Electric Power Systems Research 138 (2016) 180–187

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Setup and performances of the real-time simulation platform connected to the INELFE control system

Sébastien Dennetière[a,*], Hani Saad[a], Bertrand Clerc[a], Jean Mahseredjian[b]

[a] RTE - Réseau de Transport d'Electricité, Tour Cœur Défense, 92932 Paris La Défense, France
[b] École Polytechnique de Montréal, Campus Université de Montréal, 2900, Édouard-Montpetit, Montréal, Québec, Canada H3 T 1J4

ARTICLE INFO

Article history:
Received 8 December 2015
Received in revised form 29 February 2016
Accepted 6 March 2016
Available online 26 March 2016

Keywords:
Real Time Simulation
Electromagnetic transient studies
Modular Multilevel Converters (MMC)
HIL simulation

ABSTRACT

The VSC-based HVDC link between France and Spain (INELFE project: France-Spain ELectrical INterconnection) is currently the most powerful VSC link. This 2000 MW interconnection is composed of two parallel VSC links. For system studies and maintenance purposes, the replicas of the control systems have been acquired by the French (RTE) and the Spanish (REE) Transmission System Operators. This paper describes the hardware and software setup to perform Hardware In the Loop (HIL) simulations with the INELFE control system replicas. The converter and cable models used in the real-time simulation are presented. Modular Multilevel Converters present a major challenge for real-time simulation due to the large number of sub-modules and to the nonlinearities that shall be solved: transformer saturation and nonlinear characteristic of surge arresters that protect cables against switching transients. The paper presents how these issues have been solved in order to be able to test the control system with AC and DC faults. It is shown that iterative methods are used to provide accurate solutions in the presence of nonlinear devices but are not mandatory in this specific case. A complete setup has been developed in order to validate the modeling approach. HIL simulations have been performed with the real-time simulator connected to an external generic control system having the same interface than the replica. Real-time performance and simulation accuracy are fully achieved with the proposed solution. This solution has been used to interface the real-time simulator with the real control cubicles. The converter model is validated with on-site measurements.

1. Introduction

Interconnections between national electrical grids have been historically developed along with each country's internal networks. Interconnections were initially used for external support in the event of failure affecting the security of the national electrical supply. However, it has been demonstrated that interconnections are not only useful for exceptional situations, but also offer advantages under normal operating conditions, such as optimizing the electrical power stations' daily production, increasing opportunities for operation with renewable energies, the creation of competition, improvement of supply conditions and black start operation.

In France, RTE is accelerating the development of its grid and several projects involve power electronic-based equipment such as HVDC links, static VAR compensators. In the longer term, the share of power electronics connections into existing ac systems will significantly increase due to the massive penetration of wind power plants, and HVDC links and grids. For several years, RTE has been involved in research and development activities to model, study and mitigate potential interaction issues between HVDC links. To support these activities, numerical tools are needed that offer detailed modeling of HVDC components and controls while maintaining a good compromise between robustness, accuracy and flexibility.

The usage of electromagnetic transient analysis tools (EMT-type) to test new technical solutions is continuously increasing in importance. EMT studies performed for the installation of new equipment on the grid are to ensure highest levels of reliability and availability. EMT-type simulation tools (offline and real-time) must provide reliable and accurate simulation results, advanced visualization and analysis capabilities to power system engineers. Therefore, RTE continues its direct involvement in the development and improvement of such tools as explained in Dennetière et al. [1]. For instance collaborations with École Polytechnique de Montréal in Canada and École Centrale de Lille in France have been established for the development of models and tools suitable for

* Corresponding author. Tel.: +33 01 79 24 85 11.
E-mail address: sebastien.dennetiere@rte-france.com (S. Dennetière).

http://dx.doi.org/10.1016/j.epsr.2016.03.008
0378-7796/

EMT-type studies for Modular Multilevel Converters (MMCs). Some of these models are presented in Saad et al. [2], Peralta et al. [3] and Saad et al. [10].

After the commissioning of HVDC and FACTS devices, manufacturers usually provide customers with a black box model of their control systems. These models suitable for EMT simulations are difficult to maintain during the lifespan of equipment for the following reasons: the models are usually based on a specific version of a simulation tool that might not be supported in the future, the models usually use static libraries that can be only compiled and linked using a specific compiler version, the models cannot easily follow changes in the actual control systems because manufacturers do not necessarily maintain modeling expertise on long-term basis.

The solution is to continuously update control system models for replicating real controllers and related updates. This is a time-consuming activity and another possibility, presented in this paper, is to use manufacturer supplied physical replicas of control systems.

As a consequence, to validate the various modeling approaches for the different range of phenomena and to demonstrate interoperability and the absence of detrimental interactions, RTE decided to use hardware-in-the-loop architectures, with the actual replicas of the physical control systems. In this area, as part of its ongoing HVDC projects, RTE has recently assembled a HIL test facility called SMARte that uses the Hypersim simulator. The Hypersim [4–5] software is a real-time HIL simulation platform used for the simulation and testing of control systems. A collaboration on the development of Hypersim has been established between RTE and Hydro-Québec in 2012. This collaboration enables sharing development efforts and expertise. RTE has acquired its own real-time simulation laboratory based on Hypersim for installing control system replicas. Hypersim is now commercialized by Opal-RT.

RTE aims to expand this facility to meet its future project needs and to participate in the future development and improvement of the simulator.

2. SMARte laboratory description

In order to facilitate the maintenance and operation of control and protection systems in HVDC and FACTS devices, the replicas of actual control system and protection cubicles are acquired by RTE and installed in the real-time simulation laboratory called SMARte and based in Paris, La Défense. A replica is an exact copy of the actual control cubicles installed on site. Two types of replicas can be ordered: study and maintenance.

2.1. Study replica

The study replica is dedicated to functional verification, dynamic performance and protection studies. The replica is delivered 6 months before the commissioning of the real installation and is used for network studies between Factory Acceptance Tests (FAT) and Site Acceptance Tests (SAT) to test the control algorithms. These investigations may lead to updates or even modifications in control algorithms.

The Study replica is provided only with equipment relevant to network studies and redundancy is not included.

From a utility point of view, the modelling of HVDC control systems for EMT studies is a quite complex task because actual controls may run on multiple platforms (CPU, DSP, FPGA...) and as a consequence simulation on a single CPU would require too much time. Moreover, the HVDC controls are based on algorithms that are protected by manufacturers due to IP rights. Therefore, replicas are useful to perform network studies without any simplifications or assumptions in control systems. Off-line or real-time control system models can be also validated with replicas.

2.2. Maintenance replica

The Maintenance replica is intended to help the preparation of on-site maintenance operations and operator trainings. The preparation of maintenance operations includes testing and validation of the upgraded system version before field implementation. In order to perform preparations for maintenance, validation of upgraded control system, fault diagnostics and training of operators, the Maintenance replica includes a set of control- and protection cubicles identical to the original cubicles in the converter substations with the same interfaces, including any redundant equipment implemented in the converter cubicles. The Maintenance replica is delivered during the commissioning of the actual control system cubicles.

3. The France Spain HVDC interconnection

3.1. Context

The electrical interconnection between Spain and France currently consists of four AC lines (the last line was built in 1982): Arkale-Argia, Hernani-Argia, Biescas-Pragneres and Vic-Baixas. These lines have a total commercial exchange capacity from France to Spain of 1,400 MW, meaning that they represent only 3% of the current maximum demand in the peninsula. The new HVDC electrical interconnection line between Spain and France has a length of 64.5 km with 2000 MW capacity. It connects the towns of Baixàs, in the Roussillon region (France), and Santa Llogaia, in Alto Ampordá (Spain). Converter stations are designed and built by SIEMENS. Prysmian Cables & Systems has been awarded the contract for the installation of cables. More information on this project is available in INELFE [6].

This new HVDC interconnection is the first VSC installation operated and maintained by the French (RTE) and the Spanish (REE) Transmission System Operators (TSO). RTE decided to acquire competences in modeling and simulation of VSC-based equipment. Competences in this field were required for the INELFE project but, above all, were mandatory for the numerous HVDC and FACTS projects that are planned in a near future in the French grid. Some EMT models have been developed in this context and are described in Saad et al. [2]. EMT study examples are provided in Dennetière et al. [7]. In addition to modeling activities in the field of FACTS and HVDC, RTE decided to build a real-time laboratory that hosts replicas of the control system cubicles installed on site. Studies with the real controllers connected to the Hypersim real-time simulator will be performed. Moreover, this simulation platform will give an opportunity to validate the specific EMT models of the link.

3.2. Interconnection description

The interconnection is composed of two HVDC links. Each link has two MMC stations with a rated transmission capacity of 1,000 MW (+/-300Mvar) and a DC voltage of $\pm$320 kV. A simplified single line diagram is presented in Fig. 1. Each link is composed of two symmetrical monopole converters, two step down transformers and two underground cables. VSC-HVDC technology, using the modular multilevel converter (MMC) topology, has been selected for this project due to the dynamic performance, power flow control requirements and the low AC short-circuit ratio of the France–Spain system. More details on converter topology and data are available in Dennetière et al. [7].

3.3. DC bus faults and surge arresters

Due to the symmetrical monopole configuration, no reference to ground is available in the delta side of the transformer. A ground