Study Committee B4

B4 DC SYSTEMS AND POWER ELECTRONICS

Paper 10779

High performance HVDC – LCC converters for the new Sa.Co.I. 3 link: Preliminary analysis and simulations

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Motivation

- In the recent years, the SACOI 2 intertie was considered for a refurbishment of both converter stations and lines. Converter stations exceeds **30 years** of operation, while overhead lines and cable lines are well exceeding **50 years**.
- This paper goes into some specific detail relevant **power flow reversal**, **AC fault sensitivities** and **black start capability** and highlights how LCC technology with proper actions on the protection and control system and together with a synchronous condenser can act as VSC technology.

Figure 1 – SACOI Link.

Method/Approach

- Due to components ageing, to the point of obsolescence, the full refurbishment of the link has been planned by Terna, contextually increasing the maximum power transmission to 400 MW.
- In order to investigate the possible state-of-the-art alternatives, Terna and Sapienza University of Rome carried out a desktop study, analyzing the following transmission solutions:
  - ac, 230 kV – 50 Hz (i.e. a synchronous link between Italian mainland, Sardinia and Corsica);
  - dc, ±200 kV, using Line Commutated Converters (LCC);
  - dc, ±200 kV, using Voltage Source Converters (VSC) with half-bridge solution.

Objects of investigation

- A detailed study in terms of **losses**, **environmental impact** and **operation flexibility** has been carried out for each technological solution;

Experimental setup & test results

- Although **ac solution** offers substantial technical (operational flexibility, fault clearing time) and economic advantages (in term of losses), the environmental impact of the new 230 kV double-circuit OHL and the attendant **authorization issues** have practically dictated the unfeasibility of this alternative.
- The **LCC-HVDC solution** exhibits some advantages if compared to the VSC one, both in terms of operation **flexibility** (namely, fault clearing time) and **environmental impact** (reduced converter building footprint and height).
- LCC-converter station losses are slightly higher due to synchronous condensers; SCs increase will improve the dynamic performances of the grid both in terms of voltage stability and inertia.
- VSC can not support alone the grid in terms of inertia, it is another important element to consider in a converter technology decision process.

Discussion

- HVDC-LCC technology equipped with dc-disconnectors is able to perform **power flow reversal** in bipolar operation as well as HVDC-VSC technology; the **minimum operating power** usually in the range of 10% of the nominal power disappears, if the two converters are connected at the same pole;
- A preliminary sensitivity analysis regarding the **risk of commutation failure** has been carried out by Terna considering different values of smoothing inductances and short circuit powers.
- The installation of a SC enables LCC converter station to provide **black start capability** guaranteeing the minimum short circuit power.
- Reliability and maintenance preliminary studies performed by Terna evidence that LCC solution ensures lower failure rate (0,7 failure/year thyristor per pole vs 9,9 failure/year sub-modules per pole) and maintenance costs (260 times larger for VSC than LCC).

Conclusion

- LCC in a “high performance” fashion (combination between LCC and synchronous condensers) can have much better advantages than VSC, considering also that condensers are today an obliged step to increase short circuit power and inertia for the grid due to the spread of renewable technologies installed and reduction of traditional thermal power plants.

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Power losses

- The ac solution clearly exhibits lower losses; this was obviously due to the lower current density, enabled by the construction of a new OHL.
- LCC-HVDC station losses also includes a synchronous condenser at each terminal station, enabling the safe operation of the LCC converters themselves and increasing the short circuit power and inertia for a safer operation of the ac network, especially in Sardinia and Corsica.

Solution	Losses [%]	Losses [MW]	Yearly cost of losses(1) [M€]
AC	7	28	5.04
LCC	10.5	42	7.56
VSC	10.1	40.4	7.27

(1) Considering 3000 equivalent operating hours at full power and 60 €/MWh energy cost.

Table I - Transmission Losses Comparison: 400 MW Power Flow From Sardinia To Italy (No Active Power Tapping In Corsica).

Power flow reversal

- During slow power flow reversal, dc-disconnectors as well as firing angles of converter stations change; an example of power flow between main terminals in lossless assumptions and bipolar operation is reported in Figure 2;
- During slow power reversal, the power in the third terminal was limited to the power of one pole only. The duration of the slow power reversal corresponds to the mechanical movement time of dc-disconnectors.
- The minimum operating power usually in the range of 10% of the nominal power disappears, if the two converters are connected at the same pole (see Figure 2– Step 3).

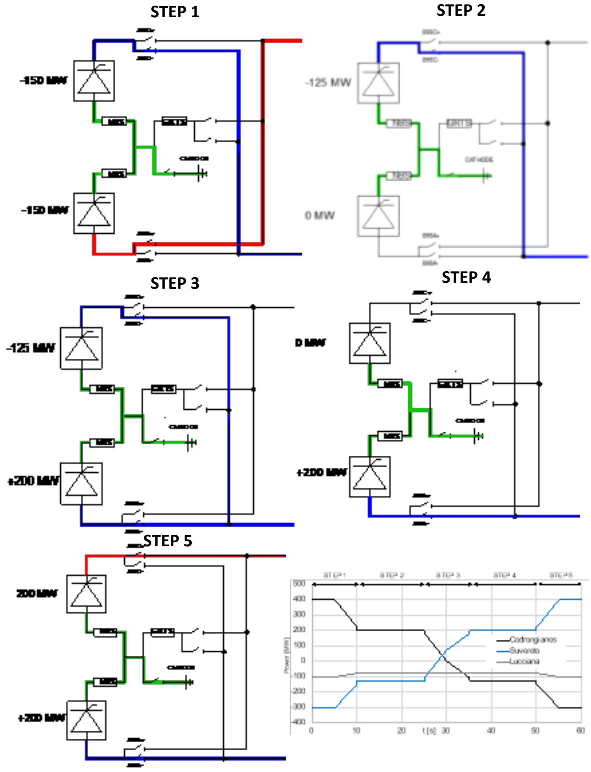

Figure 2 - Dc-disconnectors arrangement of Suvereto converter station during slow power flow reversal and Converter station powers (total) as a function of time during slow power flow reversal between main terminals in lossless assumptions.

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Commutation failure

- Considering the SACOI 3 case study, a preliminary sensitivity analysis has been carried out by Terna considering different values of smoothing inductances and short circuit powers.
- Delay time of control system has been estimated equal to 20 ms and the short circuit impedance of transformer equal to 12.5% on 200 MVA power base. Rated voltage of secondary winding of converter transformer has been assumed equal to 80 kV.

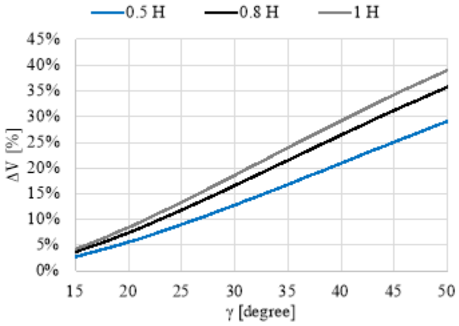

Figure 3 - Minimum voltage reduction required to produce the onset of commutation failures for a balanced three-phase ground fault as a function of margin angle, considering the minimum short circuit power at Condrongianos substation.

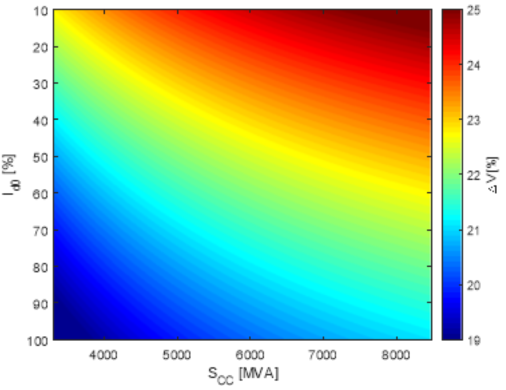

Figure 4 - Minimum voltage reduction required to produce the onset of commutation failures for a balanced three-phase ground fault as a function short circuit power and load current, considering a smoothing inductance of 1 H.

Black start capability

- In case of blackout, SC auxiliary systems, static starter and excitation systems are supplied by emergency diesel generators (DGs) (5 × 2 MW) connected to 15 kV busbars.
- A resistive load is connected to the MV busbars of DGs in order to guarantee a minimum load for DGs stable operation;
- Due to the limited reactive power capability of DGs, shunt reactors are connected to MV DG busbars, in order to compensate the capacitive reactive power of HV cables connecting primary windings of Step-up transformer to HV busbars;
- A pre-charge resistance is connected in series between MV DGs busbars and SC busbars to mitigate inrush current of Biberon and Step-up transformers during energization.
- The SC control system starts the parallel sequencies after energization SC shall be connected in parallel to the HV busbars and DGs shall provide active power for auxiliary systems and losses of SC substation until LCC converter station is switched on.

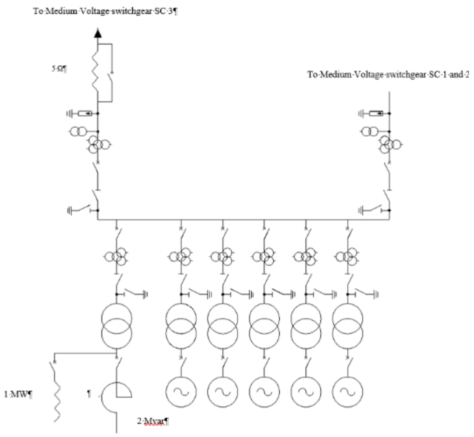

Figure 5 - Single line diagram of emergency diesel generators

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