STATE OF CONNECTICUT
CONNECTICUT SITING COUNCIL

Northeast Utilities Service Company Application to the Connecticut Siting Council for a Certificate of Environmental Compatibility and Public Need ("Certificate") For The Construction of a New 345-Kv Electric Transmission Line Facility and Associated Facilities Between Scovill Rock Switching Station in Middletown and Norwalk Substation In Norwalk, Including the Reconstruction of Portions of Existing 115-kV and 345-kV Electric Transmission Lines, the Construction of Beseck Switching Station in Wallingford, East Devon Substation in Milford, and Singer Substation in Bridgeport, Modifications at Scovill Rock Switching Station and Norwalk Substation, and the Reconfiguration of Certain Interconnections

Docket No. 272

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November 18, 2004

ANSWERS OF ABB, INC. TO FIRST SET OF INTERROGATORIES TO ABB, INC. FROM THE TOWNS OF CHESHIRE, MILFORD, ORANGE, WESTON, WILTON, AND WOODBRIDGE DATED OCTOBER 29, 2004

1. Has ABB reviewed the IRR?

   Yes.

2. Is ABB aware of any HVDC systems imbedded into an integrated alternating current system?

   Yes. Imbedded in this context is taken to mean synchronous operation with parallel AC transmission.

3. If the answer to Interrogatory #2 is in the affirmative with respect to each such system in which an HVDC system is imbedded in an integrated A/C system provide the following information:
   a. the location of the system;
   b. how long the system has been in operation;
   c. the respective lengths of each HVDC cable and A/C cable within the system;
   d. the lengths of overhead and underground cable for both HVDC and A/C lines;
   peak and average system loading.

Project Name	Location	Service Date	Cable Length (km)	Overhead Length (km)	Rating (MW)
Vancouver Island I, II	Canada	1968, 77	69,69	0	312, 370
Pacific Intertie	USA	1970, 85, 89	0	1360	1600, 2000, 3100
Square Butte	USA	1977	0	747	500
CU	USA	1978	0	687	1000
Fennoskan	Europe	1989	200	0	500
IPP	USA	1986	0	784	1920
Rihand-Delhi	India	1988	0	814	1568
Radisson-Nicolet	Canada	1991, 92	2	1000	2100
Chandrapur-Padghe	India	1998	0	736	1500
Gotland (VSC)	Sweden	1999	70	0	50
DirectLink (VSC)	Australia	2000	65	0	3 x 60
Tian-Guang	China	2000	0	960	1800
Cross Sound (VSC)	USA	2002	40	0	330
MurrayLink (VSC)	Australia	2002	179	0	220

In the table above, if the project name has (VSC) next to it, then the technology applied is the Voltage Source Converter (VSC) HVDC system. If there is no (VSC) next to the project name, conventional HVDC was utilized.

4. Does ABB agree or disagree with the statement in the IRR that the ABB report does not realistically address identified criteria?

   ABB disagrees with this general statement.

5. Please explain ABB's agreement or disagreement as set forth in Interrogatory #4.

   The ABB report addresses the 13 criteria identified by NU. For explanation, refer to ABB's responses to Interrogatories #26 – 45, and 52 – 58.

6. Does ABB agree or disagree that the conclusions reached in the ABB reports are based upon theory rather than operating experience as set forth in the IRR?

   ABB disagrees.

7. Please explain the response to Interrogatory #6.

   There is significant operational experience with HVDC (High Voltage Direct Current) links operating in parallel with AC transmission as indicated in the Table provided in the answer to Interrogatory #3. Whereas some of these systems are primarily generator outlet transmission and may be base loaded, others are operated for economic dispatch and follow variable schedules, e.g., Pacific Intertie, Gotland, Cross Sound, DirectLink, and MurrayLink.

   Although VSC (Voltage Source Converter) based HVDC transmission is a newer technology than conventional HVDC, there are five VSC-HVDC projects in operation and one project being commissioned. One of these operational projects consists of three parallel HVDC circuits operating in parallel with AC transmission. The control techniques and converter technology are established and proven and ratings have more than doubled between successive projects. Two projects are in operation with the same DC voltage level as proposed for the proposed VSC transmission options for SWCT. Some of the proposed options use converters with the about the same power rating as the Cross Sound Cable. Other options have a higher current rating than what has been used before but use the same voltage and valve design. This rapid development is similar to that experienced with thyristor valves in the 1970's. Furthermore, the network interface with AC transmission is much simpler than with conventional HVDC transmission since the reactive power can be independently controlled.

One of the VSC transmission options proposed, only Option 2 uses multi-terminal topology, which has not been used before for VSC based HVDC transmission. Many of the higher-level control techniques developed for multi-terminal HVDC are directly transferable to VSC-HVDC. VSC based HVDC is easier to deploy in multi-terminal configurations since power reversals can be made independent of system polarity.

Another area where operational experience is limited is with the modeling and scheduling of the DC links into security constrained unit commitment (SCUC) and security constrained economic dispatch (SCED) software. Nevertheless, models have been developed and are used for HVDC links in other Energy Management Systems (EMS) systems.

8. If ABB agrees that there is a lack of operating experience with respect to the conclusions reached in the ABB report as set forth in the IRR, does ABB believe this to be a matter of concern with respect to the ability of VSC-HVDC line to meet the systems need in Southwest Connecticut on a reliable basis.

   ABB does not agree that there is a lack of operating experience with HVDC links operating in parallel with AC transmission. HVDC systems designed for economic dispatch, interconnections and for generator outlet are in commercial operation. All meet applicable regional reliability criteria.

9. Please explain your response to Interrogatory #8.

   Operational experience is discussed in the answers to Interrogatories #3 and #7. The HVDC will be scheduled within the Security Constrained Dispatch algorithm used by ISO-NE and therefore requires no additional operational burden on ISO-NE operators. The use and incorporation of various control features of HVDC for remedial actions following contingencies or system disturbances need to be studied, documented and incorporated into ISO-NE operating protocols. It is to be noted that the control features of HVDC will give ISO-NE operators far greater flexibility of operation than they have today. The VSC-HVDC solution proposed for SWCT will have the ability to absorb or produce VARs, ability for fast reactive support similar to STATCOMs and even black-start capability. The VSC-HVDC schemes proposed by ABB all have redundant circuits, which promotes reliable operation. In the proposed VSC-HVDC design, redundancy is implemented for auxiliary power supplies, cooling systems, control and protection for the transmission circuit itself.

10. Does ABB concur with the statement in the IRR that there is no significant or comparable experience with a VSC-HVDC project of the magnitude and complexity and scope of that proposed in the ABB report, which addresses even a fraction of the many aspects of system need that must be resolved in Southwest Connecticut?

    No

11. Please explain the answer to Interrogatory #10.

    Although there is significant operating experience with VSC transmission, the issue is one of to what degree this experience is comparable to that proposed for SWCT. ABB proposed three different HVDC options as alternatives for Phase II. Option 1 comprises several point-to-point DC transmission links, Option 2 includes some multi-terminal DC transmission links and Option 3 includes parallel DC point-to-point transmission links between Besick and East Devon. The configuration proposed in Option 3 is the same as that used for DirectLink in Australia but with the voltage and power rating of Cross Sound Cable. Regarding the magnitude of the proposed project there are several systems in the world where the DC transmission capacity represents a major part of the power supply or transfer capacity, e.g. Systems where HVDC links supply a relatively large percentage of the local receiving system load are Gotland, Highgate, Nelson River, Square Butte, CU, IPP, Itaipu, PDCI and Three Gorges.

12. If the answer to Interrogatory #10 is in the negative, please identify the following:
    a. Each system containing significant or comparable experiences as that proposed;
    b. With respect to each system identified in Interrogatory 12a those aspects of system need which are similar to those involved in Southwest Connecticut;
    c. With respect to each system identified in Interrogatory 12a those aspects of system need in Southwest Connecticut, which are not similar to the identified system.

    Please refer to the table provided with the answer to interrogatory #3 for information about the projects referred to in the following answers:

    DirectLink is comprised of three VSC transmission links operating in parallel with each other and with AC transmission. Cross Sound and MurrayLink have the same DC voltage level as proposed for SWCT. Cross Sound has substantially the same power level as proposed for SWCT, i.e., the lower of the two alternative proposed power ratings. There are no multi-terminal VSC transmission schemes similar to that proposed for Option 2 in operation to date. The only multi-terminal schemes in operation use conventional HVDC converters. However, many of the principles developed for multi-terminal conventional HVDC are directly applicable to VSC-HVDC, e.g., master power control, loss allocation, fast-prioritised power order reallocation and protective isolation. Furthermore, the attributes of VSC-HVDC as developed by ABB simplify multi-terminal control and coordination. These include no residual earth current constraints, less dependence on communication, multimode regulators with built in back up modes, no minimum power order constraint, no polarity reversal required for power reversal, no commutation failures. There is one characteristic that differs with the VSC multi-terminal operation – DC ground faults cannot be cleared by converter control action and must involve AC breaker action. Note that only Option 2 includes multi-terminal configuration.

13. Does ABB agree with the statement contained in the IRR that the use of VSC-HVDC in Southwest Connecticut will require an unprecedented number of converter stations in one portion of the system?

    Depending on the option and power rating used, it could be less than, equal to or more than the number of converters used by ABB in other existing HVDC systems.

14. Please explain your answer to Interrogatory #13.

    The DirectLink scheme uses 6 converters. This is the same number of converters proposed in Option 3 using the lower of the two proposed power ratings. Options 1 and 2 as proposed require more converters. Use of the higher power rating, i.e., 530 MW converters require fewer converters.

15. Please identify systems, which have a similar number of converter stations to those that would be required in Southwest Connecticut.

    Please see answer to interrogatory #14.

16. Does ABB concur with the statement in the IRR that the use of each VSC-HVDC in Southwest Connecticut would require converter stations of the size not yet used anywhere?

    No, if the smaller power rating of 370 MW is used. Yes, if the larger power rating of 530 MW is used. It should be pointed out, however, that both power ratings use the same DC voltage rating and that the higher power rating is achieved by simply increasing the current rating of the components used in the VSC-HVDC converter valves. The development of VSC-HVDC converters parallels that for conventional HVDC converters. Once the basic technology was proven, increases in current and voltage levels followed. The MurrayLink and Cross Sound Cable projects operate at over twice the voltage and current levels than do the earlier Gotland and DirectLink projects for example.

17. Please identify any systems using converter stations of the size, which would be necessary for use in Southwest Connecticut for an imbedded VSC-HVDC line.

    In terms of voltage rating, MurrayLink and Cross Sound Cable are similar in size. In terms of power rating, Cross Sound Cable is substantially the same.

18. Does ABB agree with or disagree with the statement contained in the IRR that the use of VSC-HVDC in Southwest Connecticut would require the use of control technologies that are still in their infancy?

    No.

19. Please explain your answer to Interrogatory #18.

The control technologies used in VSC-HVDC transmission are used in 5 commercial projects and one project in its commissioning stage.

One of the options proposed, Option 2, involves multi-terminal operation, which has not yet been implemented to date for VSC-transmission. However, many of the principles developed for multi-terminal conventional HVDC are directly applicable to VSC-HVDC, e.g., master power control, loss allocation, fast-prioritised power order reallocation and protective isolation. Furthermore, the attributes of VSC-HVDC as developed by ABB simplify multi-terminal control. These include no residual earth current constraints, less dependence on communication, multimode regulators with built in back up modes, no minimum power order constraint, no polarity reversal required for power reversal, no commutation failures.

Most of the VSC schemes in commercial operation are dispatched manually to accommodate market demand, generation output, and optimal dispatch or network security. One VSC scheme, Gotland, is used to work together with parallel AC transmission to automatically follow wind generation variation. ABB proposes that the DC links be dispatched with guidance from security constrained unit commitment, SCUC, and security constrained economic dispatch, SCED, programs in much the same manner as generation is scheduled. HVDC links have been incorporated into such software programs in other electrical systems. Several schemes have a special control system to reach a new secure operating state following a critical contingency where speed of response is important. Such remedial action schemes e.g. run back or run on of the HVDC power flow are extremely fast acting (in the order of tens of milliseconds). Such remedial action schemes may be incorporated in the ISO-NE operating protocol and provide enhanced controllability and reliability for the SWCT grid.

As an alternative to manual dispatch, an HVDC link can be made to emulate an AC line by responding to changes in phase angle between its terminals. Such a scheme, however, has not been used in any operating system as an operational aide.

20. Please describe the control technologies that would need to be employed for the use of a VSC-HVDC system in Southwest Connecticut.

In the VSC-based HVDC transmission schemes described herein, the switching of the IGBT valves follows a pulse-width modulation (PWM) pattern (this applies to both two terminal and multi-terminal options). This switching control allows simultaneous adjustment of the amplitude and phase angle of the converter AC output voltage with constant DC voltage even with a two-level converter. With these two independent control variables, separate active and reactive power control loops can be used for regulation.

The active power control loop can be set to control either the active power or the DC side voltage. In a DC link, one station will be selected to control the active power while the other must be set to control the DC side voltage. The reactive power control loop can be set to control either the reactive power or the AC side voltage. Either of these two modes can be selected independently at either end of the DC link. One of the VSC transmission options proposed, only Option 2 uses multi-terminal topology. Many of the higher-level control techniques developed for multi-terminal HVDC are directly transferable to VSC-HVDC. VSC based HVDC is easier to deploy in multi-terminal configurations since power reversals can be made independent of system polarity.

21. Please identify each system in which the control technologies identified in Interrogatory #20 have been utilized.

    Gotland, Tjaerborg, DirectLink, MurrayLink, and Cross Sound Cable.

22. With respect to each system identified in Interrogatory #21, please describe the following:
    a. line voltage
    b. system load both peak and average
    c. a comparison between the transmission infrastructure and capacity with that of the Southwest Connecticut system.

    Please refer to the synchronous VSC projects listed in the table accompanying the answer to interrogatory #3 for voltage and system power ratings. In addition, the asynchronous project, MurrayLink, is rated +/- 150 kV, 200 MW. Systems where HVDC links supply a relatively large percentage of the local receiving system load are Gotland, Highgate, Nelson River, Square Butte, CU, IPP, Itaipu, PDCI and Three Gorges.

23. Does ABB agree or disagree with the statement contained in the IRR that the operating procedures necessary to operate an imbedded VSC-HVDC system in Southwest Connecticut would be impractical?

    Disagree.

24. Please explain your answer to Interrogatory #23.

    Operational experience is discussed in the answers to interrogatories #3 and #7 and #9. The HVDC will be scheduled within the Security Constrained Dispatch algorithm used by ISO-NE and therefore requires no additional operational burden on ISO-NE operators. The use and incorporation of various control features of HVDC for remedial actions following contingencies or system disturbances need to be studied, documented and incorporated into ISO-NE operating protocols. It is to be noted that the control features of HVDC will give ISO-NE operators far greater flexibility of operation than they have today. The VSC-HVDC solution proposed for SWCT will have the ability to absorb or produce VARs, ability for fast reactive support similar to STATCOMs and even black-start capability.

25. Please describe in narrative form the operating procedures that would need to be employed to address system changes for which an HVDC system would not be capable of responding to with the same facility as an A/C system.

It is envisioned that the HVDC terminal outputs would be scheduled by ISO-NE within the ISOs security constrained dispatch function. The use and incorporation of various control features of HVDC for remedial actions following contingencies or system disturbances need to be studied, documented and incorporated into ISO-NE operating protocols. The ability to control power flow will provide flexibility to deal with and the potential to reduce generation dependencies.

Network constraints consist of circuit transfer limits, e.g., thermal limits or stability limits with allowance for contingencies. Unlike with AC transmission, a DC circuit cannot become overloaded since its power flow is controlled. The controllability of the DC transmission (or AC transmission with phase angle regulators) provides additional operational flexibility of the constrained network. With AC transmission, the only recourse available to system operations when confronted with a transmission constraint is generation re-dispatch. SCUC and SCED can be used (and is used) to schedule controllable transmission elements, e.g., PAR (Phase Angle Regulators) and HVDC, just as well as generation. Security Constrained Unit Commitment (SCUC) and Security Constrained Economic Dispatch (SCED) can be used (and is used) to schedule controllable transmission elements, e.g., PAR and HVDC, just as well as generation.

26. Does the ABB-HVDC proposal demonstrate at least 1200-megawatt net increase in "all lines in" Southwest Connecticut import capability?

The Criterion 1 provided to ABB for the SWCT transmission system states: "Moving approximately 1200 MW of power into SWCT. Approximately 1200 MW of power injection (800 MW incremental after Phase II, and Phases I & II give 1400 MW; comparison of transfer capacity for both AC and DC line outages.)". This criterion implies that the transfer capability into SWCT will increase by 1200 mw after completion of both Phase I and Phase II projects. The VSC-HVDC schemes proposed by ABB together with Phase I (AC lines and substation projects) meet this criterion.

Redundancy built into the VSC-HVDC schemes proposed by ABB ensures a high level of transfer capability even in contingency cases. All HVDC schemes proposed involve parallel circuits for each segment. Depending on the converter rating used, incremental transfer capacity is either 3 x 370 MW or 2 x 530 MW at the receiving terminal AC output. Because of its controllability, each DC link can be loaded up to its maximum capacity regardless of generation dispatch. Available AC transmission capacity on the other hand cannot always be fully utilized since power will divide among parallel circuits according to generation dispatch and circuit impedance. Only the limiting transmission line will load to its full capacity, others will remain underutilized. Comparing transfer capacity following AC or DC line outages, each of the DC segments will still be able to deliver 2 x 370 MW or 1 x 530 MW after loss of one parallel DC circuit. In all cases the existing parallel 345 kV AC transmission together with phase I will still be able to deliver some of the required capacity. With the AC scheme, although there are two parallel circuits between East Devon, Singer and Norwalk, there is only a single circuit between Besick and East Devon.

27. Will placing large series reactors in the generator leads for Bridgeport Energy and Bridgeport Harbor 3 diminish area reactors reserve necessary for voltage control?

    There will be negligible impact. This should be confirmed by additional studies.

28. Please explain your answer to Interrogatory #27.

    Use of series reactors was considered an acceptable method and is also currently approved for use at Bridgeport Harbor Unit 2(this reactor was included in the short circuit data base provided by NU for the Phase II All-AC solution). The ABB proposal used series reactors at Bridgeport Harbor Energy and Bridgeport Harbor Unit 3 in order to meet the study scope criteria to reduce the fault levels at Pequonnock 115-kV bus to about 90% of 63kA. As a reference, with the proposed Phase II all-AC solution, the fault level is 96% of 63kA. Other methods to limit short circuit without series reactors are available, such as the use of ungrounded transformers, and would produce results comparable to levels the Phase II all AC solutions provide.

    Given the relatively small size of the series reactors proposed for Bridgeport Energy and Bridgeport Harbor 3 (the proposed reactors are comparable in size to what is used by NU for Bridgeport Harbor 2), the impact on the area reactive reserve necessary for voltage control would be small. Since the VSC-HVDC terminals can provide fast dynamic reactive power, the overall area reactive reserve will increase.

29. Will the placing of large series reactors in the generator leads for Bridgeport Energy and Bridgeport Harbor 3 diminish transient stability performance?

    There will be negligible impact.

30. Please explain your answer to Interrogatory #29.

    Given the relatively small size of the series reactors proposed for Bridgeport Energy and Bridgeport Harbor 3 (the proposed reactors are comparable in size to what is used by NU for Bridgeport Harbor 2), the impact on transient stability performance would be small. This should be confirmed by additional studies.

31. Will the placing of large series reactors in the generator leads for Bridgeport Energy and Bridgeport Harbor 3 increase the potential of the transient over voltages?

    There will be negligible impact.

32. Please explain your answer to Interrogatory #31.

Given the relatively small size of the series reactors proposed for Bridgeport Energy and Bridgeport Harbor 3 (the proposed reactors are comparable in size to what is used by NU for Bridgeport Harbor 2), the impact on transient overvoltage would be small. This should be confirmed by additional studies.

33. if your answers to Interrogatories #27, #29 or #31 are in the affirmative, can those matters be addressed so as not to negatively impact the reliability and operability of the system southwest Connecticut.

Not applicable.

34. Please explain your answer to Interrogatory #33.

Not applicable.

35. Will the use of an imbedded HVDC system in southwest Connecticut create unacceptable generation interdependencies?

No.

36. Please explain your answer to Interrogatory #35.

Multiple HVDC terminals enhance operational flexibility and controllability of the system. It is envisioned that the HVDC terminal outputs would be scheduled by ISO-NE within the ISOs security constrained dispatch function. The proposed HVDC solution will not increase the generation dependencies described by ISO-NE. The ability to control power flow will provide flexibility to deal with and the potential to reduce the generation dependencies. Network constraints consist of circuit transfer limits, e.g., thermal limits or stability limits with allowance for contingencies. Unlike with AC transmission, a DC circuit cannot become overloaded since its power flow is controlled. The controllability of the DC transmission (or AC transmission with phase angle regulators) provides an added degree of freedom in optimal operation of the constrained network. With AC transmission, the only recourse available to system operations when confronted with a transmission constraint is generation re-dispatch. Security Constrained Unit Commitment (SCUC) and Security Constrained Economic Dispatch (SCED) can be used (and is used) to schedule controllable transmission elements, e.g., PAR and HVDC, just as well as generation.

The power flow study performed by ABB investigated 24 different scenarios of generation dispatches and transfer conditions provided by NU and UI. The results of the contingency analysis (based on the contingency list provided by NU/UI) do not show any new overload or voltage problems beyond those that are also present with the all-AC Phase II solution.

37. Please explain how new generators could connect to the system without the installation of a converter system to meet future needs in Southwest Connecticut.

From a reliability perspective, bulk power transmission, whether AC or DC should not be tapped indiscriminately for connection of generation. However, if the underlying transmission is inadequate to support the new generation, it should be connected through an intermediate switching station or substation rather than a tap. With HVDC, this would require another converter station to connect into the DC transmission. If there are several generators relatively close to one another, it is usually more economical to reinforce the underlying transmission to form a collector system before installing a substation or a converter station to access the overlying bulk power transmission. Option 3 allows addition of generation without adding any converter terminals.

38. Do you agree with the statement in the IRR that the configuration necessary to connect new load substations in an HVDC system would be more expensive and complex than a connection to an all A/C system?

Yes, HVDC converter stations are more expensive than high voltage AC substations. EHV bulk power transmission is not normally used to supply distribution substations, however. Distribution substations are typically served from underlying transmission supported by strategically located substations tied to the overlying EHV system. This limits the number of high voltage substations or converter stations.

39. Please explain your answer to Interrogatory #38.

From a reliability perspective, bulk power transmission, whether AC or DC should not be tapped indiscriminately for connection of load. However, if the underlying transmission is inadequate to support the new generation, it should be connected through an intermediate switching station or substation rather than a tap. With HVDC, this would require another converter station to connect into the DC transmission. If there are several new distribution substations located relatively close to one another, it is usually more economical to reinforce the underlying transmission to form a lower voltage transmission system before installing a substation or a converter station to access the overlying higher voltage bulk power transmission. Option 3 allows addition of load west of East Devon without adding any converter terminals.

40. Do you agree with the statement contained in the IRR that HVDC station additions would create further operational coordination issues?

No. Please see answers to Interrogatory # 24 and #25.

41. Please explain your answer to Interrogatory #40.

It is envisioned that the HVDC terminal outputs would be scheduled by ISO-NE within the ISOs security constrained dispatch function. The dispatching of the HVDC terminals will be performed in conjunction with the generators, using the same basic market operation tools that have Security Constrained Unit Commitment (SCUC) and Security Constrained Economic Dispatch (SCED) functions. In the most basic terms, dispatching the HVDC terminals is very similar to dispatching generation units within ISO-NE. That is, ISO-NE will provide the Day Ahead schedules and Real Time adjustments determined by the SCUC and SCED to the operator of the HVDC terminals, in a fashion similar to the way ISO-NE is currently dispatching generators. The energy management and SCADA system can also carry out the schedule ordered by ISO-NE for the HVDC system directly and automatically. The schedules determined for HVDC through the security constrained dispatch function will always maintain the system in a secure state i.e. no overloads, no voltage or stability problems and the ability to withstand single or multiple contingencies.

The Security Constrained Economic Dispatch algorithm reschedules the system every 5 minutes to follow changes in load level and equipment availability. Note that the same changes would also result in a need to adjust the dispatch on generators. As generation is committed and dispatched to serve load, the controllable DC flows would be scheduled to maintain secure and efficient system operation. The DC transmission can also be rescheduled to a new state following contingencies if desired or needed. The use and incorporation of various control features of HVDC for remedial actions following contingencies or system disturbances need to be studied, documented and incorporated into ISO-NE operating protocols. It is to be noted that the control features of HVDC will give ISO-NE operators far greater flexibility of operation than they have today. The VSC-HVDC solution proposed for SWCT will have the ability to absorb or produce VARs, ability for fast reactive support similar to STATCOMs and even black-start capability.

42. Do you agree with the statement in the IRR that an unreasonable number of significant and immediate changes would need to be made by system operators to the settings of each of the HVDC terminals in order to have a reliable and secure dispatch with varying dispatches and line outages?

    No.

43. Please explain your answer to Interrogatory #42.

    See ABB answer to Interrogatory #41.

44. Do agree with the statement contained in the IRR that the use of an HVDC system would place an unacceptable burden on system operators to make changes in settings to have reliable and secure dispatch?

    No.

45. Please explain your answer to Interrogatory #44.

    See ABB answer to Interrogatory #41.

46. Do you agree with the statement contained in the IRR that HVDC over 330 megawatts is unproven?

No.

47. Please explain you answer to Interrogatory #46.

The development of VSC-HVDC converters parallels that for conventional HVDC converters. Once the basic technology was proven, increases in current and voltage levels followed. The MurrayLink and Cross Sound Cable projects operate at over twice the voltage and current levels than do the Gotland and DirectLink projects.

The largest VSC-HVDC Converter installed today is the 330 MW (346 MW rectifier rating) Cross Sound converter that was designed during 2000 and commissioned in August 2002. Consistent with traditional development strategies development the last four years has resulted in using larger semiconductors and thereby increased the converter size to 500 – 550 MW pending application. All testing has been completed on the 550 MW system for commercial tendering.

48. Do you agree with the statement in the IRR that multi-terminal VSC-HVDC operation is unproven?

Yes.

49. Please explain your response to Interrogatory #48.

So far multi-terminal operation, which is proposed in Option 2, only has been limited to conventional HVDC. However, many of the principles developed for multi-terminal conventional HVDC are directly applicable to VSC-HVDC, e.g., master power control, loss allocation, fast-prioritised power order reallocation and protective isolation. Furthermore, the attributes of VSC-HVDC as developed by ABB simplify multi-terminal control and coordination. These include no residual earth current constraints, less dependence on communication, multimode regulators with built in back up modes, no minimum power order constraint, no polarity reversal required for power reversal, no commutation failures. There is one characteristic that differs with the VSC multi-terminal operation – DC ground faults cannot be cleared by converter control action and must involve AC breaker action. Note that only Option 2 includes multi-terminal configuration.

50. If your answer to Interrogatory #46 and/or #48 is in the affirmative, does this mean that the proposed SC-HVDC could not be operated reliably?

No.

51. Please explain your response to Interrogatory #50.

Refer to answers to Interrogatories #7, #8, #9, #47 and #49

52. Do you agree with the statement contained in the IRR that a "typical" disturbance the concurrent mis-operation of an imbedded HVDC facility that is providing critical parallel path capability in Southwest Connecticut could readily result in a complete failure in the Southwest Connecticut System?

No.

53. Please explain your answer to Interrogatory #52.

The configuration and control and protection for the proposed HVDC systems is designed to selectively minimize the required equipment outages to safely and reliably isolate a disturbance or fault internal to the HVDC circuit protective zone. In addition a disturbance or fault external to an HVDC circuit protective zone should not cause an outage of the HVDC link. Just as with AC transmission, switchyard and network design is such that regional reliability criteria are met for anticipated faults and mis-operations such as breaker failure. Two or three HVDC circuits are proposed for each transmission segment. Each DC circuit is controllable and can therefore never become overloaded leading to cascading outages following loss of a parallel element. If there were a misoperation of a protective function, which resulted in loss of a DC link, only the circuit with the misoperation would be affected. The VSC-HVDC system is envisioned to be operated by NE-ISO in security constrained mode i.e. the system will be operated in a manner such that it will be able to withstand single or multiple system contingencies. This prudent operating protocol guards against the occurrence of cascading outages leading to a large-scale blackout.

54. Would the mis-operation identified in Interrogatory #52 be reasonably likely to occur or improbable?

Improbable.

55. Please explain your answer to Interrogatory #54.

Each HVDC circuit is independent. Redundancy is used in the auxiliary systems and in the control and protection. Extensive use of self-checking and diagnostics are used. Switchyard design would be such that failure of any circuit branch or element would not take out another circuit.

56. If your answer to Interrogatory #52 in the affirmative, can the HVDC system be designed and or to avoid the result referenced in Interrogatory #52?

Not applicable. The proposed system would be designed to meet the regional reliability criteria.

57. Do you agree with the statement contained in the IRR that increased employment of VSC-HVDC converter terminals increases the likelihood of mistuning over the range of operating and maintenance conditions resulting in unanticipated sub-synchronous intervention with generators?

No.

58. Please explain your answer to Interrogatory #57.

Sub synchronous interaction mitigation is built into the redundant converter firing control system itself to avoid destabilizing turbine-generator torsional modes throughout the torsional range for all credible operating conditions. There are no higher-level supplemental or external control loops, which have individual failure modes. This control has been thoroughly studied and successfully implemented and tested in the Cross Sound Cable project.