Discussion of Potential Technical Benefits of the Juan de Fuca Cable Project to Power Transmission Issues Facing British Columbia

We believe that due to its technical and performance characteristics the HVDC Light® technology to be used for the Juan de Fuca Cable Project offers unique potential contributions to regional transmission needs and opportunities.[1] Because this technology has not yet been introduced in this region we have prepared this brief paper to introduce its capabilities and discuss their applicability here. In this paper we have addressed three areas: potential benefits to the region's AC transmission system in general, HVDC Light®'s "black start" capabilities as applied to regional needs, and HVDC Light®'s attributes as a "virtual generator" with an emphasis on its benefits in integrating intermittent renewable energy resources such as wind power.

1. <u>Unique Capabilities & Value of HVDC Light® Technology</u>

HVDC Light® is a state-of-the-art high voltage direct current ("HVDC") transmission technology recognized internationally for its reliability and its fast and accurate power control. By its nature, HVDC Light® technology offers benefits to the functionality of an existing high-voltage alternating current ("HVAC") system in which it is embedded that go well beyond the benefits realized by adding capacity.

a. HVDC transmission systems support overall grid functionality.

Conventional high voltage direct current transmission systems embedded within a grid can improve the overall performance of the grid over and above the additional transmission capacity that they provide. For example, modulation of power flows on an HVDC line has the potential to damp power oscillations in parallel HVAC lines, thereby increasing stability, power transfers, and system reliability.[2] The precise controllability of HVDC offers advantages when the control of real power is desirable to manage normal or post-contingency flows on the network.[3] These controllability characteristics can also help minimize or mitigate the adverse effects of remedial action schemes currently established for the system. Further, HVDC can provide increased transfer capability through direct or indirect regulation of flows across critical transmission paths or provide voltage support to the system.[4] The whole system benefits from HVDC's increased flexibility for scheduling generation to manage congestion.[5] Finally, an HVDC line is not vulnerable to parallel path

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[1] "HVDC Light®" is a proprietary name for a second-generation form of high voltage direct current ("HVDC") power transmission technology.

[2] Increasing WSCC Power System Performance With Modulation Controls on the Intermountain Power Project HVDC System, D.E. Martin, W.K. Wong, D.L. Dickmander, R.L. Lee, D.J. Melvold at 5, IEEE Transactions on Power Delivery (1992).

[3] Planning Issues for HVDC, M. Henderson, J. Gagnon, D. Bertagnolli at 28, Power Systems Conference and Exposition, IEEE (2006).

[4] *Id*.

[5] Economic Assessment of HVDC Project in Deregulated Energy Markets, S. Wang, J. Zhu, L. Trinh, J. Pan ("Wang") at 2, Electric Utility Deregulation and Restructuring and Power Technologies Conference, IEEE (2008) ("DRPT 2008").

flow problems,[6] and its capacity is not affected by congestion on parallel AC systems as long as the sending and receiving ends have strong connections to AC systems.[7]

b. HVDC Light® offers additional benefits in addition to those of conventional HVDC.

HVDC Light® technology offers additional benefits to routine grid functionality.[8] It can keep voltage stable due to its ability to rapidly control both active and reactive power independently, improving utilization of the AC components of the system.[9] Further, like conventional HVDC, it can improve the transient stability of the AC system by damping power oscillations.[10] It helps alleviate bottlenecks in the overall grid by damping oscillations in the voltage flowing through the system and by otherwise supporting system voltage within safe limits; as a result, the transmission capacity of the system can be increased by more than the rating of the HVDC Light® link.[11] Further, HVDC Light® does not require the same strong connections to AC systems that are required to realize all the potential of a conventional HVDC system.[12] In short, an HVDC Light® link enhances the capacity and reliability of the AC components of the system in which it is embedded.[13]

2. Benefits to the WECC Path 3 Area

Experiences on HVDC cable projects in New York have demonstrated that the addition of an HVDC transmission line provided significant regional benefits, enhancing the grid's capacity, robustness, and ability to recover quickly from outages. The Neptune submarine HVDC

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[6] "Parallel path flows" (also known as "loop flows") are unanticipated flows of power through an interconnected grid due to electricity's property of following the path of least resistance rather than a direct "point-to-point" path from the source to the user. An HVDC line, by contrast, is a true point-to-point link.

[7] Wang at 2.

[8] It is beyond the scope of this memorandum to provide a detailed technical description of HVDC Light® technology, its features, and its performance. Such information may be found on the Internet, e.g., http://www.abb.com/industries/us/9AAC30300394.aspx?country=US.

[9] *Id.*, Power System Stability Benefits With VSC DC-transmission Systems, S.G. Johansson, G. Asplund, E. Jansson, R. Rudervall ("Johansson") at 1, 3, Cigré Session 2004 (2004); Co-ordination of Parallel AC-DC Systems for Optimum Performance, A.D. Castro, R. Ellström, Y.-J. Häfner, C. Liljegren ("Castro"), GSEE Power Delivery Conference, University of Castilla-La Mancha (1999); Investigation on Applying HVDC Light to China Southern Power Grid, Q. Chen, Y. Zhang, Q. Guo, C. Hong ("Chen") at 1, IEEE DRPT 2008; Study of HVDC Light for Its Enhancement of AC/DC Interconnected Transmission Systems, Q. Zhong, Y. Zhang, L. Lin, Q. Chen, Z. Wu ("Zhong") at 1, IEEE (2008); The Gotland HVDC Light Project - Experiences from Trial and Commercial Operation, U. Axelsson, A. Holm, C. Liljegren, M. Åberg, K. Eriksson, O. Tollerz ("Axelsson") at 5, CIRED Conference (2001).

[10] Chen at 1; Zhong at 1; Power System Reliability and Transfer Capability Improvement by VSC-HVDC (HVDC Light®); L. Zhang, L. Harnefors, P. Rey ("Zhang") at 4, Regional Meeting on Security and Reliability of Electric Power Systems, Cigré (2007).

[11] Johansson.

[12] *Cf.* Wang at 2.

[13] AC Grid with Embedded VSC-HVDC for Secure and Efficient Power Delivery, J. Pan, R. Nuqui, K. Srivastava, T. Jonsson, P. Holmberg, Y.-J. Häfner ("Pan") at 4, presented at IEEE Energy 2030, IEEE (2008); *see also* HVDC Light® System Interaction Tutorial at http://www.abb.com/cawp/GAD02181/C1256D71001E0037C1256D08002E7282.aspx.

cable connecting the grid on Long Island with New Jersey made it possible for the New York Independent System Operator to reduce the statewide installed margin reserve of generation capacity.[14] Further, the Cross Sound Cable, an HVDC Light® system connecting Long Island with Connecticut, made it possible to swiftly restore power to Long Island users following the August, 2003 blackout that affected much of eastern North America.[15]

Similar benefits should occur on the BCTC transmission system in southwestern British Columbia, including Vancouver Island and the Lower Mainland. These potential benefits stem from several factors: general challenges facing the existing grid; the need to accommodate returns of the Canadian Entitlement under the Columbia River Treaty; and power demands on Vancouver Island.

The availability of an additional link between Washington State and British Columbia would provide an alternative pathway to serve loads on Vancouver Island, easing congestion and freeing up transmission capacity on the north-to-south pathways on the Lower Mainland.[16] The ability to provide electrical capacity and supply power from the south in emergency situations would provide a distinct improvement in the reliability of electrical service to both areas. For example, the existence of such an alternative pathway could have prevented the recent Thanksgiving Day blackout in the Victoria area.

3. "Black Start" Capabilities of HVDC Light®

The "black start" capabilities of HVDC Light® systems are unique to this technology. While the Juan de Fuca Cable would provide an alternative means for restoring service to Victoria and southern Vancouver Island in the event of an outage, especially when planned improvements to the BPA grid on the Peninsula are made, it offers the potential to help recover from a blackout affecting a much broader area reaching well into the Lower Mainland.

a. HVDC Light®'s "black start" capability offers unique benefits in responding to system emergencies.

An embedded HVDC Light® transmission system is a valuable asset during a grid restoration since it will be available almost instantly after the blackout and does not need any short circuit capacity in order to become connected to the grid.[17] An HVDC Light® system has

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[14] 2007-2008 Biennial Report, New York State Reliability Council, accessed on July 20, 2009 at http://www.nysrc.org/pdf/Reports/2007-08%20Biennial%20Report%2004-02-09%20final.pdf; New York Control Area Installed Capacity Requirements for the Period May 2008 through April 2009, New York State Reliability Council, LLC, accessed on July 20, 2009 at http://www.nysrc.org/pdf/Reports/Final%202008%20IRM%20Report%2012-14-07%20_2_.pdf.

[15] THE BLACKOUT: THE TECHNOLOGY; Restoring Lost Voltage Takes Time, and a Complex Choreography, New York Times (August 16, 2003); THE BLACKOUT: A DISPUTE; Two States Argue Over Cross-Sound Cable, Despite Its Post-Blackout Help, New York Times (August 19, 2003).

[16] A ColumbiaGrid study team stated that the JDF Cable would provide "Possible Significant Benefit" (the highest possible ranking) in the "British Columbia to Northwest" transmission path. Final Draft - 2009 Biennial Transmission Expansion Plan, Rev. 2, ColumbiaGrid, February 2009 ("ColumbiaGrid Biennial Plan") at 20-21.

[17] Johansson at 8; Cross Sound Cable Project - Second Generation VSC Technology for HVDC, B.D. Railing, J.J. Miller, PI Steckley, G. Moreau, P. Bard, L. Ronström, J. Lindberg at § 5.1, Session 2004, Cigré (2004); HVDC

black start capability and can energize transmission lines to establish an initial voltage, facilitating reconnection of other resources over a broad geographic area.[18]

A recent paper described field tests in a working grid.[19] These field tests repeatedly demonstrated that power provided by an HVDC Light® transmission system can provide the auxiliary power needed to enable a thermal power station to start up and synchronize to its home grid even though it was located about 120 miles away from the HVDC Light® converter station. In fact, the tests demonstrated that HVDC Light® could successfully energize a wide range of grid components under a wide range of circumstances. A large transformer (rated at 250 MVA, or about 70% of the converter station's 350 MVA capacity[20]) located at the converter station was energized from the black condition. Another, smaller transformer (25 MVA) located 120 miles from the converter, and the intervening HVAC transmission line, were also successfully energized. At this same distance, a load of about 10 MW was then successfully switched in. This load consisted primarily of induction motors, which can draw a substantial current when starting, and which were part of the auxiliary equipment for the large generators in the thermal power plant. At this point the plant's first generator could be fired up and brought on line.

The authors noted that after the first generation unit is switched in, power generation can be increased as high as the converter station's capacity while more loads are picked up. It is not necessary to balance loads and generation since the HVDC Light® system is able to adjust system power over a wide range from absorption to generation, up to the rated power of the HVDC Light® system. This capability can speed up the restoration process significantly. Once all the generators in the grid are restored and loads connected, the HVDC Light® system can be switched to the normal power control mode.

The authors concluded that HVDC Light® technology offers substantial advantages over conventional black start procedures. Its direct and near-instantaneous voltage control can virtually eliminate harmful voltage drops associated with starting large motors, or damaging over-voltages due to the self-excitation phenomena associated with energizing long HVAC lines. HVDC Light® offers fast and direct frequency control, with a power capability of twice the power rating of the converter station. This means that the switching in of specific loads and generation sources is not as critical as in a traditional restoration, simplifying the process and making it more robust. The potential for unsuccessful energization of a transformer can be reduced since the HVDC Light® system's capacity is typically greater than that of the transformer. Finally, with HVDC Light® technology it is possible to perform "soft" energization of numerous major power system components at the same time,

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with Voltage Source Converters - a Powerful Standby Black Start Facility, Y.-J. Häfner, H. Duchen, M. Karlsson, L. Ronstrom, B. Abrahamsson ("Häfner"), IEEE PES T&D Conference (2008); see also, Benefits During Power Grid Restoration, ABB, accessed on August 13, 2009 at http://www.abb.com/cawp/gad02181/1a9363fa7a95013ec1256e230033e6c3.aspx.

[18] Johansson at 8; Häfner.

[19] Häfner, *passim.*

[20] The 350 MVA capacity mentioned here is specific to this field test and does not represent the limit for HVDC Light® technology in general or the Project in particular. Similarly, the 120-mile parameter was specific to the system examined and is not necessarily representative.

speeding up the restoration while avoiding harmful voltage transients and current stresses on the equipment.

b. The Project's black start capability could have regional benefits.

Thus, having an HVDC Light® system with an endpoint in Victoria could provide regional benefits in the event of a widespread blackout. First, an HVDC Light® transmission system can provide immediate restoration of local service, as was demonstrated in the multi-state blackout in August, 2003, when at the flip of a switch 100 MW of service was restored to Long Island users.[21] But the benefits do not end there. The ability of HVDC Light® converters to generate a voltage that can be changed very quickly in amplitude and phase makes it possible to energize a black network after a blackout. Of particular note, these benefits can be realized at long physical distances from the HVDC Light® converter station as long as a suitable transmission pathway exists between the converter and the remote grid components.

4. <u>"Virtual Generation" and Wind Power</u>

The "virtual generation" capabilities of HVDC Light® power transmission technology have been recognized internationally as particularly valuable in efforts to integrate intermittent renewable energy resources, notably wind generation, into a regional grid. Accordingly, we have assembled this short discussion of the virtual generation capabilities of HVDC Light®.

a. HVDC Light® transmission systems can function as a "virtual generator."

A primary feature distinguishing HVDC Light® transmission technology from conventional HVDC is its reliance on self-commutated voltage source converter (VSC) technology to convert AC to DC and vice versa.[22] HVDC Light® voltage source converters possess unique technical and performance characteristics, including:

- No reactive power demand;
- Independent, continuous control of active and reactive power at each terminal;
- Control of reactive power can be used to regulate AC system voltage;
- Near-instantaneous, continuous controllability of phase, amplitude, and frequency parameters; and,
- Dynamic reactive power reserve capability for contingency voltage support.[23]

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[21] THE BLACKOUT: THE TECHNOLOGY; Restoring Lost Voltage Takes Time, and a Complex Choreography, New York Times (August 16, 2003); THE BLACKOUT: A DISPUTE; Two States Argue Over Cross-Sound Cable, Despite Its Post-Blackout Help, New York Times (August 19, 2003).

[22] Middletown - Norwalk Transmission Project: Technical Description of VSC HVDC Converter and Cable Technology, ABB Power Technologies AB (2004) ("Technical Description") at 3; HVDC with Voltage Source Converters and Extruded Cables for up to ±300 kV and 1000 MW, B. Jacobson, Y.-J. Häfner, P. Rey, G. Asplund, M. Jeroense, A. Gustafsson, M. Bergkvist, Proc. CIGRÉ 2006 at 7, accessed on August 14, 2009 at http://library.abb.com/global/scot/scot221.nsf/veritydisplay/50a80fe6bb88e8f9c12571d900307a44/$File/B4_105.pdf.

[23] Technical Description at 3; Zhang at 4; The ABCs of HVDC Transmission Technologies - An Overview of High Voltage Direct Current Systems and Applications, M.P. Bahrman, B.K. Johnson, IEEE Power & Energy Magazine (March/April 2007) at 35.

These characteristics give an HVDC Light® system the attributes of a virtual generator at every point of power delivery, allowing each converter to behave within the grid like an ideal power generator with a flexible working point and no inertia.[24]

b. The unique attributes of HVDC Light® transmission systems are particularly applicable to intermittent renewable power resources.

HVDC Light® technology offers several unique benefits in managing intermittent or variable power, as is commonly found with some renewable energy sources such as wind power. The technology's inherent smoothing capability provides a means for conditioning such power and integrating it with the AC grid.[25] Its black start capability allows it to be started up from a de-energized state, as would occur at a wind farm after a calm period.[26] Finally, its ability to function as a "virtual generator" allows it to draw on other resources (such as thermal generation plants) to firm up power from intermittent generation sources.[27]

As additional renewable energy resources are developed throughout the Western United States and Canada, enhancing access to such resources will be increasingly important. As noted above, HVDC Light® "virtual generation" capabilities can help firm up power flow by matching controllable generation resources to intermittent generation sources.

Proponents of large-scale wind power developments in Europe have recognized the challenges and opportunities presented by temporal and spatial dispersal of wind energy, and the special value of HVDC Light® technology in efforts to capture such energy.[28] The proposed "Supergrid" project in Europe features offshore wind farms stretching from offshore western Ireland to the Baltic Sea, with outposts in the Western Mediterranean, all interconnected into transmission systems on mainland Europe.[29] HVDC Light® is viewed as a key component in making this project possible due to its ability to act as a "virtual generator," i.e., to generate and consume reactive power very quickly, thereby managing voltage control, fault ride-through, and grid disturbances.[30]

In a working example a bit closer to home, the Neptune submarine HVDC cable connecting the grid on Long Island, New York, with New Jersey has made it possible for the New York Independent System Operator to reduce the statewide installed margin reserve of

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[24] Technical Description at 3; Zhang at 4.

[25] Castro; Axelsson at 5.

[26] The Future Is Now: Linking up the World's Largest Offshore Wind-farm Area with HVDC Transmission, J. Kreusel, ABB Review ("Kreusel"), accessed on July 15, 2009 at http://search.abb.com/library/Download.aspx?DocumentID=9AKK104295D3404&LanguageCode=en&DocumentPartID=&Action=Launch&content=external; *see also*, Häfner.

[27] Zhang at 4.

[28] *See* Kreusel; Supergrid to the Rescue, S. Gordon, IET Power Engineer (October/November 2006) ("Supergrid") at 31.

[29] Supergrid at 31-32.

[30] *Id.*

generation capacity despite the state's growing reliance on wind generation, which tends to impair reliability.[31]

5. Conclusion

In sum, the Juan de Fuca Cable offers a number of major new benefits for the region. Of significant importance is adding 550 MW of transmission capacity: providing any additional north-south transmission capacity via a new link between BPA's Puget Sound transmission network and the BCTC transmission system in British Columbia will help improve reliability and increase capacity throughout the region in general. Further, HVDC Light® technology offers unique capabilities that would benefit the entire system. For example, HVDC Light®'s black start and virtual generation capabilities enhance a grid's robustness, capacity, and ability to recover quickly from outages. Such benefits have been realized elsewhere; for example, the two HVDC submarine power cables serving Long Island, New York, from points on the mainland. Finally, HVDC Light® technology is particularly valuable in efforts to integrate intermittent energy sources into a grid, as is characteristic of wind generation.

Beyond these direct technical benefits it is important to note that the Project can provide a much more robust export/import capability in support of the expressed Provincial desire to increase its power trading activities. Self-sufficiency in terms of energy generation does not imply that electrical isolation is desirable. In fact, just the opposite is true. Enhanced interconnectivity becomes even more important since in all years other than low water years the Province will have substantial energy available for export.

[31] 2007-2008 Biennial Report, New York State Reliability Council, accessed on July 20, 2009 at http://www.nysrc.org/pdf/Reports/2007-08%20Biennial%20Report%2004-02-09%20final.pdf; New York Control Area Installed Capacity Requirements for the Period May 2008 through April 2009, New York State Reliability Council, LLC, accessed on July 20, 2009 at http://www.nysrc.org/pdf/Reports/Final%202008%20IRM%20Report%2012-14-07%20_2_.pdf.