Multi-Terminal DC Transmission Systems based on Superconducting Cables Feasibility Study, Modeling and Control

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INTRODUCTION

This paper deals with the appropriate modeling and control strategy of a multi-terminal dc transmission (MTDC) system that incorporates high-temperature superconducting (HTS) dc cables. The system is based on voltage source converters (VSCs) for the interconnection of stiff ac grids. An overview of the high voltage direct current (HVDC) power transfer technology along with the possibilities it enables, as well as an introduction to the concept of multi-terminal topology are presented. The operation principles of the superconducting technology are described and the control strategy of HTS-based MTDC networks is presented. To validate the performance and the dynamic response of the system under steady state as well as under fault and load change conditions, a typical four-terminal MTDC network in ring topology is developed in MATLAB/Simulink.

MTDC SYSTEMS

MTDC systems have numerous advantages over the point-to-point dc connections due to the reliable and continuous system operation and the power dispatch flexibility. With a MTDC network it is possible to have more than two interconnected ac networks, as well as to link an increased number of remote generation to the main grid. The common practice is the interconnection of each offshore wind-farm with one independent dc transmission line. Consequently, any installation requires the construction of a new dc line. This is considered as an obstacle for new installations, both for financial and environmental reasons. The concept of MTDC networks provides the opportunity to connect any new installation to the nearest existing dc line, a feature that reduces the investment and operational costs. Such a system could be combined with HTS cables, leading to applications with even lower losses and more techno-economic advantages.

CASE STUDY – VEM ANALYSIS

To study an HTS-based MTDC system, the four-terminal system of Fig. 1 is examined. For the HTS cables the distributed parameters model is used and the configuration is the one of EPRI. The same cross-section is used also for the conventional dc cable, but copper is considered instead. Filters and phase reactors on the ac side are also included, whereas for the VSCs the typical two-level topology is used. PWM at carrier signal frequency of 4050 Hz is used. On the dc side, smoothing inductors and capacitors, filters can be found.

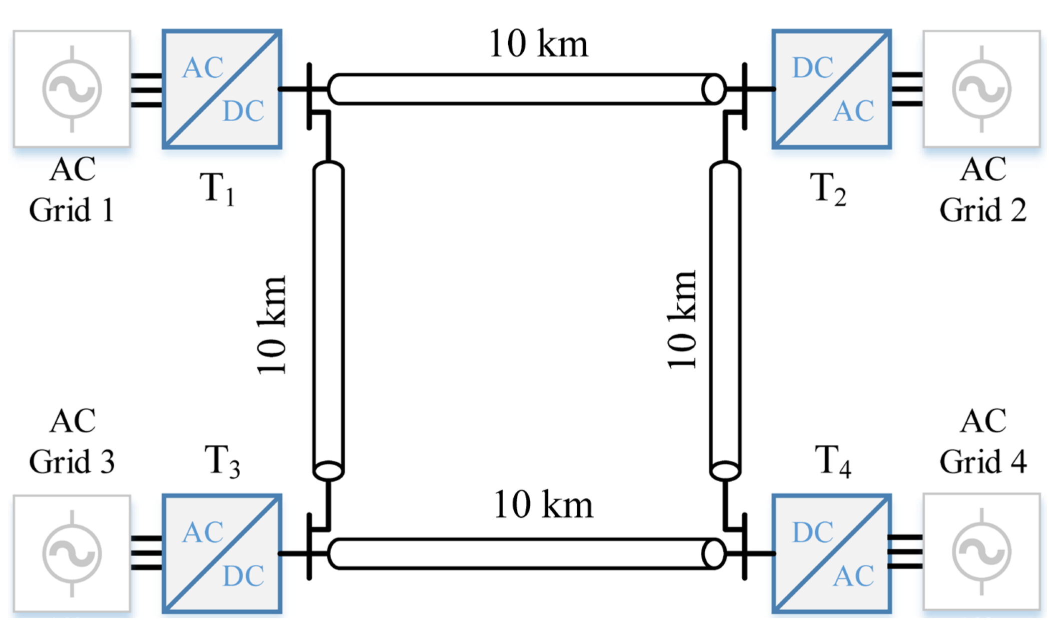

Fig. 1. Configuration of a four-terminal VSC-MTDC grid.

The Terminals operate independently and each Terminal is able to control two physical quantities, which are determined by the nature of the interconnected networks. In this case, the Terminals connect four stiff ac networks and each Terminal applies the same droop control method. Cascade control using PI controllers for fast system response is used. This is implemented by two control loops in series, while the external loop is the input for the inner one. The inner loop is responsible for the control of the most rapidly changing parameter, such as current, while the exterior loop controls other physical parameters, such as active power.

TEST CASES

Initially a steady state scenario is simulated and then the dynamic behavior of the system was tested in case of power flow changes and faults. Our power base reference is set at 500~MVA. The reference conditions were defined as follows:

- T_1 injects to the grid 0.8 p.u. *P* and 0.6 p.u. *Q*.
- T_2 absorbs from the grid 0.7 p.u. *P* and 0.3 p.u. *Q*.
- T_3 injects to the grid 0.4 p.u. *P* and 0.2 p.u. *Q*.
- T_4 absorbs from the grid 0.5 p.u. *P* and *Q*.

All ac grids operate at 400 kV and transformers are used to step down the voltage at 60 kV. The dc voltage is then converted to 100 kV. A fault scenario that occurs at 1.0 s and lasts 0.1 s is also studied and the MTDC system response is examined. The fault takes place at the point of common coupling point of the ac network 1 with T_1

RESULTS

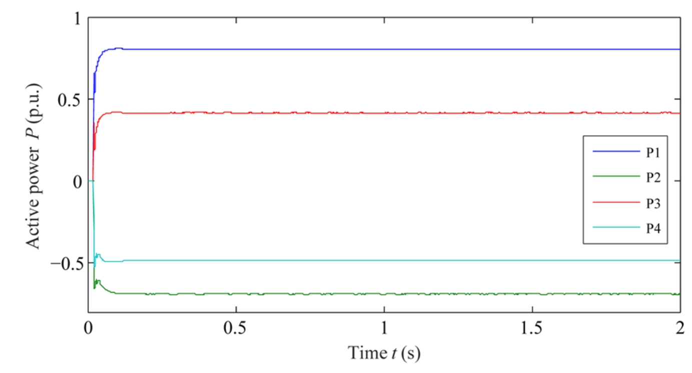

Fig. 2a. Steady-state scenario: active power flow.

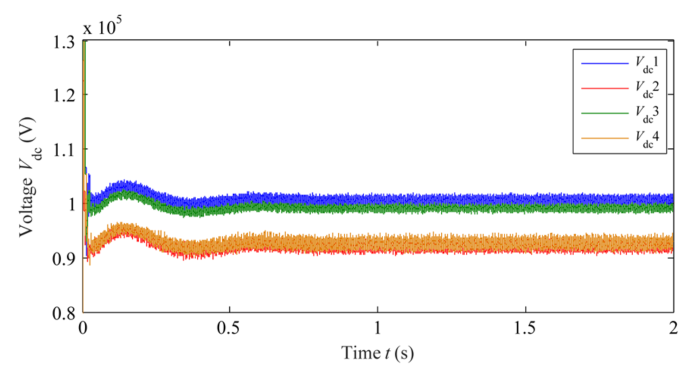

Fig. 2b. Steady-state scenario: dc voltage.

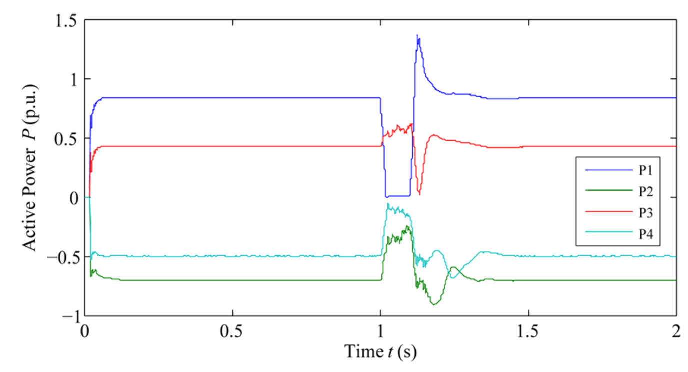

Fig. 2c. Fault scenario: active power flow.

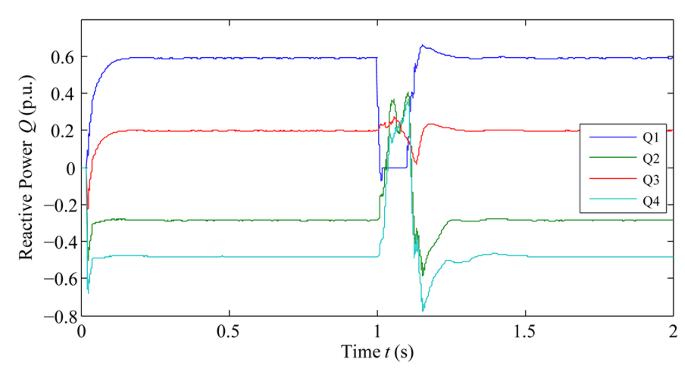

Fig. 2d. Fault scenario: reactive power flow.

In Figs. 2a and 2b, active power flow and voltages on dc side for the steady-state scenario are presented. The voltage drop is larger at the T_2 and T_4, compared to T_1 and T_3, due to the fact that the first two terminals absorb power from the grid, whereas the last two inject. In Figs. 2c and 2d, results for the fault scenario are illustrated. It is evident that T_1 and T_3 that inject power experience greater disturbances and fluctuations in their active power outputs than in their reactive, whereas for the receiving stations, T_2 and T_4, the opposite occurs.

The same fault scenario is simulated in case of a conventional cable to compare their transient response. For brevity, results only for current I_{dc31} is presented in Fig. 3. In case of the HTS cable, the peak over-current during post-fault period reaches 3 kA, i.e. 1 kA more than in case of the conventional cable. Although such a fact is expected, such over-currents can lead the cable to quenching.

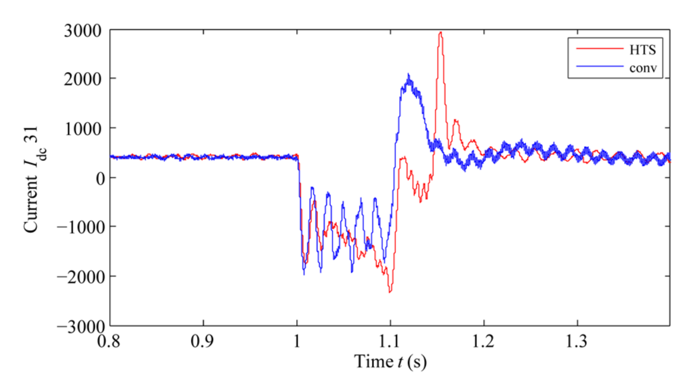

Fig. 3. Current I_{dc31} in case of HTS and conventional cable.

CONCLUSIONS

Feasible modeling of a four-terminal MTDC network utilizing HTS cables to interconnect stiff ac systems is developed and presented. Feasibility study of control techniques applied on conventional MTDC systems are also presented and discussed. Steady-state operation as well as faults are studied. Modeling approaches are not implying themselves better results, however indications on how more efficient control is to be structured are stated. It is observed that by the proposed control approach, the system, despite its low-damping characteristic, presents a well-damped behavior. The proposed structure indicates that HTS-based MTDC grids are technically feasible.

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