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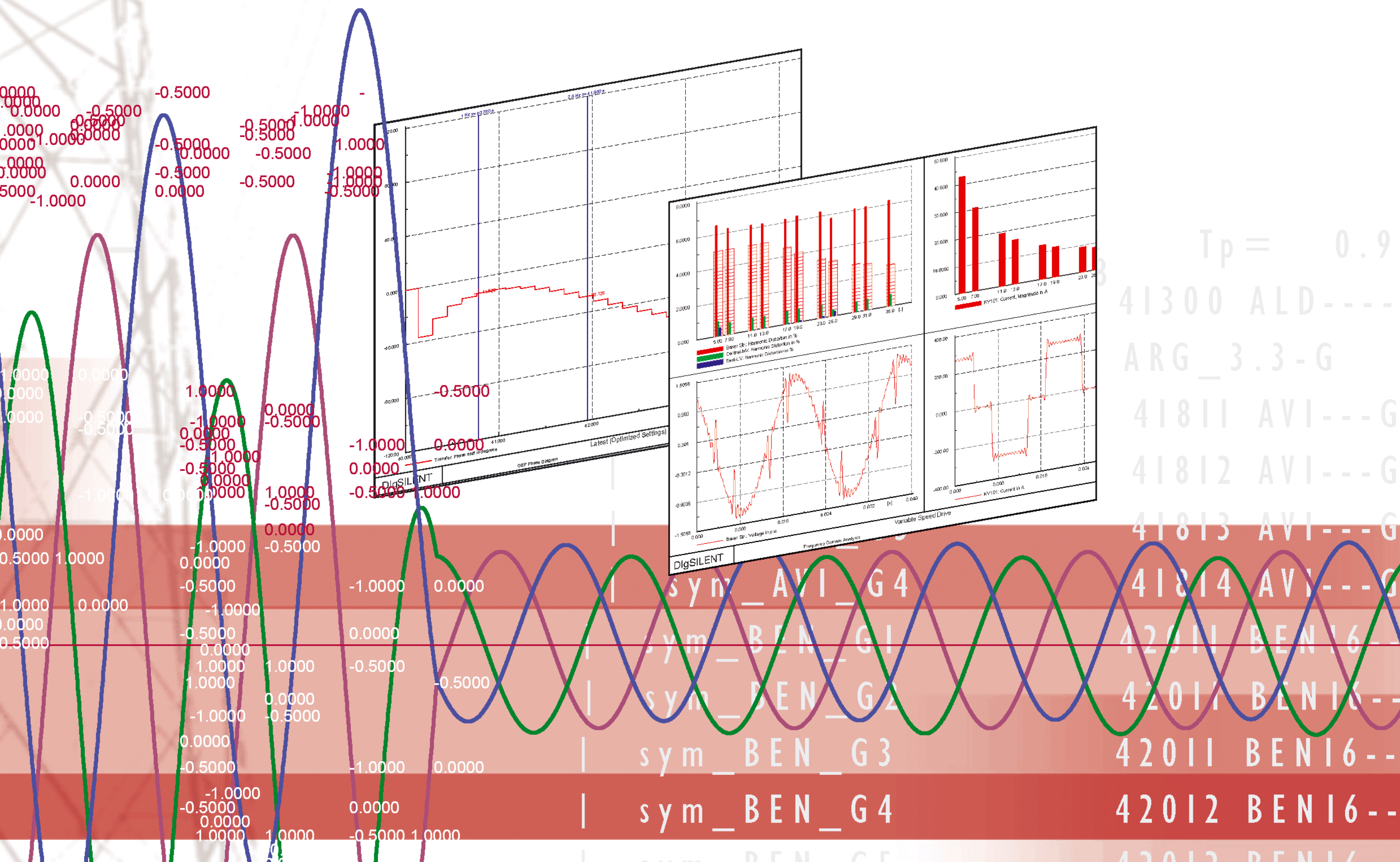
Description, Modelling and Simulation of a Benchmark Test System for Converter Dominated Grids (Part II)

98% - RES Benchmark on Basis of Fast Voltage Source controlled Converters (EMT & RMS)

Prepared for

DIgSILENT PowerFactory Users



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0.1	29.05.2018	Initial Implementation	M.Schmieg
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1 Introduction

This paper presents the implementation in PowerFactory of a fast voltage controlled based method for converter dominated power systems, as proposed in /2/ and its behavior within a benchmark system, as proposed in /1/. Its principal function and overall stability are demonstrated for a representative 9 bus system with a 98% share of renewables, full-scale converter based WT generation (Type 4). Nonetheless, the proposed converter regulation strategy would be applicable for other power sources such as VSC-based HVDC, PV- or storage systems.

The proposed converter control method takes into account that the further development of actually operated power systems will not allow a fundamental change in control- and operation philosophy as e.g. proposed by /3/. In other words, the traditional synchronous machine based control of voltage and frequency for balancing reactive and active power demand as such has to be maintained, however with a steadily increasing percentage of converter based generation such as wind power (WT), PV generation, battery storage and other PQ-controlling devices. As mentioned already in /1/, this will require converter based systems to be also operated in voltage source and frequency balancing control modes (VSCC). The critical challenge here is the frequency control as the share of inertia based, synchronous generation may fade out in future to a relative low margin. As a consequence, load balancing has to be implemented in a superfast way aiming in the limitation of frequency excursions within acceptable operational limits.

Of course, a number of issues are still open and need further investigations. Among those are:

1. The proposed fast voltage control of converter based generation (here, the 98%-RES case) is showing a very stable behavior. The remaining synchronous generation is "swinging" around the quite rigid RES-generation. The damping of the machine oscillation can be tuned via PSS as it is done in classical systems. However, it is unclear, if the dynamic interactions between thousands of converters in case of very large interconnected systems (such as the ENTSO-E system) can be easily and robustly tuned resulting in an unconstrained and unconditioned damped behavior.

2. The comparison of the EMT- and RMS- based simulations for identical cases and models are showing an excellent match for all relevant quantities. However, it is still to be investigated if large, geographically extended systems with considerable travelling wave effects will still behave in the same way. We might possibly end-up in a situation where stability analysis in dominant converter based, geographically extended systems will further need EMT-simulations to validate classical stability results.

3. The stability of low inertia systems will not allow any more the application of classical, feeder based frequency dependent load shedding mechanisms. The time left to decide if a relay should operate is too short as the system frequency will have already reached the next frequency stages when the first stage has decided to operate. As a consequence, there might be the need to operate sufficient active power reserve as required for a certain "design" contingency. However, in case of more severe faults, the system might inevitable collapse or possibly split into several regions or sub-grids. Instead on relaying on frequency depending load reduction, a voltage reduction schemes included in the fast converter control might help preventing system collapse situations.

4. The benchmark presented in this paper and respective PowerFactory project is based on a hyper-fast performance of the Type 4 WT-control. Except for the PLL, there is no delay assumed between the measured voltage at the WT-busbar and the grid-injected current. Consequently, any delay of data acquisition, signal filtering, etc. are neglected. Here, further analysis is required to determine the maximum acceptable signal- and control processing delays which do not jeopardize the effectiveness of the proposed control scheme. Of course, the direct feedthrough of voltage and current quantities require specific algorithmic capabilities of the simulation software.

5. A further serious aspect to be considered are the torsional interactions of the very fast converter controls with turbine shaft dynamics of large power plants but also small diesel units designed with flexibles clutches.

So far, we consider the presented 98%-RES project as a first step allowing to further investigate the above mentioned issues aiming in supporting a solid and stable transition from synchronous machine dominated power systems towards stable and robust developments with very high RES share.

Unfortunately, grid code requirements imposed by utilities in the past years have not adequately supported a global view on system stability issues. Even the latest German grid codes VDE-AR-N 4105/4110/4120 and 4130 do not consider basic stability issues by setting-up sustainable requirements for the control characteristics of converter based generation.

2 The PowerFactory 98%-RES Model

The benchmark model has been generally described in /1/ covering the grid definitions as well as the synchronous generator and WT type 4 converter models and parameters. In the course of the preparation of the project, two levels of converter modelling has been tested. Initially, the DC-intermediate circuit has been detailed on basis of dedicated DC components along with a more detailed PWM-converter setup.

However, it was found that the response of the model version where the DC- intermediate circuit has been included in a static generator control setup along with a simplified static generator concept, will basically produce comparable results. Consequently, the finally presented model is based on a static generator model (Elm.GenStat) with an implicit DC-intermediate circuit being part of the converter control.

As indicated in Fig. 1 the dq-quantities are generated via the "AC voltage" and "AC current measurement" blocks along with the PLL output signals in the block "Park Transformation". The i_{dq}, u_{dq} and further calculated pq-signals are fed along with the measured PLL-frequency, the remote bus voltage (remote bus control) and the simulated voltage of the DC-intermediate circuit to the main control block "Udc_Q Controller".

As described in /1/ section 3.6 the "Udc_Q Controller" together with the "Damping Terms" and the "Modulation Limitation" include the following main functions:

1. Reactive power control consisting of the superimposed remote bus voltage control and fast local voltage control with damping terms and transient current limiting control logic. The fast local voltage control is only taking the converter reactance into account, neglecting the converter active losses. As a consequence, the model would not initialize correctly if the active power losses are considered for the

static generator (Elm.GenStat). However, those losses are neglectable compared to the rating of the device.

2. The active power control path includes the presently in Europe (ENTSO-E) applied frequency dependent power reduction or power increase in case of frequency excursion outside the 50±0.2 Hz band, a voltage dependent power reduction as well as the damping terms along with the transient current limiting logic.

The active power side is insofar simplified that the active power source (wind, solar irradiation, battery storage, etc.) is neglected. It is simply assumed that an active power resource is available at any time within the rating of the unit.

Converter Frame:

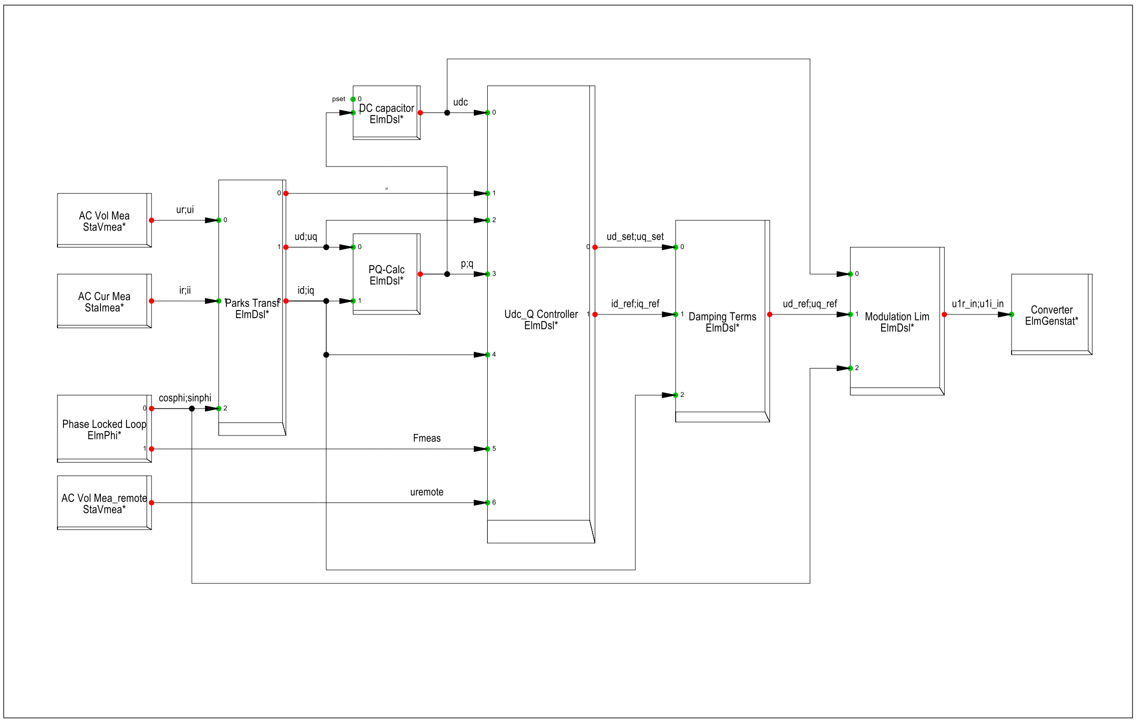


Figure 1: Overview of the proposed Converter Model Frame.

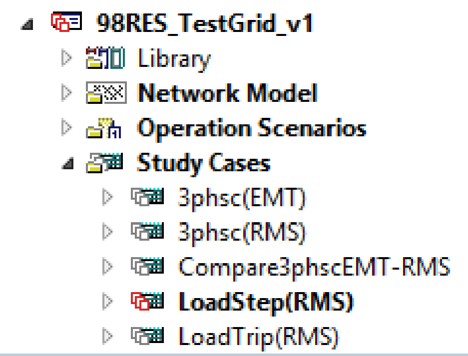
All details of the various model components can be studied in the project “98RES_TestGrid_v1.pfd” made available by DIgSILENT via the FAQ access “https://www.digsilent.de/en/faq-powerfactory.html” (no login required).

The synchronous generator model incl. prime mover (IEEEG1), AVR (EMAC1T) and a specifically designed PSS is tuned to provide sufficiently fast active power response along with a fast and damped voltage support.

All applied plant models are identical for the prepared EMT- and RMS-simulations. There are no variations and no specific operation scenarios.

3 EMT- and RMS- Simulation Cases

Aiming in a demonstration and verification of the robustness of the proposed voltage source controlled converter solution, a total of three fault scenarios have been prepared as follows:



Case 1: 3-phase fault with a duration of 150ms for both EMT as well as RMS simulation setup. In addition, a study case has been prepared to graphically display selected EMT/RMS – variables within one single graphics board

Case 2: Trip of a 800 MW load at busbar "A"

Case 3: Connect an additional 250 MW load at busbar "A"

When running the simulations, there are very few warning messages which can be totally ignored. The basic integration formula settings are as follows:

RMS cases: adaptive step-sizes ranging from 5ms to 200ms, simulation error (grid) = 1 kVA
EMT cases: adaptive step sizes ranging from 0,01ms to 8ms, simulation error (grid) = 1 kVA

The simulation stop time is preferably set to 2.5s if the initial transients shall be viewed and to 5, 25 or even 50s if the long term transients are of importance. The user will note that in case of considerable frequency excursions due to the applied fault, noticeable frequency deviations can be observed between the EMT- and RMS cases. Those deviations are caused by the neglection of the frequency dependency of grid component in case of the RMS simulation model.

Note: The user may add or modify the prepared cases as per individual interest. However, it shall be mentioned that the model has been tested and released for the three prepared cases only. Especially when defining faults or events, that potentially require protection or additional control systems to operate which are not included in the initial model, the prepared project may not work any longer (e.g. when switching in a larger load which cannot be supplied by the WTGs and the SG).

3.1 Case 1: 3phase Fault, 150ms at Busbar "A"

Figure 2: RMS/EMT-quantities for the synchronous machine SG 2

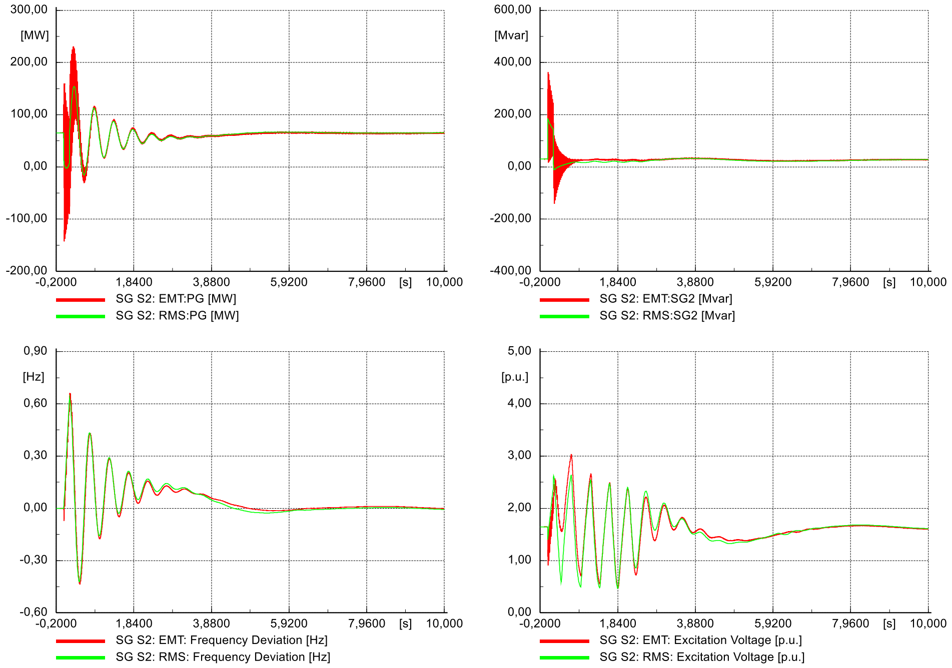


Figure 3: RMS/EMT-quantities for Synchronous Machine SG2 (2,5s zoom)

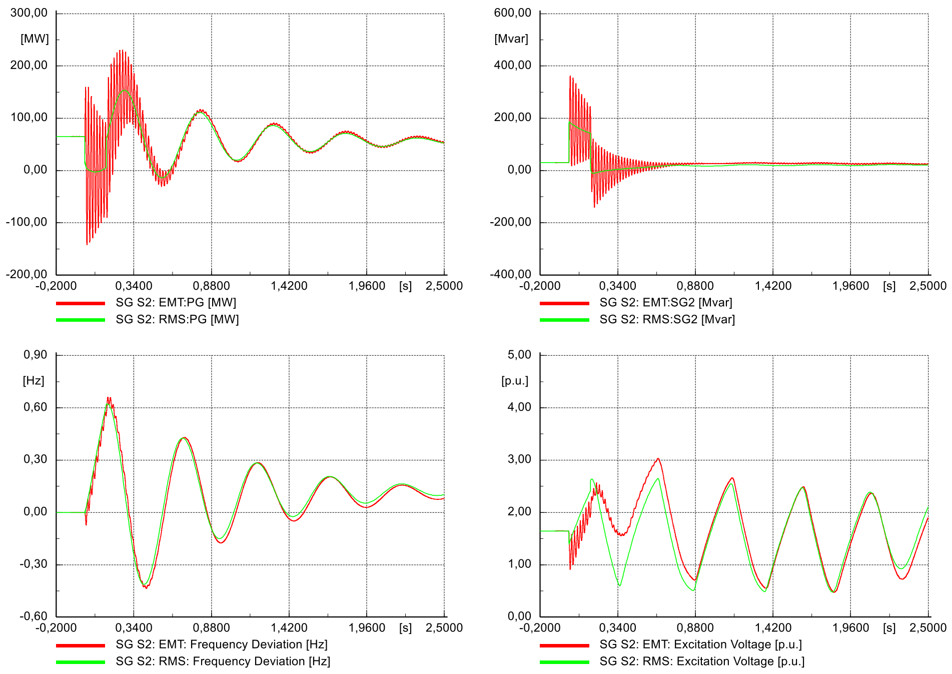


Figure 4: EMT/RMS-quantities for grid objects

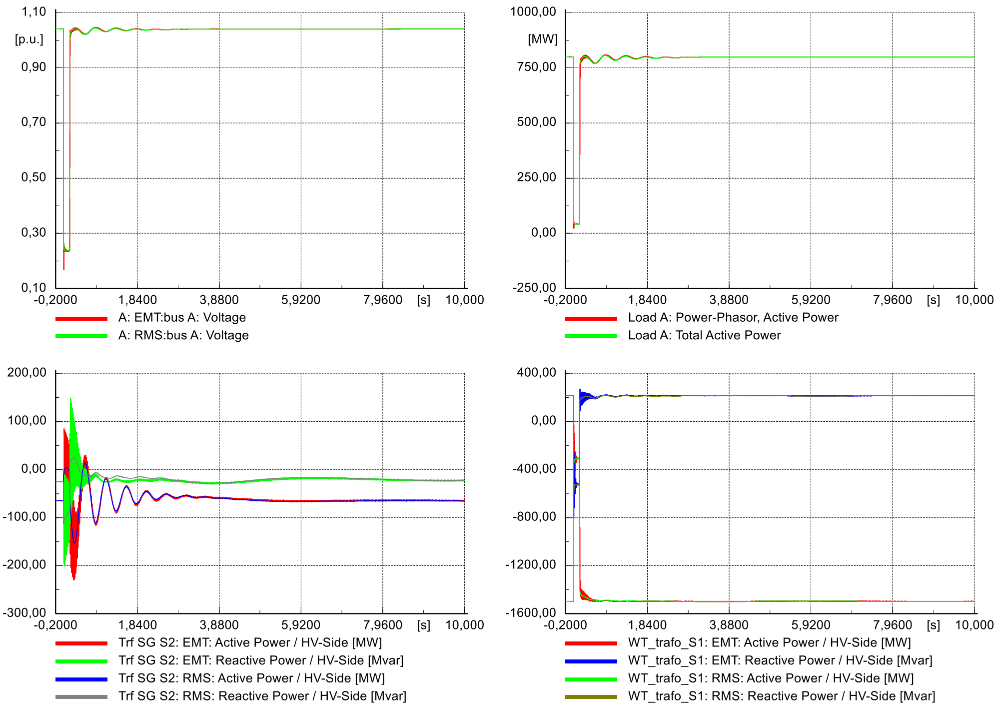


Figure 5: EMT/RMS-quantities for grid objects (2,5s zoom)

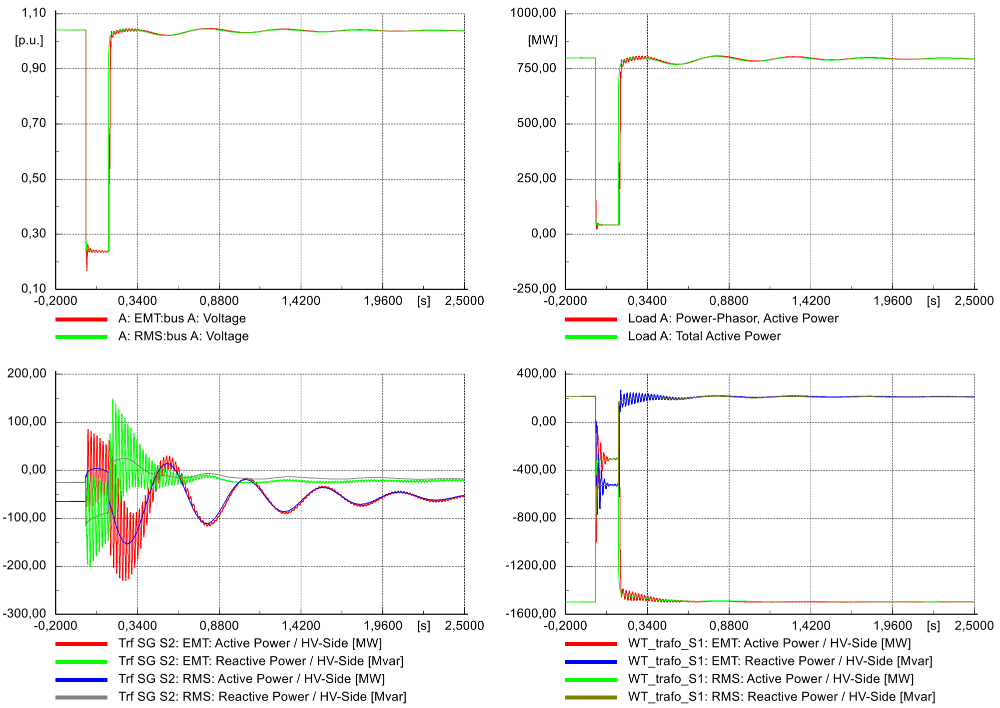


Figure 6: EMT/RMS-quantities for WTG1 (2,5s zoom)

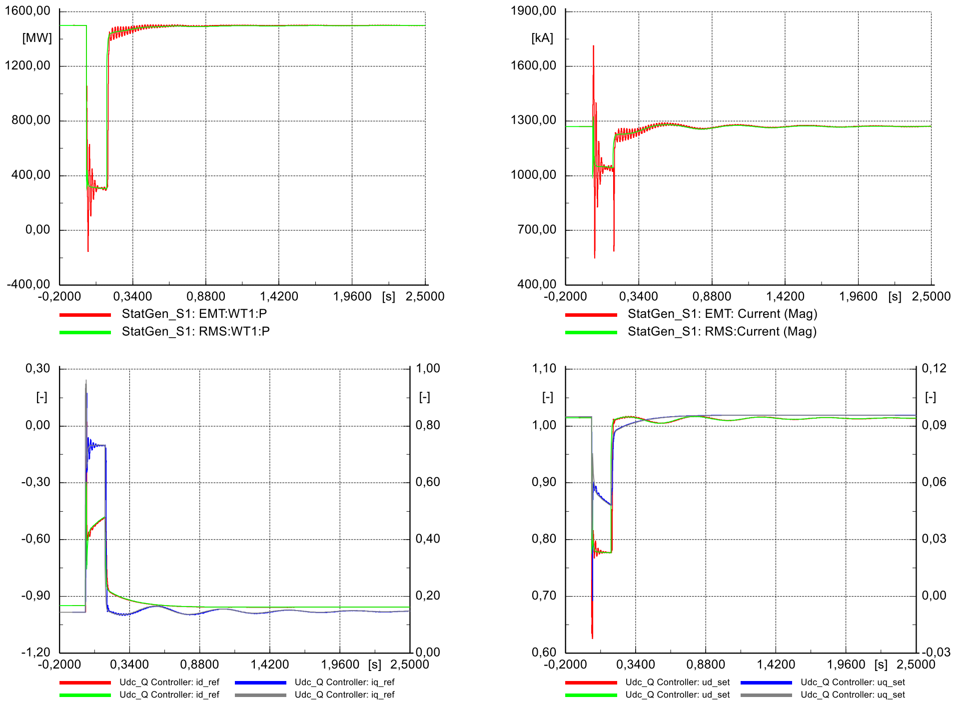
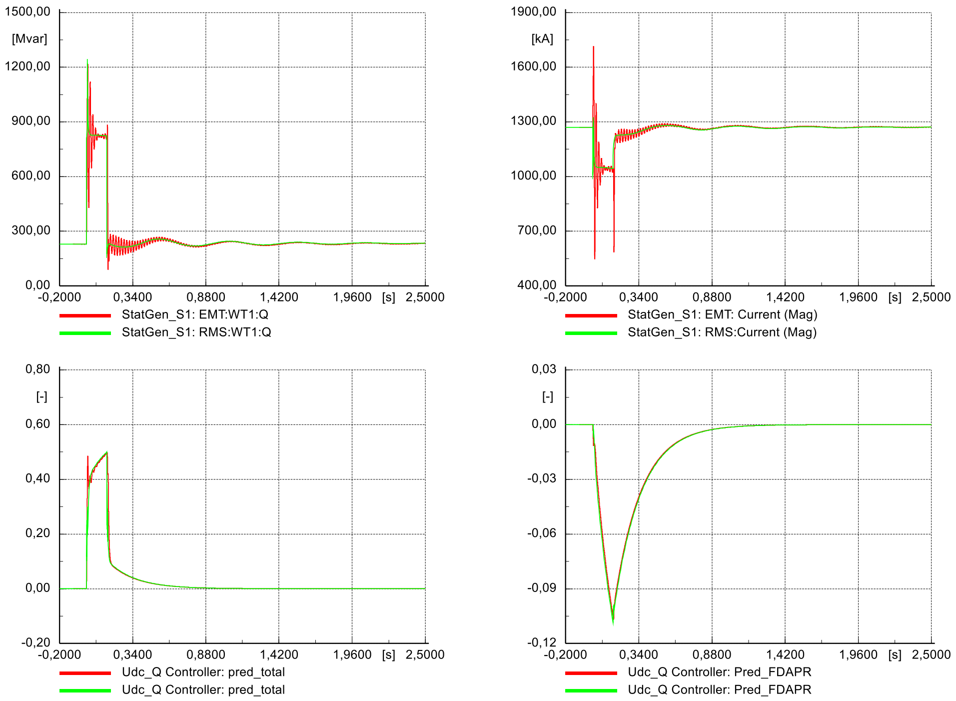


Figure 7: EMT/RMS quantities for WTG1 (2,5s zoom); con't



3.2 Case 2: Trip of 800 MW Load at busbar "A"

Figure 8: RMS-quantities for the synchronous machine SG2

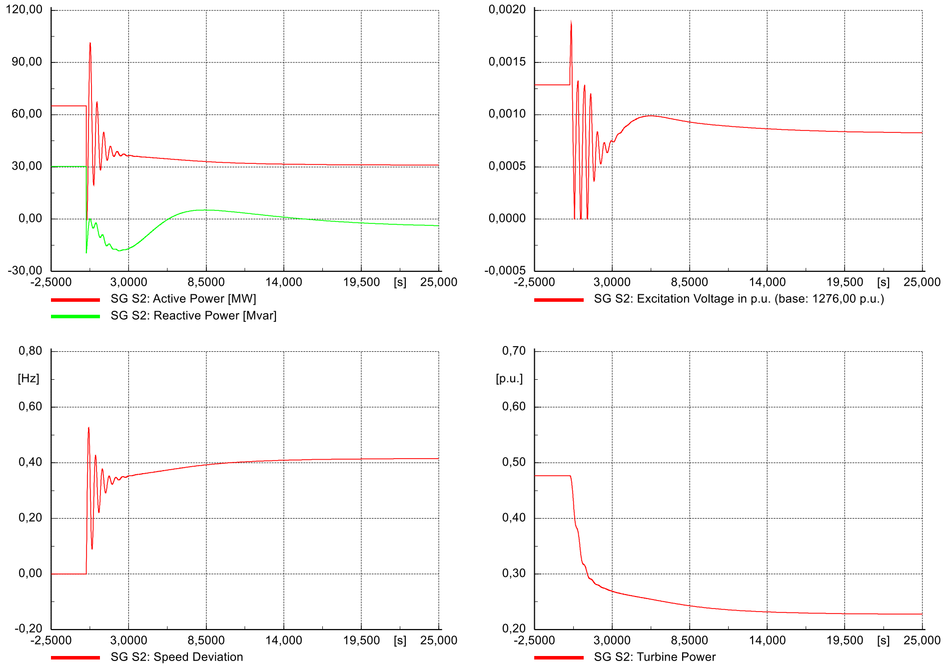


Figure 9: RMS-quantities for grid objects

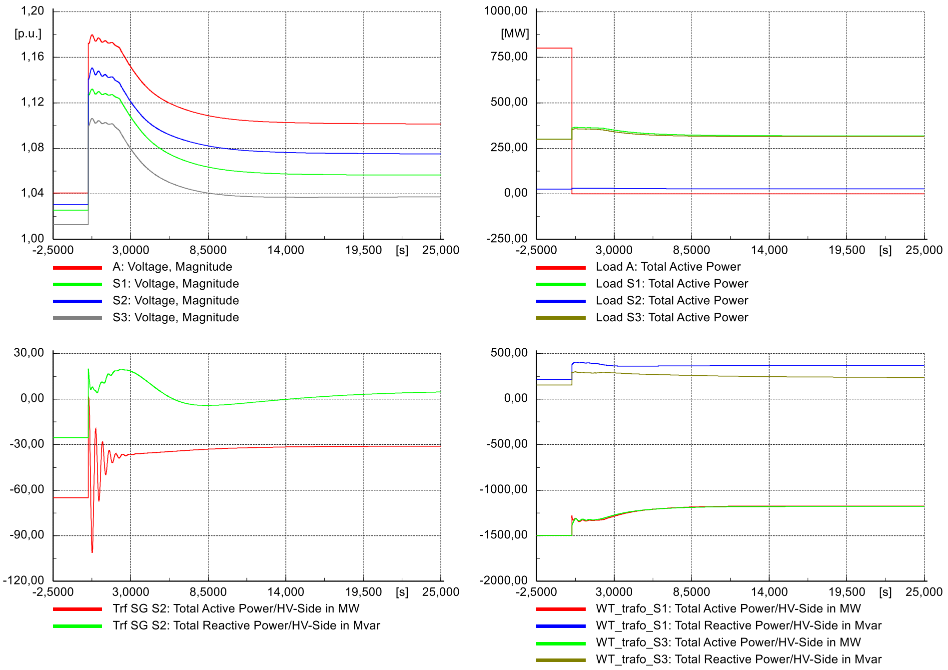
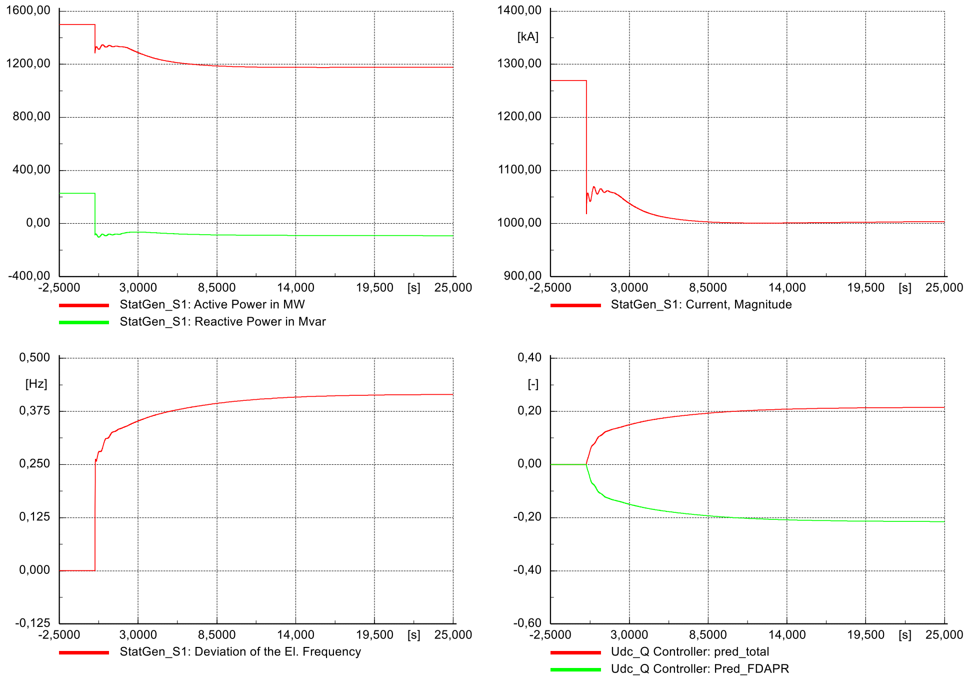


Figure 10: RMS-quantities for WTG1



3.3 Case 3: Connection of a 250 MW load at busbar “A”

Figure 11: RMS-quantities for the synchronous machine SG2

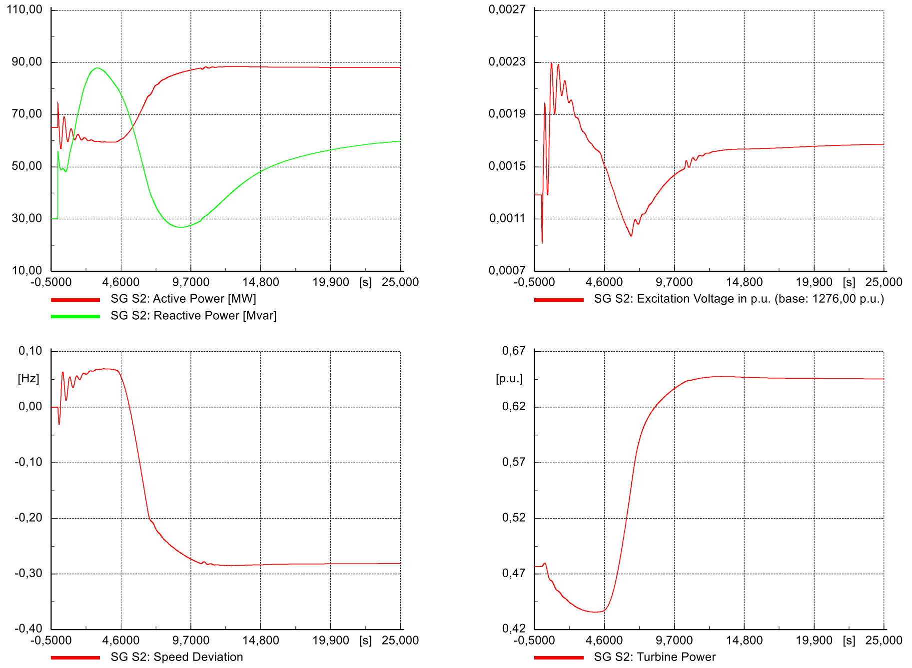


Figure 12: RMS-quantities for grid objects

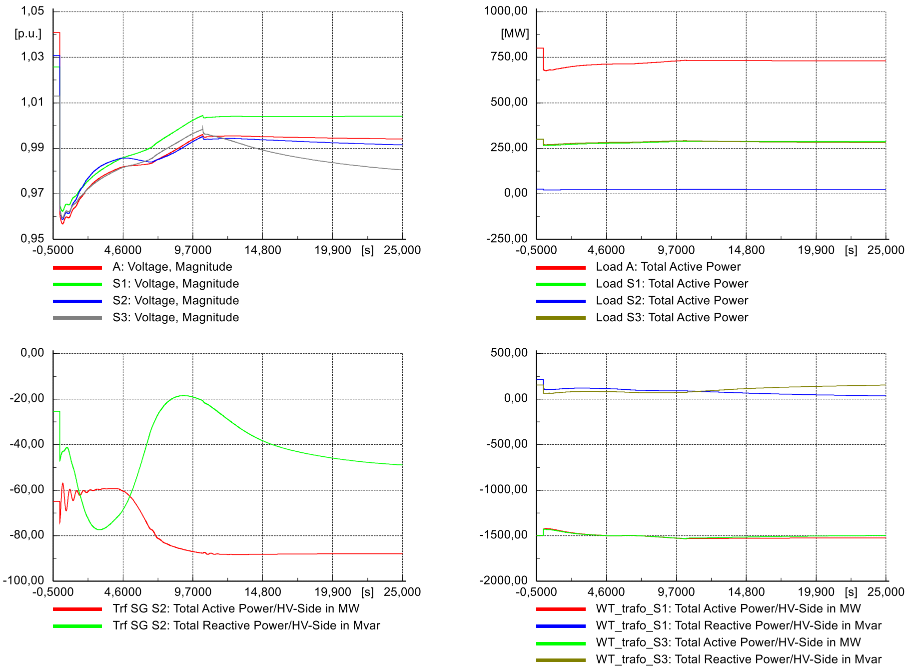
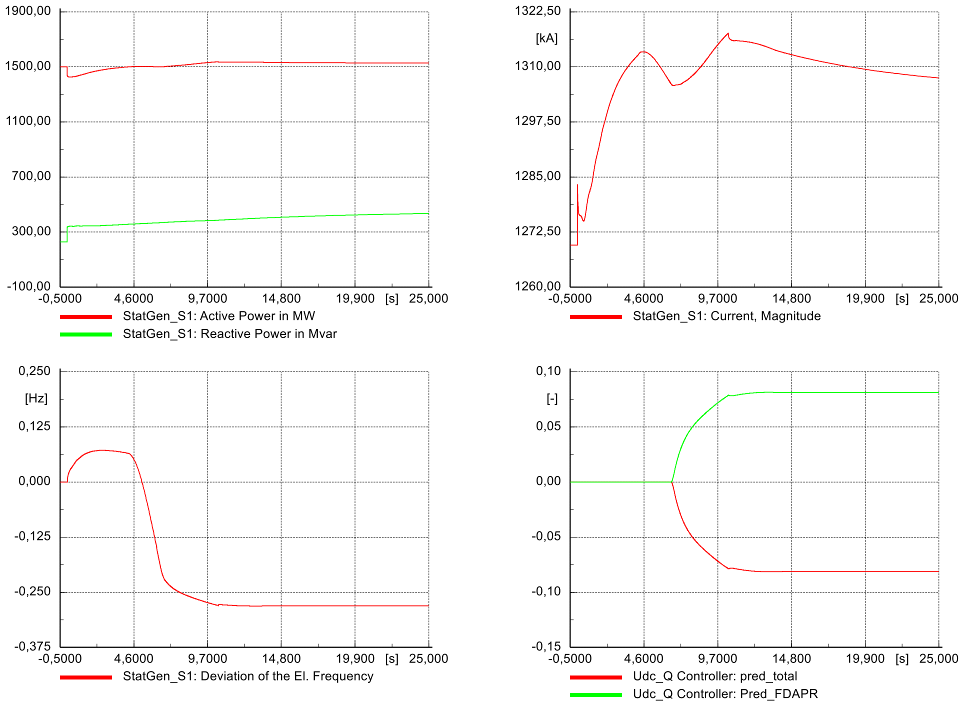


Figure 13: RMS-quantities for WTG1



3.4 Conclusions

The benchmark project presented is demonstrating in a number of representative cases that the fast voltage source controlling converter (VSCC) method can successfully handle power systems with an extra high share of converter based generation. Compared to other discussed technologies such as the "Virtual Synchronous Machine" method, the VSCC method is straight forward with a minimum of dynamic characteristics to be considered. It simply balances active and reactive power via frequency and voltage, fast efficient and fully compatible. It integrates seamless with actually operated power system technologies.

However, the reader is encouraged to ad his own control technique proposal and solution to the VSCC-method presented, finally aiming in finding the best possible control technique for high RES share integration to existing power systems.

4 References

/1/ I. Erlich, A. Korai, "Description, Modelling and Simulation of a Benchmark System for Converter Dominated Grdis (Part I)", June 2018

/2/ I. Erlich, A. Korai et al., "New Control of Wind Turbines Ensuring Stable and Secure Operation Following Islanding of Wind Farms," in IEEE Transactions on Energy Conversion, vol. 32, no. 3, pp. 1263-1271, Sept. 2017

/3/ H. Weber, P. Basker, A. Nayeemuddin, "Power System Control with Renewable Sources, Storage and Power Electronic Converters", 2018 IEEE International Conference on Industrial Technology (ICIT), 19.-22.2.2018, Lyon, France