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Unique challenges and remedies during operation of world's first ±800kV Multi Terminal HVDC System – North East Agra Project

R.K.TYAGI
A.DUBEY
M.J.BAISHYA
Powergrid Corporation of India Limited

Background

- The prestigious ±800 kV, 6000 MW Multi terminal HVDC North East Agra (NEA800) project, owned by Power Grid Corporation of India Limited, is the world's first ±800 kV Multi terminal HVDC power transmission project.
- Multiterminal HVDC control and protection architecture is more complex as compared to the one of a point-to-point HVDC power transmission system.
- During the initial operation of Multi Terminal HVDC operation for NEA800, some of the challenges faced are unique in nature and since it was being faced for the first time, the remedial actions and modifications in control action and settings which had been implemented are unique in nature.
- Since the initial challenges in multi terminal HVDC operation faced were unique, the solutions had to be thoroughly tested and implemented practically.
- This paper discusses a few of such unique challenges faced during operation of the multi terminal HVDC power transmission of NEA800 project aiming to share the knowledge for future projects.

Approach

- In this paper, the fault analysis and solutions implemented presented is for few unique challenges faced during the Multiterminal HVDC operation of NEA800 project.
- NEA800 project has three converter stations, Biswanath Chariali (BNC) located in Assam, Alipurduar (APD) in West Bengal and Agra in Uttar Pradesh.
- SLD for NEA800 project is as follows :

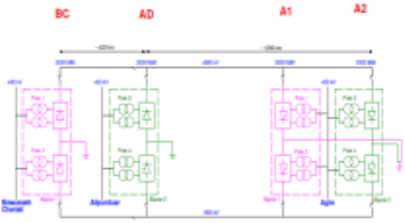

Fig.1 SLD for NEA800 multiterminal operation

- The ac network connected to HVDC poles in all three stations – BNC, APD and Agra is 400 kV. BNC and APD stations are connected via the 400kV ac grid.
- Each pole of NEA800 in BNC, APD and Agra project is designed for 1500 MW nominally and additionally 33% more during overload conditions.
- DC line-1 connecting Pole-1 at BNC, Pole-3 at APD and Pole-1 and Pole-3 at Agra shall operate in 800kV in forward direction.
- DC line-2 connecting Pole-2 at BNC, Pole-4 at APD and Pole-2 and Pole-4 at Agra shall operate in -800kV in forward direction.
- In reverse direction, provision for power flow is implemented only from Agra to BNC.
- As per implemented scheme in NEA800, multiterminal HVDC operation is possible only in forward direction of power flow in which BNC and APD are the rectifier stations and Agra is the common inverter station.
- As a part of multi terminal HVDC operation, the feature of interstation power compensation between BNC and APD is available in case any pole trips in either BNC or APD. This is possible due to the connected 400kV ac grid between BNC and APD.

Discussion

- In this paper, 02 nos. of unique challenges faced during multiterminal HVDC operation of NEA800 project has been discussed. Root cause analysis for the challenges have been discussed alongwith the solutions implemented have been discussed.
- In case study - I, the effect of complete ac grid failure in one of the parallel rectifier stations have been analyzed and how it affects the multiterminal HVDC operation of NEA800. After this fault, based on the analysis, modifications had to be made on the protection settings.
- In case study – II, violation of maximum limit for inter station power compensation between parallel rectifier stations was observed during multiterminal HVDC operation of NEA800. To prevent any such violation in future, changes in control logic has been implemented successfully.

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Case study – I : Complete ac grid failure in one of the parallel rectifier stations

- As a part of multiterminal HVDC control and protection philosophy, when multi terminal HVDC power flow is ongoing and a permanent fault occurs in one of the rectifier stations, that particular faulty rectifier station should be isolated and power flow should continue from the healthy parallel rectifier stations to the inverter end uninterrupted.
- Prior to this multiterminal trip, the logic for pole trip due to low ac voltage detection in the connected ac grid of any of the converter stations was not implemented.
- Also, as per protection philosophy, if the system detects low ac voltage, then DC line fault level protection will be locked for 5 seconds.
- In this particular case, during multi terminal power flow between BNC, APD and Agra as per SLD given in Figure-2, Pole 1 at BNC, Pole 3 at APD and Pole 1 & Pole 3 at Agra HVDC stations were in service and connected to dc line 1. Multi terminal power flow was ongoing in DC line 1. For DC line 2, Pole 4 at APD and Pole 4 at Agra were in service in DC line 2.

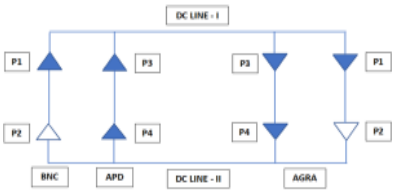

Fig.2 SLD for multiterminal operation

- While in operation, due to overvoltage in the connected 400kV and 220kV ac grid of APD, the 400kV and 220kV ac lines of APD tripped on ac overvoltage protection. Upon tripping of all connected ac lines at APD, the Pole DC power for Pole-3 and Pole-4 fell to zero as there was no input ac power into Pole-3 and Pole-4 at APD. Thereafter, low ac voltage was detected for Pole-3 and Pole-4 at APD locking the DC line level protection.
- Immediately low ac voltage from APD signal was also sent to BNC thereby locking the DC line protection level at BNC too.
- However, as stated earlier, due to no trip logic from low ac voltage detection, both the poles at APD continued to remain in deblocked condition without any power flow.
- After 4 seconds delay, DC undervoltage protection tripped Pole-4 at APD, leading to tripping of Pole-4 at Agra as both the poles were connected via DC line 2 and for DC line 2 multi terminal power flow was not ongoing.
- Pole-3 at APD continued to remain in service even after Pole-4 at APD tripped due to DC undervoltage protection due to the voltage read by Pole-3 DC Voltage Divider (DVD) at APD station was +800 kV as Pole-1 at BNC station was in service and DC line-1 section remained connected at APD.
- DC line protection level part at BNC for DC line-1 was unblocked only after 5 seconds as per logic.
- After the level protection gets enabled, Master Control at Agra started decreasing Agra end (Inverter) voltage for DC line 1 to maintain the current order of APD Pole-3 (as there was no DC Current).
- This sudden drop of the DC line 1 voltage by Master Control to match APD Pole-3 power order caused the DC line fault level protection at BNC to treat it as line fault and after 3 restart attempts, Pole-1 at BNC tripped as in Fig.3. This also tripped APD Pole-3 instantly as there was no longer any voltage read in DC line 1 by APD.
- Due to tripping at BNC Pole-1 and APD Pole-3, multiterminal operation in dc line 1 came to standstill.

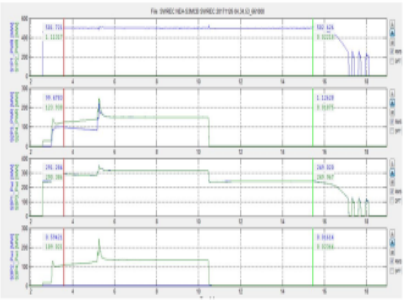

Fig.3 TFR for Pole trip at BNC and APD

Analysis and modifications

- Settings to detect AC undervoltage for operating Poles were reviewed and Pole trip logic in case of AC undervoltage detection has been implemented.
- In case, 400kV ac voltage is less than 0.75 pu, pole will trip after a delay of 1.5 sec.
- In case, 400kV ac voltage is less than 0.3 pu, pole will trip after a delay of 1.1 sec.

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Case study – II : Inter station power compensation limit violation

- As a part of the multi terminal HVDC operation, there is a provision for inter station power compensation between the parallel rectifier stations – BNC & APD.
- In case, any one of the connected poles in any of the rectifier station trips during multi terminal operation, the balance power after intra station power compensation shall be transferred to the parallel rectifier station via the connected AC grid between the parallel rectifier stations. This is inter station power compensation.
- A maximum limit is to be set by the operator for the quantity of power allowed for inter station power compensation. The inter station power compensation should not exceed the limit set by the operator.
- During this case of exceeding the inter station power compensation, multiterminal HVDC operation was ongoing from BNC and APD to Agra. Both Pole 1 & Pole 2 were in operation at BNC station and both Pole-3 & Pole-4 were also in operation at APD station. The inter station power compensation limit from APD station to BNC station was set at 500 MW. Prefault SLD is shown in Fig.4.

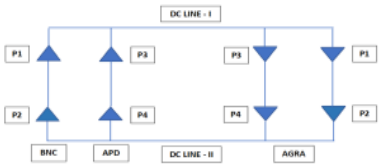

Fig.4 Prefault SLD

- Suddenly, Pole-3 at APD station tripped and immediately power from Pole 3 was transferred to Pole 4 at APD station.
- After trip of Pole-3 at APD, internal compensation was carried out in Pole-4 of APD, with new power order of 1200MW.
- Another problem eventuated in the APD Pole-4 valve cooling system. Due to a problem in valve cooling system of Pole-4 at APD station, power runback was issued in several steps.
- Runback refers to a reduction in pole power level in case of any restraint in the operating conditions to a power level at which the pole is capable of handling the power.
- The runbacks in Pole-4 at APD were carried out in 9 steps as shown in Fig.5. In each step 74-76 MW was reduced in Pole 4 at APD station and compensated in each pole at BNC station through parallel AC network.

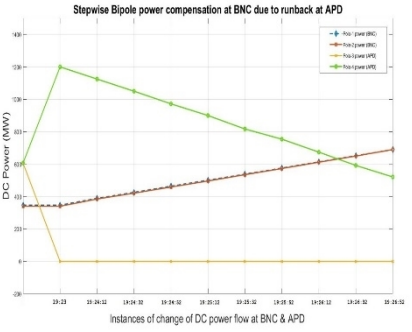

Fig.5 Power compensation steps from APD Pole-4 to BNC Pole-1 & Pole-2

- Combined net compensation carried out for both Pole 1 and Pole 2 at BNC station was 680 MW even though maximum compensation limit from APD station to BNC station was set to 500 MW. The excess 180 MW transferred from the APD station to the BNC station should not have occurred.

Analysis and modifications

- The problem was with the time frame after which the compensation limit was getting reset to maximum compensation in place of balance compensation.
- To rectify the problem, the compensation limit set by the operator is decreased with the used compensation when the inter station power compensation at BNC has taken place from APD. Thereafter, the operator needs to make a decision to increase the compensation limit again.

Conclusion

- The North East Agra multiterminal HVDC operation had commenced in March 2017.
- The multiterminal HVDC operation has been functioning reliably with all the necessary modifications made in control logic and settings to accommodate the learnings from the challenges discussed as above.