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Commissioning of the France Spain HVDC VSC control system replicas

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SUMMARY

Due to the numerous HVDC and FACTS projects expected on the French transmission grid, the French Transmission System Operator (RTE) decided to build a real-time simulation facility. Hardware-in-the-loop (HIL) simulations are performed in this facility using the Hypersim simulator and replica panels. The objectives of this facility are mainly to study abnormal interactions, to test multi-vendor and multi-infeed schemes. It can also be used to validate the various modeling approaches for a large range of different phenomena and to support maintenance activities.

The VSC based HVDC link between France and Spain (the INELFE project: France-Spain ELectrical INterconnection) is, actually, the most powerful VSC link in the world. This 2,000 MW interconnection is composed of 2 parallel VSC links and has been commissioned in August 2015. For system studies and maintenance purposes, 2 replicas of the control systems have been ordered by RTE (French TSO) and REE (Spanish TSO). The 40 control system panels of the INELFE project have been delivered and installed in the RTE real-time laboratory in August 2015.

The paper presents the rationale for real-time simulation in this project. Installation and commissioning of the replicas have been performed in a quite limited time (around 2 months). The technical solution used to prepare the commissioning is described in the paper. HIL set-up configuration and replica validation against on-site results are presented.

KEYWORDS

EMTP, Hardware-in-the-loop (HIL) simulation, HVDC transmission link, Modular multilevel converter (MMC), Real Time Simulation, Voltage source converter (VSC),

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Introduction

The increase penetration of power electronics equipment in the network will have more and more impact on the grid performance and reliability. HVDC converters and SVC include control system and protections with a dynamic behaviour much more complex compared to standard AC devices, thus requiring skills and tools dedicated to this technology.

In the last 5 years, five SVCs have been installed on the French Grid. In 2015, the 2,000 MW France-Spain High Voltage Direct Current (HVDC) Modular Multilevel Converter (MMC) [1] has been commissioned and is the first Voltage Source Converter (VSC) installation operated and maintained by RTE and REE [2]. Future network development plans foresee installation of several other HVDC links embedded in the existing AC grid to support the rapid changes in the energy mix and the integration of renewable energy.

RTE is in charge of the development, operation and maintenance of the French grid and, through these missions, has the obligation to maintain a high level of reliability for all network components during their whole lifespan including HVDC and SVC.

In this context, RTE has decided to evolve its simulation tools by developing a new activity using real-time simulation connected to replicas of real control system cubicles. A replica is an exact copy of the actual control and protection system installed on site. Therefore, a real-time simulation laboratory called SMARTE has been set up in 2012 in Paris La Défense. Control system replicas are acquired and installed in this laboratory for each new power electronics project on the French grid.

Figure 1: Baixas Station – RTE converter station site

This paper presents the installation and the commissioning of the first HVDC-MMC replicas in European TSO. Installation and commissioning of the replicas have been by RTE. The technical solution used to prepare the commissioning is described in this paper. HIL set-up configuration and replicas validation against on-site results are presented.

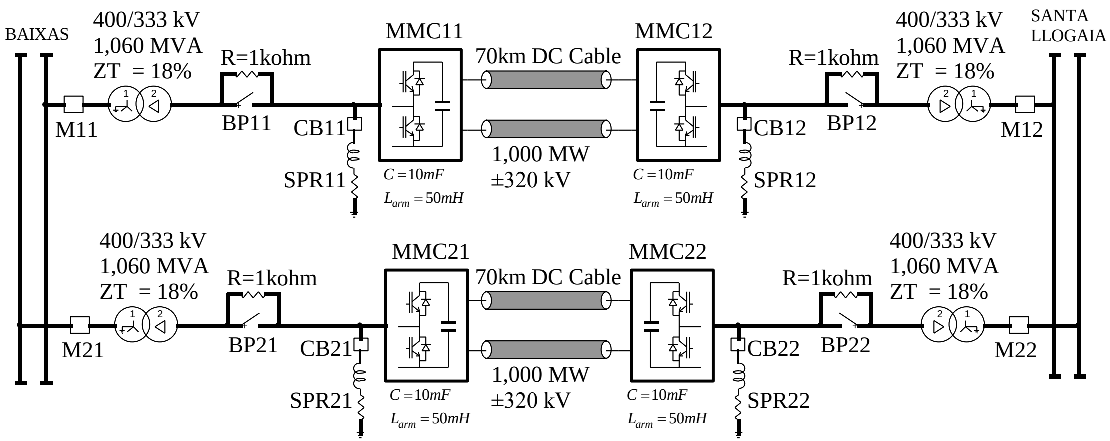


Figure 2 : Single line diagram of INELFE interconnection

RTE Real-time laboratory

The real-time simulation laboratory includes several simulators [3] and control replica panels. The real-time simulator chosen by RTE is Hypersim which has been developed and used by Hydro-Quebec for more than 20 years and recently commercialized and developed by Opal-RT. A collaboration agreement on the development of Hypersim has been established with Hydro-Québec to share development efforts and expertise.

A replica is an exact copy of the actual control and protection system installed on site. In 2013 and 2014, 5 replicas of SVC equipment have been installed in the laboratory [4]. The objectives of this facility are mainly to study adverse control interactions, to test multi-vendors and multi-infeed schemes. It can also be used to validate the various modeling approaches for the different range of phenomena and support maintenance activities. Another objective of the laboratory is to develop R&D activities at RTE regarding HVDC and EMT type simulation tools.

Replicas of the France Spain link for network studies and maintenance

For system studies and maintenance purposes, 2 replicas of the control systems have been ordered by RTE and REE. A total of 40 control replica panels of the INELFE project have been delivered and installed in the RTE laboratory in August 2015. The INELFE replicas in RTE laboratory is shown in Figure 3. In the future, it is possible to configure a connection between replicas (SVC and HVDC) with the same real-time simulator in order to perform interaction studies.

Figure 3: INELFE replica

Two types of replicas have been ordered for the INELFE project [5]: Study and Maintenance.

1. Study replica

The study replica is dedicated to functional verification, dynamic performance and protection studies. The Study replica is provided only with equipment relevant to network studies and redundancy is not included. For the INELFE project, this replica include 7 panels.

Modeling of detailed and specific HVDC control systems for EMT studies is a quite complex task because actual controls may run on multiples platforms (CPU, DSP, FPGA…) and as a consequence simulation on a single CPU require long computation times. 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.

In addition, some transient studies cannot be performed on offline software due to a large simulation time (several minutes) and some functions of the real system may not be included in the offline model. For instant, the real procedures of the start-up, shut-down and black-start sequences, etc.

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.

For both replicas, RTE was in charge of: delivery, supervision of the transportation, installation in the laboratory, wiring connection between replica panels and commissioning. Siemens supervisor has been provided for a support only during commissioning. The 40 control panels of the INELFE project have been delivered in RTE laboratory in August 2015. Installation and commissioning of both replicas have been performed in a quite limited time (around 2 months).
In addition, RTE has decided to interface the replicas with a Hypersim simulator and to develop the power circuit model. The main advantages of this approach are:

- Cost reduction
- Development of an adequate model that meets RTE needs
- Better understanding of modeling assumptions impacting model validity.

Real Time Model and HIL setup configuration

Circuit configuration of the INELFE project is presented in Figure 4. One link is composed of two converter stations and two dc cables using a wideband model. The power circuit has been developed and modeled by RTE in Hypersim. Several articles can be found on this challenging task as [6]-[9]. The entire system requires only 3 cores to meet the real-time simulation requirements. Wideband model is used for the DC cables. Each convertor station is mainly composed of (see Figure 2):

- Main AC breaker that allows connecting and disconnecting the converter station to the ac grid.
- Three single phase units of power transformer connected in YD.
- Bypass switch in parallel with an insertion resistance installed between the converter and the transformer. The insertion resistance is used during start-up sequence to prevent inrush current during capacitor charging of the converter. During normal operation, this resistance is bypassed by the bypass switch.
- A star point reactor composed of high impedances of inductances and resistances in order to get a reference to ground.
- AC/DC converter using the MMC technology [1].
- Several surge arresters are installed to meet the insulation coordination requirements.

The real-time simulator is connected to the replicas through standard I/O interfaces (+/-10V for analog signals, +24V for binary signals) for mainly sending/receiving following analog and digital signals:

- Measured voltages and currents,
- Number of inserted and blocked submodules of each arm,
- Command of the circuit breakers and disconnectors.

Similar components used by SIEMENS for factory tests are implemented in Hypersim simulator. The main differences are:

- Diodes and switches are represented by two-value resistors (Ron, Roff). In Hypersim, these components does not use a fixed admittance models as depicted in [10]. Therefore, unrealistic resonances due to fictitious capacitors and inductors are avoided using the Ron/Roff approach.
- Surge arresters using the V-I characteristics are included in the model.

Since each replica includes 2 converter stations, two different configurations of the replica can be used: station configuration or link configuration. Station configuration will represent the two converters at Baixas station and Link configuration will represents one HVDC link as depicted in Figure 4. This approach allows us to cover a wider range of studies and activities.

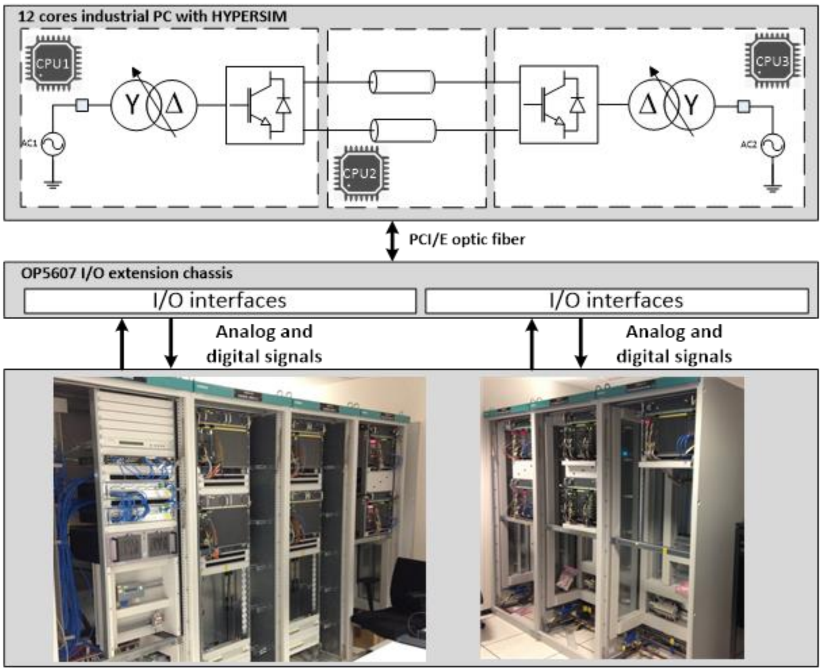


Figure 4: HIL configuration of the INELFE Replica with Hypersim simulator

Hypersim model validation

Before connecting the INEFLE replica to Hypersim simulator, it is essential to validate the power circuit model developed in Hypersim simulator to insure good reliability and accuracy. Therefore a comparison with the offline EMTP-RV software was made. A generic control system has been developed in Simulink and transferred automatically to EMTP-RV [11] by means of DLL (Dynamic-Link Library) and to Hypersim by means of a dynamic library (.so). This approach simplifies software interoperability and guaranties the concordance of control diagrams [12]. Model development and validation are described in [5].
The real time simulation is running with a time-step of 25-30µs, which is lower than replica requirement.

INELFE Replica validation

During commissioning of the replica in RTE laboratory, several dynamic performance tests (DPT) were performed and compared against the Factory Acceptance Tests (FAT) of real control panels in SIEMENS laboratory. These comparisons include EMT transient events

such as: AC and DC faults, fast power reversal, step changes, etc. The results of the replica and the real control system were satisfactory concordant.
In addition, the HIL simulation using the replica and Hypersim simulator was compared with on-site results at Baixas station. In this section, power reversal of Link 1 is analyzed and validated. Test case details are illustrated in the HMI (Human Machine Intereface) presented in Figure 5. Initially, a 100 MW is transmitted from Baixas to Santa-Llogaia. An active power reversal is applied with a ramp rate of 50 MW/min to reach 100 MW from Santa-Llogaia to Baixas. During the entire procedure, at Baixas station, ac voltage control is used with a ramp rate of 40 Mvar/kV, the short-circuit level at the Point of Common Coupling (PCC) is 9,000MVA, telecommunication between both stations is activated and tap changer of the transformer is constant. From Figure 5, one can notice that the active power values shown in the HMI, i.e. Psum, are not equal between Baixas and Santa-Llogaia stations due to losses in dc cable and converter stations.
Figure 6 shows the comparisons between On-site (red curves) and real-time simulation with replicas (blue curves) results.

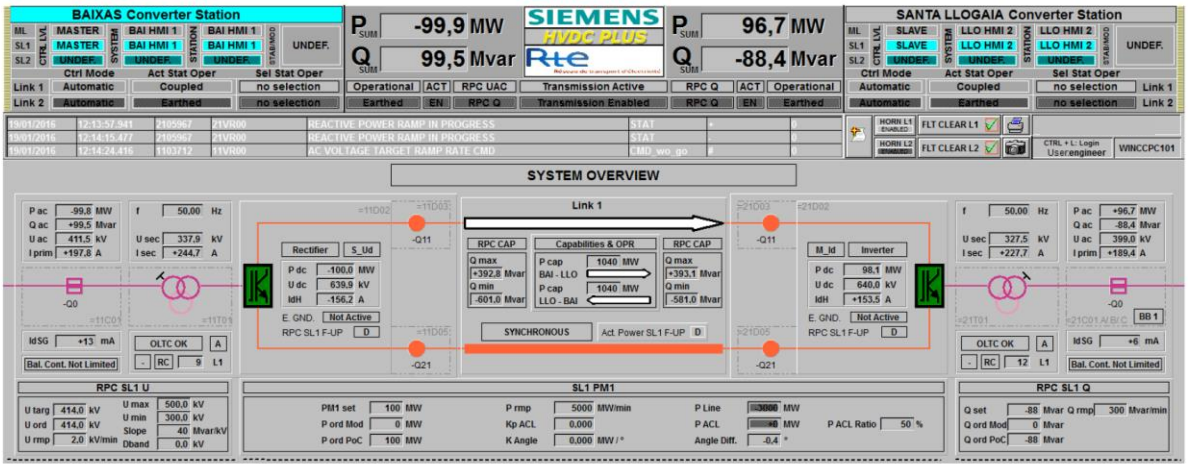
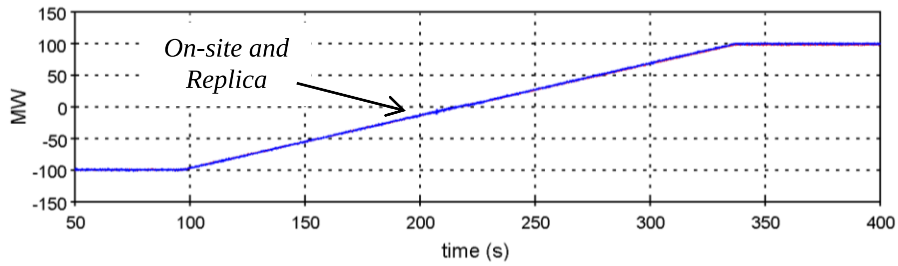
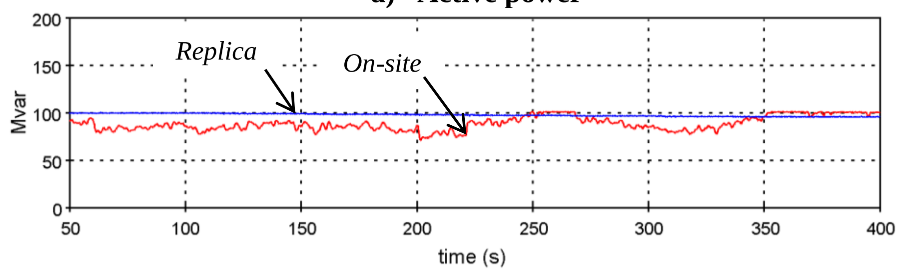


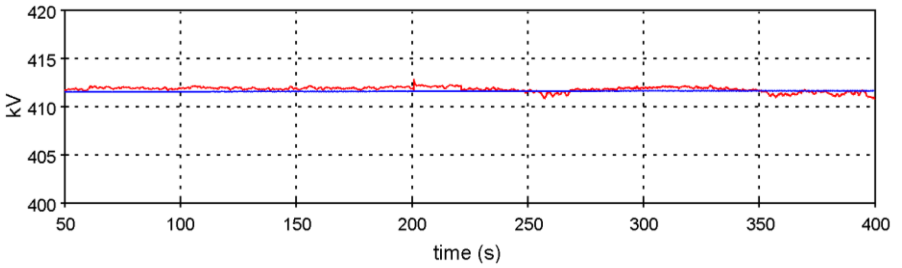
Figure 5: Replica and On-site HMI



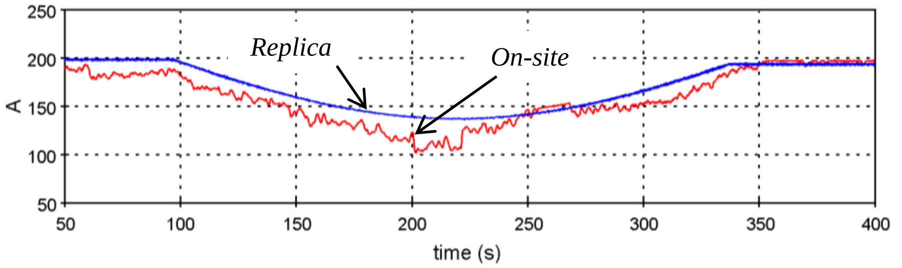
a) Active power



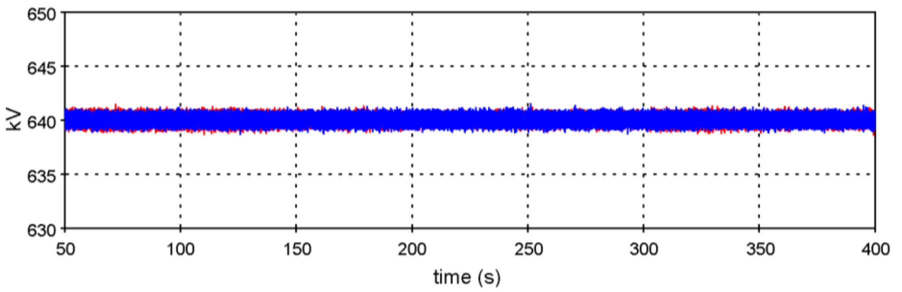
b) Reactive power



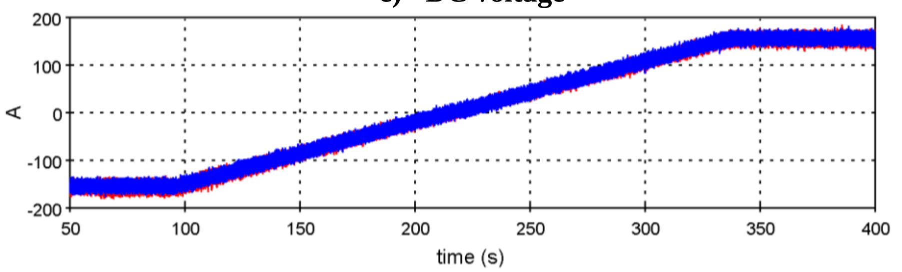
c) AC voltage rms at PCC



d) AC current rms at PCC



e) DC voltage



f) DC current

Figure 6 : Comparaison between On-site and Replica results - variables at Baixas station

Comparison between on-site results and real-time simulations with replicas for the active power, dc voltage and dc current variables are very close. It should be highlighted that DC harmonics are also very close. Regarding AC voltage and reactive power at Baixas station, one can notice some slight differences, this is mainly due to the continuous ac voltage noise variations of the real grid voltage which is not represented in Hypersim model. This variation impact the reactive power (since ac voltage control is used) and also the ac current variable (Figure 6.d). Therefore, this discrepancies are due to the ac grid representation which is modelled, in this article, as a simple equivalent thevenin source. It is expected, that a more realistic ac grid model including several substations and equivalent power plants will improve the accuracy of simulation with replicas.

Conclusion

This article describes the commissioning of the INELFE replica at RTE real-time laboratory. Setup configurations of both replicas: Study and Maintenance, and the Hypersim real-time platform are illustrated. Procedure for model validation is described and a comparison between replica and on-site results are presented. It can be concluded, that the HIL simulation between the INELFE replica and the Hypersim simulator give satisfactory results and good accuracy compared to the on-site Baixas station. It is expected, that a more detailed ac grid model will improve replica accuracy.

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