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HVDC Systems and their Applications

Paper 10143_2022

LCC-HVDC and Hybrid LCC-MMC-HVDC Transmission: A Comparison in the Brazilian Power System

Edson WATANABE[1], Robson DIAS[1], Laís PROENÇA[1], Emanuel VAN EMMERIK[1], Alquindar PEDROSO[1], André ALVES[1], João MOOR[2], Braulio CHUCO[2], Carlos VIZEU[3], John GRAHAM[4], Paulo ESMERALDO[4] and Augusto TIETZ[4]

[1]Coppe/Universidade Federal do Rio de Janeiro, [2]CEFET-RJ, [3]PowerConsult, [4]State Grid Brazil Holding

Brazil

Motivation

- Brazilian Interconnected Power System (BIPS) has six bipolar LCC-HVDC links in three interconnections;
- The inverter stations are electrically close, in the southeast region, with a high possibility of multi-infeed interactions (Multiple Commutation Failure (CF)).
- Therefore, due to these interactions, the BIPS is subject to transient power interruptions in the HVDC links .

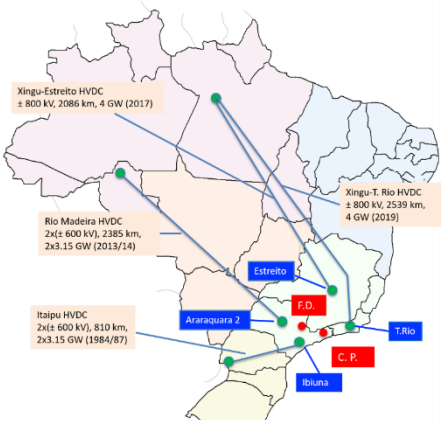

Fig. 1 – HVDC links in Brazil.

Approach

- HVDC systems studied using an EMT simulation program considering equivalent circuit for the BIPS;
- Scenario of the BIPS: 2025/2026 ONS (Brazilian National System Operator) light load scenario;

Objects of investigations

- Use of synchronous compensator (SC) or STATCOM to mitigate CF;
- Use Xingu – Estreito HVDC link as reference to test two hybrid LCC/MMC and all MMC links to evaluate the mitigation of multi-infeed problems.

Simulation Cases

SC and STATCOM: All LCC-HVDC links;
Estreito – Xingu links:

i) Case **0 MMC**: All LCC-HVDC;
ii) Case **1 MMC**: LCC/LCC in Pole 1 and LCC/MMC in Pole 2;
iii) Case **2 MMC**: LCC/MMC Pole 1 and 2;
iv) Case **4 MMC**: all converters are MCC.

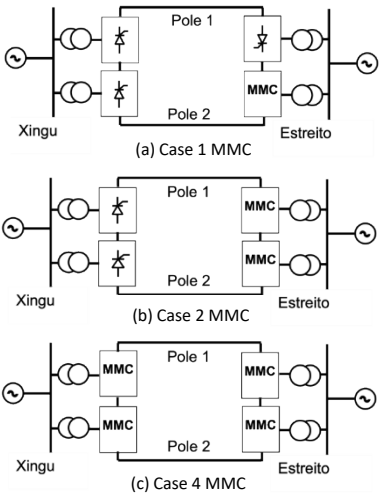

Fig. 2 – HVDC links in investigation.

Simulation Results

- **SC** and **STATCOM** improve system resilience for CF;
- Case **1 MMC** can avoid CF in Pole 2 with LCC for most of the critical faults;
- Cases **2 MMC** and **4 MMC** present no CF and decreased energy deficits in the other HVDC links.

Discussion

- **STATCOM** shows better performance than SC;
- In case **1 MMC** the MMC works as a huge STATCOM during faults and mitigate CF;
- Cases **2 MMC** and **4 MMC**: MMCs help to control grid voltage and decrease energy deficit in other LCC.

Conclusions

- **LCC-HVDC** is a low-cost and robust solution for long distance high-power transmission, but has problems like CF and multi-infeed interactions;
- **SC** and **STATCOM** improve resilience against CF;
- **Hybrid LCC/MMC (1 MMC**) may be a relatively low-cost solution to mitigate most of CF problems;
- For the future, **all MMC** may be the solution.

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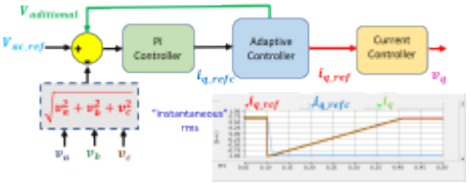
SC or MMC STATCOM to Mitigate CF

Faulted Busbar (SC or STATCOM)	Nominal Voltage	R with SC	R with MMC STATCOM
Ibiúna (4x300MVA)	345 kV	22 Ω	10 Ω
Araraquara2 (2x300MVA)	500 kV	56 Ω	17 Ω
Estreito (2x300MVA)	500 kV	MI	18 Ω
T. Rio (2x300MVA)	500 kV	MI	27 Ω
Fernão Dias	500 kV	50 Ω	19 Ω

- R: Minimum resistance value that does not cause CF at the other LCC;
- Faults at worst point on wave.

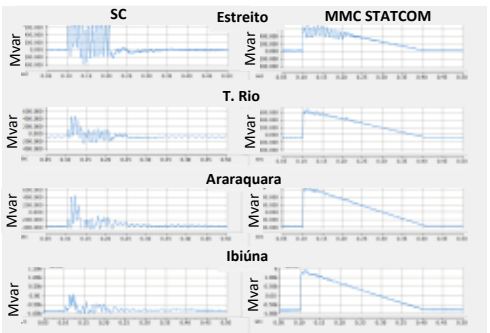
MMC AC Voltage Control Diagram



- Adaptive controller inserted in classic AC-voltage control circuit for fast control;
- "instantaneous" rms used for fast short-circuit detection.

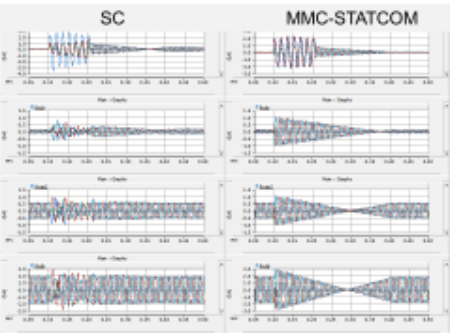
Reactive Power: SC vs STATCOM

15 Ω single-phase fault at Estreito



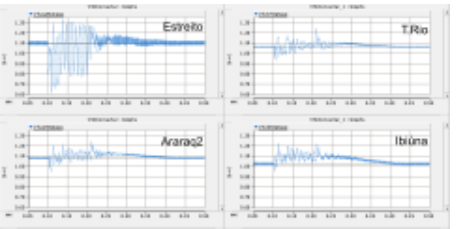
- **SC:** all inverters present CF;
- **MMC STATCOM**: only LCC at Estreito fails.

Injected currents at 500/345 kV: SC vs. MMC STATCOM



- Uncontrolled currents (SC) vs. Controlled currents.

"Instantaneous" RMS voltage at LCC buses with MMC STATCOM



- single-phase fault of 15 Ω at Estreito bus @ t = 0.1 s.

LCC/MMC-HVDC and All-MMC HVDC

- Single-phase short-circuit at 500 kV Fernão Dias Bus;
- Energy Deficit: $ED = \int_{t=0}^{t=0,4} [P_{av} - p(t)]dt$
  P_{av}: link average pre-fault active power
  $p(t)$ the link post-fault active power;
- **0 MMC**: CF in all LCC;
- **1 MMC**: No CF at Estreito.

Case	Estreito ED (GWs)	PIT (ms)	P90% (ms)
0 MMC	0.379	38	98
1 MMC	0.066	NCF	65
2 MMC	0.027	NCF	0
4 MMC	0.014	NCF	0

Case	0 MMC	1 MMC	2 MMC	4 MMC
Total Energy Deficit - TED (GWs)	1.464	1.029	0.974	0.959

TED: Sum of Energy Deficit in all links; NCF: No CF

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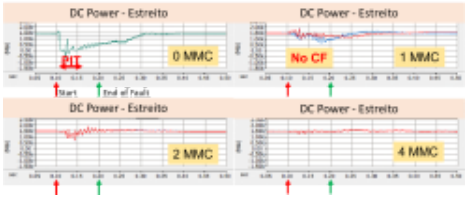
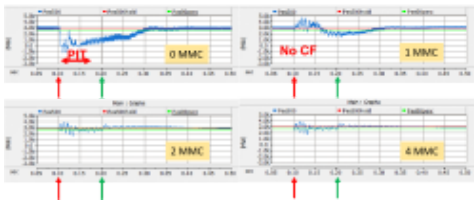
DC Power for all cases at Estreito



- Single-phase short-circuit at 500 kV Fernão Dias Bus during 100 ms;
- Case **1 MMC** shows a significantly different response between the poles. Pole 1 sends its DC voltage measurement as a control signal to Pole 2 to equalize its DC voltage and keep balanced powers in Pole 1 and Pole 2.

Active AC Power at Estreito



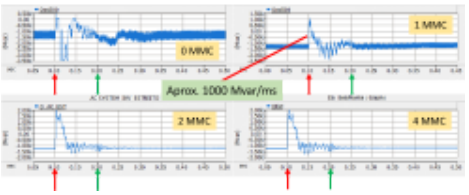
- Active power injected at Estreito AC side for all 4 cases;
- The red line is the average pre-fault value, and the green line represents 90% of this pre-fault value.

Instantaneous Energy Deficit at Estreito

ED at Estreito as function of time after a bolted single-phase fault at Fernão Dias for all 4 cases:

- **0 MMC** case resulted in ED of 0.4 GWs;
- **1 MMC** case ED is less than 0.1 GWs;
- **2 MMC** and **4 MCC** avoid ED.

Reactive Power at Estreito



- Y-axis with 4000 Mvar range for all 4 cases;
- Reactive power ripple reduction is clearly visible going from **0 MMC** towards **2 MMC**.

"Instantaneous" RMS Voltage at Estreito

- **Voltages at Estreito**: Light Green for analog RMS, Dark Blue for "instantaneous" rms, Red for moving average RMS, Light Blue moving average RMS moving at T. Rio;
- **0 MMC**: Red, Orange and Yellow for single phase moving average RMS measurement, phase A, B and C, respectively.
- "Instantaneous" RMS: $v_{rms} = \sqrt{v_a^2 + v_b^2 + v_c^2}$

Conclusions

- **MMC-STATCOM** with fast reactive power control based on "instantaneous" RMS voltage makes it better than the synchronous compensator;
- **1 MMC:** MMC in Pole 1 avoids CF in Pole 2 (LCC);
- **Hybrid HVDC**: During faults, MMC is a **huge STATCOM**;
- **Recovery time** and **Energy Deficit (ED)** are better indicators than **PIT**;
- **ED** indicates how much global inertia is needed in the network;
- **All MMC HVDC:** recommended for future systems.