Study Committee B4

DC Systems and Power Electronics

10113_2022

A novel control Strategy of bipolar Balance for multi-terminal HVDC and its application on a three-terminal HVDC Project

Qi GUO[1, 2], Mengjun LIAO[1, 2], Ziming SONG[3], Libin HUANG[1], Lijun DENG[2], Mingzhang SU[2]

[1]State Key Lab of HVDC, EPRI, CSG [2]CSG Key Lab for Power System Simulation [3]Toshiba International (Europe) Limited

Motivation

- **Bipolar Balance Control Strategy (BBCS)** is used for protecting HVDC system from outage when the Electrode System (ES) is out-of-service or a fault occurs in the ES.
- The BBCS is **more complex in Multi-Terminal HVDC** (MTDC) than two-terminal HVDC:

  (1) A need of decision in **power allocation** among the converter stations that are in the dc current control

  (2) A special balance is observed in **an asymmetric case** that one converter is out-of-service

Objects of investigation

- **A novel control strategy** for balancing the bipolar system in a three-terminal HVDC system is presented.
- It is mainly **about an emergency pole balance control** during the time period from the onset of the fault occurrence to the time when the system settles to a new operation equilibrium under this control.
- The control strategy accounts for converter operation mode, the minimum permissible operation current of converter and the priority assigned by energy dispatch to derive a feasible solution.

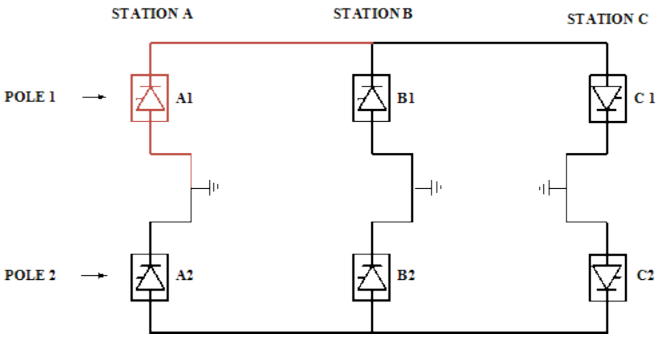

Figure 1: The operation with a mix of monopole and bipole of a three-terminal HVDC system
(The converter A1 in red is out-of-service)

Protection for ES Fault

- As the ES is the joint part of the bipolar system, a fault in the ES area in a unbalanced status may lead to a Bipolar Emergency Stop of Fault (ESOF).
- Electrode Bus Differential Protection (EBDP) and Electrode Line Unbalance Protection (ELUP) are the main protections against the faults F1 and F2. They will activate and the bipolar balance control will be triggered to remain system operation

$$I_{diff\_EBDP} = (I_{dE} - I_{dE\_op}) - (I_{dEE1} + I_{dEE2}) + I_{dEG}$$

$$I_{diff\_ELUP} = I_{dEE1} - I_{dEE2}$$

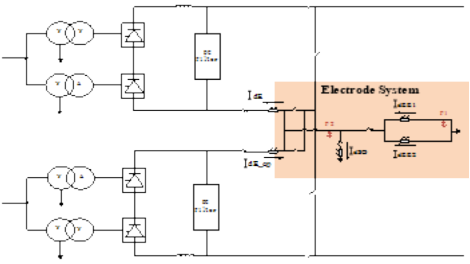

Figure 1: A typical bipolar HVDC system with the ES highlighted in colour

BBCS for two-terminal HVDC systems

- Method 1: to adjust the dc current of the pole that has a higher load towards the one that has a lower load.

$$I_{ord\_P1\_new} = I_{act\_P2}$$

- Method 2: to allocate the unbalanced dc current to the two poles.

$$I_{ord\_P1\_new} = I_{act\_P1} - 0.5 * (I_{act\_P1} - I_{act\_P2})$$

$$I_{ord\_P2\_new} = I_{act\_P2} + 0.5 * (I_{act\_P1} - I_{act\_P2})$$

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Terms and Definitions

- **The unique station**: the station that operates uniquely as an only rectifier or inverter in the three terminal HVDC system.
- **"3+3" configuration**: the symmetric case where all the six converters are in operation.
- **"2+3" configuration**: the asymmetric case where one converter is out-of-service.
- **"2+2" configuration**: the asymmetric case where two converters (not in the same station) are out-of-service.
- **MPTL**: the minimum power transmission level of converter

Assumption

For the sake of clarity, it was assumed:

- Station C is the inverter and in voltage control. Station A and B work as the rectifier and both in current control
- The power in the positive side (Pole 1) is less than that in the negative side (Pole 2)
- Station B has a high priority for ramping-down
- the minimum power transmission level (MPTL) and rating capacity of every converter of all six are the same

BBCS for Stations A and B

It is simply performed as they are rectifier and in current control

- To calculate the unbalanced dc current
- To update the dc current order to the pole having a higher current

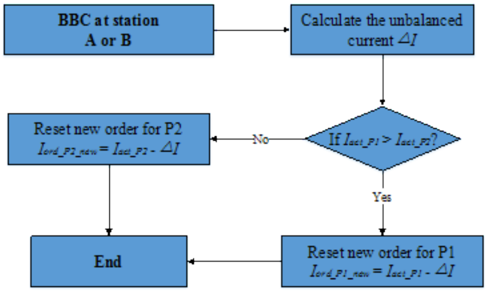


Figure 3: The flowchart of the BBCS control at station A and B

Issues of BBCS for the multi-terminal DC systems

- A need of decision in power allocation when the BBC is requested at unique station
- In "2+3" configuration, a need of power up for the pole with two converters in some cases.

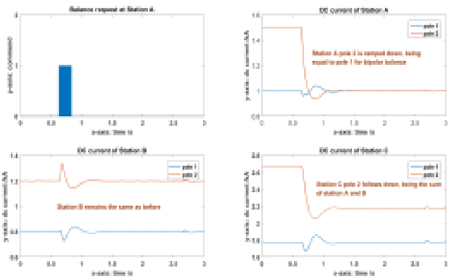
Table 1: An example that need of power-up in "2+3" configuration (Assumed the MPTLs of all six converters are the same as 300A)

Station A	Station B	Station C
Out-of-service	300A	300A
300A	300A	600A

Simulation case

Table 2: The results of the bipolar balance control at Station A (currents in Ampere)

Items	Converter	Station A	Station B	Station C
Initial condition	pole 1	1000	800	1800
	pole 2	1500	1200	2700
After BBCS action	pole 1	1000	800	1800
	pole 2	1000	1200	2200



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BBCS for Stations C

The process of the BBCS at station C is briefly summed up in the following three cases.

Case 1: “3+3” configuration

- The power difference at C is used to set the power order at B, subject to the MPTL of Station B IMPTL-B. If the value of the IMPTL-B is used, Station A is called upon to make up the remaining difference.

Case 2: “2+3” configuration

- If IC1 < IMPTL_C2 = IMPTL_A2 + IMPTL_B2 (the MPTL of C2), set the dc current orders at A2 and B2 to its minimum respectively and let IB1 regulate IC1 to (IMPTL_A2 + IMPTL_B2); otherwise, regulation takes place similarly to Case 1.

Case 3: “2+2” configuration

- The remaining converter in A and B is used to regulate the converters at the same polarity side in C.

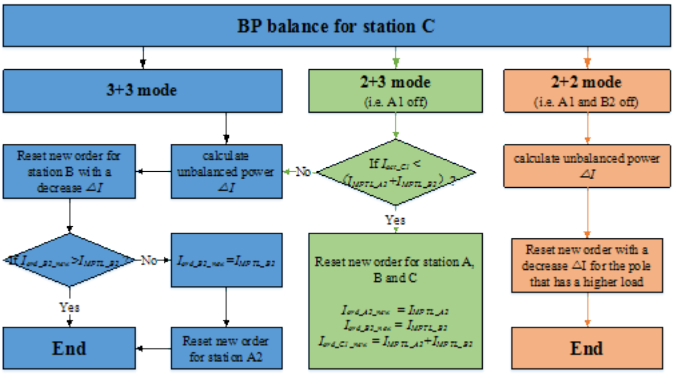
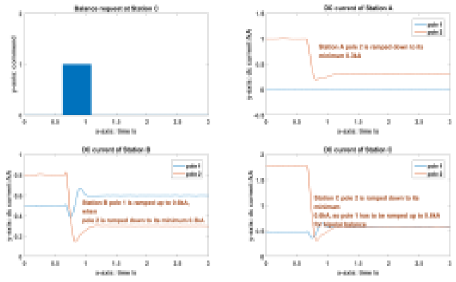


Figure 4: The flowchart of the BBCS procedure for station C (unique station)

Simulation case

Table 2: The results of the bipolar balance control at Station C (currents in Ampere)

Items	Converter	Station A	Station B	Station C
Initial condition	pole 1	0	500	500
	pole 2	1000	800	1800
After BBCS action	pole 1	0	600	600
	pole 2	300	300	600



Conclusion

- The BBCS is one of the vital functions used in HVDC systems to ensure the system stable during ES faults
- A novel BBCS was present for a three-terminal HVDC system, with the allocation of the amount of power by taking into account the converter operation mode, priority of assignment and the converter’s MPTL.
- The proposed BBCS has been successfully implemented in the Lugaozhao three-terminal HVDC project in China.
- This method is equally applicable to multi-terminal VSC systems.