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Development and Comparison of DC grid Model in Powerfactory and Dymola for Controller Design

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Abstract— Dealing with large AC systems interfaced with DC grids through converters poses new challenges on simulation platforms. A linearized model is essential for many common control design procedures while various converter control mode implementations are required to emulate different operating conditions in the DC grid. Currently many of the domain specific tools are unable to provide such linearized model when the model contains DC Grid components. To overcome this limitation of the domain specific simulation platforms, it is proposed to use the general purpose modeling language Modelica and the tool Dymola to generate linear models to develop extensions for controller design while PowerFactory Digsilent is used for time domain simulations. In this way it is possible to validate the actual system performance of the controller which is designed based on the linearized model. In this paper VSC HVDC is considered for the DC grid.

Index Terms—HVDC, DC Grid, Dymola, PowerFactory.

I. INTRODUCTION

WITH numerous applications of High Voltage DC (HVDC) transmission, DC grid is foreseen as a possible solution [1-3]. To ensure system stability, first the control schemes of such DC grids with a large number of voltage source converters (VSC) should be verified in simulation with the designed controllers. For this purpose, the freely available ObjectStub library has been used [4]. The model library contains models suitable for load-flow and power system dynamic stability studies in AC power systems. All component models are transparent and can easily be modified or extended. Based on the existing AC components, extensions have been introduced for component based modeling of VSC HVDC system. Based on these extensions the modeling of VSC HVDC grids with general topologies is straightforward using the point-and-click interface of a Modelica simulation tool such as Dymola, which has been used in this study.

In this paper a procedure for controller design and time domain simulation testing of DC grid control for multiple simulation platforms is described.

II. CONTROLLER DESIGN AND VERIFICATION PROCEDURE

The proposed controller design and verification procedure is shown in the flowchart in Fig.1.

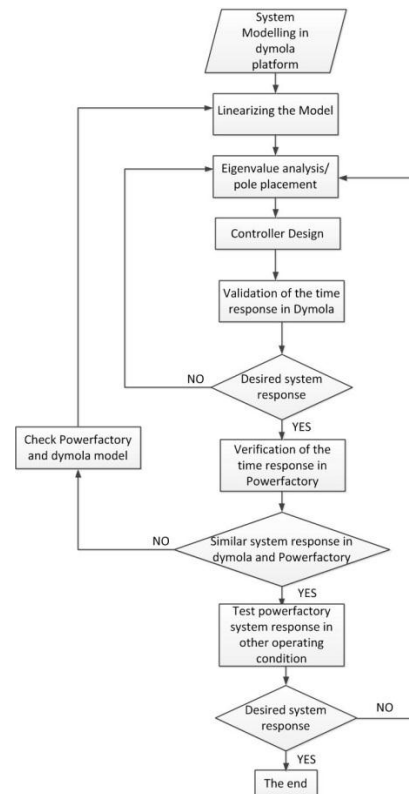


Figure 1 Flowchart for controller design and verification

III. TEST SYSTEMS

For verification, simple test systems are developed in both the simulation platforms. First a small AC network (Kundur two area systems) [5] is used for eigenvalue and time domain response comparison as shown in Figure 2. Next, a four station DC grid connected to stiff AC sources is simulated for comparing system responses in a multi terminal VSC-HVDC, [Figure 3]. As final step, a mixed AC/DC system by combining two copies of the AC network of the Kundur

system with the four station DC grid, called AC Grid A and B, is constructed.

In AC grid A, two of the generators have been replaced by DC terminals as shown in Figure 5. In Grid B shown in Figure 6, two additional HVDC terminals are connected at buses 6 and 10, respectively.

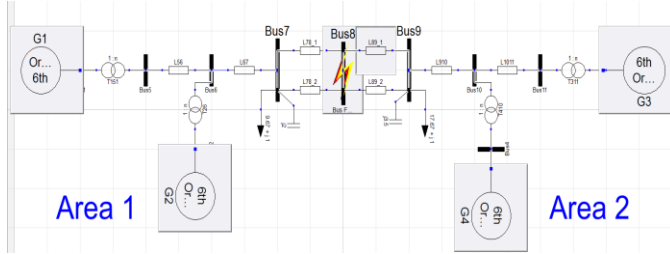


Figure 2 The AC test system: two area Kundur system

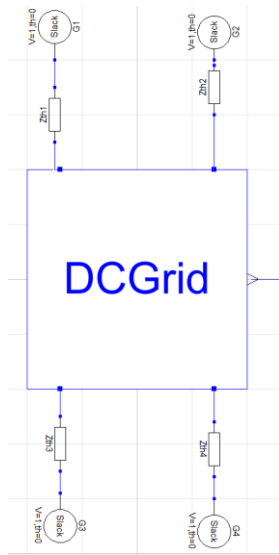


Figure 3 The DC test system: the four station DC grid

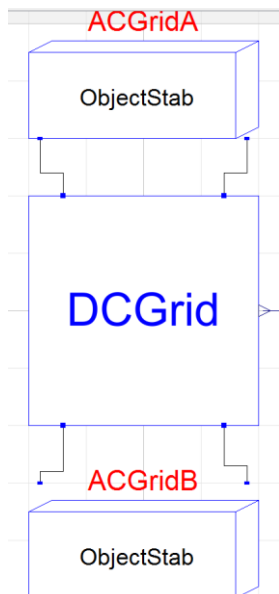


Figure 4 Integrated AC/DC system

Similar systems are also developed in PowerFactory for comparison. Here only figures from the graphical editor of Dymola are shown as they are easier to understand from figures compared to PowerFactory (where the main circuit is divided in many inter connected pages).

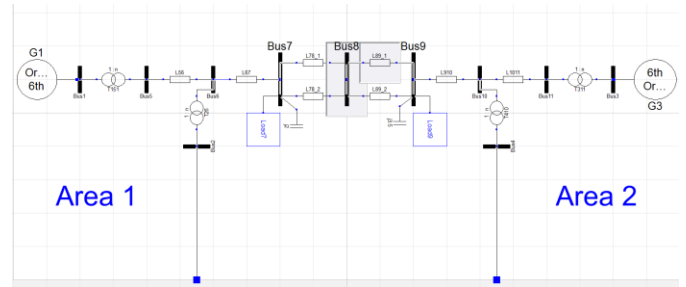


Figure 5 AC Grid A

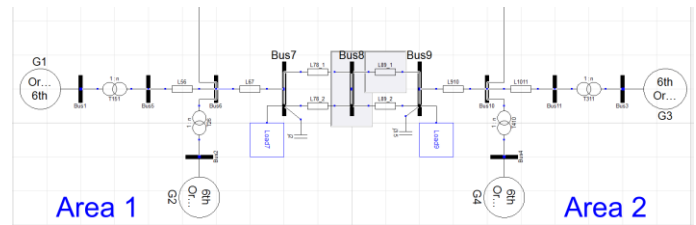


Figure 6 AC Grid B

IV. MAIN CIRCUIT PARAMETERS

Similar main circuits are implemented (both Dymola and PowerFactory models) during this comparison process.

1. Cable

Double PI link cables are used for the DC grid. The cable parameters used in the models are shown below

Table 1 Cable parameters

Pole Cable	
C0	0.2754 $\mu\text{F}/\text{km}$
R0	0.0146 Ω/km
L0	0.7487 mH/km
Metallic Return	
C0m	0.384 $\mu\text{F}/\text{km}$
R0m	0.0146 Ω/km
L0m	0.4714 mH/km

2. DC System Structure

A four station bipole system is considered in this paper. The DC system is shown in Figure 7. The four stations are connected with six sets of cables as shown. Each of the cable sets consists of positive pole, negative pole and

metallic returns cables. The neutral point system, to which the metallic return cables are connected, is directly grounded at station 1.

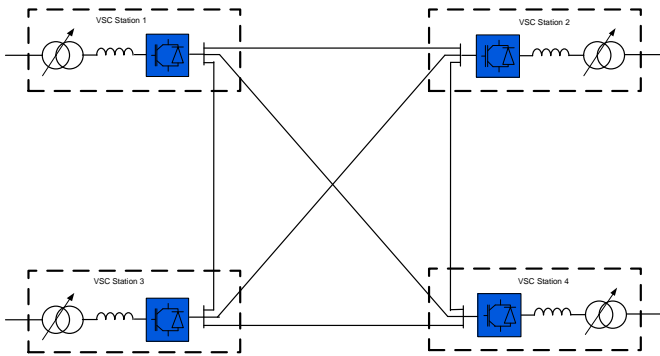


Figure 7 DC System

3. Generator and controllers of the generator

The generator parameters are taken from the Kundur system [5]. In Modelica the standard 6th order generator model as in [4] is used. In PowerFactory, a new generator model as in [4] is used. In PowerFactory, a new generator frame is created as shown below.

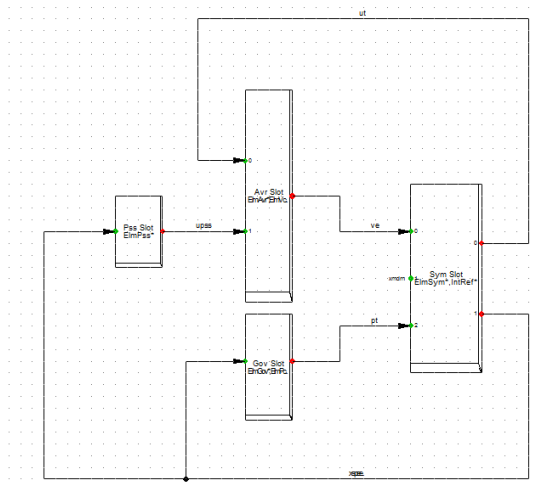


Figure 8 PowerFactory frame for generator

The four slots are used for the PSS (PSS Slot), Exciter (AVR Slot), Governor (Gov. Slot) and synchronous machine (Sym Slot). Simple models for exciter, governor and PSS are developed as in [5]. The parameters for the controllers are same as in Modelica [4].

4. Measurement time delay

The measurement time delay is implemented in the Modelica model as PowerFactory. This is only for filter bus voltage, DC voltage and AC side currents in the current controller loop. The delay is implemented in Modelica as shown in Figure 9.

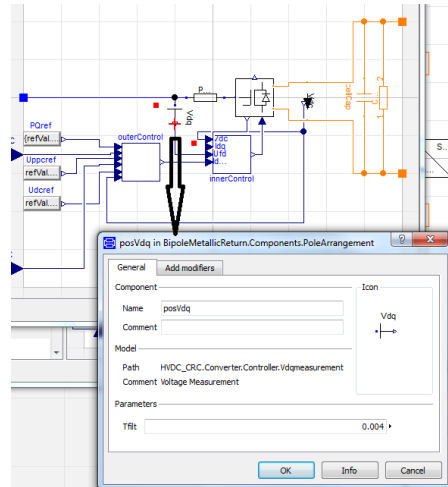


Figure 9 Measurement time delay in dymola

5. Synchronization loop (PLL) in dymola

The PowerFactory uses a PLL in the synchronization loop. A similar PLL is developed in Modelica as shown below in Figure 10 and Figure 11. A PI controller with similar control bandwidth as in PowerFactory is used in Modelica.

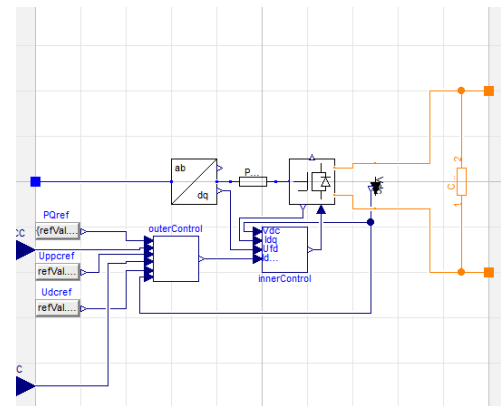


Figure 10 Synchronization loop in filter bus voltage measurement

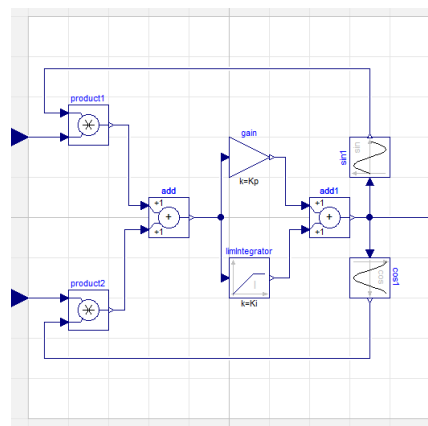


Figure 11 PLL structure in dymola

V. STUDY CASES

A few test cases are created to compare the system responses of the Modelica model in Dymola, and PowerFactory. The system bases are 100MW and 320kV. The test cases are given below

- a) System Configuration AC system
 1. Eigenvalue comparison.
 2. Three phase short circuit fault at bus 8.
- b). System Configuration Four Station DC system
 3. Change in power reference of station 2 from 350 MW/pole to 150 MW/pole.
 4. Change in voltage reference of station 3 from 0.97 pu to 0.96 pu.
- c). System Configuration mixed AC/DC System
Generator with Exciter PSS and governor
 5. Case1: Reference power change in station1 from 350 MW/pole to 300 MW/pole.
 6. Case2: Reference power change in station 2 from 350 MW/pole to 300 MW/pole

VI. AC SYSTEM COMPARISON

1. Eigenvalue comparison

First the eigenvalues of the AC network without any generator controller are compared to verify the similar implementation of the generators and network models. The comparison is shown in Figure 12 where all the eigenvalues are plotted. It can be seen they are very similar in PowerFactory and Dymola. (The small difference in few of the machine modes exists due to difference in the ObjectStab synchronous machine model used in Dymola and the model in PowerFactory). The local and inter area modes that are of main interest agree very well.

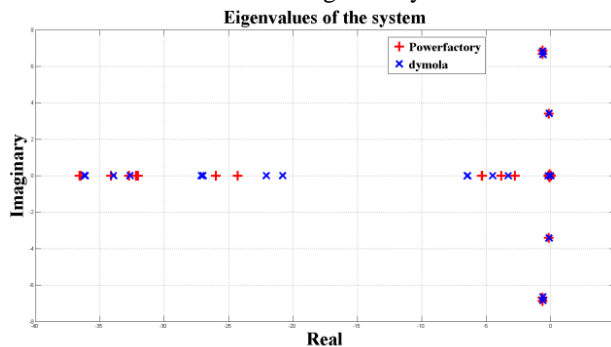


Figure 12 Comparison the eigenvalues computed from PowerFactor and Dymola models.

2. Three phase short circuit fault at bus 8

A three phase short circuit fault at bus 8 is simulated at 1s and the fault is cleared at 1.07s. The fault impedance is 0.01ohm resistive. The angle difference between generator

1 and generator 2 is monitored. The responses from PowerFactory and Dymola are compared in Figure 13. It can be seen the responses are very similar. The active power outputs of the four generators are shown in Figure 14. The Dymola (blue) and PowerFactory (green) results are similar, which indicates that a control design based on a linearized model from Dymola could work well with the simulation model in PowerFactory. It is to be noted that the main advantage of using Dymola for linearization lies in DC grid controller design, as the linearization with PWM block is not well developed in the current PowerFactory version 14.1.3. This is discussed next.

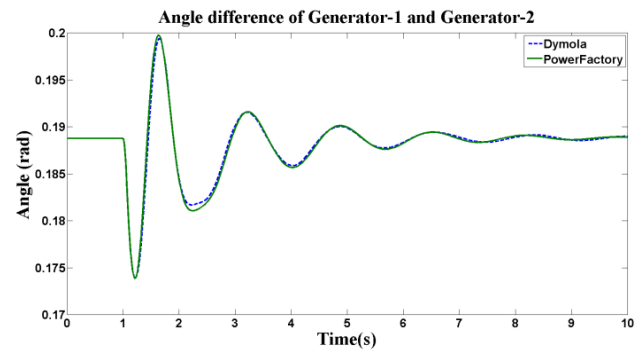


Figure 13 Comparing angle difference with the controllers (exciter, PSS)

VII. DC SYSTEM COMPARISONS

The four station DC system connected to stiff AC sources shown in Figure 3 is used for this case. In the first case, the power reference at station 2 is changed from 700MW to 300MW (150MW/pole) at 1s. System responses are shown in Figure 15 and it can be seen that the Dymola (blue) and PowerFactory (green) system responses are very similar. This validates the network and converter control implementation in both platforms.

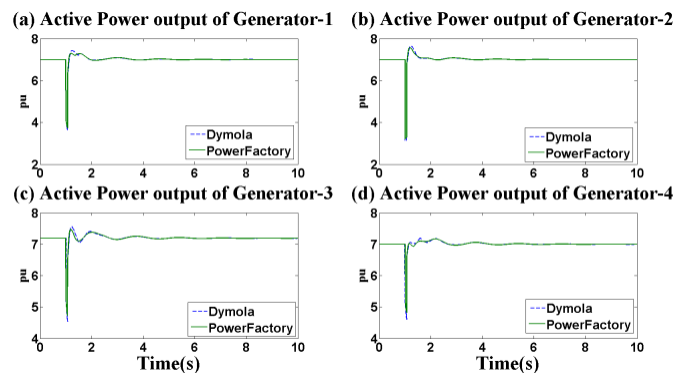


Figure 14 Comparison of active power output of the generators

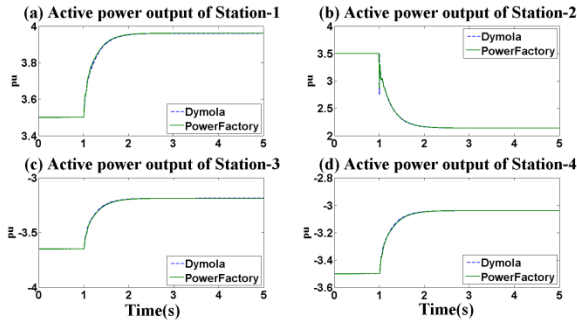


Figure 15 Comparison of power output in the DC grid (positive pole)

In the next case, a change of the DC voltage reference at station 3 is considered. While the previous case was operating on droop control, in this case station 1, 2 and 4 are operating on fixed power while station 3 is working in DC voltage control. The DC voltage reference of station 3 is changed from 0.97 pu to 0.96 pu at time 1s. The system responses are compared in Figure 16 and they appear very much similar.

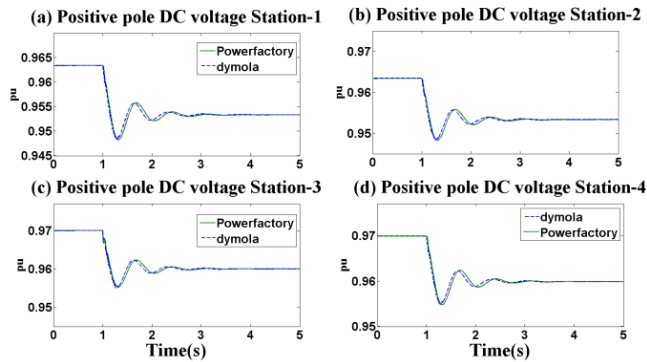


Figure 16 System responses with voltage reference change

VIII. AC/DC SYSTEM COMPARISONS

The combined AC/DC system as shown in Figure 4 is used in this case. First the power reference of station 1 is changed from 350MW to 300 MW/pole. The system responses are compared in Figure 17 and it can be seen that they are similar with little difference in overshoot and damping. Next the power reference of station 2 is changed to 300 MW/pole and the system responses are compared in Figure 18. It can be seen that the responses are similar with little difference as before in Figure 18.

IX. CONCLUSIONS

The system responses are compared for various operating conditions and it can be seen that the system dynamics matches well while comparing system implemented in PowerFactory and Dymola for various system operations. It is thus possible to use a linearize model from Dymola to design the DC grid controllers while validating them with time domain response in PowerFactory. Further work will focus on

developing systematic control design procedures based on the Modelica models.

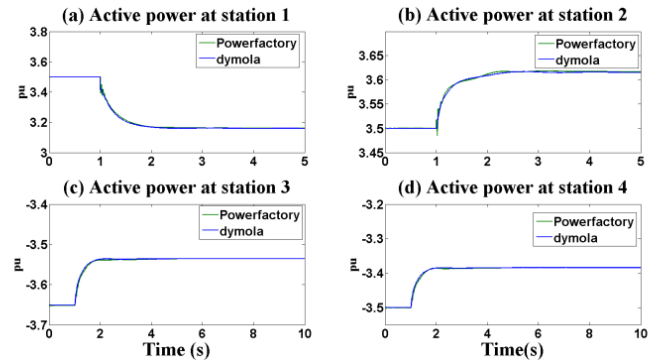


Figure 17 AC/DC system response with change in power reference in station 1 (positive pole)

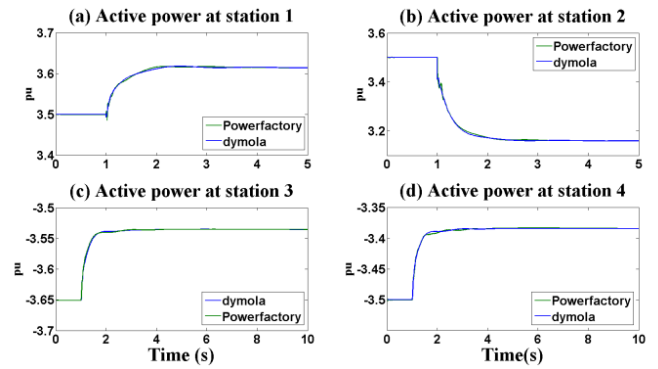


Figure 18 AC/DC system response with change in power reference in station 2 (positive pole)

X. REFERENCES

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