



Multivariable control with grid objectives of an HVDC link embedded in a large-scale AC grid



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ABSTRACT

The HVDC links are increasingly used not only to interconnect asynchronous AC systems but are also embedded into a same meshed AC power system. Thanks to its speed and flexibility, the HVDC technology is able to provide transmission system advantages as transfer capacity enhancement and power flow control. In addition, studies have shown that the way of controlling the HVDC converters impacts the stability of the AC system. This can be particularly exploited to enhance the dynamic power system performances during transients. In this paper a robust multivariable control design for HVDC link converters is proposed. It is based on the coordination of the control actions of the HVDC converters and the use of a control model which takes into account the dynamics that mostly impact stability of the neighbor zone of the HVDC link. This new methodology was used to synthesize the controller for an actual grid 1000 MW HVDC link reinforcement project called “Midi-Provence” in the southern part of the French grid. The synthesis, implementation and validation processes are presented in detail. The new controller is tested in comparison with the standard vector control. A large-scale dynamic model of the whole European power system, currently used and updated by the European TSO's for the interconnection studies has been used with Eurostag simulation software.

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Introduction

The HVDC link is a mean of transmission of electric power based on high power electronics. Thanks to its speed and flexibility, the HVDC technology is able to provide the transmission system advantages as transfer capacity enhancement and power flow control [1]. Initially, it was used in power systems to interconnect asynchronous AC systems. The ends of the HVDC link are electrically independent one from each other and this reduces significantly the propagation of perturbations between the two AC grids as it is the case of the England–France interconnection [2]. Nowadays, HVDC links are increasingly embedded into a same meshed AC system in order to enhance the grid's transmission capability and flexibility of the power system. In this context, the HVDC link co-exists with other AC system elements as for instance AC lines and generators. Several projects of insertion of this type of device in a meshed AC system are under-way in Europe, as for instance France–Spain HVDC project [3], France–Italy interconnection and Midi-Provence

HVDC project [4]. This latter is our case of study. In fact, a 1000 MW HVDC link will be inserted in France between the two areas Fos and Gaudière, in order to enhance capacity of power transmission and the stability of the Midi-Provence region. The need of such HVDC link is due to the fact that only one single 400 kV AC line interconnects the two areas (see Fig. 1).

It was shown that the strategy used to control the HVDC converters can impact the stability of the system in which the link is embedded [5–12]. This conducted us develop a methodology which takes into account, in a control model, the neighbor zone of the HVDC link and the dynamics that most impact transient stability. This control model captures the dynamics that are relevant for the transient stability of the power system. The controller synthesis is done on the base of this control model. As a consequence, power system performances are enhanced in addition to local performances. Preliminary results have been presented in [13]. This approach is fully developed here in order to take into account some key critical fault situations at the synthesis stage using the robust H_∞ theory. Also the methodology is adapted to handle realistic large-scale cases as the European power system. As a matter of fact, in other papers [14,15], the transient stability is considered as an *a priori* objective for the synthesis of coordinated controllers for HVDC. However, the effectiveness of these methods had not been proved in the case

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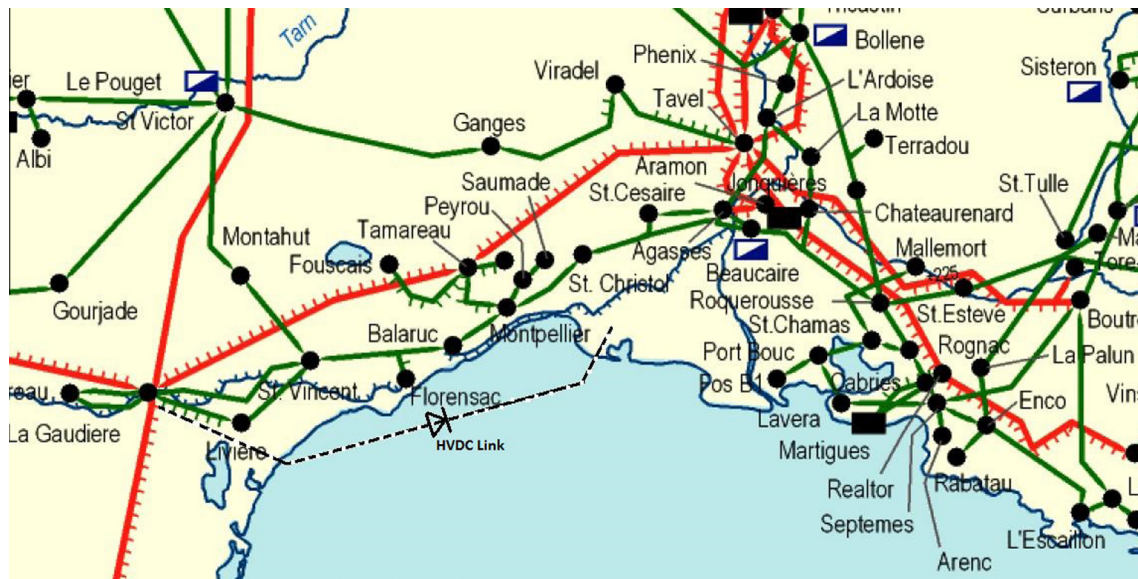


Fig. 1. Midi-Provence interconnected power system.

of large-scale power systems. The proposed control is tested in comparison with the standard vector control via simulations performed with Eurostag [16]. The rest of the paper is organized as follows: in Section ‘The Midi-Provence HVDC project’, the large-scale case used for this work is described. Then in Section ‘Control model synthesis’, the method for developing the control model for the power system is presented. This control model is used in Section ‘Synthesis of the control law’ to synthesize a robust multivariable output-feedback controller for the HVDC converters. Section ‘Computation and implementation of the controller’ deals with the computation and implementation of the controller. Finally, in Section ‘Simulation tests’, simulation results are presented to illustrate the performances and the robustness of the new controller. An earlier version of this paper was published in [17].

The Midi-Provence HVDC project

Midi-Provence project aims to strengthen the link between the two dynamic regions, Provence-Alpes-Côte d’Azur and Languedoc-Roussillon by inserting an HVDC link of 1000 MW capacity between them. These two regions are in the actual situation of the grid mainly connected by a single 400 kV AC line going from Tavel (Est of Gard) to La Gaudière (in the Aude) (see Fig. 1). In case of outage of this line, the north–south corridor of this region and thus towards to Spain is limited to only one substation. This HVDC project responds thus to a need of enhancement of both stability and transport capacity in this region [4]. The Midi-Provence zone is considered as part of the whole European system. For the latter, we used the reference model which is maintained and generally used for interconnection studies by the European TSO’s. It is a detailed non-linear model including generators along with their regulations (AVRs, PSS and Governors) and where the high voltage network (225,400 kV) is modeled. It consists of 1121 generators, 7625 nodes, 10,404 lines, 2550 transformers and 458 GVA global apparent power. The Midi-Provence HVDC link is of 230 km length and 1000 MW power capacity. It is placed as shown in Fig. 1.

Note that we have considered a 2020 forecast winter situation.

Control model synthesis

The large-scale model mentioned in Section ‘The Midi-Provence HVDC project’ cannot be used for the synthesis of the control. As a

consequence, a reduced order model called a *control model* which must preserve the dynamics that most impact the stability of the neighbor region of the HVDC link should be extracted from the whole European model. The way to do this it is not a straightforward reduction method, but a specific methodology developed in accordance with the objectives of the control. It is detailed in the rest of the paper.

Structure of the control model

The control model is composed of two parts: the AC power system (grid and machines) and the HVDC link. We retain in the control model the *most critical machines*, i.e., those which cause the system loss of synchronism after a severe perturbation. All the other machines are skipped. Also, after this operation, the lines which no longer connect machines are considered as irrelevant topology and are also simplified.

Construction of the control model

The study area selection

The study area is the zone which is impacted by the HVDC link and corresponds to the neighbor zone of the HVDC interconnection of which transient stability depends on the HVDC dynamics (see Fig. 1). The extent of this zone is detected by standard stability studies usually run by TSOs.

Critical machines selection strategy

The machines retained in the control model are based on both non-linear and linear analysis as explained below.

1. *Selection on the base of CCT.* First, a transient stability margin of the power system is estimated by the Critical Clearing Time (CCT) which is defined as the maximal fault duration for which the system remains transiently stable [18]. The instability is then manifested by the loss of synchronism of a group of machines. The most critical machines are the ones which have the smallest CCT for a given class of faults. The latter faults are the ones put into evidence by the stability studies for the region usually run by TSOs and mentioned above. Doing so for the case Midi-Provence considered in this paper, 14 machines have been retained for the control model.

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