POWERFACTORY

Benchmark of a Three-Terminal VSC-HVDC System in PowerFactory

DIgSILENT GmbH*

Abstract

This white paper documents the implementation of a detailed EMT model of a three terminal HVDC system using 2-Level Voltage Source Converters (VSC) in *PowerFactory*, and compares the simulation results against PSCAD® and Mat-Lab/Simulink®.

This work is intended for *PowerFactory* users who want to learn about EMT models of power electronic devices in the software, their level of modelling detail, and the accuracy of the simulation results when compared to other tools.

1   Introduction

The time domain solver in *PowerFactory* supports both electromechanical (RMS or phase domain) and electromagnetic (EMT) type simulation. While the *PowerFactory*' users community is very well familiar with RMS models and has been using them extensively for many years, EMT models are still not that well known. However, EMT models in *PowerFactory* can achieve a level of accuracy as high as in dedicated EMT simulation tools, such as Matlab/Simulink or PSCAD. Whereas these tools are primarily used for the design and performance assessment of single power equipment, *PowerFactory* facilitates the analysis of electromagnetic transients on a wider system perspective, with equivalent accuracy and without the additional effort to maintain dedicated EMT network models. Not least, the built-in RMS-EMT co-simulation can enable

a combined analysis at a large system scale [1], where required.

The document is organized as follows. Section 2 provides a description of the topology and control logic of the test HVDC system that is taken from [2]. In section 3 we highlight usual implementation differences that were found during manual model conversion and that have a non-negligible impact on the simulation results. User's attention is called to these aspects when porting the models across simulation tools. Finally, section 4 compares the simulation results between *PowerFactory* (version 2021SP2), PSCAD (version 4.6.2) and Matlab/Simulik (version 2020a) for balanced and unbalanced faults.

2   Model Description

Figure 1 shows the structure of the three terminal HVDC system in *PowerFactory*. The three 2-level converters are connected to each other by simple RLC elements. It should be further noted that VSC-1 is connected to a 60Hz grid, while VSC-2 and VSC-3 to a 50Hz one.

The converters operate as follow:

- VSC-1 : d.c. and a.c. voltage control

- VSC-2 : constant active power absorption from the grid and a.c. voltage control

- VSC-3 : constant active power injection in the grid and a.c. voltage control

All three converters operate in a.c. voltage control

---

*DIgSILENT GmbH, Heinrich-Hertz-Str. 9, 72810 Gomaringen, Germany, www.digsilent.de

mode. In the present operating condition, VSC-2 imports 200 MW from the a.c. grid (at 420kV), whereas VSC-3 exports 200 MW to the a.c. grid (at 500 kV). The power balance in the multiterminal HVDC system is established by VSC-1, which then supplies the d.c. losses.

Figure 2 shows the block diagram of the PI-based inner-loop current controller. The measured three phase a.c. currents and voltages are transformed into dq coordinates that rotate with grid frequency. The transformation takes place with the help of the voltage angle that is determined by the PLL. The transformation is done in such a way (the d-axis of the voltage is aligned with the voltage) such that the real part of the current (Id-) represents the active power / d.c. voltage control, whereas the imaginary part of the current (Iq-) represents the reactive power / a.c. voltage control. The dq currents are compared against the reference values and the difference is fed to the PI controllers

that regulate the modulation index of the converter in order to track the references. The modulation index is limited before it is fed to the converter.

The model in *PowerFactory* can be simulated as switched model by providing the real and imaginary parts of the modulation index without having to explicitly model the IGBT / Diods and PWM pattern / carrier signals. This modelling approach considerably simplifies the implementation, as PWM and carrier signals are handled internally.

Figure 3 shows the outer-loop control of the converters. The outer-loop control provides the reference values to the inner-loop control. The a.c and d.c voltage control is a PI-based control, whereas the reference values for controlling the active power is calculated by dividing the reference value of the active power (provided by the user) with the d-component of the a.c. voltage.
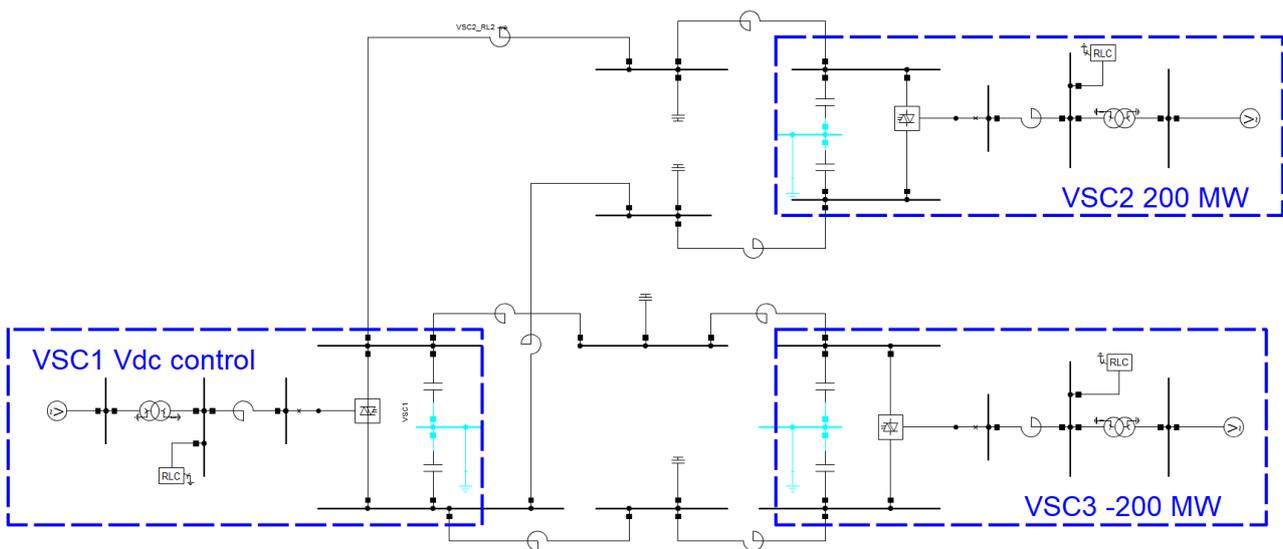
Figure 1: Single line diagram of the HVDC system as modeled in *PowerFactory*
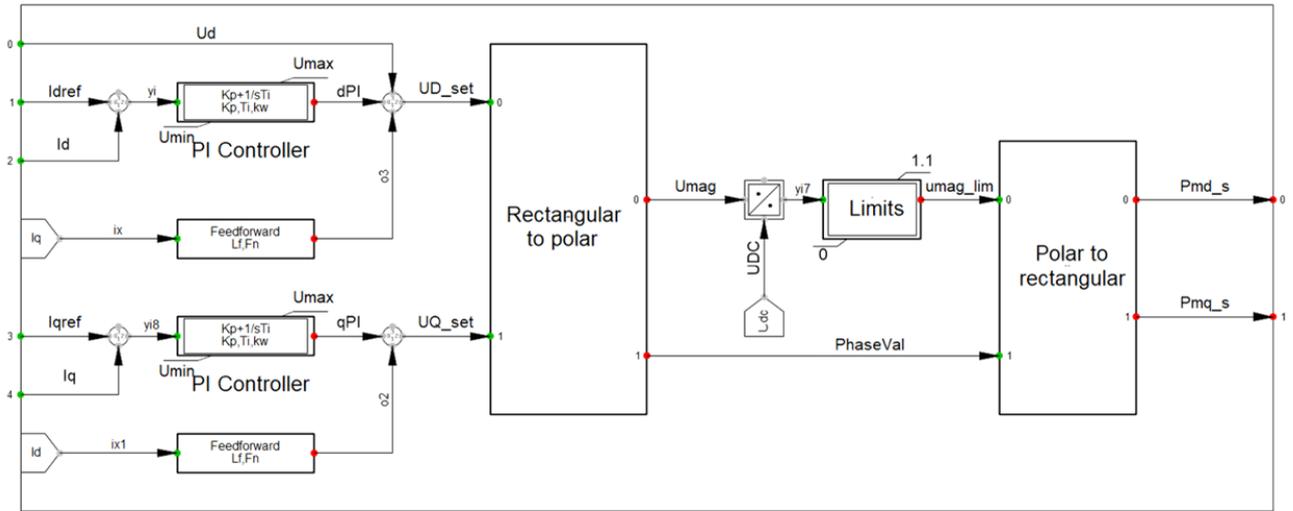
Figure 2: Proportional-Integral based current control
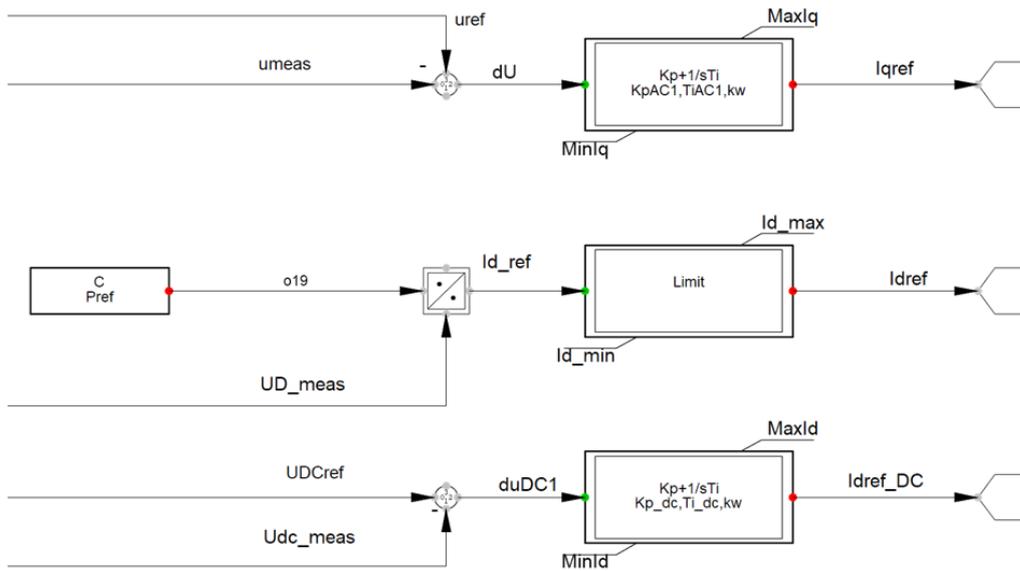
Figure 3: a.c. voltage, d.c. voltage and active power control

3 Common model differences

When benchmarking models, it is crucial to have an equivalent implementation of all control blocks and measurement devices in the different tools.

Some common differences encountered in the models are listed below:

- Steady state operating outputs of PI controllers. In some cases, it might happen that the PI controllers settle at a different operating point while error in reference and measured quantities goes to zero. This will cause the PI controllers to reach the saturation at different times. This has a high impact on the dynamics of the controller

- Implementation of the wind-up logic in the PI controllers. Indeed, various implementations of wind-up limits are possible. It must be made sure then that the implemented logic is equivalent in all the models

- Structure and working principle of the phase-locked loop (PLL) devices. Indeed, various detection logics are possible and they may yield different results

- Processing of control signals. For instance, different numerical methods are available to gain phase domain quantities from instantaneous quantities in the EMT simulation, such as Fast-Fourier Transformation (FFT), true RMS calculation, or space phasor. It must be checked therefore that signals used in the control are obtained according to same principles in both models

- Transformation from $\alpha\beta$ - quantities to dq-quantities. Indeed, there are few ways to transform the stationary quantities into rotating quantities depending upon the alignment of the Phase A with the PLL angle [4]. Moreover, it should also be checked whether power-invariant or amplitude-invariant tranformation is used. Hence consistency in components transformation shall be thoroughly verified

- Differences in the layout of built-in network models (in particular switched models of an VSC)

In order to match the simulation models in all three tools, the following modifications were made in all three models with regard to the original one [2]:

- Use of voltage space phasors in the a.c. voltage control

- PI-controllers with back-calculation based anti-windup limits

- Implementation of the same PLL logic in all three tools for comparison, consisting in a PI-based logic with q-component of the voltage as input. The angle of the PLL is generated through the integration of the frequency (rad/s).

4 Simulation results

Two fault cases are simulated in order to compare the dynamic response of the system in *PowerFactory*, PSCAD and Matlab/Simulink.

- A three-phase fault at high voltage side of the VSC-3 transformer with a duration of 150ms

- A two-phase fault at high voltage side of the VSC-1 transformer with a duration of 150ms

The simulations are carried out with 2μs time step. Switching frequency of the converter is 1980Hz [3].

Figures 4 and 5 shows the comparison of the results for the three-phase fault case. Similarly, Figures 6 and 7 show the comparison of the results for the two-phase fault case. Note the zoom-in subplots in Figures 4 and 6 for better comparison.

In all case, the simulation results show a nearly perfect match between the three tools.
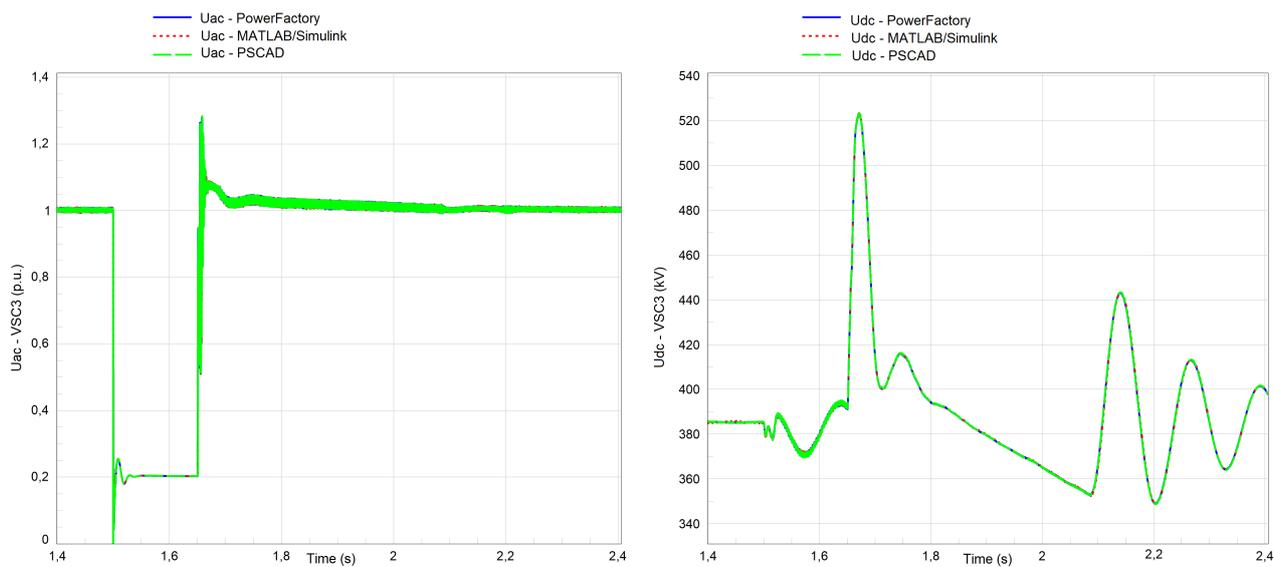
Figure 4: Uac / Udc voltages of VSC3
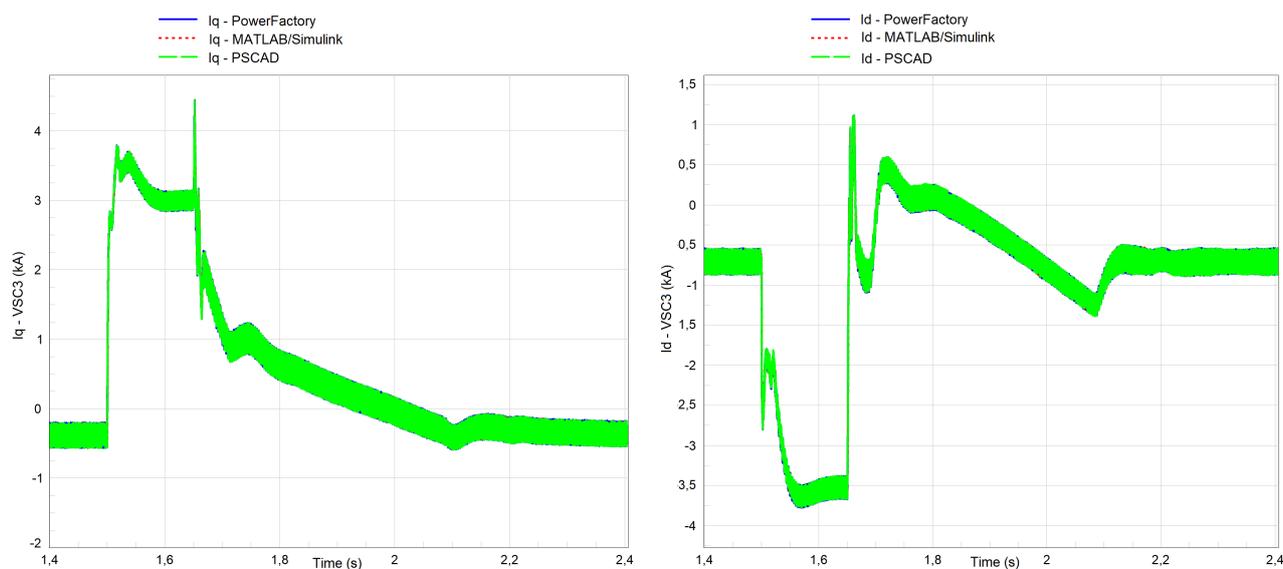
Figure 5: Id / Iq of VSC3
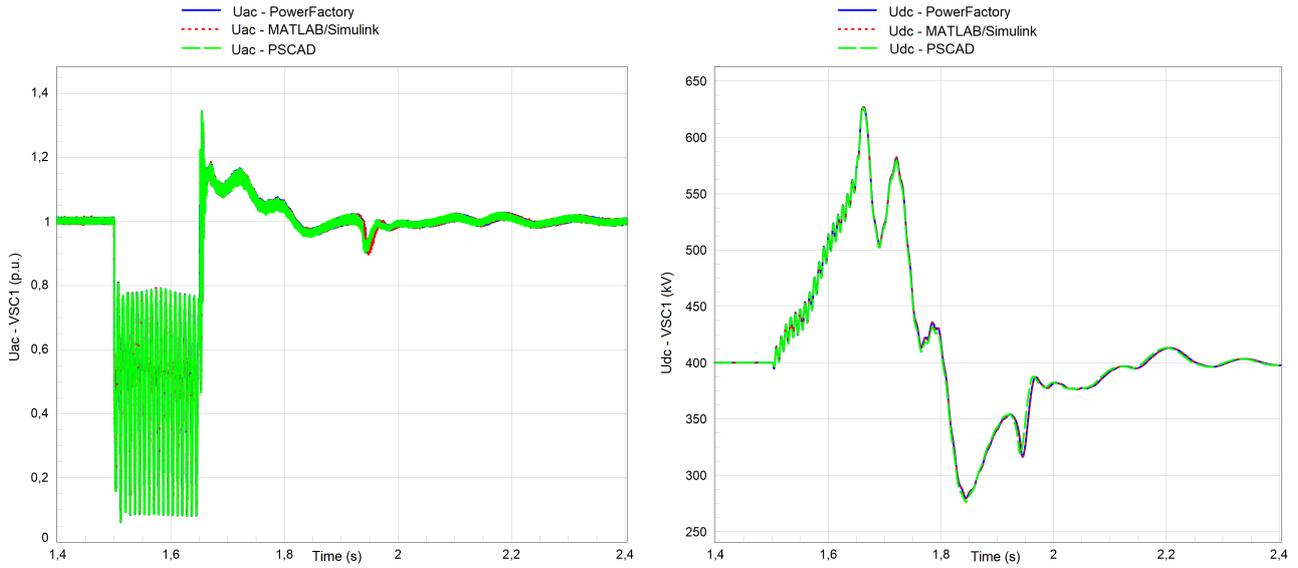
Figure 6: Uac / Udc voltages of VSC1
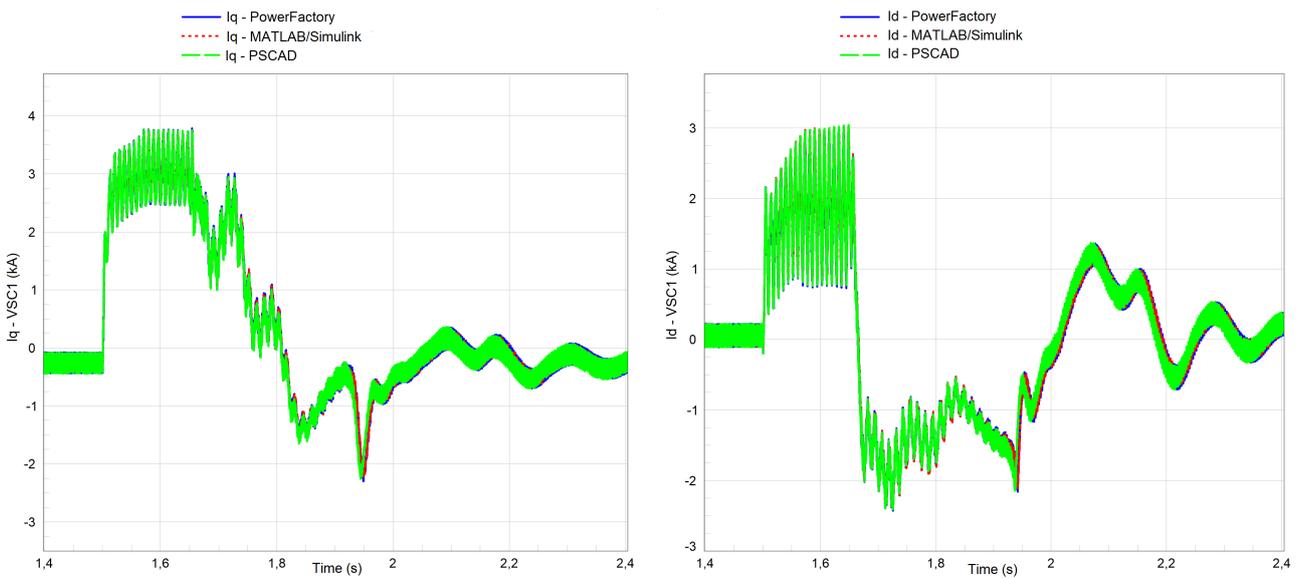
Figure 7: Id / Iq of VSC1

5 Summary and Outlook

The benchmark of the three-terminal 2-level VSC HVDC system from [2] shows a nearly perfect match between the simulation results in *PowerFactory*, PSCAD and Matlab/Simulink. To achieve these results, special attention was drawn to the equivalent implementation of the model in all three tools. This includes a consistent handling of limiters, dq- and $\alpha\beta$-transformations, conversion between RMS- and EMT-quantities and sign conventions in all three tools.

For the purpose of this exercise, the model in [2] has been manually reimplemented in *PowerFactory* and Matlab/Simulink. However, it is anticipated that model portability across simulation platforms will become of crucial importance in a near future. Following model exchange scenarios can be then envisaged:

- Standardization of model interfaces: the standarized I/O model interface based on IEC 61400-27-1 (Annex F) has proven to be a feasible solution for real-code implementations of power electronic based equipment

- Common dynamic modelling language for model exchange, like for instance the Functional Mockup Interface (FMI) standard by the Modelica Association

References

[1] A Constantin, A Ellerbrock, F Fernandez and J Ruess; *Co-Simulation of Power Electronic Dominated Networks* in IEEE Power and Energy Magazine, April 2020 Show Edition.

[2] PSCAD™Application Example available at: *3-terminal HVDC link with 2-level VSC terminals*, last accessed 02th Nov. 2020

[3] DIgSILENT Technical Documentation: PWM Converter, DIgSILENT GmbH, Gomaringen, Germany, 2020

[4] Matlab™Documentation available at: *Park Transform. Implement abd to dq0 transform*, last accessed 02th Nov. 2020