System Stability Analysis for Underground Transmission Options using HVDC Light®

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Prepared for: **Northeast Utilities**

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Summary

Northeast Utilities (NU) has contracted ABB to develop HVDC Light® options for Phase II of Southwest Connecticut Reliability Improvement. This report presents the stability analysis performed to verify the feasibility of the HVDC Light® solution from a stability point of view.

This stability analysis indicates no stability limitations to the implementation of HVDC Light® in the Southwest Connecticut electric transmission system. In fact, the results with HVDC Light® show better damping in some cases. This is not surprising because HVDC Light® provides high-speed voltage control at both ends of each DC line, including reactive power injection if needed.

A single base case condition was analyzed for this report, as provided by NU. This base case models light load conditions and zero transfer of power between New England and New York. Light load is considered to be the most critical load level for stability analysis in the ISO-NE region. Only HVDC Light® Option 1 was modeled for this report. Option 1 replaces all Phase II AC 345 kV lines and cables with five two-terminal HVDC Light® lines.

Additional base case conditions and fault scenarios may need to be studied to provide comprehensive assurance of system stability with the HVDC Light® options.

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1 Introduction

ABB was contracted by Northeast Utilities (NU) to perform system studies to investigate the feasibility and performance of underground HVDC Light® solutions against the system criteria outlined in the August 6th meeting. The number 10 criterion states that "the project needs to result in a dynamically stable system." The work presented in this stability report is meant as a feasibility study to determine if there are any stability road blocks to the implementation of underground HVDC Light® Options. The three different HVDC Light® Options proposed by ABB are shown in Figure 1-1.

Dynamic simulations of the proposed HVDC Light® Option 1 were performed in this study. The dynamic model used by NU for the Cross Sound DC system was also used for the five HVDC Light® transmission lines of Option 1, with input parameters updated to represent the preliminary design for Phase II DC Option 1.

HVDC Light® Option 2 has not yet been studied because a PSS/E power coordinating model does not yet exist for HVDC Light® multi-terminal operation. Were Option 2 to become the preferred option, a PSS/E dynamic model would be written and tested by ABB.

Option 3 differs from the Phase II AC solution only in replacing the Beseck – Devon 345 kV overhead line with HVDC Light® transmission. Option 1 is a more significant departure from the Phase II AC solution than is Option 3, and thus the simulation of Option 1 was deemed to be the most critical task given the limited time available for this study.

This study investigated the stability performance under light load conditions only, for the following reasons:

1. Based on discussions with NU, it was understood that light load conditions are more problematic for stability in Connecticut than peak load conditions.
2. Only the light load stability model was available.
3. The schedule for this feasibility study did not allow time to develop the necessary model and perform the analysis for peak load conditions.

Nevertheless, it would still be prudent to investigate system stability performance under peak load conditions at a future date.

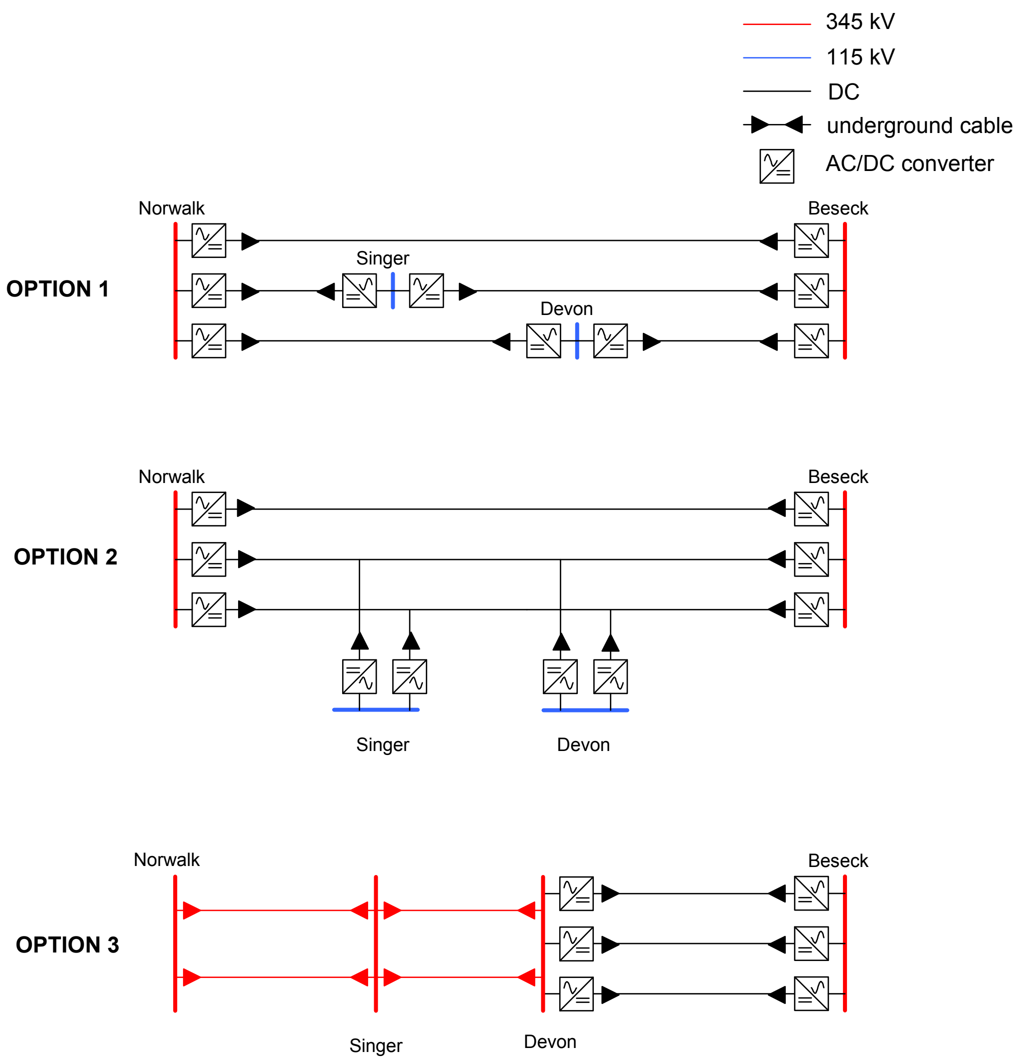

Figure 1-1. HVDC Light® Configuration Options

2 Dynamic Model Development

2.1 Phase II AC Model

Northeast Utilities provided the following dynamic files that model the electric system dynamics with the Phase II AC solution:

Table 2-1. Dynamics Files Provided by NU (in PSS/E version 26 format)

light-ph2-ALT2-101603.SAV	Light load case with Phase II AC upgrades and zero transfer between NE and NY.
test.SAV	Same as above case, except adjusted by NU to fix some initialization errors.
ph1-light.SNP	Dynamics data. Originally from Phase I model, but it also works for the Phase II AC case.
DSUSR.DLL	Compiled user-written models, including CHVDCL and PWRHL2 models for the Cross Sound HVDC Light® transmission line.
GNET-CONL.idv	Script file to convert generators and loads for dynamic simulation.
bkollplot.idv	Script file to generate stability plots.
RELAY.DAT	File for plotting relay characteristics.

The Norwalk – Glenbrook 115 kV project impedances were updated with the latest information from NU. A 30 second no disturbance simulation was made with the files listed in Table 2-1, and all plot channels were flat, indicating a good base case condition.

While NU has initially only provided one power flow case, which represents light load conditions and zero transfer between NE and NY, additional load levels and transfer scenarios should be considered in a future stability analysis. Light load conditions were studied for this report since they are more critical for stability analysis of the ISO-NE system.

2.2 Phase II DC Model

2.2.1 Power Flow Case

The "test.sav" power flow case representing the Phase II AC solution was modified to represent the Phase II HVDC Light® solution. The following Phase II AC equipment was removed from the case:

- Beseck – Devon 345 kV overhead transmission line
- Devon – Singer – Norwalk 345 kV underground AC cables and associated intermediate buses
- Devon and Singer 345-115 kV transformers

The following HVDC Light® Option 1 equipment was added to the case:

- Ten 195 kV AC buses representing the AC converter buses of the 5 HVDC Light® transmission lines.
- A filter capacitor at each converter bus
- A "generator" at each converter bus to represent the converter injection of MW and Mvar and regulation of voltage. The generator impedance (Zsource) is set equal to the converter series reactor impedance. The generator base MVA is set equal to the converter MVA rating.
- A transformer for each converter, to connect from the converter 195 kV AC bus to the utility AC bus (i.e., Beseck 345 kV, Norwalk 345 kV, E. Devon 115 kV, Pequonnock 115 kV).
- Close in the Bridgeport Energy – Pequonnock 115 kV line

The converter real power injections were set so that the total injections at the 4 substations approximately match the Phase II AC case.

2.2.2 Dynamic Model

As mentioned above, the CHVDCL and PWRHL2 FLECS code that models the behavior of HVDC Light® transmission was already included in the DSUSR.DLL file provided by NU. The CHVDCL model represents the AC/DC converter at either end of the DC line, including the voltage control capability. The PWRHL2 model represents the active power coordination between the two converters at either end of the DC line. Thus, all that was required for the 5 new DC lines was to add CHVDCL parameters for each of the 10 converters and PWRHL2 parameters for each of the 5 DC lines. The parameters were set using preliminary information available from the ABB HVDC Project Division for the proposed HVDC Light® Option 1. These HVDC Light® parameters have not been optimized for the exact AC characteristics at the proposed interconnection locations.

A 30 second no disturbance run was simulated for the DC Light dynamic model, and all channels were very flat, just as in the Phase II AC case.

3 Fault Simulations

The faults shown in Table 3-1 were simulated in the Phase II AC and DC cases. A fault was simulated at each Phase II interconnection bus, tripping the most highly loaded branch. A second fault was simulated at each Phase II interconnection bus, with tripping of all Phase II DC lines at that bus (all Phase II AC lines for the Phase II AC case). These extreme cases of tripping all DC lines at a station are unlikely, but they are included to demonstrate the robustness of the DC solution. All 345 kV faults from the Phase I stability study were also simulated.

The set of faults in Table 3-1 demonstrates and compares the dynamic performance of the system after the addition of the proposed Phase II AC and DC options.

Table 3-1. Faults Simulated in Stability Analysis

ID	Fault Type	Fault Description	Local Clearing	Remote Clearing	Element Removed
Interconnection Point Faults					
BES1	3 phase	Beseck 345 on the Millstone line	4 cycles	4 cycles	Beseck-Millstone 345
BES2	3 phase	Beseck 345	4 cycles	4 cycles	All 3 Beseck DC lines
BES2-AC	3 phase	Beseck 345	4 cycles	4 cycles	Beseck-Devon 345
EDEV1	3 phase	East Devon 115 on the Devon 2 line	5 cycles	5 cycles	East Devon – Devon 2 115
EDEV2	3 phase	East Devon 115	5 cycles	5 cycles	Both East Devon DC lines
EDEV2-AC	3 phase	East Devon 115	5 cycles	5 cycles	Devon 345 bus and branches
PEQ1	3 phase	Pequonnock 115 on HVDC Light® #4 to Norwalk	5 cycles	5 cycles	HVDC Light® #4 to Norwalk
PEQ2	3 phase	Pequonnock 115	5 cycles	5 cycles	Both Pequonnock DC lines
PEQ2-AC	3 phase	Pequonnock 115	5 cycles	5 cycles	Singer 345 bus and branches
NOR1	3 phase	Norwalk on the Plumtree-Norwalk Line	4 cycles	4 cycles	Plum-Nor Line
NOR2	3 phase	Norwalk 345	4 cycles	4 cycles	All 3 Norwalk DC lines
NOR2-AC	3 phase	Norwalk 345	4 cycles	4 cycles	Both 345 cables from Singer
345 kV Faults from Phase I Stability Study					
PLUM1	3 phase	Plumtree on the 321 Line	4 cycles	4 cycles	321 Line
PLUM2	3 phase	Plumtree on the Plum-Nor Line	4 cycles	4 cycles	Plum-Nor Line
PLUM3	3 phase	Plumtree on the 345 kV side of an auto	4 cycles-345 kV bkrs	5 cycles-115 kV bkrs	Plumtree Auto
PLUM4	1 phase	Plumtree on auto 345 kV side w/stk center bkr.- 321 line	115-5 cycles,345-12 cycles	14.25 cycles	321 Line and a Plumtree Auto
PLUM6	3 phase	Plumtree on auto 345 kV side w/stk center bkr.- 321 line	115-5 cycles,345-12 cycles	14.25 cycles	321 Line and a Plumtree Auto

ID	Fault Type	Fault Description	Local Clearing	Remote Clearing	Element Removed
NOR3	3 phase	Norwalk on the 345 kV side of the auto	4 cycles-345 kV	5 cycles-115 kV bkrs	Norwalk Auto
NOR4	1 phase	Norwalk on the 345 kV side of the auto w/ stk bkr.	115-5 cycles,345-12 cycles		Norwalk Auto
NOR5	3 phase	Norwalk on the 345 kV side of the auto w/ stk bkr.	115-5 cycles,345-12 cycles		Norwalk Auto
LMT1	3 phase	Long Mountain on the 321 Line	4 cycles	4 cycles	321 Line
LMT2	3 phase	Long Mountain on the 398 Line	4 cycles Pl Valley	4 cycles Long Mtn.	398 Line
LMT3	3 phase	Long Mountain on the 352 Line	4 cycles	4 cycles	352 Line
FRST1	3 phase	Frost Bridge on the 352 Line	4 cycles,5cycles 115 kV bkr	4 cycles	352 Line, Frost Bridge Auto
FRST2	3 phase	Frost Bridge on the 329 Line	4 cycles	4 cycles	329 Line
FRST3	1 phase	Frost Bridge on the 352 Line w/stk 1T	5 cycles 115 kV bkr	14.15 cycles	352 Line, Frost Bridge Auto, 329 Line
FRST4	1 phase	Frost Bridge on the 329 Line w/stk 1T	13 cycles 115 kV bkr	14.15 cycles	329 Line, 352 Line, Frost Bridge Auto
FRST5	3 phase	Frost Bridge on the 352 Line w/stk 1T	5 cycles 115 kV bkr	14.15 cycles	352 Line, Frost Bridge Auto, 329 Line
FRST6	3 phase	Frost Bridge on the 329 Line w/stk 1T	13 cycles 115 kV bkr	14.15 cycles	329 Line, 352 Line, Frost Bridge Auto
Card 2T	3 phase	3p flt @ Card St. w/ stk 2T	4 cycles	Card 3T = 10.5 Millstone 1T, 2T = 12.75	368 Line, 383 Line

4 Simulation Results

The 26 simulated faults show no stability problems with Phase II DC Option 1 in the provided light load, zero NE-NY transfer case. Simulations on the Phase II AC case show no problems as well.

The standard plots, created using the provided *bkollplot.idv* file, are included in Appendix A for the Phase II AC option and Appendix B for the Phase II DC Option 1. For each fault, the first seven pages of plots are those created by the provided *bkollplot.idv* file. For the Phase II DC simulations, there are 3 additional pages of plots showing the MW, Mvar, voltage, and current at each of the 10 DC converters, plus the voltages at the AC interconnection points. For the Phase II AC option, the last plot shows the voltages at the AC interconnection points.

With the Phase II AC model, the Keswick GCX impedance entered the relay characteristic for the following extreme contingencies: PLUM6, NOR5, FRST5, FRST6, and CARD2T. Although entering the Keswick GCX is not acceptable for normal contingencies, it is acceptable for extreme contingencies such as these three-phase faults with delayed clearing. With the Phase II HVDC Light® model, the impedance did not enter the relay characteristic for these faults. The reason is that the HVDC Light® controls provide additional damping of system oscillations following these faults.

For some faults, there are lightly damped oscillations of approximately 1 Hz that are present in both the Phase II AC simulations and the Phase II DC simulations, although the oscillations are better damped in DC case. These oscillations are visible in some of the bus voltages and line flows, and they are mostly damped out by 10 seconds. The damping seems to be acceptable with the AC option, and even better with the DC option.

No loss of supply was seen in any of the simulations.

Note that HVDC Light® converters are capable of damping power system oscillations in a similar fashion to PSS (power system stabilizer) equipped generators or conventional HVDC controls. The HVDC Light® controls can optionally include a supplemental power system stabilizing controller. In addition, the effectiveness of such a stabilizing function is dependent on the nature of the oscillatory mode. Typically, HVDC systems that are run in parallel with other ac lines can be effective in enhancing inter-area modes. However, no stabilizing function was included in this study.

5 Stability Conclusions

For the base case and faults modeled in this stability analysis, no stability problems were found with Phase II HVDC Light® Option 1. The system stability performance is as good or better with HVDC Light® as compared to the Phase II AC solution. Additional analysis is recommended to confirm this conclusion. Additional power flow base case conditions and additional fault cases should be studied in the future.

Because of its capability for high-speed voltage control and oscillation damping, the HVDC Light® options are expected to perform as well in future stability analyses as they have in this study.

Appendix A. Stability Plots for Phase II AC Option

Appendix B. Stability Plots for Phase II DC Option 1