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This draft report is Burns & McDonnell working progress document to seek the comments from Burns & McDonnell, UI, and NU. After reviewed by the related parties, the draft will be revised based on the comments provided.

EXECUTIVE SUMMARY

Executive summary will be provided after the report is revised for the comments.

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DRAFT

PART I INTRODUCTION

The Independent System Operator New England (ISO-NE) issued its “Southwestern Connecticut Electric Reliability Study” in December 2002. The ISO-NE study proposed a solution to the reliability problems in Southwestern Connecticut (SWCT) which consisted of virtually all overhead transmission facility construction. The improvement project was split into two line segments for construction purposes. One new line segment would run from Bethel to Norwalk and the other new line segment would extend from Middletown to Norwalk.

Northeast Utilities System (NU) retained Burns & McDonnell to provide a “Switching Transient Study of the Middletown – Norwalk Transmission Facilities” (Switching Study). The Middletown – Norwalk transmission facilities would be located in SWCT. After issuance of the ISO-NE study in December 2002, preliminary line routing investigations indicated that part of the Middletown – Norwalk transmission facilities may be constructed as underground cable rather than the overhead lines studied by ISO-NE.

The Switching Study provided by Burns & McDonnell was to investigate the transient over-voltages that may result from switching the underground cable circuits being considered between Middletown and Norwalk. Although underground cables are also being considered for the facilities between Bethel and Norwalk, the switching events on Bethel to Norwalk sections were investigated separately by NU. Therefore, this report does not consider switching events of the Bethel to Norwalk facilities that may cause transient over-voltages on the system.

The report is presented in the following five main parts:

- Part I – Introduction
- Part II – Study Assumption
- Part III – Modeling Data
- Part IV – Switching Transient Analysis
- Part V – Conclusions and Recommendations

OVERVIEW OF STUDY PURPOSE

Following switching to energize or de-energize the transmission line, a switching transient over-voltage is created and travels along the line. This switching transient over-voltage will reach its highest levels at the transition points connecting the underground cable to the overhead line.

The switching transient over-voltage is a short-duration voltage surge, which can be created by in-rush current, charging capacitance and arcing due to breaker switching. This voltage surge can be magnified significantly by the charging capacitance of an Extra High Voltage (EHV) transmission line, especially for long underground cable circuits. The charging capacitance of a high-pressure fluid-filled (HPFF) 2500 kcmil underground cable circuit operating at 345 kV is about 21 MVar/mile while the charging capacitance of a 1590 kcmil Aluminum Conductor Steel Reinforced (ACSR) overhead circuit operating at 345 kV is less than 1 MVar/mile.

During the transient time frame, the oscillating over-voltage will exceed the normal operating voltage. The oscillating over-voltage will be transmitted to the lower voltage level system through the substation transformers. The magnitude of the transient over-voltage has to be limited to avoid exceeding substation equipment surge ratings and to prevent affecting the end-use customer. Without the limitation, the over-voltage may cause damage to the system protective devices.

The transition points between the overhead and underground sections create significant line impedance discontinuities. These discontinuities within a high voltage line between two substations will increase the switching surge voltage at transition points due to the higher surge impedance of the underground cable than the overhead line. Consequently, a line configuration that alternates between long segments of overhead lines and underground cables is more vulnerable to switching transient over-voltage. The potential problems are not limited to 345 kV transmission systems. The transient over-voltage problems could spread and be magnified into the 115 kV transmission systems.

This Switching Study was performed to investigate transient over-voltages associated with the following switching conditions on the Middletown to Norwalk transmission facilities:

- closing a breaker to energize the line from each end,
- opening a breaker to de-energize the line from each end, and
- fault clearing of three phases to ground faults with stuck breaker.

In the preparation of this report, the information provided by NU and other sources was used by Burns & McDonnell to make certain assumptions with respect to conditions which may exist in the future. While Burns & McDonnell believes the assumptions made are reasonable for the purposes of this report, Burns & McDonnell makes no representation that the conditions assumed will, in fact, occur. In addition, while Burns & McDonnell has no reason to believe that the information provided by NU, and on which this report is based, is inaccurate in any material respect, Burns & McDonnell has not independently verified such information and cannot guarantee its accuracy or completeness. To the extent that actual future conditions differ from those assumed herein or from the information provided to Burns & McDonnell, the actual results will vary from those presented.

The estimates and calculations prepared by Burns & McDonnell relating to equipment characteristics are based on our experience, qualifications, and judgment as a professional consultant. Since Burns & McDonnell has no control over availability of materials and equipment, and other factors affecting such estimates or calculations, Burns & McDonnell does not guarantee that actual values will not vary from the estimates and calculations prepared by Burns & McDonnell.

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PART II STUDY ASSUMPTIONS

PROJECT CONFIGURATION

The Middletown to Norwalk transmission facilities consist of three transmission line sections: Beseck to East Devon, East Devon to Singer, and Singer to Norwalk. Figure II-1 shows the project area and system configuration.

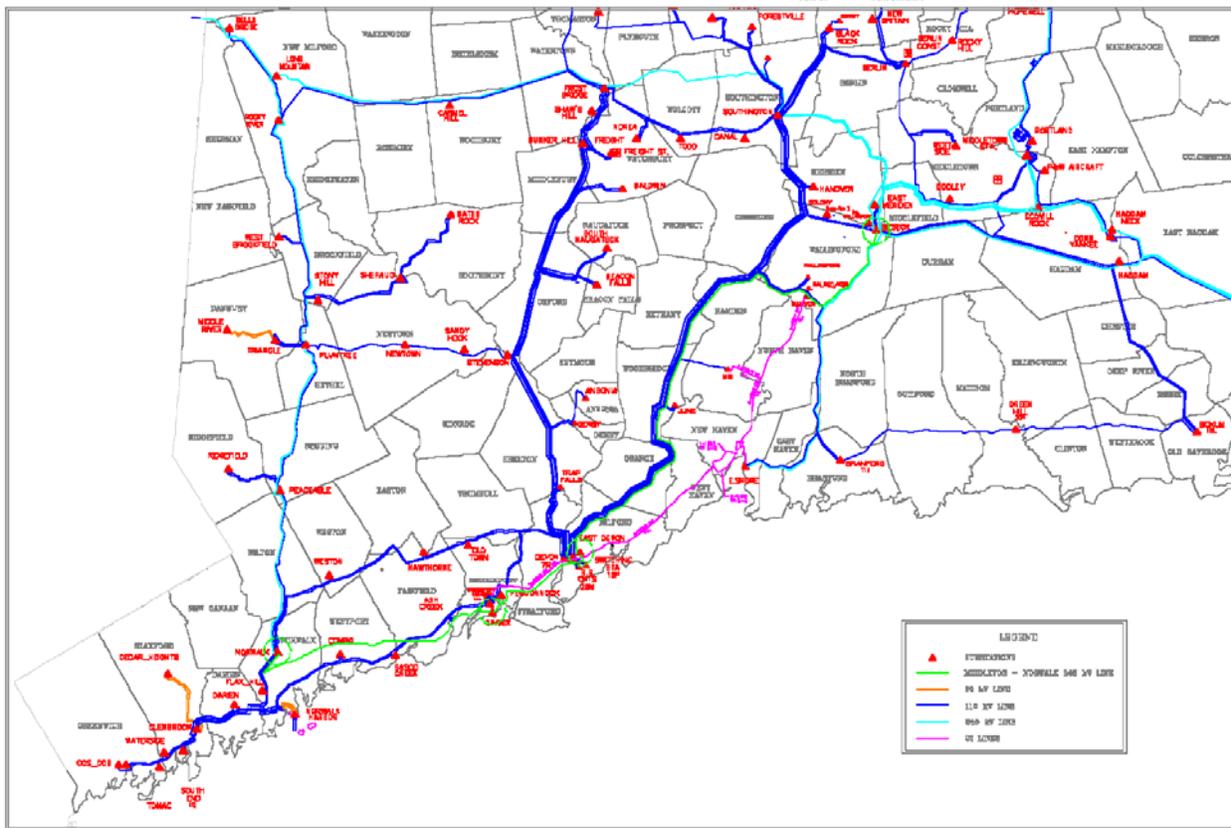


Figure II-1. Project Area and System Configuration

The proposed Beseck 345 kV substation is located at the northeast of Wallingford, which will be connected to the existing Scovill Rock and the proposed Meriden 345 kV substations through the 345 kV transmission line. The proposed line starts from the Beseck 345 kV substation, forwards to west, and is continued to southwest until it reaches the proposed East Devon 345 kV substation. The proposed East Devon 345 kV substation is located at the east side of Devon. The line from Beseck to East Devon is 33.3 miles long.

The line started from the East Devon substation keeps forward southwest and reaches the proposed Singer 345 kV substation. The proposed Singer 345 kV substation is located near Bridgeport harbor. The line from East Devon to Singer is 8.2 miles long.

The line is continued toward southwest, and ends at the proposed Norwalk 345 kV substation, which will be connected to the Bethel to Norwalk transmission facilities. The proposed Norwalk 345 kV substation is located at the middle of Norwalk, the north of Norwalk harbor. The line from Singer to Norwalk is 15.5 miles long.

Northeast Utilities (NU) provided the configuration for the 20.495 mile of the Bethel - Norwalk line, which consisted of three proposing combinations with the 11.895 mile underground cable and the 8.6 mile overhead line from Plumtree to Norwalk 345 kV substations.

The configuration of the Plumtree – Norwalk line was called configuration X': 2.1 mile 2-1750 kcmil XLPE underground cable started from the Plumtree 345 kV substation, and transited to 4.9 mile bundled-1590 kcmil ACSR overhead line. The line was transited to 9.7 mile 2-2500 kcmil High-Pressure Fluid Filled (HPFF) underground cable, transited to 3.7 mile bundled-1590 kcmil ACSR overhead line. The overhead line was transited to 0.095 mile 2-1750 XLPE kcmil underground cable, and ended at the Norwalk 345 kV substation.

NU provided the configuration of the Middletown – Norwalk transmission facilities for the switching transient study. The Middletown – Norwalk transmission facilities consisted of the underground cable from Norwalk to East Devon 345 kV substations through Singer 345 kV substation, and the overhead line from East Devon to Beseck 345 kV substations.

The Norwalk – Singer line was 15.5 miles long using 2-2500 kcmil HPFF underground cable, the Singer – East Devon line was 8.2 miles long using 2-2500 kcmil HPFF underground cable, and the East Devon – Beseck line was 33.3 miles long using bundled-1590 ACSR overhead line.

Two circuits were modeled for the underground cables, and one circuit was modeled for the overhead line. Each underground cable circuit used 60% reactance compensation for the underground cable charging. The reactance compensation was modeled with a half of total reactance compensation at each end of each underground circuit.

TRANSIENT OVERVOLTAGE CRITERIA

An American National Standard, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI/IEEE C37.04-1979) describes the transient over-voltage factor for capacitance switching.

“5.13 Rated Capacitance Current Switching” explains “Capacitance current switching may comprise part or all of the operating duty of a circuit breaker such as the charging current of an unloaded transmission line or cable or the load current of a shunt capacitor bank. A circuit breaker may be modified or especially designed for such duty.”

In the subsection of 5.13, 5.13.4 Rated Transient Overvoltage Factor defines “Definite Purpose Circuit Breakers” as “circuit breakers specially designed for capacitance switching.” It describes “the transient overvoltage factor shall not exceed the following more than once in 50 random 3-phase operations:

- (1) 2.5 for circuit breakers rated 72.5 kV and below,
- (2) 2.0 for circuit breakers rated 121 kV and above.”

Burns & McDonnell applied 2.0 transient over-voltage factor, which was 690 kV, for the switching transient over-voltages at the 345 kV underground cable circuit breaker based on ANSI/IEEE C37.04-1979, Rated Transient Overvoltage Factor.

POST CONTINGENCY VOLTAGE CRITERIA

Transmission Reliability Standards for Northeast Utilities guides the voltage assessments during normal and contingency conditions.

The standards describe “Transmission system voltage variations from initial pre-contingency values are not to exceed 10%. Voltages for facilities equal to or greater than 230 kV, during normal or emergency conditions, shall not exceed plus or minus 5% of nominal. For facility voltage classes below 230 kV, during normal conditions, voltage variance shall not exceed plus 5% or minus 10% of nominal.”

Burns & McDonnell evaluated the post-contingency voltages based on the above standards. The post-contingency voltages were investigated not to exceed +/-5% of nominal for 345 kV transmission system, and not to exceed +5% and -10% of nominal for 115 kV and lower than 115 kV transmission system.

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PART III

MODELING DATA

For the switching transient study, the study area was the 345 kV and 115 kV transmission systems in Southwest Connecticut.

The study model was developed for all 115 kV and 345 kV transmission facilities of the Southwest Connecticut as far as Southington, Reservoir Road Junction, Berlin, Frost Bridge, Norwalk Harbor, Green Hill, and East Meriden 115 kV substations, Haddam Neck, Long Mountain, Beseck, and Scovill Rock 345 kV substations, and the High Voltage Direct Current line connection point at New Haven Harbor. Figure III-1 shows the study system for the switching transient analysis.

For the post-contingency load flow study, the load flow model was provided by NU. The load flow model was based on the projected 2007 peak load conditions. The Bethel – Norwalk line and the Middletown – Norwalk line were incorporated to the load flow model along with the reconfiguration of the Norwalk – Glenbrook 115 kV transmission facilities and the area of the Scovill Rock and Meriden 345 kV transmission facilities by Burns & McDonnell.

SWITCHING TRANSIENT STUDY MODEL

The following model data were developed for the switching transient study:

- The positive and zero sequence impedance of the 115 kV and 345 kV transmission systems were modeled by using the same impedance as the ASPEN model provided by NU.
- Burns & McDonnell calculated the impedance of the Bethel – Norwalk and the Middletown – Norwalk transmission systems from the mileage and the impedance values provided by NU. Appendix A-1 and A-2 show the impedance for the Bethel – Norwalk and the Middletown – Norwalk transmission facilities.
- Zero sequence susceptance (B0) used the same values as positive susceptance (B+) for the underground cables.
- All 345 kV overhead lines for the Bethel – Norwalk and the Middletown – Norwalk lines were bundled 1590 ACSR.
- Transient voltage measurements were recorded at all 345 kV substations in the southwestern Connecticut area and the 115 kV substations located at one bus away from the 345 kV substations. NU added the West River and Norwalk Harbor 115 kV substations to the measurements. Total

twenty four substations were monitored for the switching transient voltages. Appendix A-3 shows the measured elements for the switching transient over-voltage study.

- Generators were modeled as three-phase, 60 Hz voltage sources. The voltages at the GSU high side were modeled to reflect the same voltages as in the load flow model provided by NU. Appendix A-4 shows the voltages at the generators and the GSU high sides in the model.
- Equivalent impedance models were used for tie line points. The equivalent impedance for the tie line points was calculated based on the tie-line flows at the load flow model provided by NU. Import points were modeled as generators, and export points were modeled as loads. The voltages of the equivalent generators were modeled to reflect the same voltages as in the load flow model. Appendix A-5 shows the equivalent impedance models for tie-line points.
- Equivalent impedance models were used for the loads in the study system. The capacitors of the NU 115 kV system were modeled into the system. Appendix A-6 shows the equivalent impedance models for loads.
- Two 345/115 kV autotransformer were located at the Norwalk 345 kV substation. The Norwalk – Glenbrook 345 kV line was modeled as 115 kV instead directed by NU. The 8.5 mile 115 kV underground cable for the Norwalk – Glenbrook used 1-3000 kcmil Cross Linked Polyethylene (XLPE). The impedance was calculated based on the provided mileage and impedance shown in Appendix A-1.
- Three Bridgeport plants were located at the Singer 345 kV substations.
- Three phases to ground faults were analyzed at 345 kV substations and 345/115 kV transformers. Three phases to ground faults were modeled with a normal clearing time of 4 cycles and 12 cycle delayed clearing time with the stuck breaker.

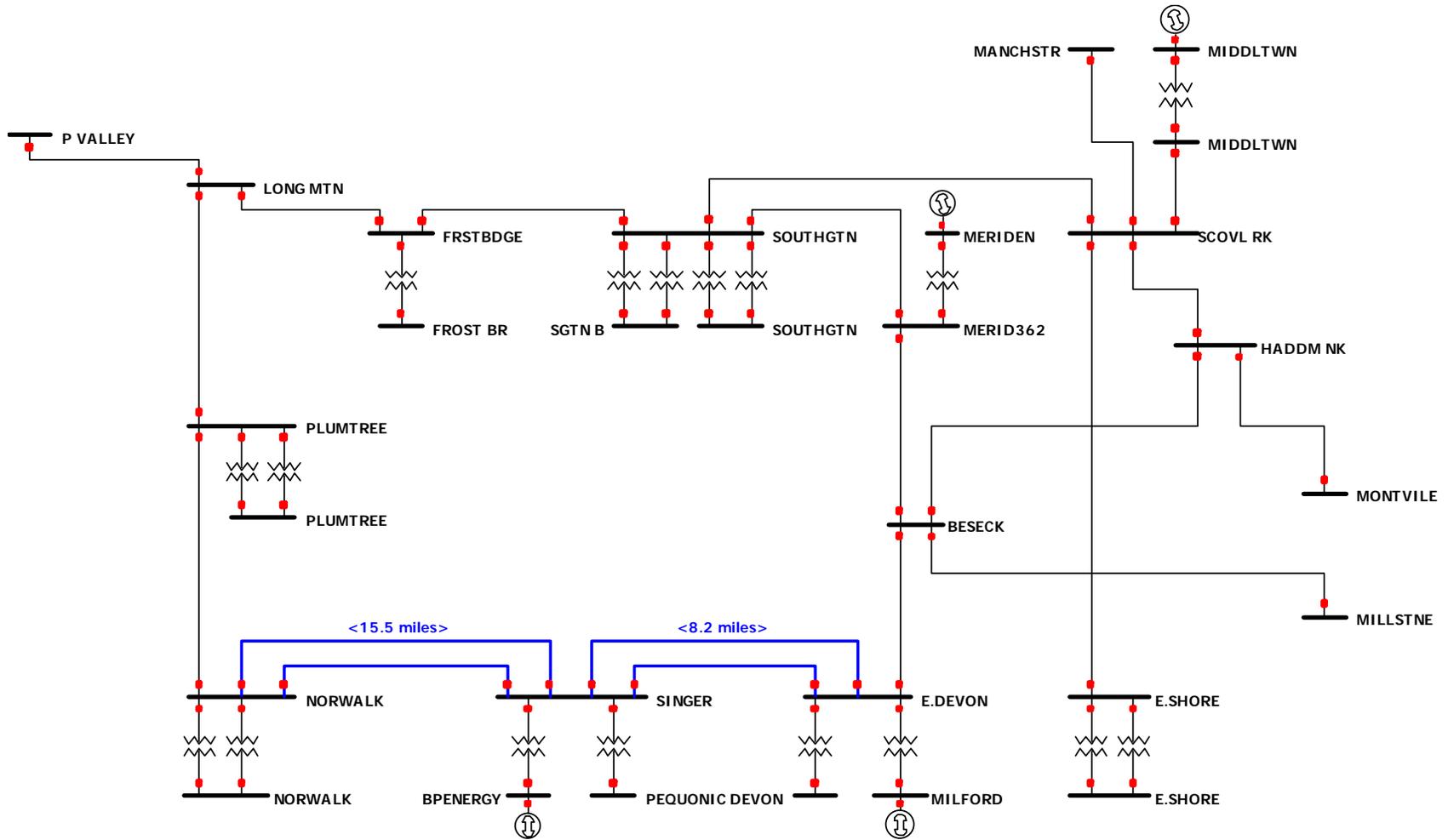


Figure III-1. Switching Study Area One Line Diagram

POST CONTINGENCY LOAD FLOW STUDY MODEL

The post contingency load flow model was provided by NU. The load flow model included Northeast Power Coordinating Council (NPCC) transmission system and represented the 2007 load conditions in the Southwest Connecticut.

The model was modified by Burns & McDonnell to incorporate the Bethel – Norwalk and the Middletown – Norwalk transmission facilities including the proposed Plumtree – Norwalk 115 kV system, the reconfiguration of Norwalk – Glenbrook 115 kV system, and the reconfiguration of the Meriden and Scovill Rock 345 kV transmission system. The system changes were shown in Appendix A-7, which is macro file to change the load flow model in Power System Simulation/Emulation (PSS/E) program.

The variable reactance compensation on the underground cables used generator models at the each end of the underground cables for the Plumtree – Norwalk and the East Devon – Singer – Norwalk lines with zero active power output and zero to 100%, 80%, or 60% reactive power compensation. Appendix A-7 shows that the compensation was modeled as 100% reactive power compensation.

The following modifications were made by Burns & McDonnell:

- The impedances of the Bethel – Norwalk and the Middletown – Norwalk lines were changed with the same values as the switching transient model used. The impedance of the East Devon – Beseck 345 KV line was calculated based on 33.3 mile bundled 1590 ACSR overhead.
- The Norwalk – Glenbrook 345 kV line was replaced to 115 kV line, and the autotransformer was moved to the Norwalk 345 kV substation based on the information provided by NU.
- The impedances of the Meriden and Scovill Rock 345 kV system were changed based on the system reconfiguration.
- The switch shunts at the Norwalk, Glenbrook, Pequonnock, and Devon 345 kV busses, and the Plumtree 115 kV bus were removed, and the generator models were modeled at the each end of the underground cables for the reactance compensation.
- The Weston – Hawthorn and the Weston – Norwalk 115 kV lines were out-of-service.
- The Hawthorn – Norwalk 115 kV line was in-service.

For the contingency analysis, all the systems within the zones of CL&P, Willingford, UI, and UI loads and the tie lines between the zones were simulated for voltage violations. Single contingency was analyzed with each single branch outages and each tie-line outages between zones. Multiple contingencies were

added to the contingency list which included the bus disconnections and double circuit tower outages provided by NU. Appendix A-8 shows the bus disconnections and double circuit tower outage contingencies.

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PART IV

SWITCHING TRANSIENT ANALYSIS

In the switching transient analysis, line energizing, line de-energizing, and fault clearing for three phases to ground fault with stuck breaker were analyzed to investigate the potential transient over-voltages.

SWITCHING SCENARIOS

The switching transient study used configuration X' for the Bethel – Norwalk line, which was described in Part II, System Configuration, and used the following configuration for the Middletown – Norwalk line: 15.5 mile 2-2500 kcmil HPFF underground cable from Norwalk to Singer 345 kV substations, 8.2 miles 2-2500 kcmil HPFF underground cable from Singer to East Devon 345 kV substations, and 33.3 miles bundled-1590 kcmil ACSR overhead line from East Devon to Beseck 345 kV substations.

The switching transient study used 60% reactance compensation for the underground cable charging. Line energization was investigated with or without +/-150 MVar dynamic compensation at the Singer 345 kV substation. Line de-energization and fault clearing were investigated with +/-150 MVar dynamic compensation at the Singer 345 kV substation.

The following two scenarios were used for the line energization switching transient study:

Scenario 1. 60% reactive compensation for the underground cable capacitance charging without dynamic compensations.

Scenario 2. 60% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensation at Singer 345 kV substation.

In scenario 2, the synchronous breaker closing was investigated to improve the switching transient over-voltages for the underground cable energization after the uncontrolled breaker closing showed the potential switching transient over-voltages with scenario 1. The line de-energizations were investigated by using scenario 2.

The bus breaker configurations at Norwalk, Singer, and East Devon were provided by NU, and were investigated whether the fault clearing caused the potential switching transient over-voltages when three phases to ground faults with stuck breaker were cleared by delayed breaker operations.

The bus configurations at the Norwalk, Singer, and East Devon 345 kV substations were modeled with a breaker and a half breaker configuration. One underground circuit was connected to the East Devon 345 kV substation, and the other circuit was connected to the Norwalk 345 kV substation from the same bay at the Singer 345 kV substation. Three phases to ground faults with the stuck breaker were cleared by opening the 345/115 kV transformer or/and opening the neighboring circuit at Norwalk, Singer, and East Devon 345 kV substations. Figure IV-1 shows the bus configurations at the Bethel – Norwalk and the Middletown – Norwalk transmission system.

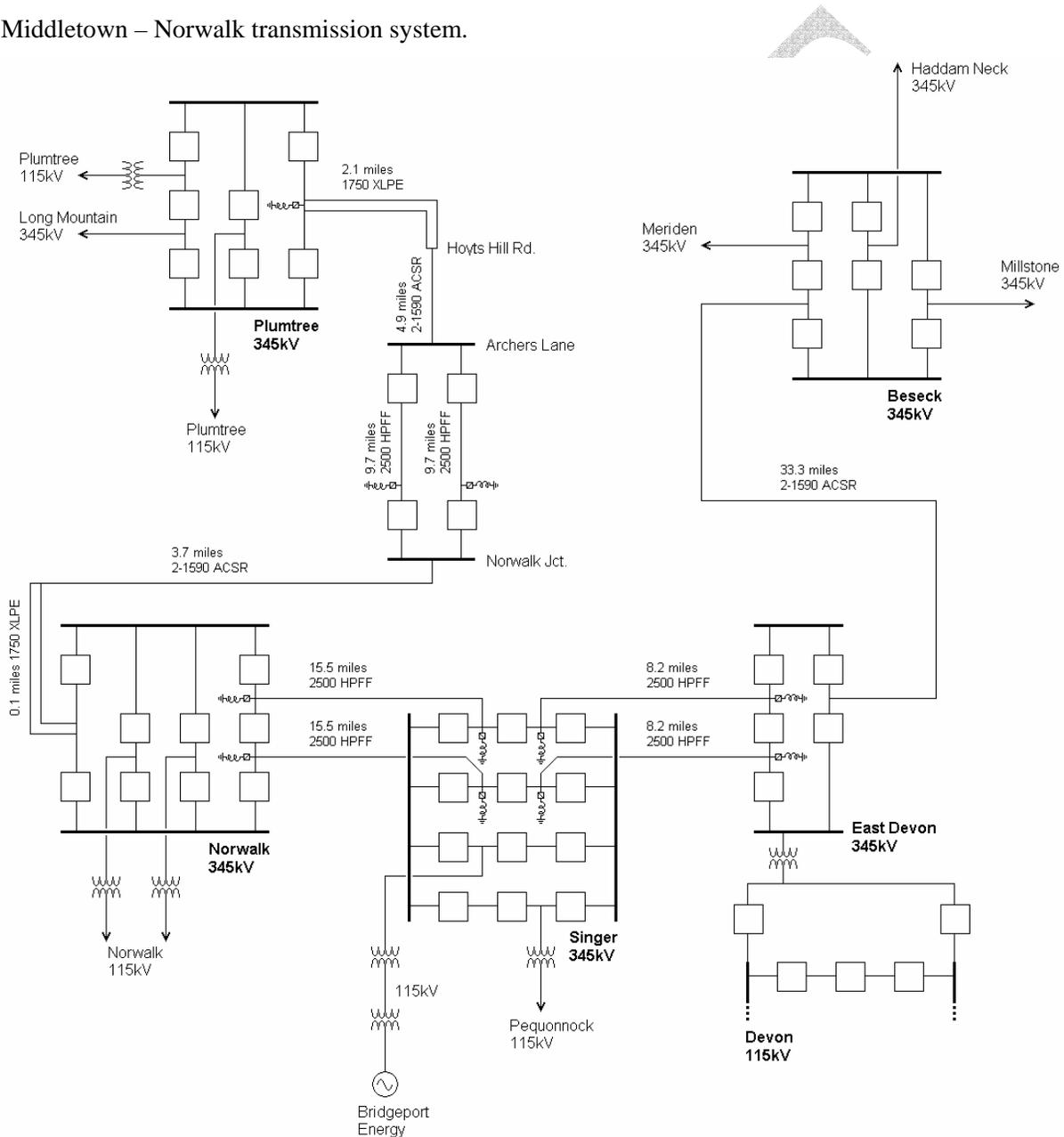


Figure IV-1. Bus Configurations

Line Energizing

The following underground cable energizations were investigated with scenario 1 and scenario 2:

- Case 1. Close breaker at Norwalk, all other Norwalk/Singer breakers were open.
- Case 2. Close breaker at Norwalk, one Norwalk-Singer cable was in-service.
- Case 3. Close breaker at Singer, all other Singer/Norwalk breakers were open.
- Case 4. Close breaker at Singer, one Singer-Norwalk cable was in-service.
- Case 5. Close breaker at Singer, all other Singer/East Devon breakers were open.
- Case 6. Close breaker at Singer, one Singer-East Devon cable was in-service.
- Case 7. Close breaker at East Devon, all other East Devon/Singer breakers were open.
- Case 8. Close breaker at East Devon, one East Devon-Singer cable was in-service.

Line De-Energizing

The following underground cable de-energizations were investigated with scenario 2:

- Case 1. Open breaker at Norwalk first, all other Norwalk/Singer breakers were closed.
- Case 2. Open breaker at Norwalk first, one Norwalk-Singer cable was out-of-service.
- Case 3. Open breaker at Singer first, all other Singer/Norwalk breakers were closed.
- Case 4. Open breaker at Singer first, one Singer-Norwalk cable was out-of-service.
- Case 5. Open breaker at Singer first, all other Singer/East Devon breakers were closed.
- Case 6. Open breaker at Singer first, one Singer-East Devon cable was out-of-service.
- Case 7. Open breaker at East Devon first, all other East Devon/Singer breakers were closed.
- Case 8. Open breaker at East Devon first, one East Devon-Singer cable was out-of-service.

Fault Clearing for Three Phases to Ground Faults with Stuck Breaker

The following fault clearing for three phases to ground faults with stuck breaker was investigated with scenario 2:

- Case 1. Norwalk-Singer three phases to ground fault with stuck breaker at Norwalk, open the first Singer breaker at 4 cycles, and open Norwalk and the second Singer breakers at 12 cycles.

- Case 2. Singer-Norwalk three phases to ground fault with stuck breaker at Singer, open the first Norwalk breaker at 4 cycles, and open Singer and the second Norwalk breakers at 12 cycles.
- Case 3. Singer-East Devon three phases to ground fault with stuck breaker at Singer, open the first East Devon breaker at 4 cycles, and open Singer and the second East Devon breakers at 12 cycles.
- Case 4. East Devon-Singer three phases to ground fault with stuck breaker at East Devon, open the first Singer breaker at 4 cycles, and open East Devon and the second Singer breakers at 12 cycles.
- Case 5. East Devon-Singer three phases to ground fault with stuck breaker at East Devon, open Singer breaker at 4 cycles, and open East Devon cable and transformer breakers at 12 cycles.
- Case 6. Norwalk-Singer three phases to ground fault on single cable at Norwalk, open Norwalk and Singer breakers at 4 cycles.
- Case 7. East Devon-Singer three phases to ground fault on single cable at East Devon, open East Devon and Singer breakers at 4 cycles.

CABLE CHARGING COMPENSATION SCENARIOS

The post contingency load flow study used five scenarios to investigate the possible reactance compensation levels for the underground cable charging and to avoid the possible voltage violations with the single, or the first and second contingencies during post contingency with or without dynamic compensations at the Norwalk, Singer, or East Devon 345 kV substations.

Each scenario was designed to investigate the voltages of the 345 kV underground cable substations, which had 100%, 80% or 60% reactance compensation of the underground cable charging with or without dynamic compensations at the Norwalk, Singer, or East Devon 345 kV substations.

The post contingency load flow study used the same configurations as the switching transient study for the Bethel – Norwalk and the Middletown – Norwalk line. The following five scenarios were used for the post contingency load flow study based on the different reactance compensations along with or without dynamic compensations:

- Scenario 1.** 100% reactive compensation for the underground cable capacitance charging without dynamic compensations.
- Scenario 2.** 80% reactive compensation for the underground cable capacitance charging without dynamic compensations.

Scenario 3. 80% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensations at the Norwalk and East Devon 345 kV substations.

Scenario 4. 60% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensations at the Norwalk and East Devon 345 kV substations.

Scenario 5. 60% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensation at Singer 345 kV substation.

The reactance compensation of the underground cable charging was locked not to adjust the compensation during post contingency time with the single, or the first and second contingencies. The reactor was expected to respond to the system after two minutes while the transformer tap was expected to respond to the system after 30 seconds.

During post contingency with single contingencies, the reactor and transformer taps were not adjusted in order to keep the voltages within the acceptable ranges. During post contingency with the first and second contingencies, transformers were allowed to adjust their taps for the first contingency and the transformers were not allowed to adjust their taps for the second contingency while the reactors were not allowed to respond all the time.

The post contingency load flow study with the single, or the first and second contingencies is valid under the situation that the single, or the first and the second contingencies happen within two minutes.

To improve the voltage control during post contingency, dynamic compensation were introduced due to its fast response capability to control the voltages. The operation voltage of the dynamic compensations at the located substation was set to 357 kV.

The post contingency study was not planned to justify the need of the dynamic compensation. The study was planned to investigate the appropriate reactance compensation level for the underground cable capacitance charging to keep the operation voltages at the normal steady state. NU indicated that the justification of the dynamic compensation would be provided through a separate study.

SIMULATION RESULTS

Switching Transient Study

Line Energization

1. Scenario 1

The energization of the Norwalk – Singer or Singer – East Devon 345 kV underground cable showed the potential transient over-voltage larger than 2.0 Vp.u. when the underground cable was energized at the Singer 345 kV substation while the underground cable showed the potential transient over-voltage close to 2.0 Vp.u. when the underground cable was energized at the Norwalk or at the East Devon 345 kV substation.

Appendix B-1 shows the summary of the switching transient over-voltages for the underground cable energization. Appendix C-1 shows the diagrams for the transient over-voltages.

2. Scenario 2

After the synchronous closing breaker was used to improve the switching transient over-voltages for the underground cable energization, the energization of the Norwalk – Singer or Singer – East Devon 345 kV underground cable showed the potential transient over-voltage less than 1.5 Vp.u. when the underground cable was energized first at the Norwalk, Singer, or East Devon 345 kV substation.

Appendix B-2 shows the summary of the switching transient over-voltages for the underground cable energization. Appendix C-2 shows the diagrams for the transient over-voltages.

Line De-Energization

The de-energization of the Norwalk – Singer or Singer – East Devon 345 kV underground cable showed the potential transient over-voltage less than 1.5 Vp.u. when the underground cable was de-energized first at the Norwalk, Singer, or East Devon 345 kV substation.

Appendix B-3 shows the summary of the switching transient over-voltages for the underground cable de-energization. Appendix C-3 shows the diagrams for the transient over-voltages.

Fault Clearing for Three Phases to Ground Faults with Stuck Breaker

The fault clearing for three phases to ground fault with stuck breaker on the Norwalk – Singer or Singer – East Devon 345 kV underground cable showed the potential transient over-voltage between 1.5 Vp.u. and

1.6 Vp.u. at the Norwalk, Singer, East Devon, or Meriden 345 kV substation when the fault was cleared by the delayed breaker operations.

Special attention was given to the fault clearing for three phases to ground fault on single cable from the Norwalk – Singer or Singer – East Devon cable while the other cable was out-of-service. The result showed the potential transient over-voltages close to 1.5 Vp.u., which diagrams are shown at Case 6 and Case 7 in Appendix C-4. Figure IV-2 shows the breaker opening procedures to clear the three phases to ground fault on single cable from the Norwalk – Singer.

Appendix B-4 shows the summary of the switching transient over-voltages for the three phases to ground fault clearing with stuck breaker. Appendix C-4 shows the diagrams for the transient over-voltages.

Closing Breaker for Single Cable Energization with Three Phases to Ground Fault

Further investigation was given to identify the potential transient over-voltage when the underground cable was energized without clearing three phases to ground fault. Figure IV-3 shows the energization of the Norwalk – Singer 345 kV underground cable. The single cable was energized first at the Norwalk 345 kV substation with three phases to ground fault. The breaker at the Norwalk 345 kV was re-opened at 4 cycles to clear the fault.

The result showed the potential transient over-voltage close to 1.5 Vp.u. at the Norwalk 345 kV substation when three phases to ground fault at the Norwalk 345 kV substation was cleared by re-opening the single Norwalk – Singer 345 kV underground cable. Figure IV-4 shows the diagrams for the transient over-voltage at the Norwalk 345 kV substation.

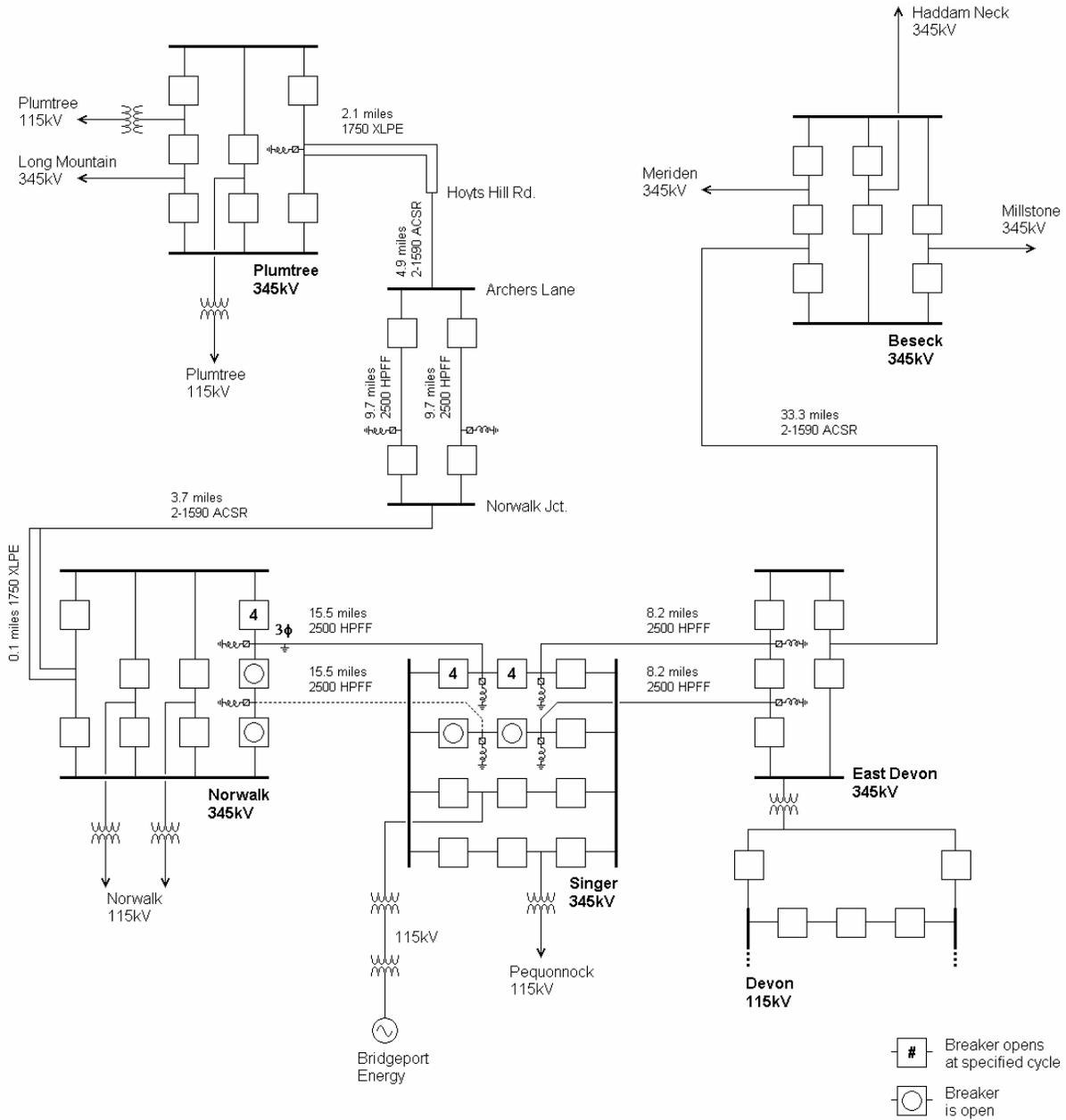


Figure IV-2. Breaker Operation to Clear the Three Phases to Ground Fault on Single Cable from the Norwalk – Singer

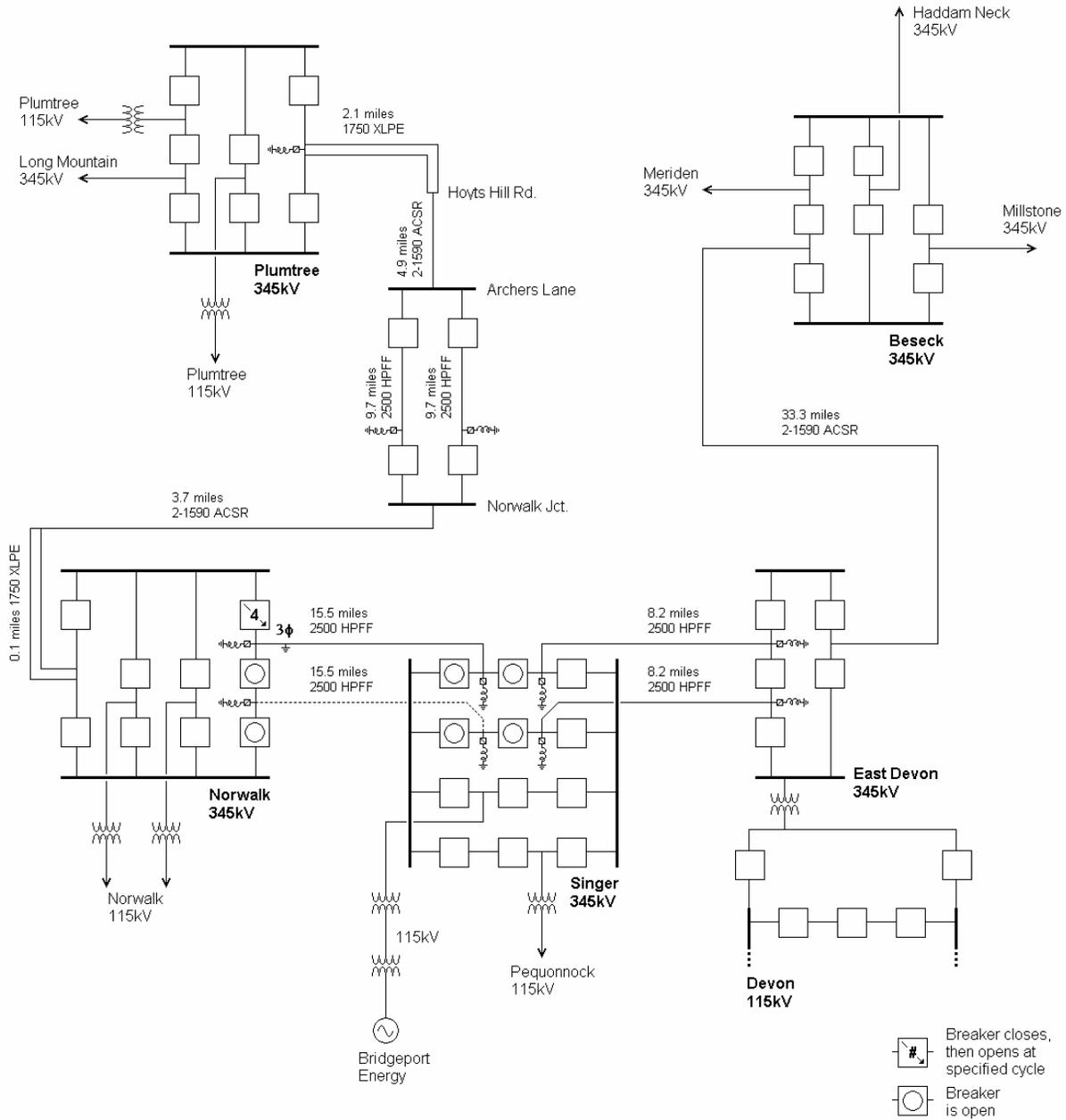


Figure IV-3. Closing Breaker with Three Phases to Ground Fault

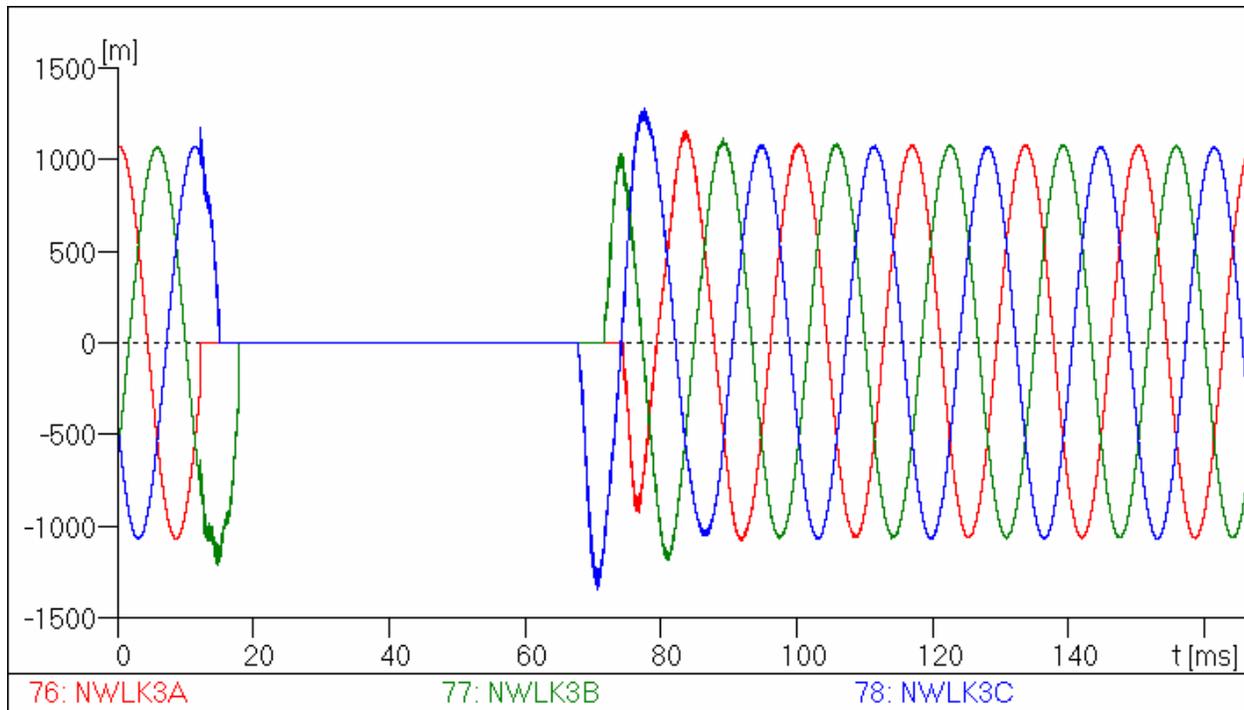


Figure IV-4. Transient Over-Voltage at Norwalk for Closing Breaker with A Fault

Post Contingency Load Flow Study

The post contingency load flow study was performed to look at the preliminary voltage issues in the area of the underground cable substations in order to provide the appropriate reactance compensation to keep the voltages within the controllable ranges for single contingency (n-1), or the first and second contingency (n-1-1). The post contingency load flow study was not intended to provide a comprehensive thermal investigation.

NU proposed to install +/-150 MVar dynamic compensation at Norwalk, Singer, or East Devon to investigate the switching transient over-voltages and the voltage violations for the post-contingency load flow. Two dynamic compensation locations were tested to investigate the switching transient over-voltages and the voltage violation during post-contingency with 80% and 60% reactance compensation conditions of the underground cable charging.

Burns & McDonnell performed post-contingency load flow analysis for the dynamic compensations: 80% and 60% reactance compensation for the underground cable charging with +/-150 MVar dynamic

compensations at Norwalk and East Devon substations, and 60% reactance compensation for the underground cable charging with 150 MVar dynamic compensation at Singer substation.

For the first and second contingency (n-1-1), the first contingency was applied to Brideport Harbor #3 or the 345 kV underground cable outage, and the second contingency was applied to each single component outage in the study area.

The Plumtree area was observed to have voltage violations below than 0.95 Vp.u. during scenarios 1 and 2 with single, and the first and second contingencies. NU confirmed that the voltages at the Plumtree area were an existing problem, and not associated with the underground cable project. NU will address the voltage control of this area through a separate investigation. The voltage profile in the Plumtree area was not considered to investigate the voltage violation with all scenarios.

Appendix D shows the summary of the post contingency load flow results with the first and second contingencies. The summary shows the pre-contingency and post-contingency voltages.

Scenario 1. 100% reactive compensation for the underground cable capacitance charging without dynamic compensations.

The results showed the system was not able to control the system voltages because the 100% compensated reactive power absorbed too much reactive power, and the voltages of the 345 kV underground cable substations were around 0.99 Vp.u. at normal operation condition.

By opening Bridgeport Harbor #3 unit, or the East Devon – Beseck line, the system could not control the voltages within the ranges due to the loss of reactive power source. The results showed the system was not converged by opening Bridgeport Harbor #3 unit, or the East Devon – Beseck line.

Scenario 2. 80% reactive compensation for the underground cable capacitance charging without dynamic compensations.

The results showed the voltages of the 345 kV underground cable substations were around 1.01 Vp.u. at normal operation condition. The system operation voltage at the underground cable substations was planned to be controlled close to 1.035 Vp.u. at the normal steady state condition.

Although the 80% compensated reactance made the system need less reactive power supply than 100% compensated reactance to keep the voltages within the acceptable ranges, the voltage of 1.01 Vp.u. at normal steady state condition was not acceptable to control the system during a system disturbance. Appendix D-1 shows the voltages with scenarios 1 and 2.

Scenario 3. 80% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensations at the Norwalk and East Devon 345 kV substations.

+/-150 MVar dynamic compensations were installed at Norwalk and East Devon 345 kV substations with 80% reactance compensation for the underground cable charging in order to hold the voltages at 1.035 Vp.u. for steady state operation condition.

The result showed that the underground cable substation voltages were between 1.031 Vp.u. and 1.034 Vp.u. at the underground cable 345 kV substations with the maximum 150 MVar outputs from the dynamic compensations. It was not acceptable since the dynamic compensation would not provide the voltage control capability to response the system disturbance due to its maximum output at steady state.

Scenario 4. 60% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensations at the Norwalk and East Devon 345 kV substations.

After the reactance compensation for the underground cable charging was reduced to 60% with the dynamic compensations at Norwalk and East Devon, the underground cable substations hold the voltages at 1.035 Vp.u. for steady state operation condition without the maximum dynamic compensations.

The output of the dynamic compensation was about 100 MVar at the Norwalk, and about -60 MVar at the East Devon to hold 1.035 Vp.u. for the underground cable substations at steady state operation condition.

The result showed that the system was able to keep the voltages within the acceptable ranges with the first and second contingencies except the Plumtree area shown in Appendix D-2.

Scenario 5. 60% reactive compensation for the underground cable capacitance charging with +/-150 MVar dynamic compensation at Singer 345 kV substation.

After the dynamic compensation was installed at Singer with 60% reactance compensation for the underground cable charging, the voltages at the underground cable substations were 1.035 Vp.u. for steady state operation condition without the maximum dynamic compensation.

The output of the dynamic compensation was about 30 MVar at the Singer to hold 1.035 Vp.u. for the underground cable substations at steady state operation condition.

The result showed that the system was able to keep the voltages within the acceptable ranges with the first and second contingencies except the Plumtree area shown in Appendix D-3.

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PART V

CONCLUSIONS AND RECOMMENDATIONS

The switching study results indicated that the transient over-voltages were acceptable with the proposed bus configuration at the Norwalk, Singer, and East Devon 345 kV substations shown in Figure IV-1.

The Middletown to Norwalk underground cable facilities did not cause the switching transient over-voltages while the underground cable was de-energized, or three phases to ground fault with stuck breaker was cleared.

The results indicated the energization with the uncontrolled breaker closing caused the potential transient over-voltage larger than 2.0 Vp.u. The result showed the synchronous breaker closing reduced the switching transient over-voltages to the acceptable level. The synchronous breaker closing or the pre-insertion resistance breaker is a possible means to reduce the switching transient over-voltages to the acceptable level when the underground cable is energized.

The study was performed with the Bethel – Norwalk cable in service. The switching transient over-voltage for the Middletown – Norwalk underground cable will be decreased when the Bethel – Norwalk cable is out of service due to the reduced capacitance charging.

The result showed the fault clearing for three phases to ground fault on single cable from the Norwalk – Singer or Singer – East Devon cable did not cause the potential switching transient over-voltages while the other cable was out-of-service. The result showed the potential transient over-voltages close to 1.5 Vp.u. The result indicated that both underground circuits of Norwalk – Singer or Singer – East Devon line are not required to be out of service due to the switching transient over-voltages.

Based on the results, the recommendations are as follows:

1. It is recommended that the synchronous closing breaker or the pre-insertion resistance breaker be used to avoid the potential switching transient over-voltages when the underground cable is energized.
2. It is recommended that the underground cable be de-energized first at the Singer 345 kV substation in order to decrease the potential switching transient over-voltages.

The following are the remaining issues to be addressed and investigated:

1. NU needs to investigate the need for the dynamic compensation,
2. The switching transient study for the Bethel – Norwalk underground cable needs to be investigated with the Middletown – Norwalk underground cable,
3. The system performance with the proposed Middletown – Norwalk transmission facilities should be investigated with other related analyses such as load flow, short circuit, voltage response, and stability. The switching study does not provide the complete impacts to the transmission system.

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