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B4 – DC SYSTEMS & POWER ELECTRONICS

PS1 – HVDC SYSTEMS AND THEIR APPLICATIONS

Paper ID_10465

FEASIBILITY STUDY OF ADDING A THIRD FULL BRIDGE VSC HVDC TERMINAL TO AN EXISTING LCC-BASED HVDC TRANSMISSION SYSTEM

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Motivation

- The advantages of a VSC include black start capability, independent control of active and reactive power, the ability to support weak AC networks and no commutation failures (CFs).
- These attributes drive the need to research Multi-Terminal Hybrid HVDC (MTHDC) systems and examine the feasibility of interconnecting renewable energy sources or loads in between an existing point-to-point LCC HVDC system by adding a VSC HVDC as a third terminal to facilitate such an interconnection.
- Such a multi-terminal arrangement may revitalize an existing classic HVDC transmission link by adding operational flexibility.
- Potential applications could be (i) a Multi-Terminal India-Bangladesh HVDC system (LCC at Rangia, LCC at Muzaffarnagar & VSC at Barapukuria), (ii) CASA -1000 HVDC project (LCCs at Sangtuda and Peshawar, and VSC at Kabul could be foreseen in future.

Method/Approach

#	Configuration of the Third Terminal
1.	Half Bridge VSC with diode as FRT device
2.	Half Bridge VSC with HHB as FRT device [1]
3.	**Full Bridge VSC**

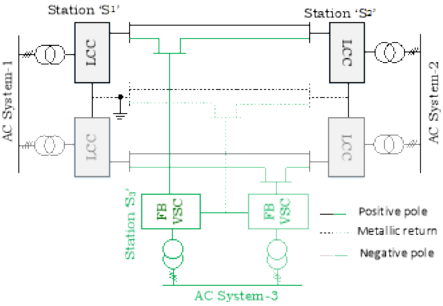
- A three-terminal hybrid HVDC system comprising a point-to-point LCC link connected through overhead lines and a voltage source converter (FBVSC) in between is proposed.
- The steady state and dynamic performance of this hybrid system are analyzed with the help of a simulation study using an electromagnetic transient modelling program.
- Simulation performance obtained in this option (with the FBVSC as a third terminal) is compared with the results obtained in [1], in which the third terminal is an HBVSC, with a hybrid HVDC breaker as an FRT device.

Objects of Investigation

- Control development for a proposed hybrid system is established to achieve steady state operation, operating challenges are addressed, and dynamic performance is validated with a detailed simulation study under AC and DC faults

System Description

- Station 1 (S1) is the LCC rectifier operates in DC power control mode, station 2 (S2) is LCC inverter operates in αMAX control mode, and station 3 (S3) is FBVSC inverter which is selected to operate in active/reactive power control mode without affecting LCC control modes.
- It is assumed that the third terminal VSC station is allocated anywhere, and there is no switching substation, thus a delta connected DC transmission system is considered
- For simplicity, only the positive pole has been considered in this study.



Challenges and control actions

- The CF of S2 will appear as a DC fault to S3.
- At the FBVSC, protection is designed to be selective to discriminate between a dc fault and a CF.
- Additionally, FBVSC employs current control based on the dc link voltage, like VDCOL functionality in the LCC. This will help reduce the sudden increase of dc current from the VSC during such scenarios.
- Also, to avoid the inrush currents to the LCC inverter post AC faults in the AC network connected to the inverter stations (i.e., S2 and S3), the power/current orders are adjusted during the fault with the help of a master controller.
- The LCC inverter is also prone to CFs, even when there is a severe AC fault at the third VSC terminal when the pre-fault power of VSC inverter is >50% of the LCC link capacity. Gamma at steady state is increased with power reference of VSC inverter
- DC fault handling: FB cells can interrupt the DC fault current with the proper modulation control.

Energization

- The hybrid 3-terminal system is energized in two steps: I) Energizing the two LCCs in the same way as a point-to-point HVDC; II) Energizing the FBVSC.
- Pre-condition: The LCC is operating at full power from S1 to S2; the pole line between S1 and S3 is connected to S3 but disconnected to S1; and the pole line between S2 and S3 is connected to S3 but disconnected to S2.

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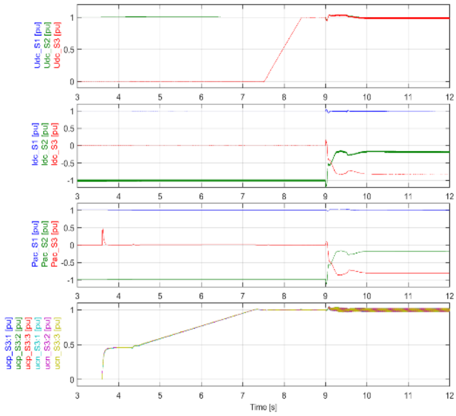
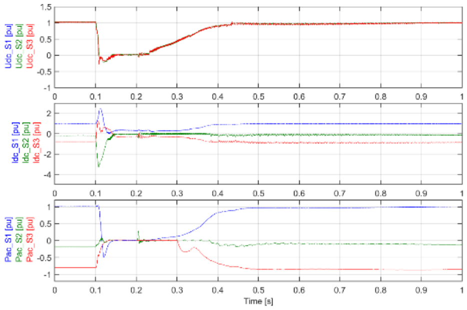


Temporary AC Fault in the PCC of S2

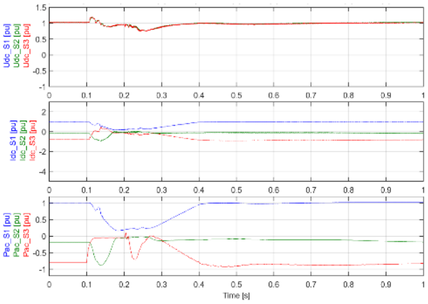
- A solid 3-phase to ground fault is applied at 0.1s for a duration of 100ms. During AC fault, the LCC inverter undergoes CF which reduces the DC voltage.
- The VDCOL of the LCC rectifier (S1) acts and reduces the current order to the lower limit of VDCOL capability. At post fault it is increased back to 1pu slowly to avoid the risk of multiple CFs.
- DC fault protection is not triggered at the VSC. Instead, the VDCOL functionality built into the FBVSC (S3) acts to reduce the DC current from the VSC by reducing the DC voltage reference, thereby avoiding the overcurrent trip action of the VSC
- During the fault (as the DC voltage is low), the VDCOL of the VSC reduces the AC power order as well to balance the AC-DC powers in the VSC converter.
- The S1 behaves in the same way as in a point-to-point LCC HVDC link, i.e., the VDCOL of S1 reduces the current order during the CF at S2, thereby the ALPHA of S1 increases.



- Once the AC fault at the LCC inverter is cleared, recovery is attempted by increasing the DC voltage reference slowly at the VSC.
- Post fault, the power order of S1 is slowly ramped back up to 1pu with the help of the master controller to reduce stress on the LCC inverter valves during recovery, and a smooth recovery within 240ms is observed.

Temporary AC Fault in the PCC of S3

- A solid 3-phase to ground fault in the AC network connected to S3 and applied at 0.1s for a duration 100ms
- AC power of S3 is limited, leading to rising voltage in the cell capacitors of S3.
- DC current of S3 reverses (the rectification operation of VSC is observed) and it increases the DC current of S2, which reduces the commutation margin of the LCC inverter (the overlap angle of S2 increases).
- Special control actions discussed above have been used to avoid the unexpected CF at S2. Around 0.13s (after telecom delay), the power order from S1 is adjusted to the pre-fault power order of S2 i.e., 0.2pu with the help of the master controller.
- Power recovery is made slower deliberately in order to avoid possible commutation failure in S2
- It takes about 200ms to recover the power to the pre-fault level after the AC fault clearing.



Temporary DC Fault

- The temporary DC fault near to S1 is applied at 0.1s with a restart waiting time of 200ms.
- The VDCOL of the FBVSC (S3) acts to reduce the overcurrent from the converter before triggering the DC fault detection
- Once detects the fault, the LCC rectifier is ordered down and FBVSC starts the below control actions:

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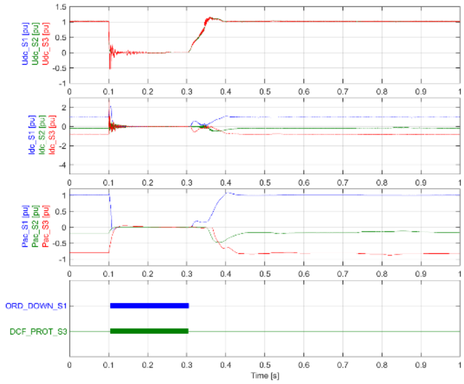
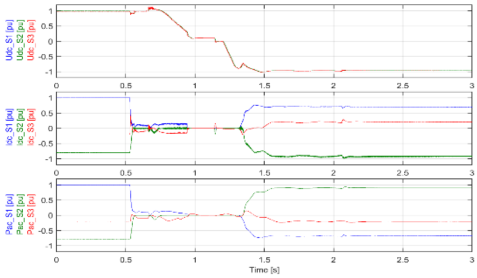
- (i) Reduce the DC voltage reference of the VSC, controlling the DC current to zero. (ii) Block the upper arms and provide the reactive power support with the help of the lower arms to the AC network connected to the VSC (S3). (iii) Attempt the recovery after the restart waiting delay of about 200ms, and the recovery time is observed to be within 100ms.



Power Reversal between S1, S2

- FBVSC can reverse its DC pole voltage by adjusting the modulation, generating negative DC voltage, so a polarity reversal arrangement is not required.
- Firstly, reduce the power flow to zero in all the DC lines
- Then, same power reversal sequence of point-to-point LCC link is adopted except that it is coordinated with FBVSC
- DC voltage of the VSC is reduced in coordination with LCC DC voltage by switching the VSC to DC current control with zero current reference, retard is then ordered at the LCC rectifier
- Next, establish the reverse power in between the LCC converters first, then ramp up the FBVSC DC current order
- Switch the VSC back to power control soon after it reaches the predefined power limit.



Comparison of FBVSC with HBVSC+HHB [1]:

- In FBVSC option, the converter control limits the DC fault current to zero, whereas in HBVSC option, the HHB interrupts/breaks the DC fault current from VSC.
- During CFs in S2, the implemented control functionality in the FBVSC option helps to limit the DC current contribution from the VSC, whereas in HBVSC+HHB option, the HHB interrupts dc current [1].
- For power reversal between S1 & S2: (i) FBVSC option- No need of any polarity reversal arrangement, the control is modified in the FB converter to obtain the reverse DC voltage and the DC side disconnectors are not operated. (ii) HBVSC+HHB option- In order to match the polarity of DC voltage at the VSC station, the polarity reversal arrangement is made with the help of 4 high-speed switches (HSS).
- Additional control actions are required in the FBVSC option to help handle DC faults, in order to tackle the power reversal without disconnecting the VSC from the LCC link, which makes the FBVSC control option a bit complex for effective coordination.
- From a components point of view, the FBVSC option uses two additional IGBT switches to form an FB cell compared to an HB cell, therefore increasing losses in the FBVSC option, whereas the HBVSC+HHB option uses the HHB and the polarity reversal arrangement switches, thus increasing complexity in the DC switchyard.
- The technical performance for both the FBVSC and HBVSC+HHB [1] is observed to be similar from the results obtained, and with a properly designed control system, it is similar and in line with the conclusion in [2].

Conclusion

- Technical feasibility of operating a three-terminal hybrid HVDC (LCC – FBVSC – LCC) system is evaluated and performance is demonstrated under AC, DC faults.
- The operational challenges and required additional control actions are discussed for the considered configuration. The importance of VDCOL control action in FBVSC is discussed during CFs of S2 and during DC faults (prior to the DC fault detection).
- Further, the procedure of power reversal between LCC stations is discussed and demonstrated.
- Based on the comparative study in this paper for FBVSC and HBVSC+HHB, the proposed hybrid HVDC system configuration is feasible for operation, irrespective of the converter topology.

[1] V. Rakesh Reddy, Ying. J. Hafner, Soubhik Auddy, K. Vinothkumar, "Feasibility Study of Adding a Third VSC based HVDC Terminal on an Existing Point-Point LCC based HVDC Transmission System," 2020 IEEE Electric Power and Energy Conference (EPEC), Edmonton, AB, Canada, 2020, pp. 1-6, doi: 10.1109/EPEC48502.2020.9320039.

[2] D. H. R. Suriyaarachchi, C. Karawita and M. Mohaddes, "Applicability of full-bridge and half-bridge VSC for tapping LCC HVDC," 13th IET International Conference on AC and DC Power Transmission (ACDC 2017), 2017, pp. 1-6, doi: 10.1049/cp.2017.0049.