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Modelling and analysis of CIGRE HVDC offshore multi-terminal benchmark grid

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Abstract

HVDC power transmission systems are being commissioned in the North Sea to link inland power grids with large offshore wind power farms. The growing number of large wind farms is driving the need to design more reliable high power transportation systems, leading to the conception of multi-terminal HVDC grids. These future grids will be purely formed by power electronics converters, the control of which will have to be designed to ensure proper performance and robust operation. This paper presents the analysis of the benchmark system proposed by the CIGRE working group SC B4, focusing on the proper selection of the components models and parameters. The small signal model of the system is first formulated. Then the bandwidth of the different control loops is obtained and the fidelity of the HVDC line model is selected accordingly. Finally, the performance of the benchmark system is studied by means of small signal analysis and compared numerical time series simulation of the non-linear model.

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1. Introduction

New power transmission systems will be required to connect multiple wind farms located far offshore with onshore connection points. High voltage direct current (HVDC) technology [1] is the main candidate for implementing these new power transmission systems, forming a multi-terminal HVDC (MT-HVDC) grid. Towards the implementation of such systems, the CIGRE SC B4 working group has proposed the use modular multi-level converters (MMC) with overhead lines and undersea DC cables [2].

In a MT-HVDC system [3], the operation of every converter may be reflected to each node of the system, leading to interactions among power converters, and interactions between converters and transmission lines [4]. The analysis of VSC-HVDC with different control parameters and structures has been performed in [5], using a small signal model of the converter. Also, the impact of current controlled DC choppers in MT-HVDC systems has been studied in [6], by using detailed numerical simulation.

This paper analyses the stability margins of the control scheme proposed in [2], by means of small signal studies using accurately linearised models of the different elements in a multi-terminal HVDC system. The stability results are compared with a numerical simulation of the non-linear model of the system implemented in SIMULINK/SimPowerSystems.

2. Modelling

The system under study is a four-terminal symmetric monopole (± 200 kV) MT-HVDC system, as illustrated in Fig. 2. It connects the offshore wind power plant at F1 and an offshore oil platform at E1 to the onshore nodes B3 and B2, this last one located further inland (labelling of converters is derived from [2]). This benchmark system consists of long overhead lines and cables in series, and HVDC-MMC power converters, in order to study interactions among these elements.

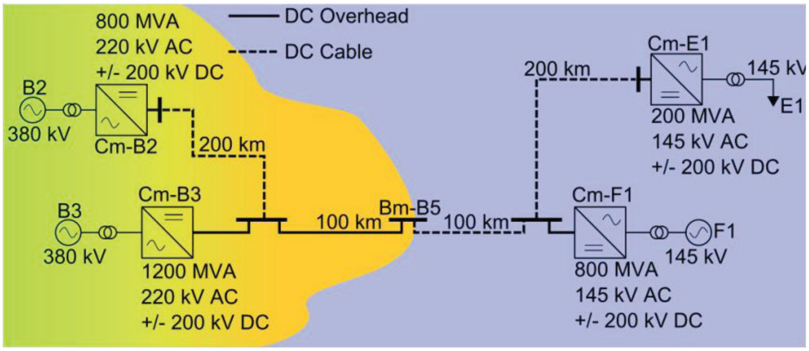

Fig. 1. Benchmark DC system proposed by CIGRE.

The power converters forming the benchmark system have different control objectives. On the one hand, onshore converters, Cm-B2 and Cm-B3, are converters regulating AC power with droop control of the DC voltage. The droop control modifies the external power set-point of the converter in order to maintain the DC voltage within the operational range (1 ± 0.15 pu). On the other hand, the offshore converters have different control objectives. Converter Cm-F1 accepts the power drawn from the wind farm, and implements a dead-band control of the DC voltage. This is to manage extreme cases; *e.g.* a fault on the AC side blocking the operation of the droop converters. Finally, the converter Cm-E1 supplies the power demand of the oil platform. This converter does not actively contribute to the DC voltage regulation.

Different regulatory specifications for the power converters may exist depending on the country hosting the power stations. However, some minimum operational requirements are shared in those regulations. As a guideline, some typical requirements are defined in [7], requiring the power converter station operate under difference