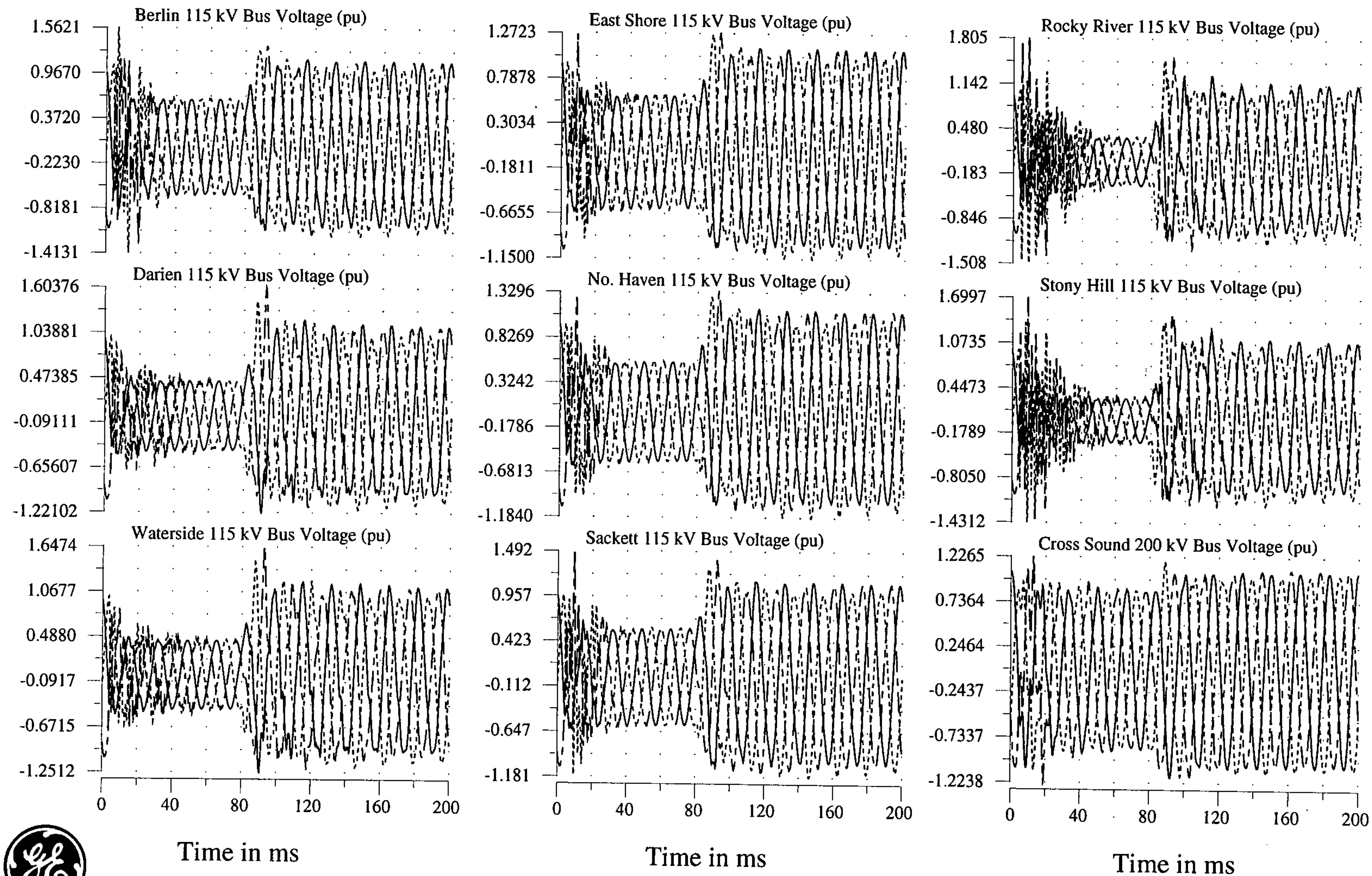


07-Nov-03 17:35:27 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_02

115 kV Bus Voltages and Capacitor Bank Locations

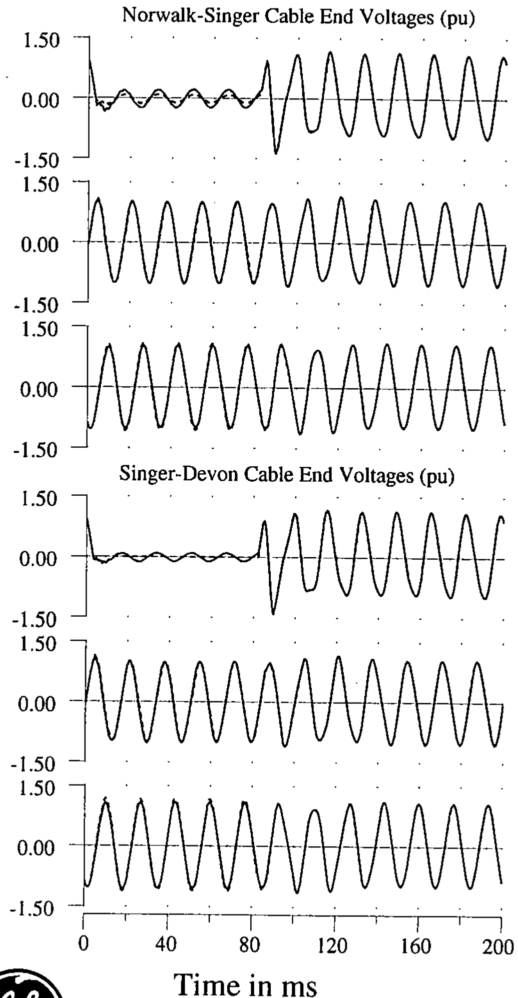


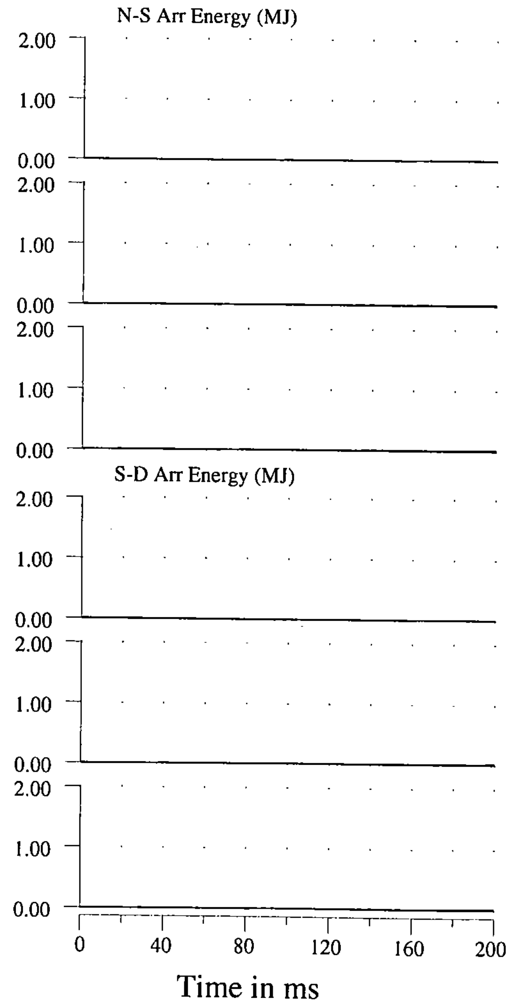
07-Nov-03 17:35:27 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_02.PL4

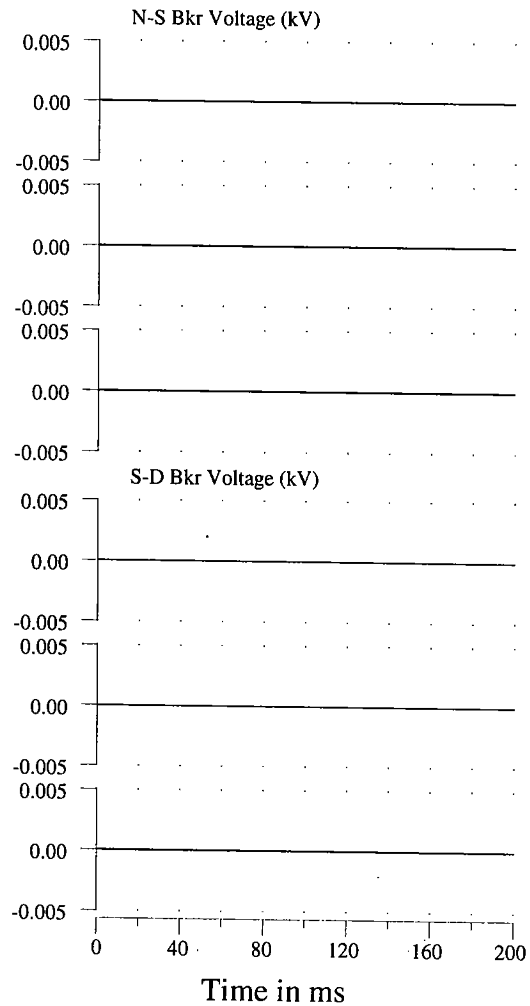
Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_03

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)





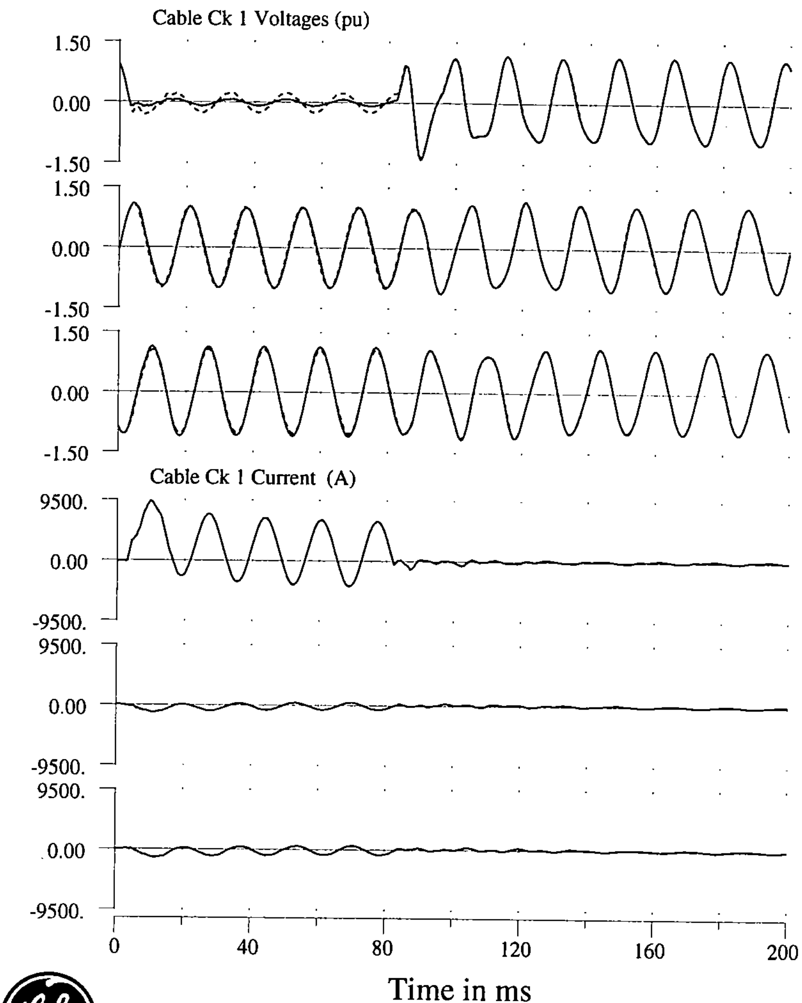


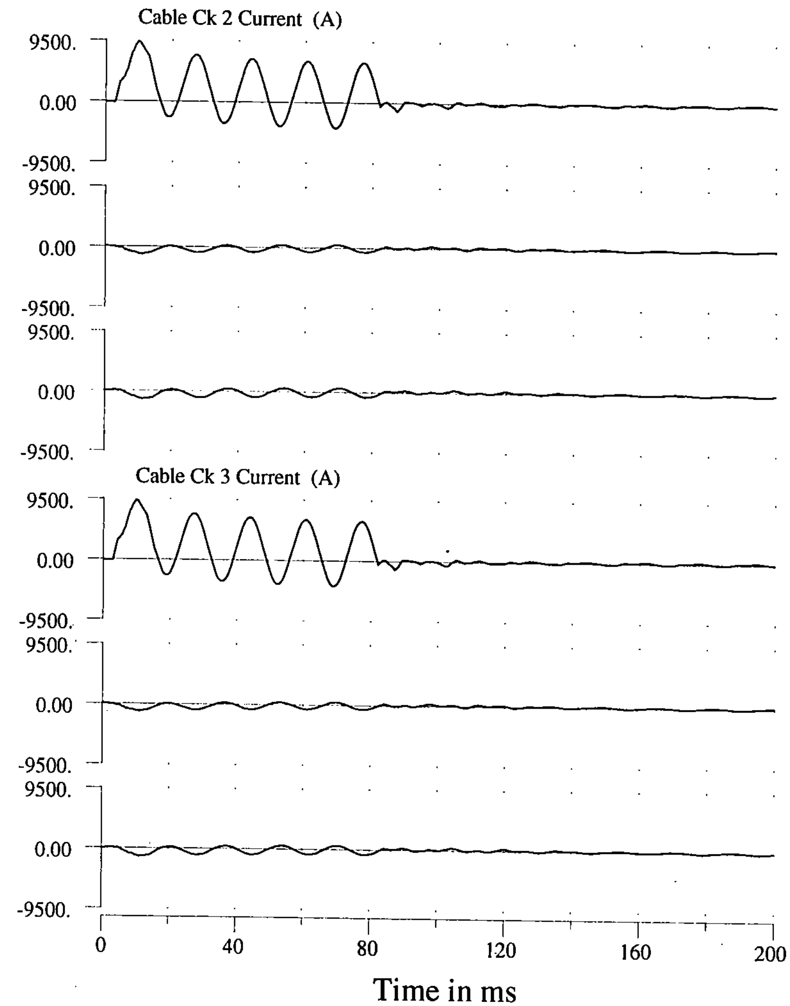
07-Nov-03 17:38:55 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_03

Devon-Beseck 345 kV Cables



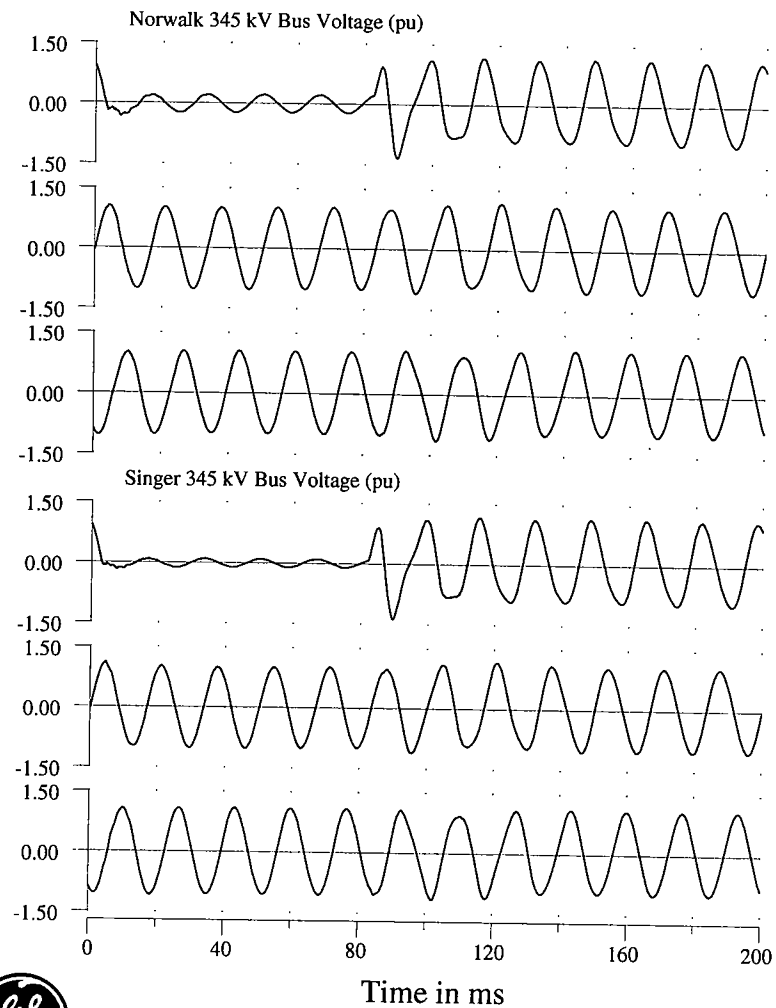


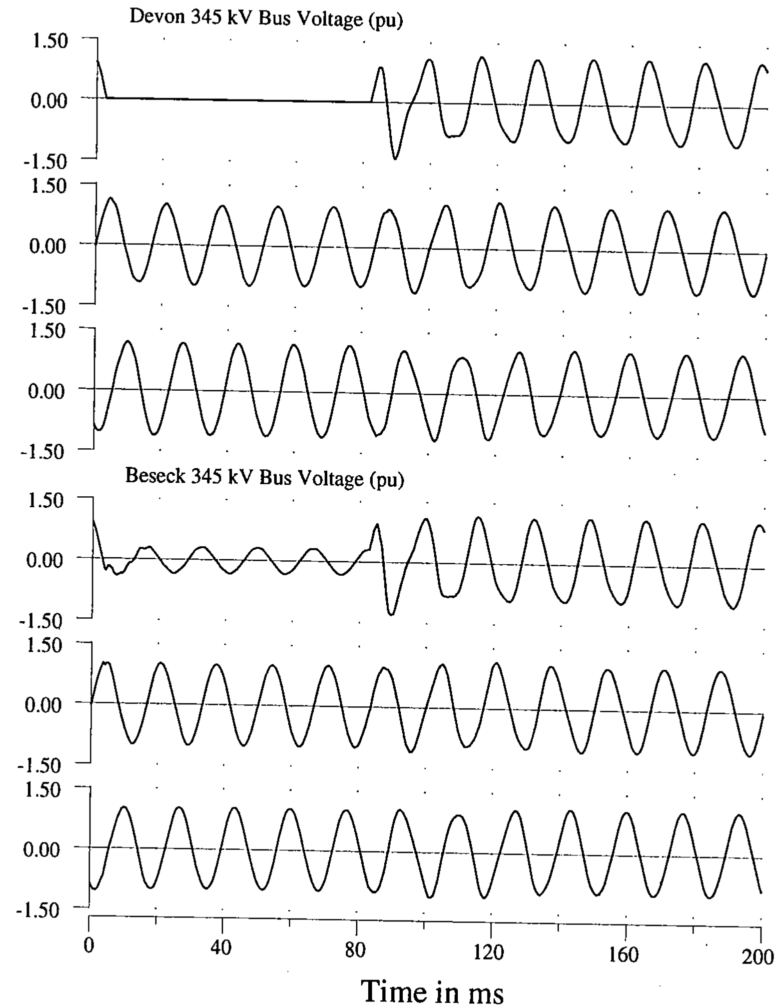
07-Nov-03 17:38:55 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_BDF_03

345 kV Bus Voltages





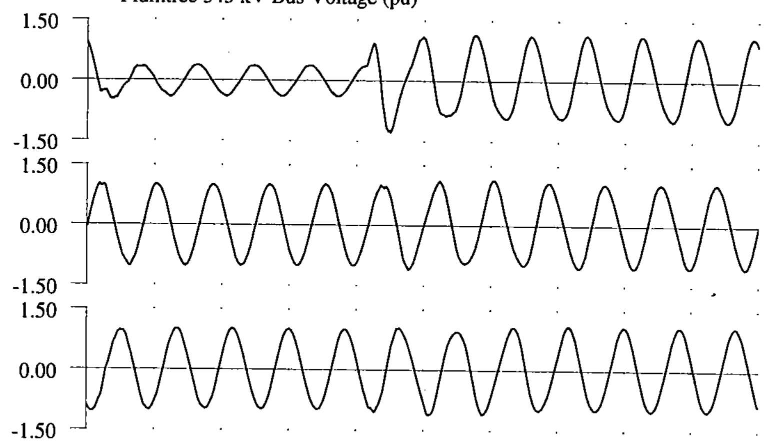
07-Nov-03 17:38:55 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

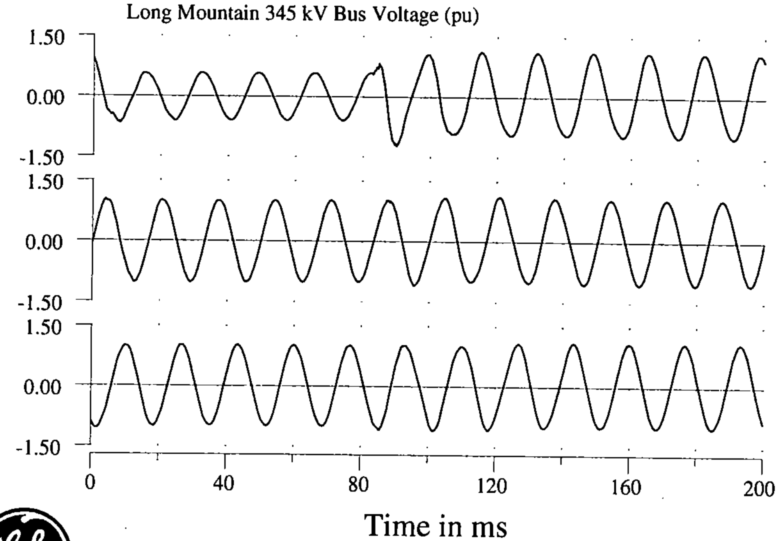
PH2P_BDF_03

345 kV Bus Voltages

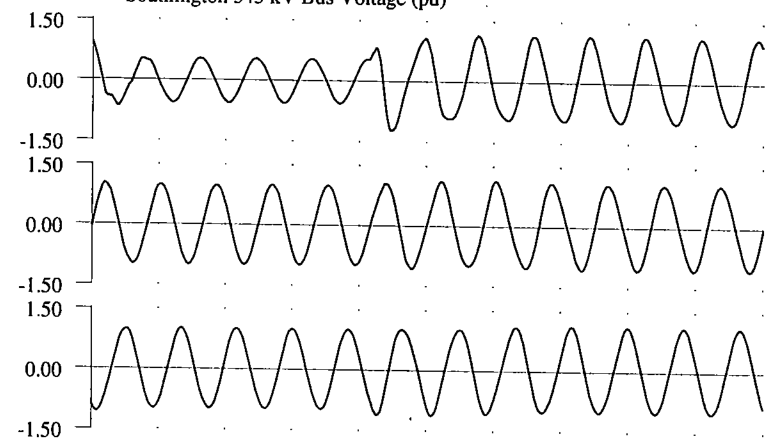
Plumtree 345 kV Bus Voltage (pu)



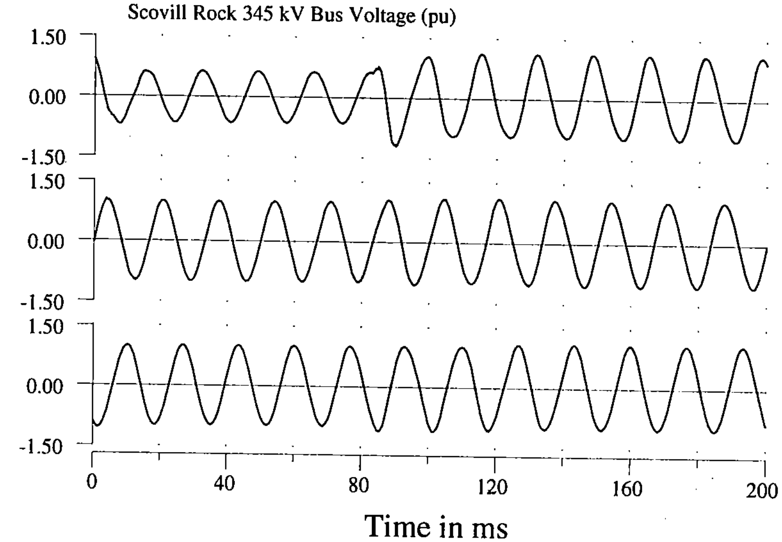
Long Mountain 345 kV Bus Voltage (pu)



Southington 345 kV Bus Voltage (pu)



Scovill Rock 345 kV Bus Voltage (pu)

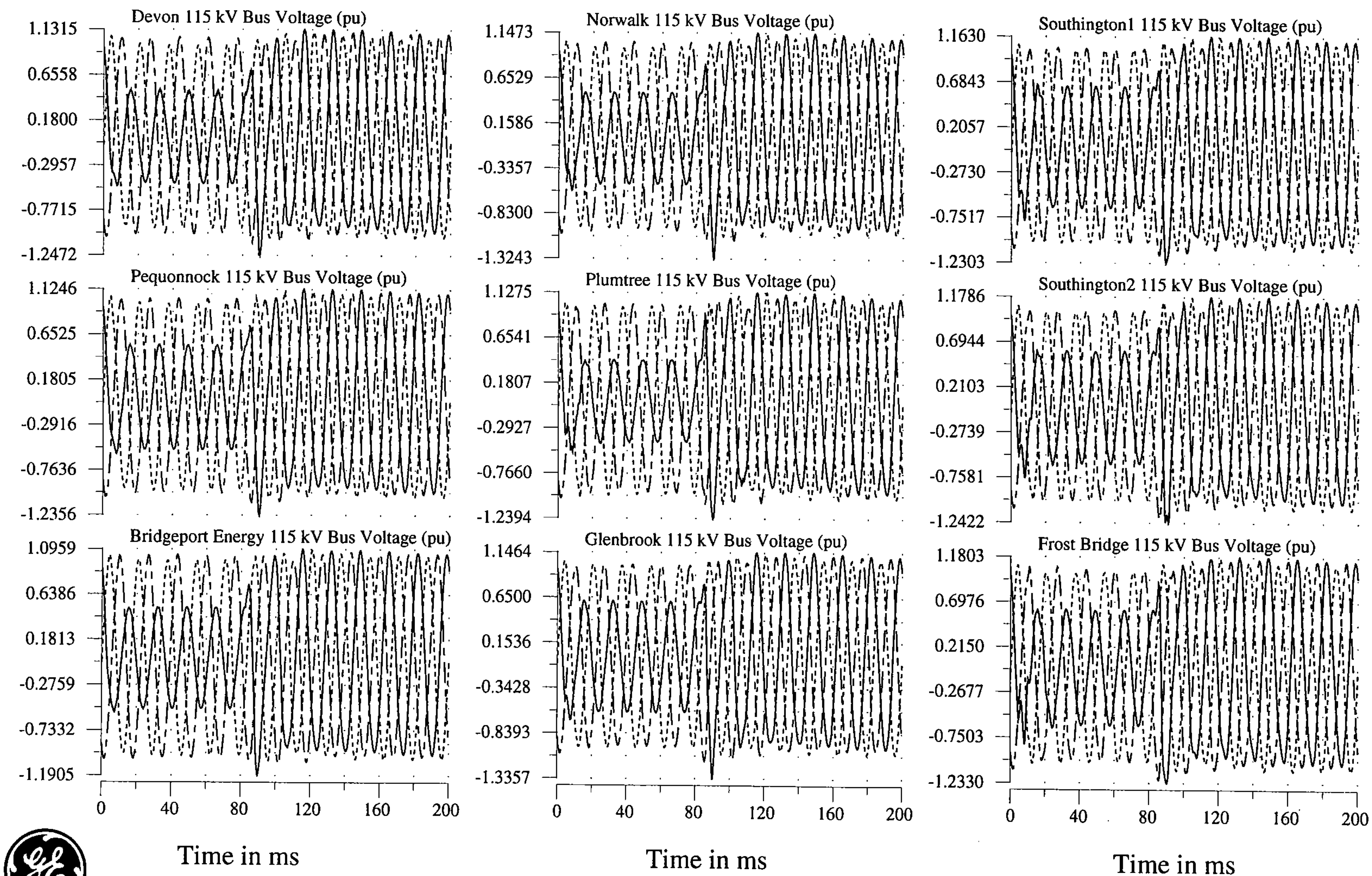


07-Nov-03 17:38:55 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

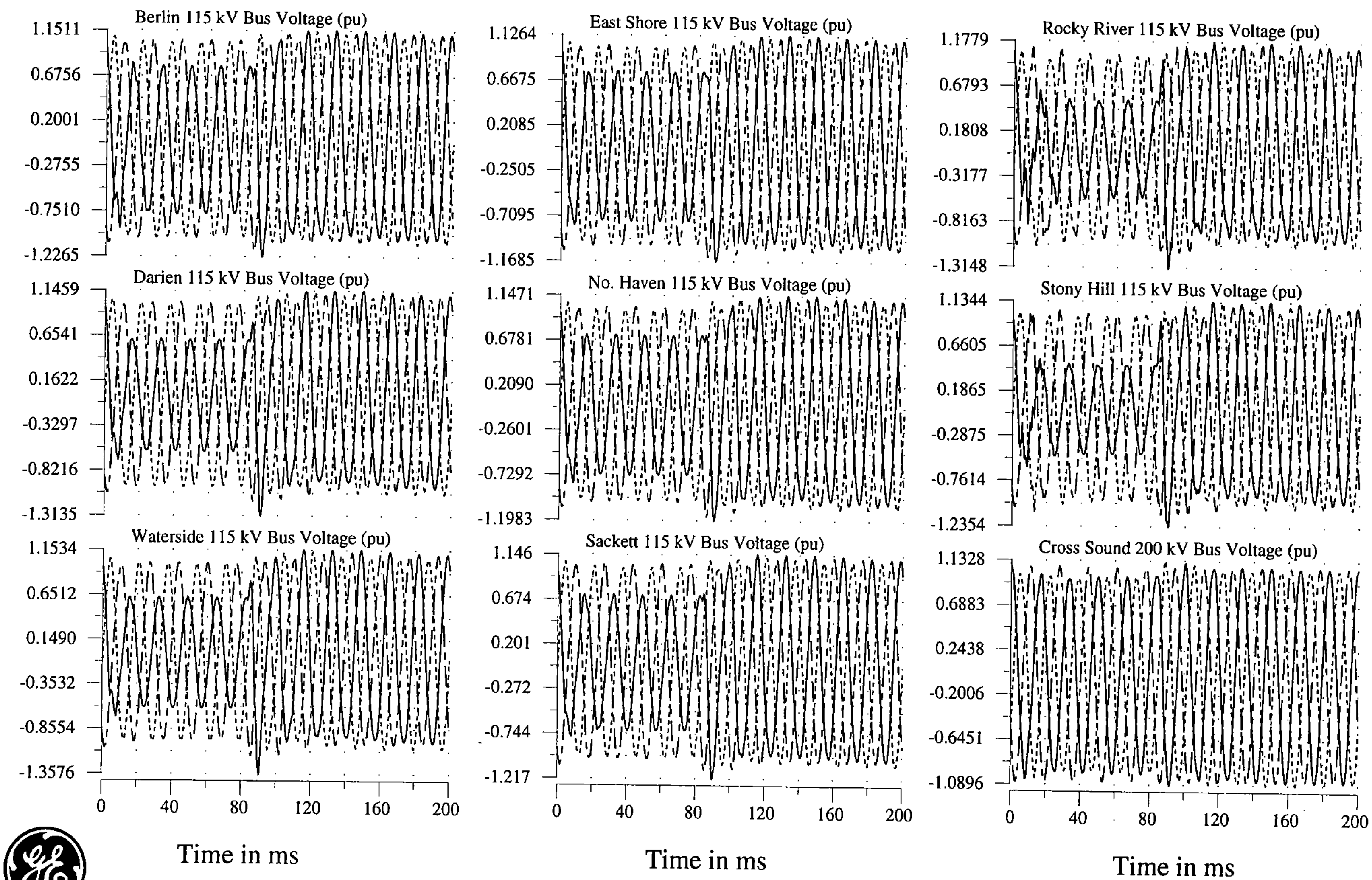
PH2P_BDF_03

115 kV Bus Voltages and Capacitor Bank Locations



07-Nov-03 17:38:55 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_BDF_03
115 kV Bus Voltages and Capacitor Bank Locations

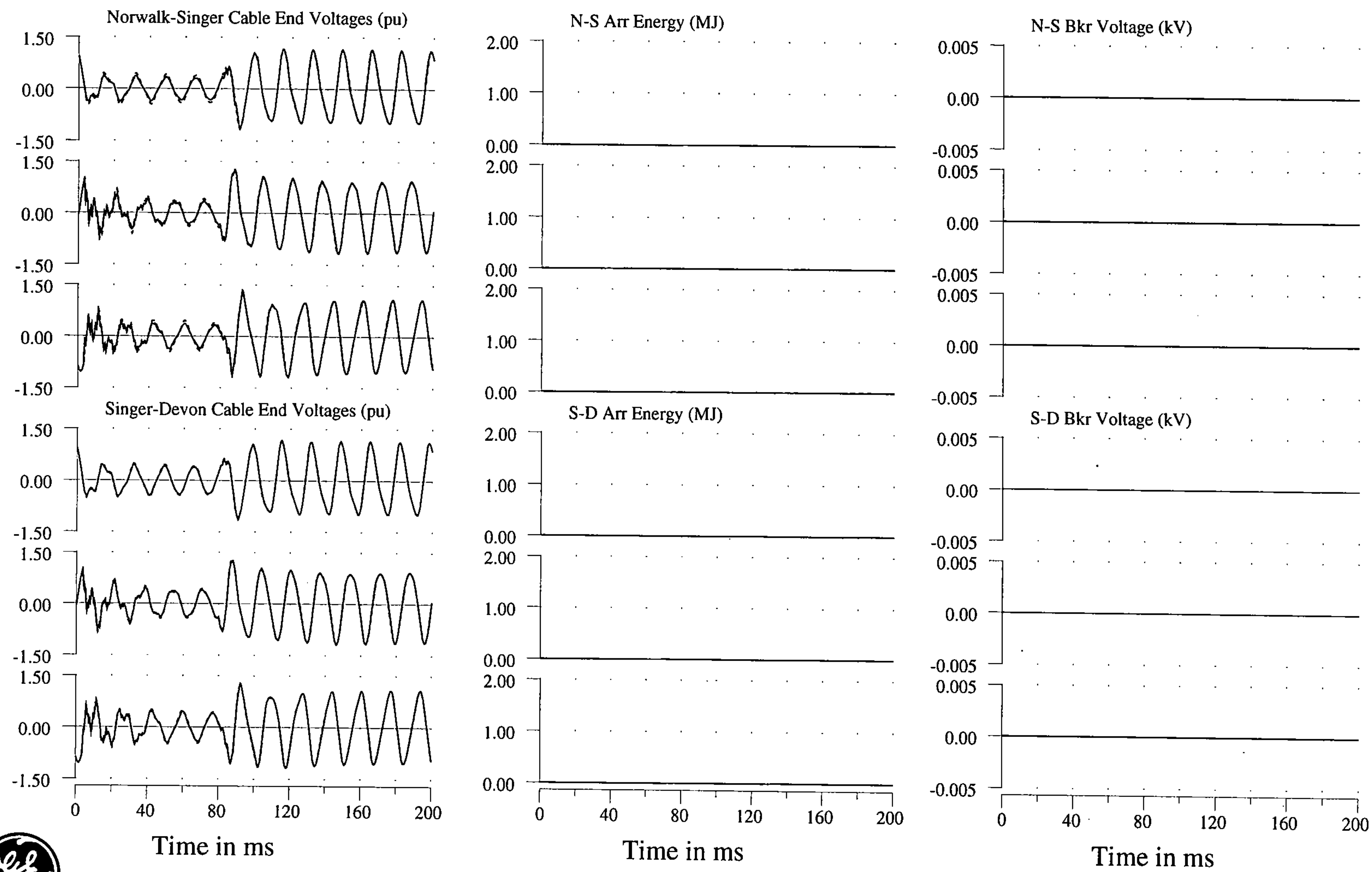


07-Nov-03 17:38:55 C:\Projects\atp\NU_PHASE2P\ps\PH2P_BDF_03.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_01

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

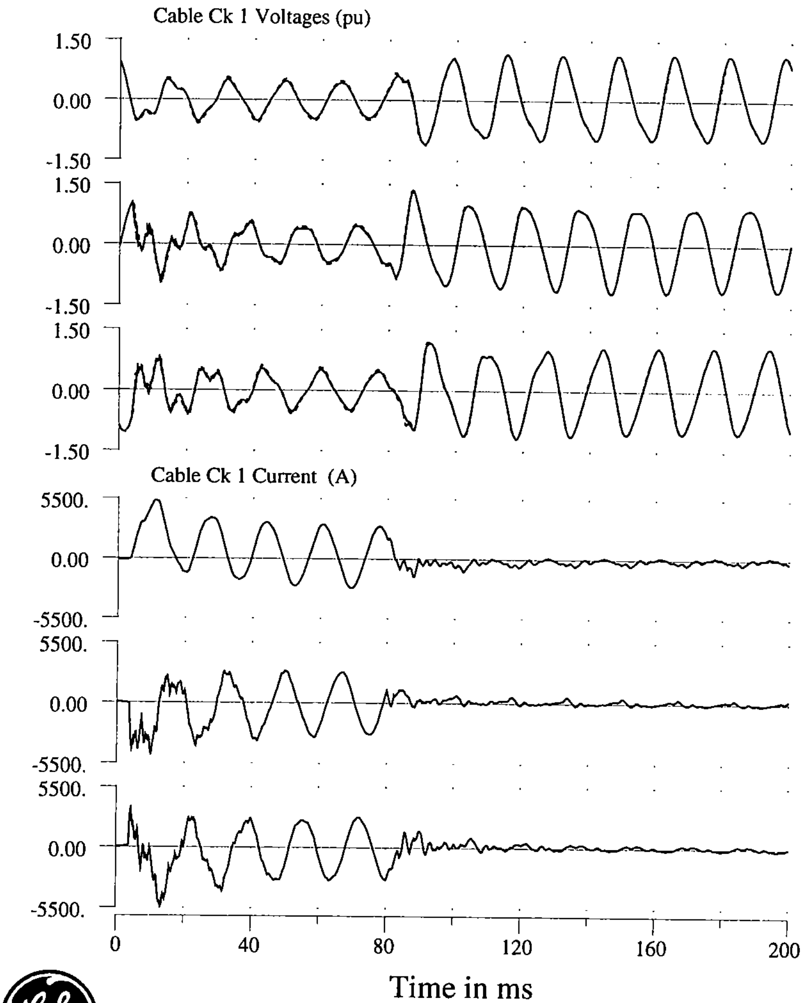


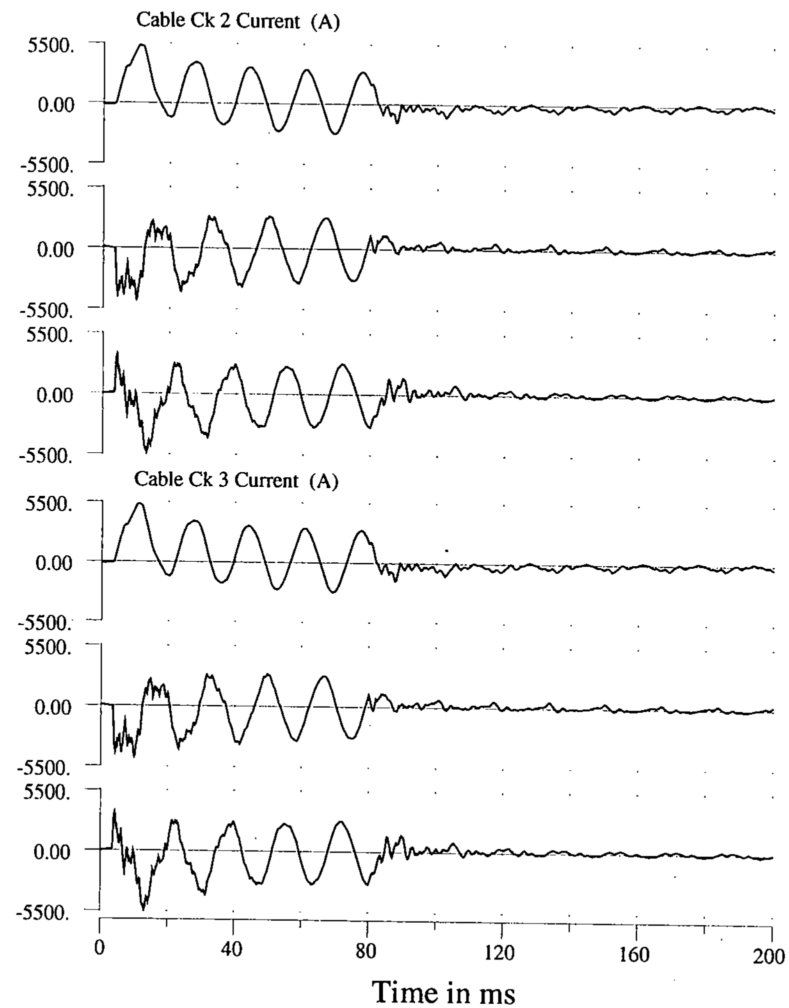
07-Nov-03 17:42:32 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

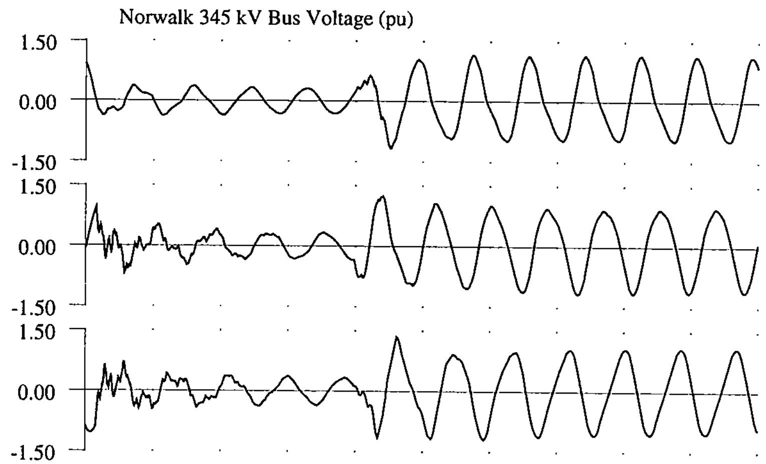
PH2P_PF_01

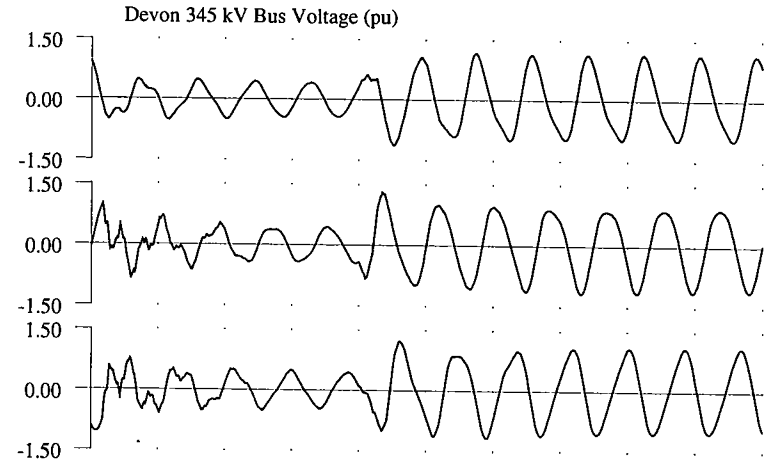
Devon-Beseck 345 kV Cables

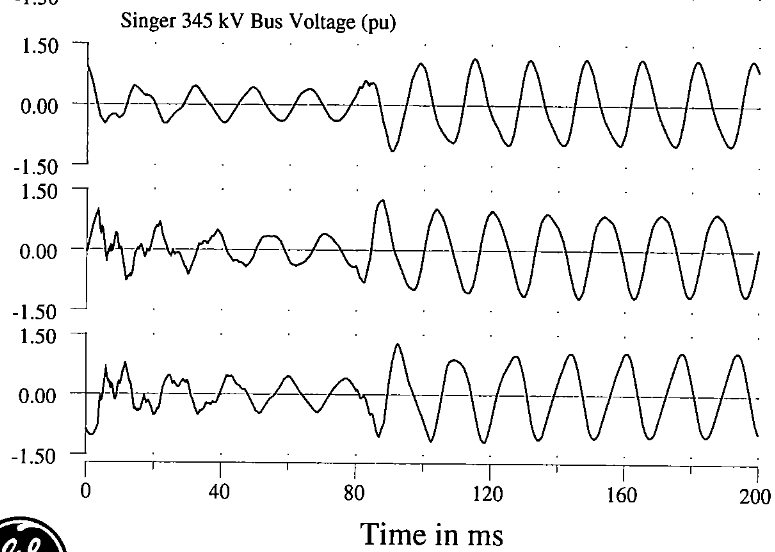


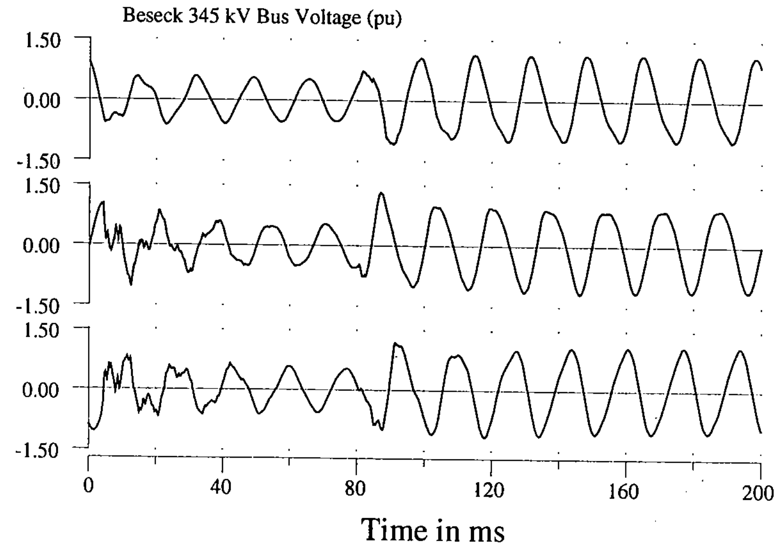


Northeast Utilities: Phase 2 Cable Transient Study
PH2P_PF_01
345 kV Bus Voltages







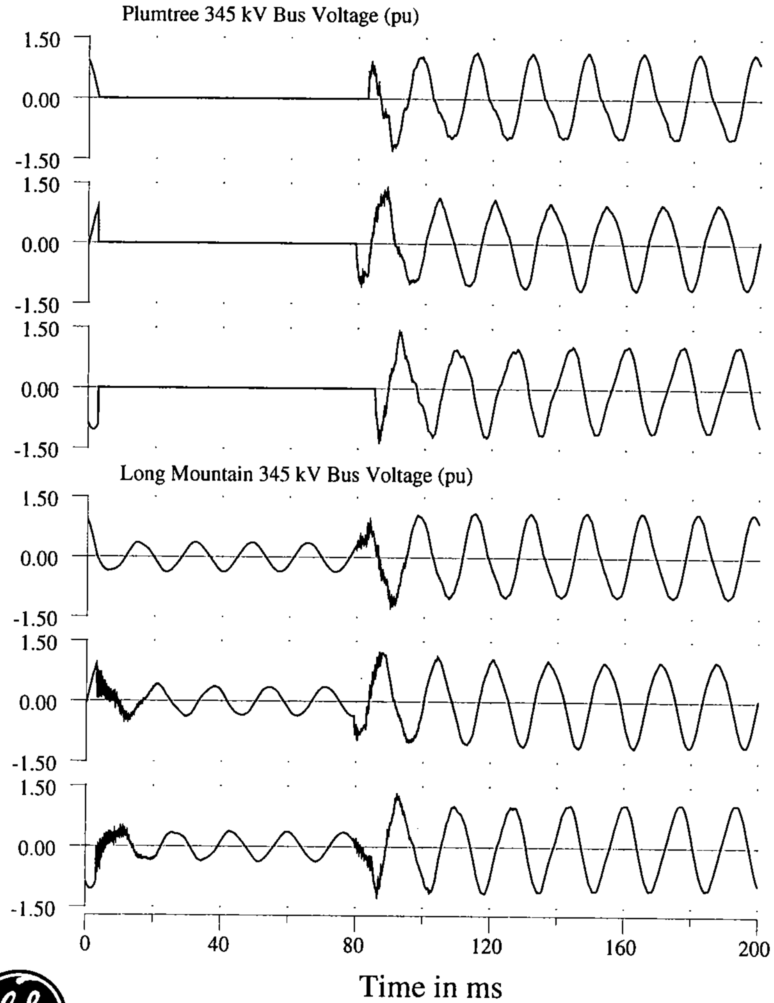


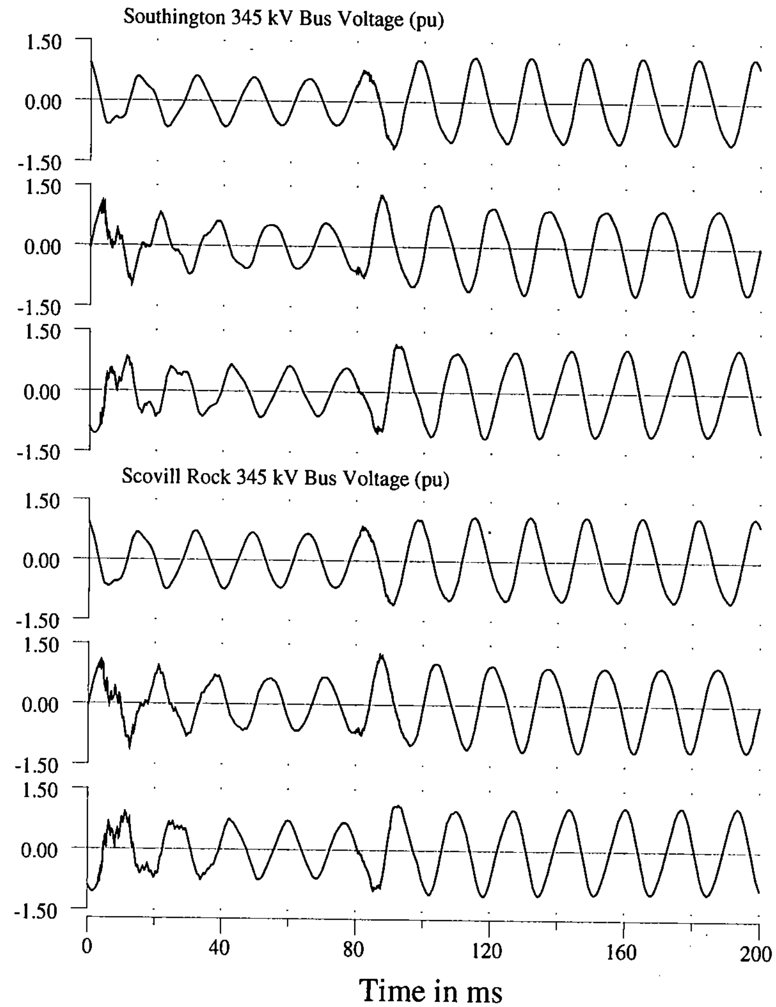
07-Nov-03 17:42:32 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_01

345 kV Bus Voltages



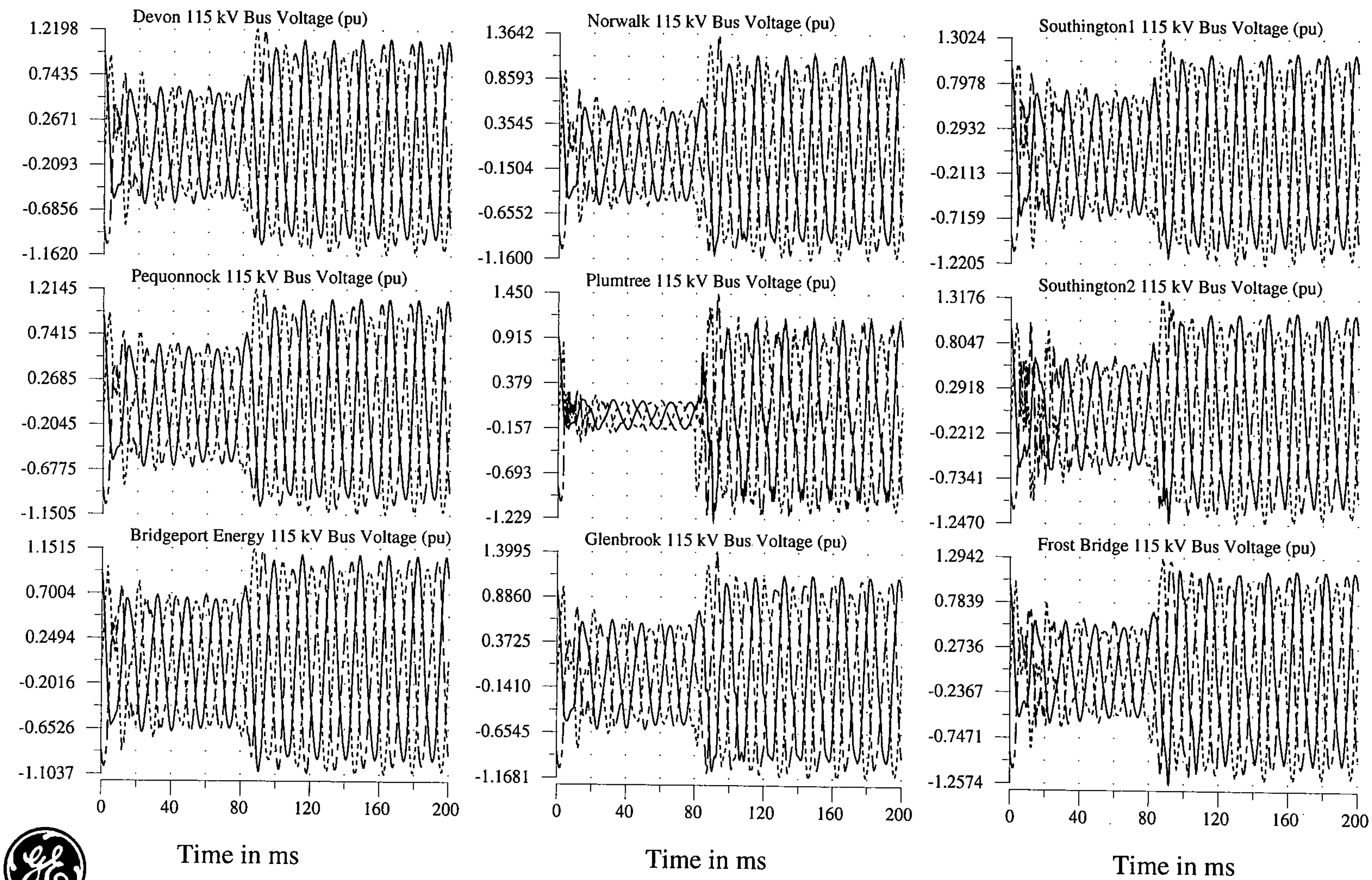


07-Nov-03 17:42:32 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_01

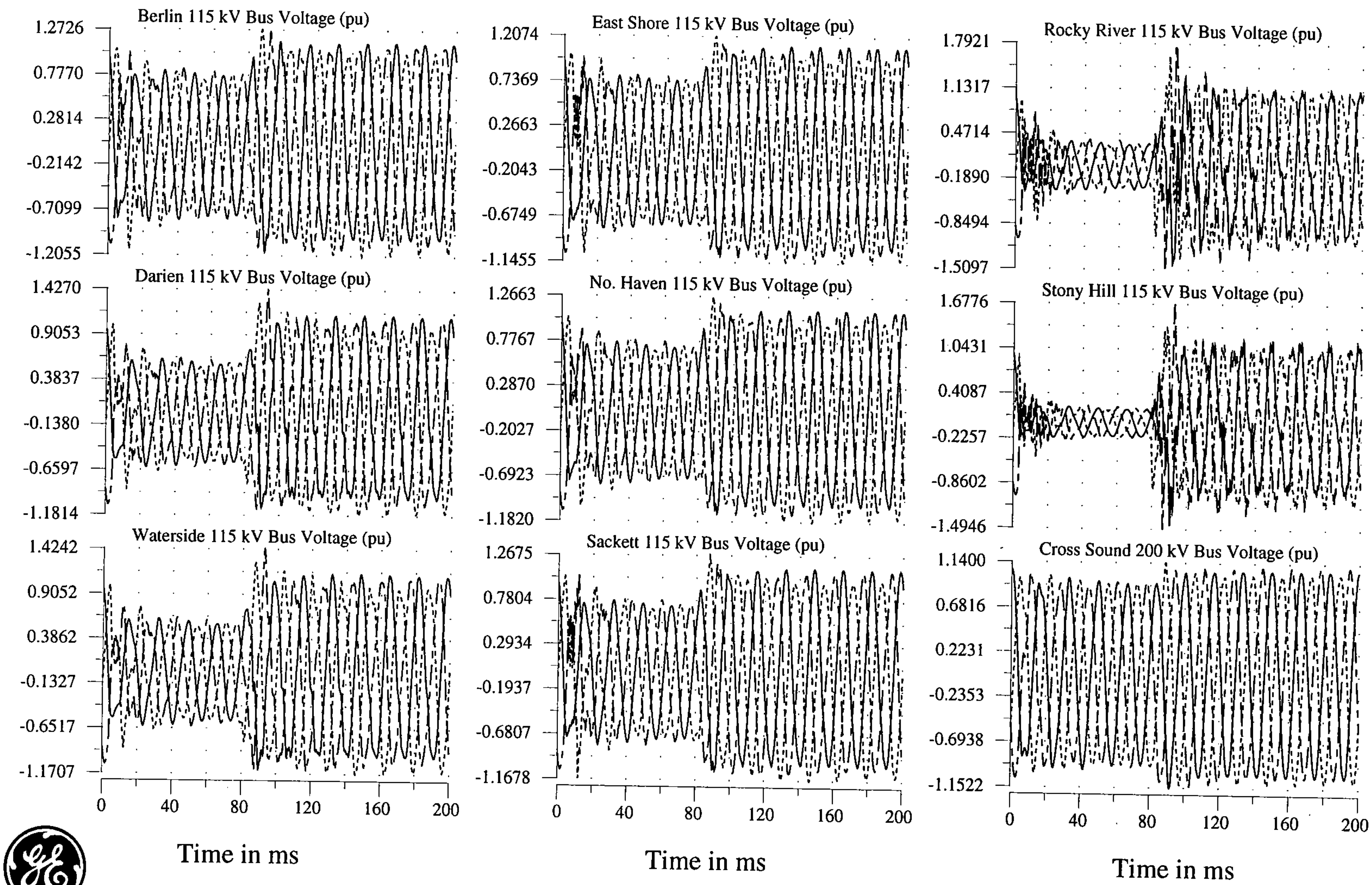
115 kV Bus Voltages and Capacitor Bank Locations



Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_01

115 kV Bus Voltages and Capacitor Bank Locations

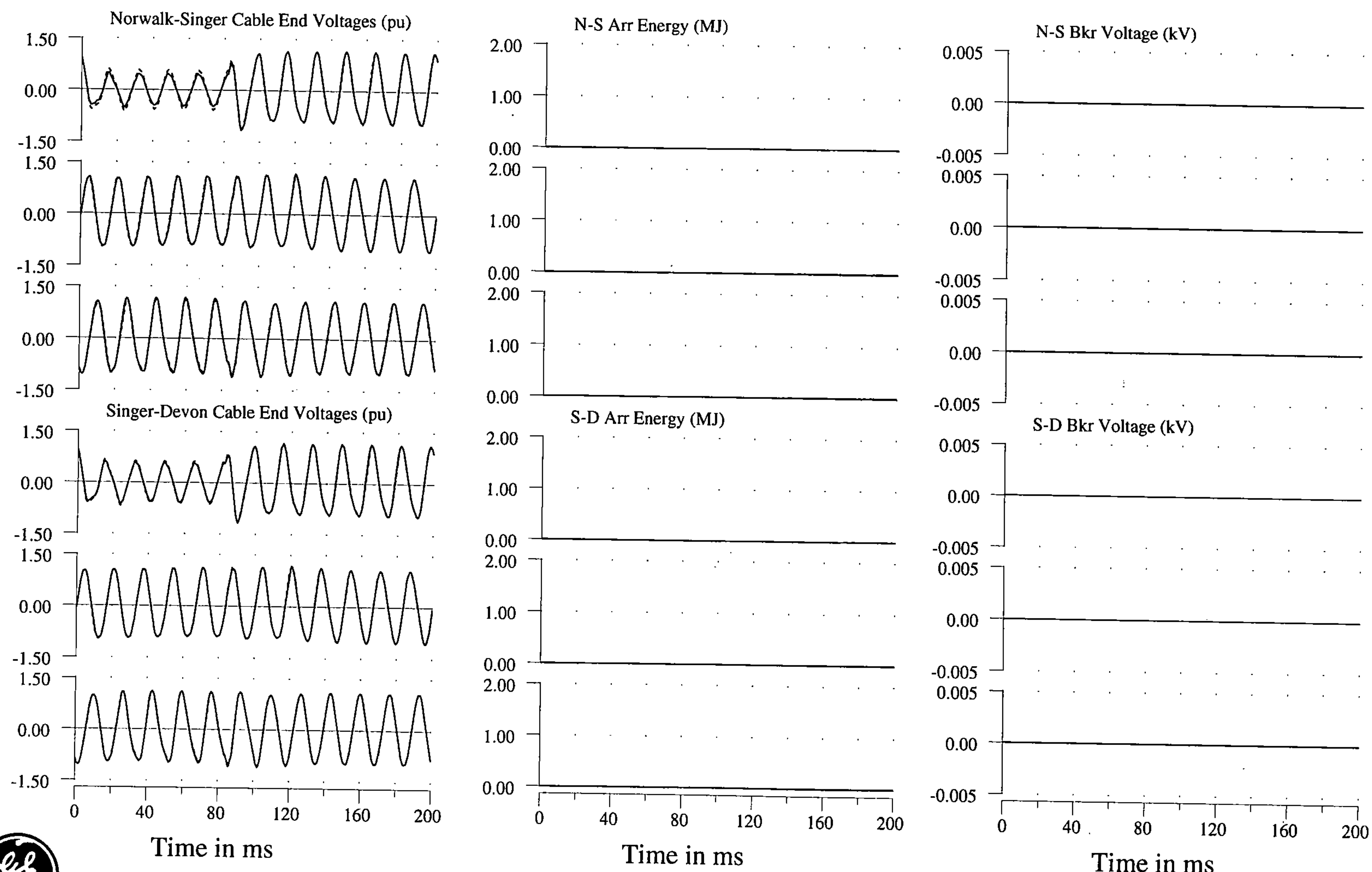


07-Nov-03 17:42:32 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_01.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_02

Case Summary Plots for Phase 2 345 kV Cables (Ck 1)

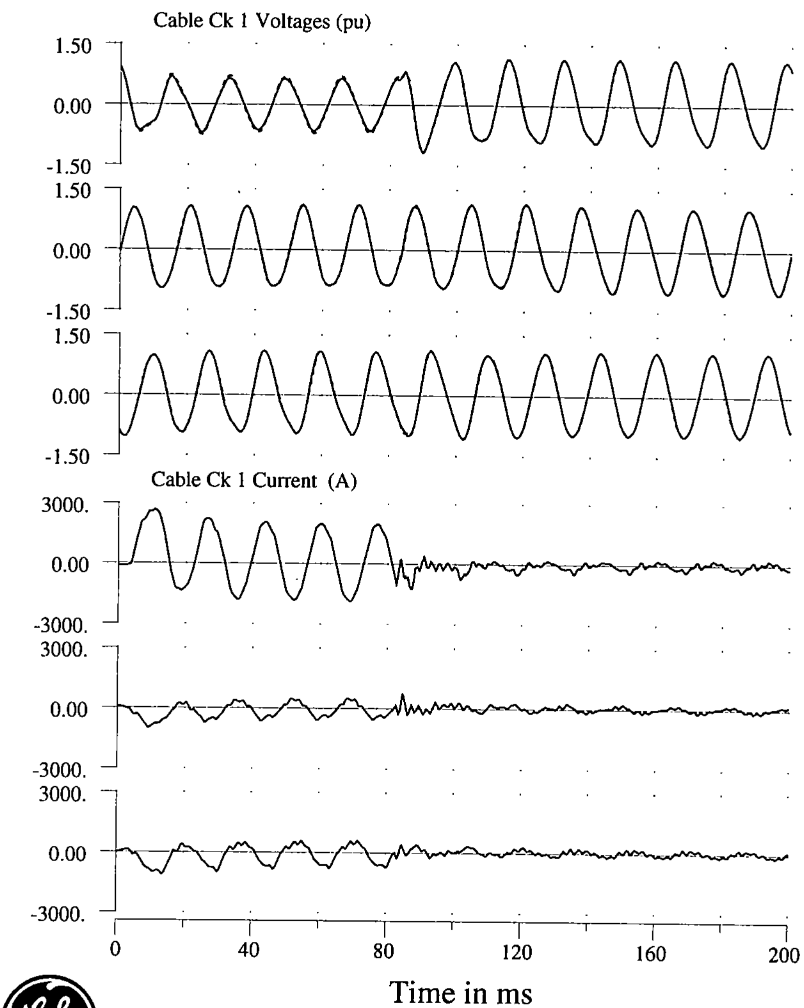


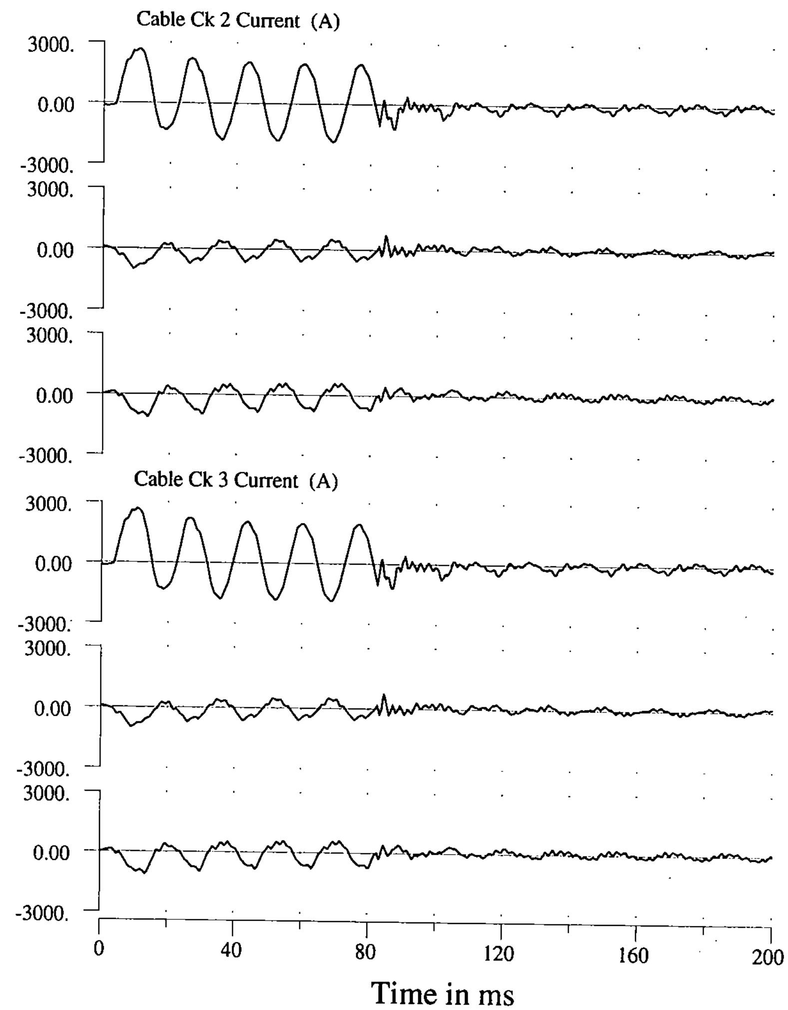
07-Nov-03 17:44:14 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_02

Devon-Beseck 345 kV Cables

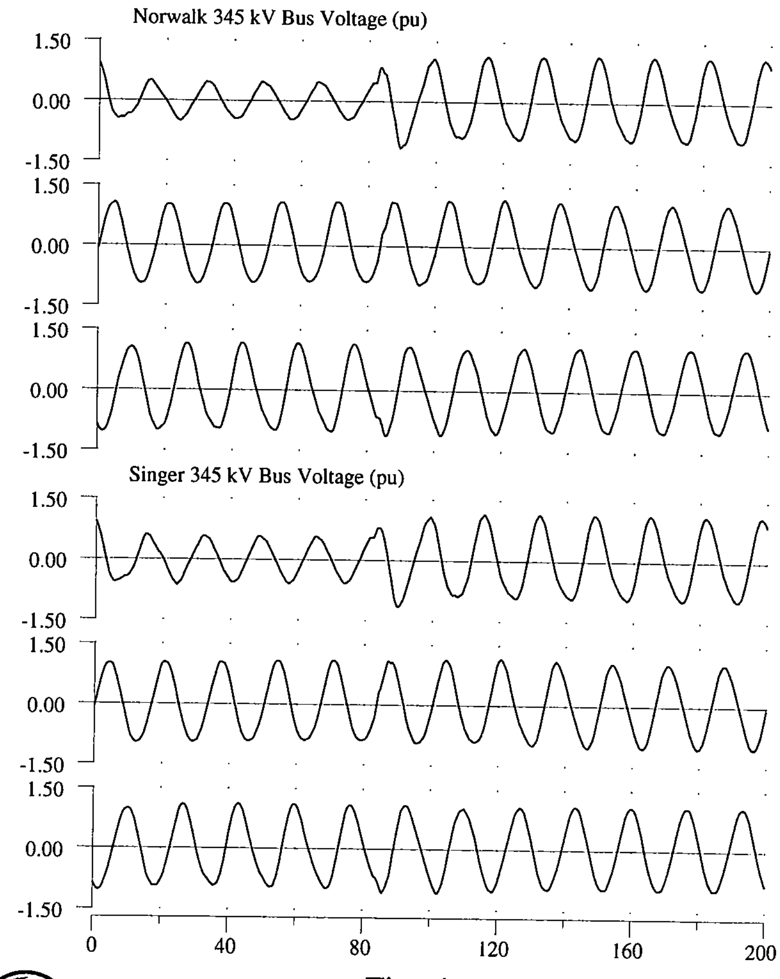


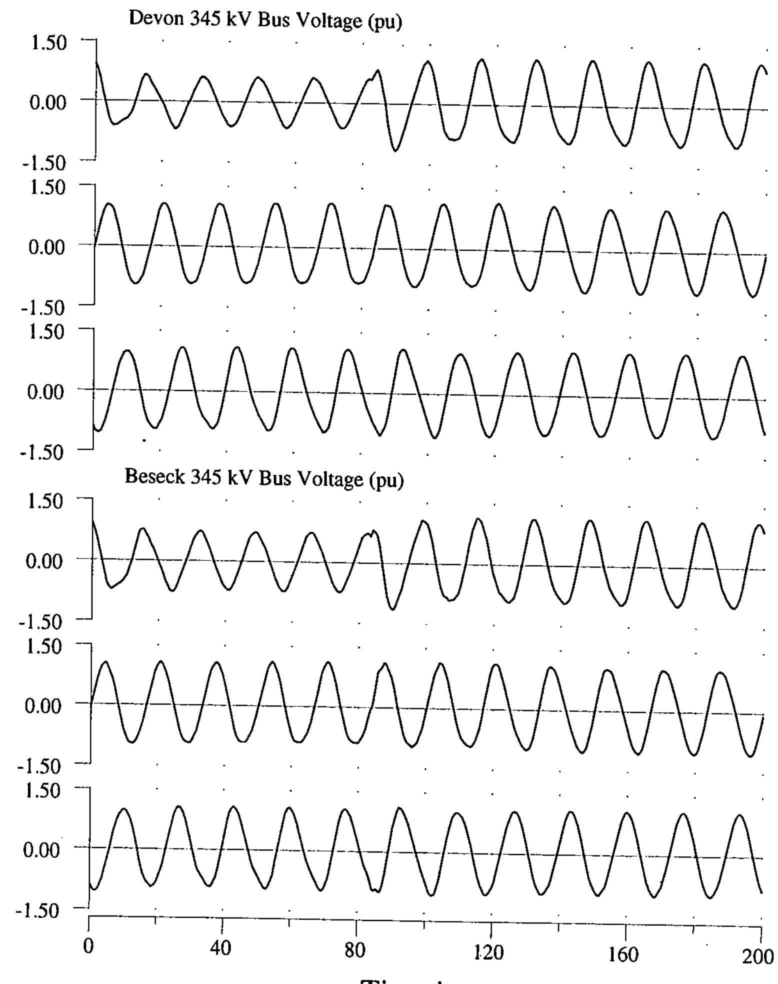


Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_02

345 kV Bus Voltages



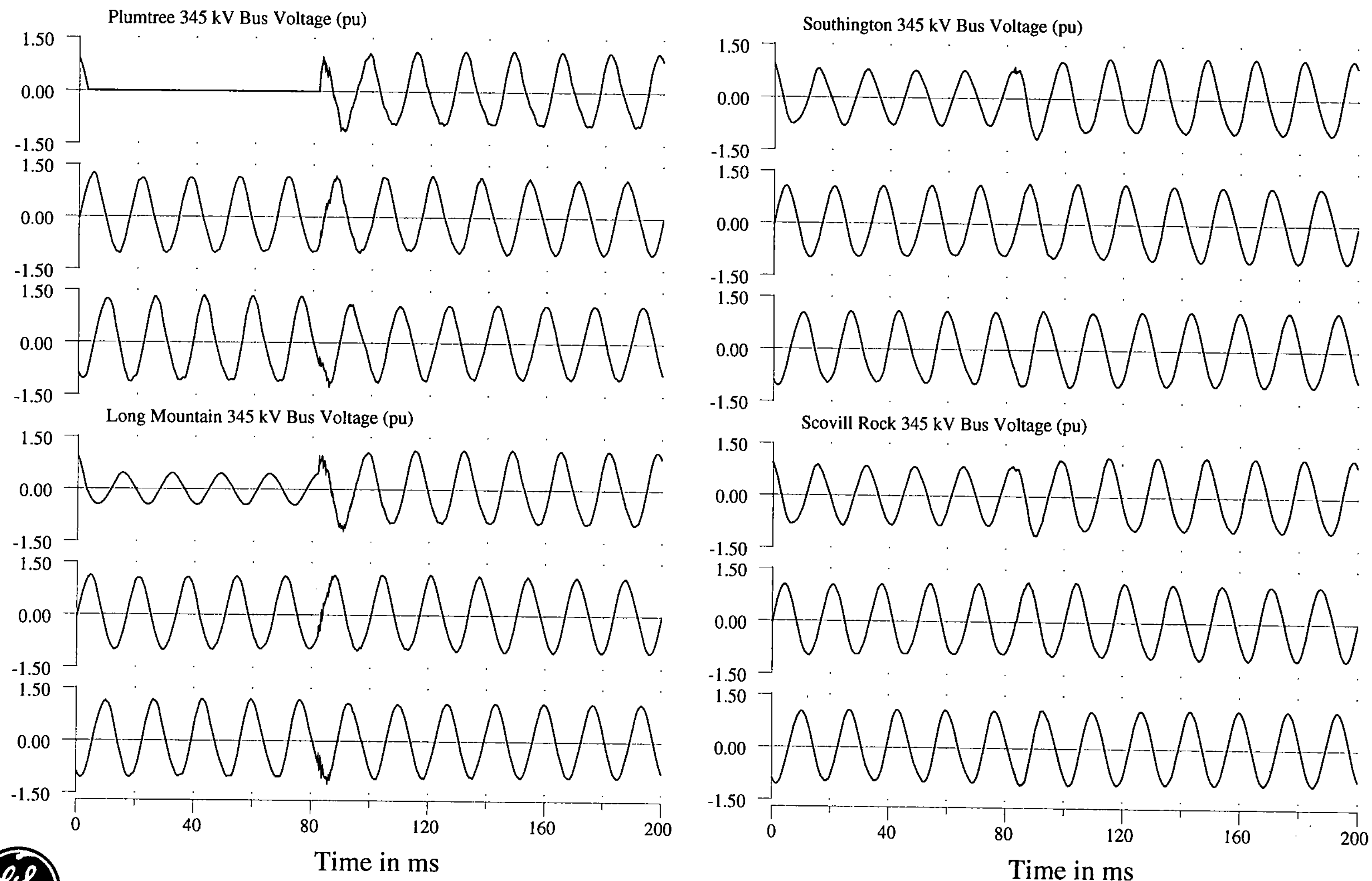


07-Nov-03 17:44:14 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

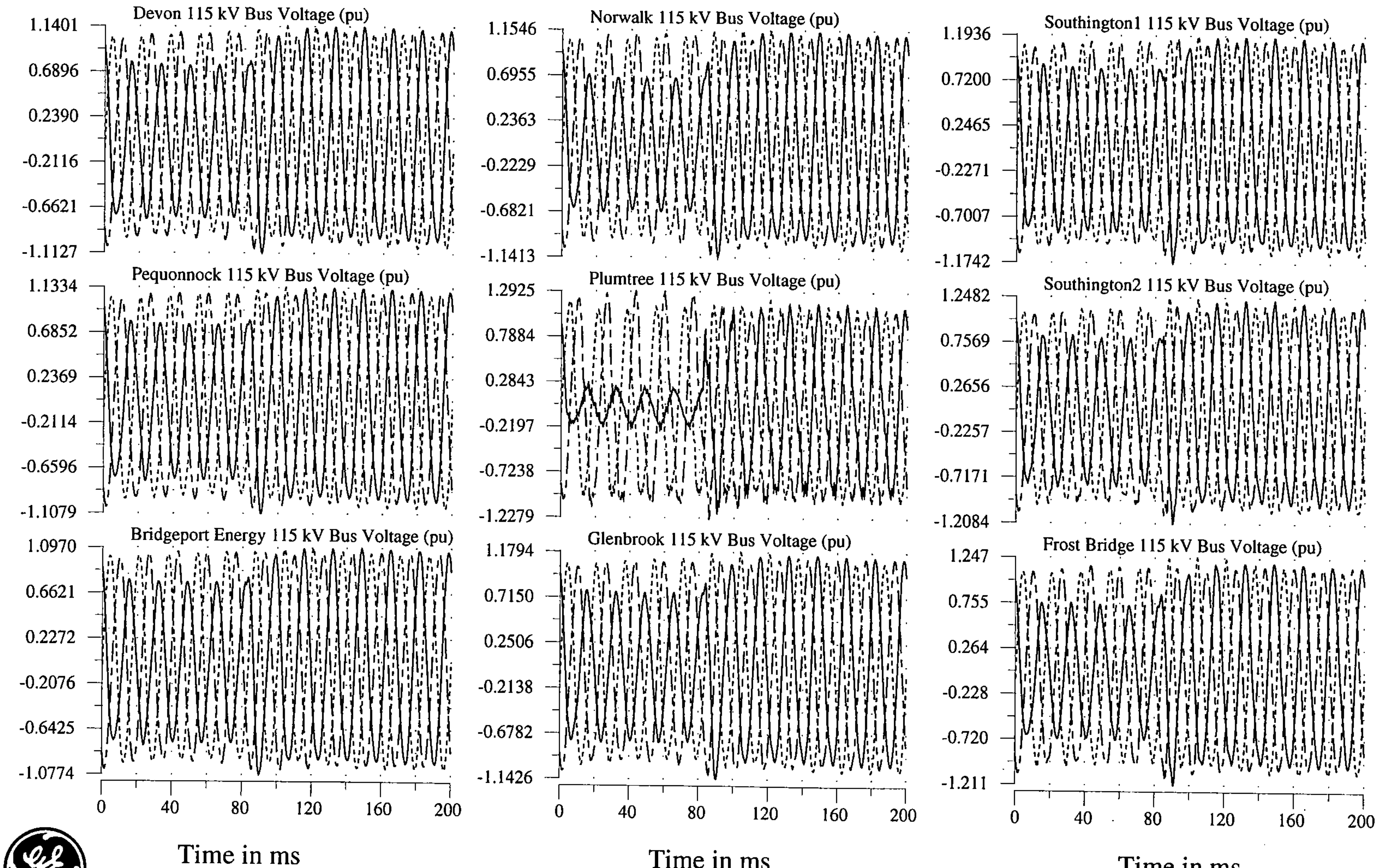
PH2P_PF_02

345 kV Bus Voltages



07-Nov-03 17:44:14 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study
PH2P_PF_02
115 kV Bus Voltages and Capacitor Bank Locations

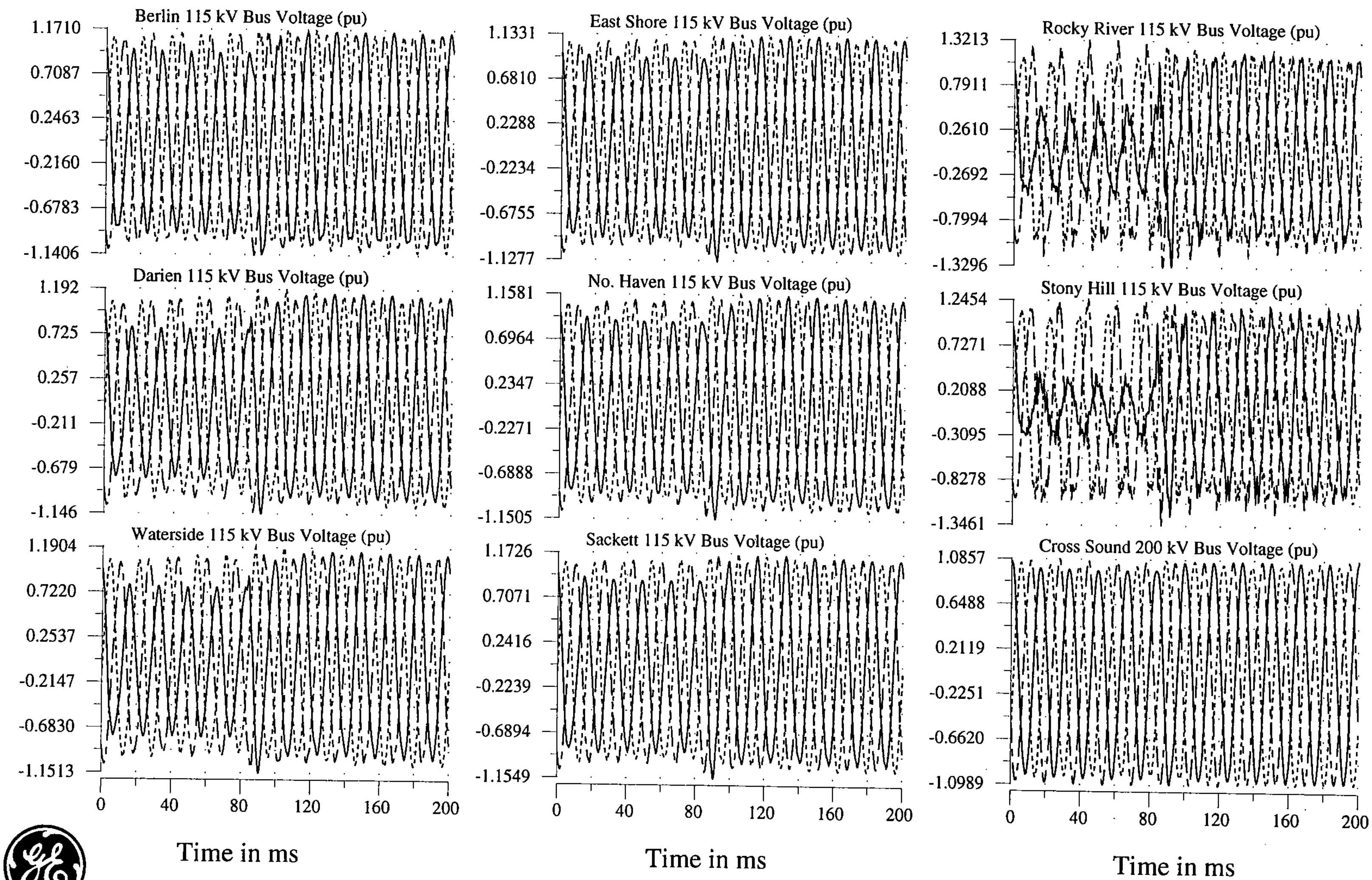


07-Nov-03 17:44:14 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_02.PL4

Northeast Utilities: Phase 2 Cable Transient Study

PH2P_PF_02

115 kV Bus Voltages and Capacitor Bank Locations



07-Nov-03 17:44:14 C:\Projects\atp\NU_PHASE2P\ps\PH2P_PF_02.PL4