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HVDC Systems and their Applications

10141_2022

The Multi-terminal Hybrid HVDC Benchmark Model

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Motivation

- The Hybrid HVDC system is a brand-new HVDC topology to be applied in bulk power transmission, and it is becoming a promising transmission system to be applied around the world;
- The main idea of developing a benchmark model of a Hybrid HVDC system is to give a basic, efficient and reliable simulation model that can be used in a simple and fast analysis or be starting more detailed modeling of Hybrid HVDC systems to be applied in a specific study or work.

Approach

- The proposed Hybrid HVDC simulation model is being developed using a typical commercially-available electromagnetic transients' simulation software;
- It will be performed considering Steady-State and AC short-circuit simulation analysis.

Objects of investigation

- Analyze the behavior of the proposed Hybrid HVDC simulation model considering steady-state and AC single-phase short-circuit conditions;
- Test the benchmark model performance and ensure that the developed control functions will operate as expected within the model to return to the reference value.

Proposed topology

- Monopolar configuration of LCC operating as a rectifier and two VSCs operating as inverters (steady-state condition) in a multiterminal configuration (MTDC);
- LCC is a 12-pulse bridge configuration and is called SC--LCC;
- VSC are comprised of MMC Full-Bridge and are called QA--VSC1 and JN—VSC2;
- Overhead line connection among the converters.

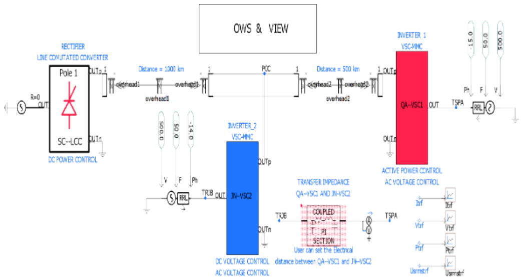

Fig. 1 – Representation of the three terminal Hybrid LCC-VSC-VSC MTDC.

System Parameters

- **LCC** Parameters

Parameter	Unit	Value
Rated AC bus Voltage	kV	525
Rated DC Power	MW	1500
Rated DC Voltage	kV	500
DC Current (Rectifier)	kA	3.0
Converter Transformer Ratio	kV/kV	525/210
Rated capacity of each converter Transformer	MVA	900
Transformer leakage reactance	pu	0.16
Smoothing reactance	H	0.3

- **VSC** Parameters

Parameter	Value	Unit
Rated AC Bus Voltage	525	kV
Rated Power	1500	MVA
Rated DC Voltage	500	kV
Connecting Transformer Ratio	525/250	kV/kV
Transformer Leakage Reactance	0.14	pu
Bridge Arm Reactance	0.1	H
Number of sub-modules in Each Arm	80	-
Rated Voltage of sub-module	6.75	kV

Simulation Cases

- **Condition 1** - LCC = 1500 MW, QA-VSC1 = 1000 MW and JN-VSC2 = 500 MW. LCC in Power Control, QA-VSC1 in AC_Power/AC_Voltage Control and JN-VSC2 in DC_Voltage Control/AC_Voltage Control.
- **Condition 2** - LCC = 1500 MW, QA-VSC1 = 1000 MW and JN-VSC2 = 500 MW. LCC in Power Control, QA-VSC1 in AC_Power/AC_Voltage Control and JN-VSC2 in DC_Voltage Control/AC_Voltage Control.

Control Philosophies

- **LCC** – DC Current or DC Power;
- **VSC-MMC** – AC Power or DC Voltage;

AC Voltage or Reactive Power

Discussion

- The transient behavior seen at the beginning of each simulation, in steady-state conditions, cannot be considered real. The system starting procedures have not been studied yet in detail.
- Users can apply all the control loops combinations that were proposed to the VSC, meaning AC Power or DC Voltage control as AC Voltage or Reactive Power control.

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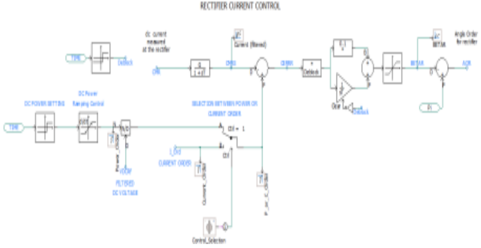
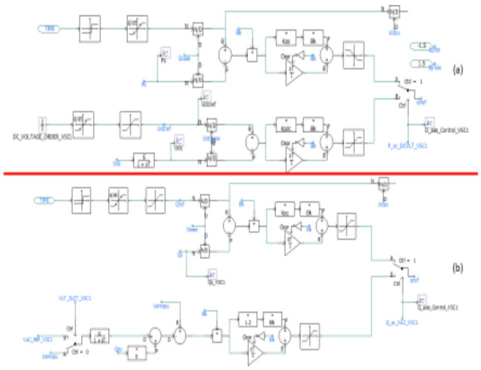
The Multi-terminal Hybrid HVDC Benchmark Model continued

Line Commutated Converter (SC-LCC) control Loop



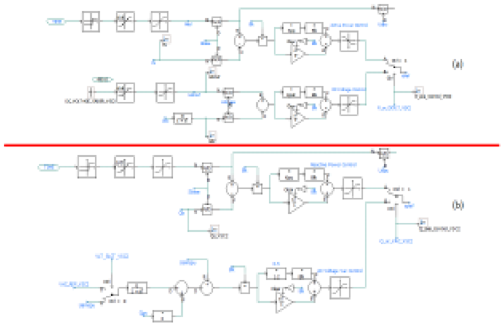
- LCC control Loop (DC Power or DC Current)

QA—VSC1 Control loops



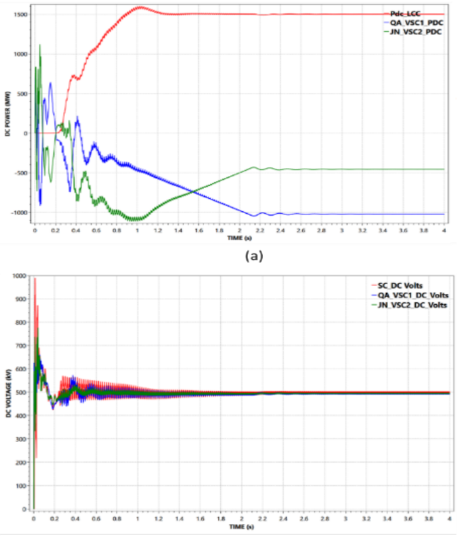
- QA--VSC1 d and q-axis control Loops, (a) and (b) respectively;

JN—VSC2 Control loops



- JN--VSC2 d and q-axis control Loops, (a) and (b) respectively

Condition 1 – Steady-State condition

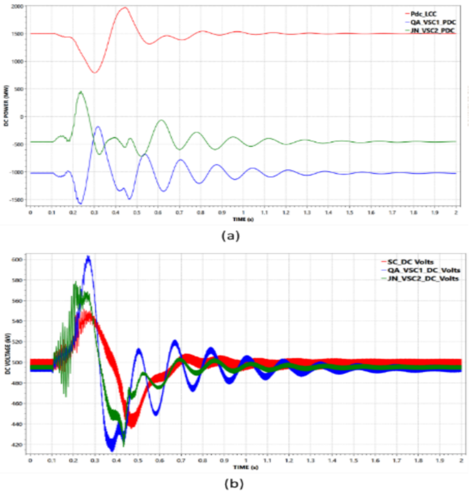


(a)

(b)

- a) DC Power in all system converters
- b) DC Voltage in all system converters

Condition 1 – Single-Phase Short-Circuit at the JN--VSC2 AC grid



(a)

(b)

- a) DC Power in all system converters
- b) DC Voltage in all system converters

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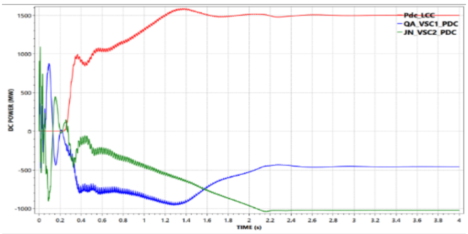
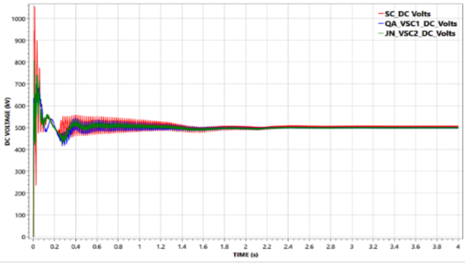
The Multi-terminal Hybrid HVDC Benchmark Model continued

Condition 2 – Steady-State condition



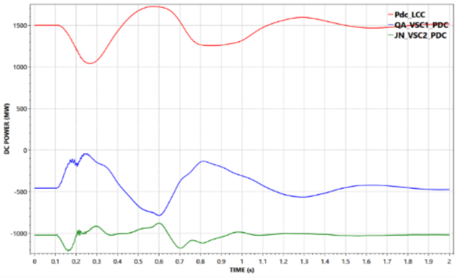
(a)



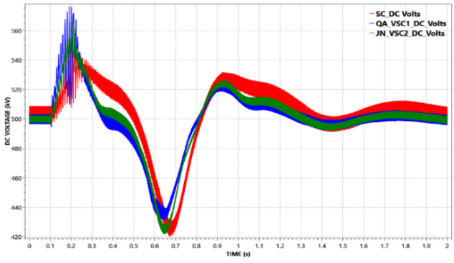
(b)

- a) DC Power in all system converters
- b) DC Voltage in all system converters

Condition 2 – Single-Phase Short-Circuit at the QA--VSC1 AC GRID



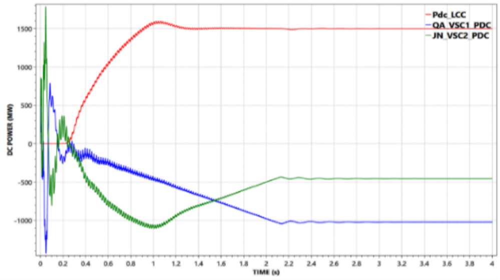
(a)



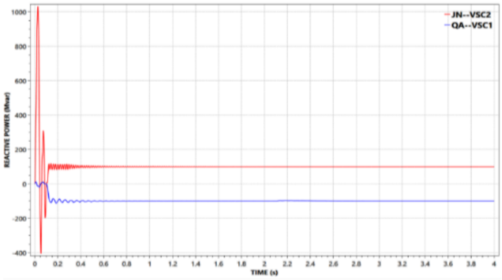
(b)

- a) DC Power in all system converters
- b) DC Voltage in all system converters

Condition 3 – Steady-State condition



(a)



(b)

- a) DC Power in all system converters
- b) Reactive Power in all VSC converters

Conclusion

- Considering all the developed simulations, such as steady-state and AC single-phase short-circuit, the proposed Hybrid HVDC system benchmark model has presented a stable dynamic performance considering all the applied control loops as well as all the control philosophies for each converter.
- Reference values of the control loops are reached by the converters in steady-state, even after the applied AC single-phase short-circuit.
- The simulation model issued in this paper is the beginning of the work to prepare the final benchmark model of the Hybrid HVDC system considering one LCC and two VSCs in MTDC configuration as one product of the WG B4.79 (Hybrid HVDC Systems).
- Keep developing the control loops of the Hybrid HVDC system simulation model considering the application of a DC short-circuit and describe, in detail, the control actions of the LCC and VSC-MMC to eliminate it.