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HVDC Overhead Line Design Considering LCC vs. VSC Technology

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SUMMARY

- The Bipole III project was initially planned assuming classic Line Commutated Converter (LCC) technology.
- Due to fast development of Voltage Source Converter (VSC) technology, the VSC scheme was later included as a bid alternative after its feasibility for Bipole III was examined and confirmed.
- This paper discusses the impact that HVDC converter technology choice has on the overhead line design in terms of switching surges and fault currents caused by dc line faults.

• INTRODUCTION

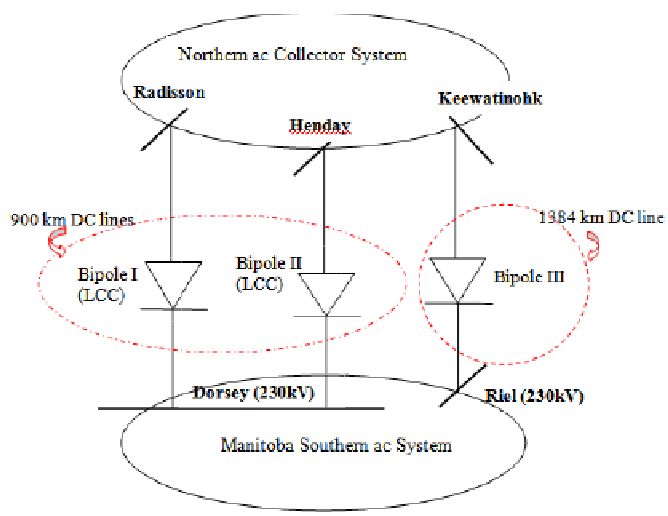

Figure 1 Manitoba Hydro Nelson River three-bipole HVDC system (ISD 2018)

Introduction

- Nearly 70% of the power in Manitoba is transmitted over a distance of 900 km overhead line via the Nelson River HVDC system to the southern major load centre.
- The Nelson River HVDC system currently consists of two bipoles constructed on the same right-of-way and terminated at a common station at Dorsey [1].
- Both Bipoles utilize Line Commutated Converter (LCC) technology with a total rating of 3854MW.
- The third +/-500kV bipole (Bipole III) is being planned as a strategic north-south transmission project to enhance system reliability and security in the event of catastrophic loss of Dorsey station or the existing HVDC transmisison corridor.

Introduction (Cont.)

- Bipole III will be located on a separate corridor with an overhead transmission line length of approximate 1384 km and its converters terminated at new substations, Riel (inverter) in the south and Keewatinohk (rectifier) in the north.
- After Bipole III,the sending end ac system, consisting of three rectifier stations in the north, will operate asynchronous to the receiving end ac system connected to the Riel and Dorsey stations in the south.
- Since Riel and Dorsey stations are electrically close, as well as the electrical proximity of Keewatinohk to the existing rectifier stations, this will form a three bipole, multi-infeed, multi-egress Nelson River HVDC system as shown in Fig.1 [2].

VSC Converter

- The Bipole III project was initially planned assuming LCC technology with consideration of multi-infeed impacts [3].
- The application of Voltage Source Converter (VSC) to HVDC projects has been undergoing fast development since its introduction in 1997 [4-5].
- With the successful commissioning of the 950 km Caprivi Link Interconnector in Namibia in 2010, the application of VSC to overhead lines has been shown to be feasible [6].
- The technical feasibility of using VSC technology for Bipole III has been examined since 2010 when available ratings made it a potential alternative.
- Due to the rating of Bipole III, two parallel valve groups per pole (575MW per valve group) are considered necessary in a bipolar configuration.

VSC Converter (Cont.)

- VSC technology, while relatively new, was confirmed to be a feasible alternative for Bipole III [7-8].
- Due to electrical proximity among the three-bipoles, DC line faults of Bipole III VSC transmission would impact operations of the existing Bipole I and II, in particular increasing the risk of commutation failures.
- Further evaluation confirmed that commutation failures and associated large transient power losses could be minimized to achieve acceptable three bipole performance [9].
- As a result, the VSC technology was included as an alternative bid option for Bipole III in 2012.

Technical Data

- Due to the rating of Bipole III, two parallel valve groups per pole (575MW per valve group) are considered necessary in a bipolar configuration.
- Fig. 2 shows a simplified single line diagram and DC line reactors were installed at line terminals (not shown).
- Each terminal of the VSC model consists of two parallel valve groups per pole for a total of four valve groups at each terminal.
- Each valve group is comprised of a Modular Multilevel Converter (MMC) arrangement with 60 cascaded half-bridge modules per arm per phase [9].
- The VSC scheme controls real power and ac voltage at the inverter, and dc voltage and reactive power at the rectifier.
- No ac filters or DC filters are required for the VSC scheme.

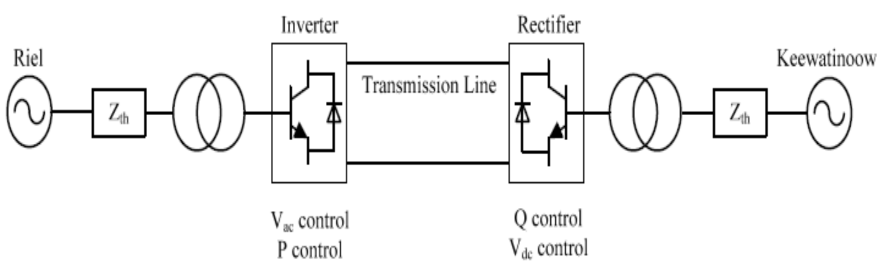

Figure 2 Bipole III VSC transmission scheme

Case STUDY

1. **Overvoltage due to DC Line Faults for Bipole III LCC Scheme.**
2. **Overvoltage Due to DC Line Faults for Bipole III VSC Scheme.**
3. **Transient Currents due to DC Line Faults for Bipole III VSC Scheme.**
4. **Impact on the Bipole III DC Line Design.**

1. Overvoltage due to DC Line Faults for Bipole III LCC Scheme.

- The line was segmented into six sections and a fault is applied at the mid-point of the negative pole.
- The overvoltages at the mid-point (Vmid), and every sixth of the dc line of the healthy pole were included.
- With a 0.25H smoothing reactor, it shows that the overvoltage reaches a peak of about 1.5pu (750 kV) at the line mid-point (Vmid) and reduces to about 1.3pu at the converter terminals(VRec, Vinv).

1. Overvoltage due to DC Line Faults for Bipole III LCC Scheme. (Cont.)

- The impact of dc filters and smoothing reactor size are summarized in Table 1.
- The smoothing reactor contributes insignificantly to the overvoltage while the dc filter serves as the most critical factor.
- The first set of dc filters (Config. 1) consists of single tuned filters, one 12th and one high pass unit, which is the same as the existing Bipole II scheme. The highest overvoltage is found to be about 1.5pu.
- The second set of dc filters (Config. 2) uses multi-tuned design and provides higher tuning frequency of 36th, in addition to the 12th and 24th harmonics. The highest overvoltage reaches about 1.74pu with the Config.2 filter design.
- The filter design of Config. 2 does offer better harmonics control and reduce the possibility of communication interfere along the dc line.

1. Overvoltage due to DC Line Faults for Bipole III LCC Scheme. (Cont.)

Table 1 Overvoltage with different converter terminations (LCC scheme)

Smoothing Reactor Size (H)	Overvoltage (pu)	
	Config. 1	Config. 2
0.15	1.50	1.74
0.25	1.49	1.73
0.5	1.48	1.72
0.75	1.47	1.72

1. Overvoltage due to DC Line Faults for Bipole III LCC Scheme. (Cont.)

- Removing the filter tuned at 24th/36th in Config. 2 was found to reduce the overvoltage to the same level as Config. 1.
- The highest overvoltage reached about 1.5pu and the smoothing reactor size does not seem to affect the value significantly in this case.
- A comparison of impedance profiles of different converter terminations seen from the dc side is illustrated in Fig.4.
- It appears that the scheme without the 24th/36th filter has lower inductive impedance in the frequency range of interest, which may reduce the reflected voltage transients from the converter terminal. However, an analytical equation has not been derived due to the complex nature of the problem.
- In the simulation, the impact of converter transformer impedance ranging between 0.15pu to 0.20pu, and the increase in ac system strength by 50% was also investigated. No significant impact on overvoltage was found.

2. Overvoltage Due to DC Line Faults for Bipole III VSC Scheme (Cont.)

- Bipole III assumes a bipolar VSC scheme for system reliability. The typical overvoltage waveform at the mid-point of the healthy pole for a dc pole-to-ground fault of the other pole is shown in Fig. 5.
- The dc line reactors with a value ranging from 25mH to 300mH were investigated [17-18].

2. Overvoltage Due to DC Line Faults for Bipole III VSC Scheme (Cont.)

- Fig. 6 shows the sensitivity of the overvoltage in terms of line dc reactor sizes. The overvoltage represents the worst case (at the mid-point of healthy pole) scenarios
- With the dc reactor considered, the overvoltage varies from 1.57pu to about 2pu (1000 kV).
- The VSC scheme will show more of a capacitive impedance characteristic with the IGBT charging capacitors.
- It's expected that the converter terminal impedance will become more inductive with the increase in dc line reactor size, thus reducing the overvoltage.

2. Overvoltage Due to DC Line Faults for Bipole III VSC Scheme (Cont.)

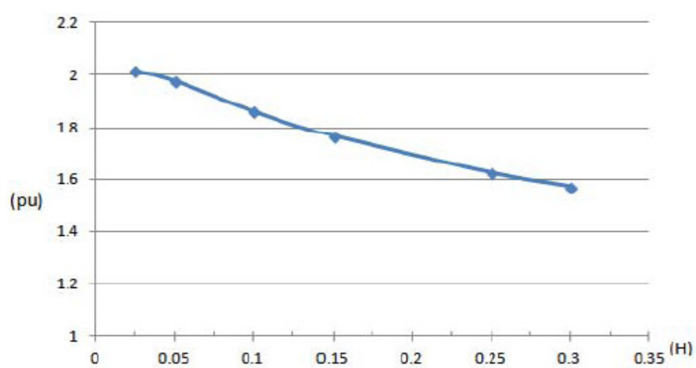

Figure 6 Overvoltage vs. different dc line reactor sizes (VSC)

3. Transient Currents due to DC Line Faults for Bipole III VSC Scheme

- DC line faults have different impact on the VSC scheme depending on its topology. In general, the expected fault currents can be considered to be similar to a LCC scheme for a full-bridge VSC scheme or a half-bridge scheme with fast dc breaker.
- The study assumes a half-bridge VSC scheme and evaluated the option of ac side clearing for the dc line-to-ground fault; a similar scheme as the Caprivi Link [6].
- Three fault locations (rectifier end, mid-point or inverter end) were investigated. The fault was cleared with AC breakers opening at both ends within 6 cycles after fault initiation. The typical waveforms of fault currents seen by the HVDC line and shielding wire are shown in Fig. 7 and Fig. 8.

3. Transient Currents due to DC Line Faults for Bipole III VSC Scheme (Cont.)

- The simulation shows that the timing of protection and blocking the IGBT has a significant impact on fault currents. Both normal IGBT blocking after 300µs of fault initiation and delayed blocking of 1ms were evaluated.
- The impact of dc line reactor sizes and protection actions are illustrated in Fig. 9.
- As both the ac system and charging capacitors contribute to the fault currents, fast protection action will reduce the discharge of capacitors, thus producing lower fault current.
- The study shows that the delayed protection has a more prominent impact with smaller dc line reactor sizes. The increase in dc reactor sizes will reduce the fault current to some extent. The worst fault currents are about 30kA for the dc line and shielding wire for the dc reactor sizes considered.

3. Transient Currents due to DC Line Faults for Bipole III VSC Scheme (Cont.)

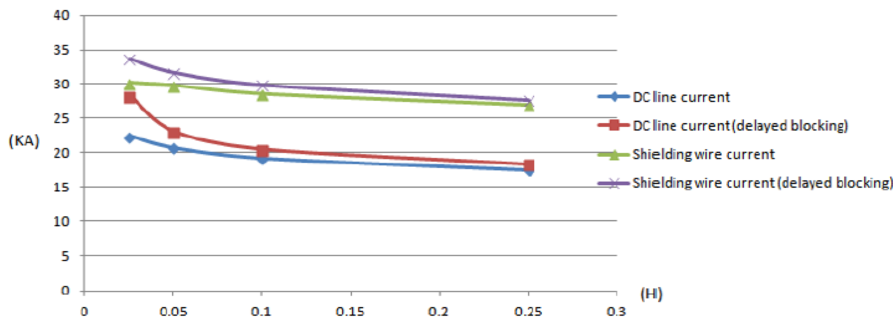

Figure 9 Impact of protection and dc line reactor size on fault currents

4. Impact on the Bipole III DC Line Design

- Considering concurrent occurrence of conductor swings due to wind and switching surges, the Bipole III line has two levels of clearance, 3.2m and 2.5m depending on the criterion used.
- The 3.2 meters clearance follows the CIGRE 1% wind guideline [14] while the 2.5 meter clearance assumes a more conservative approach based on the practice used in other utility which considers 1-hour yearly wind conditions.
- The 3-sigma switching surge withstand capability of Bipole III HVDC line is summarized in Table 2 based on industry practice and Bipole I/II design experience [12,14,19].

4. Impact on the Bipole III DC Line Design (Cont.)

Table 2 Switching surge withstand capability of Bipole III HVDC line

Clearance (meters)	3-Sigma Withstand Capability (pu)	Criterion
2.5	1.7	Method 2 (1 hour yearly wind)
3.2	2.0	Method 1(CIGRE 1% wind)

4. Impact on the Bipole III DC Line Design (Cont.)

- In terms of overvoltage, both LCC and VSC converter schemes can produce acceptable levels with regard to Bipole III dc line withstand capability.
- The VSC scheme will present more challenges as it will require an increase in dc line reactor size to limit the overvoltage.
- The dc line reactor has an overall impact on VSC performance and a too large dc line reactor is not preferred [17].
- Coordination of the converter design with the HVDC line withstand capability is considered necessary if the VSC were selected for the Bipole III.

4. Impact on the Bipole III DC Line Design (Cont.)

- DC line-to-ground faults in a LCC scheme will typically result in a few kA fault current with a clearing time in about 50ms depending on the smoothing reactor size and control actions.
- As shown in the study, the VSC scheme with ac side clearing will significantly increase fault current (about 30kA) and duration (a few hundred milliseconds).
- This will put additional stress on the HVDC line hardware and OPGW selection.
- Such requirements were considered as options in the Bipole III line design.

CONCLUSIONS

- The study shows that overvoltage due to dc line-to-ground faults will in general be higher in a bipolar VSC scheme than a bipolar LCC scheme.
- Overvoltage in a VSC scheme can be mitigated with increase in the inductance of dc line reactors. However, such measure needs to be coordinated with the converter design to ensure overall acceptable performance.
- The dc filter can also affect the overvoltage for a dc line-to-ground fault in a LCC scheme and it would be beneficial to coordinate the converter and line design to ensure optimum performance of reducing overvoltage stresses and communication interference along the HVDC line.
- The VSC scheme with ac side clearing would impose additional stresses on the line design and needs to be considered.