High Voltage Ride-Through of DFIG-based Wind Turbines

C. Feltes, *Student Member, IEEE* , S. Engelhardt, *Member ,IEEE* , J. Kretschmann,
J. Fortmann, *Member, IEEE,* F. Koch, I. Erlich, *Senior Member, IEEE*

Abstract-- **With the rapid increase of large offshore wind farms in Europe, a new problem associated with the response of wind turbines to temporary overvoltages has arisen. This problem has not been a focus of discussion up to now. The majority of wind turbines use voltage source converters with a DC-link. When the grid voltage exceeds a certain limit the current flow through the line-side converter may reverse, resulting in a rapidly increasing DC voltage. To handle such situations, special countermeasures are required. This paper identifies and outlines the problem and recommends possible measures to ride through the overvoltage safely. Additionally, active voltage control structures to limit the overvoltages are proposed.**

***Index Terms*—Wind power, control system, doubly-fed induction generator, HVRT, voltage control.**

I. INTRODUCTION

In Germany, many offshore wind farms are currently in various planning stages [1]. Since their ratings range up to several hundreds MW, they will have considerable impact on the grid. Many publications in the past discussed the reactions of wind turbines on voltage drops such as those that may appear during short circuits [2],[3]. Problems arising from situations of overvoltages were addressed by some papers, but have not yet been adequately discussed. Many wind turbine manufacturers use generators based on the concept of the Doubly-Fed Induction Machine (DFIM). These machines basically consist of a slip-ring induction generator whose rotor is connected to the grid through a back-to-back converter. The major advantage of this design is the fact that the converter does not have to be rated for the machine's full power, but only for about a third of it. However, since it is not fully decoupled from the grid, the machine is directly affected by grid disturbances, which can lead to difficult operating conditions.

Situations with overvoltages may arise due to load shedding or unbalanced faults. The resulting overvoltages may have different magnitudes and durations, depending on the disturbance scenario. Therefore, the international grid code requirements concerning high voltage ride-through (HVRT) slightly differ. In Australia, grid codes [4] stipulate wind turbines to withstand even an overvoltage of 1.3 p.u. for 60 ms (Fig. 1).

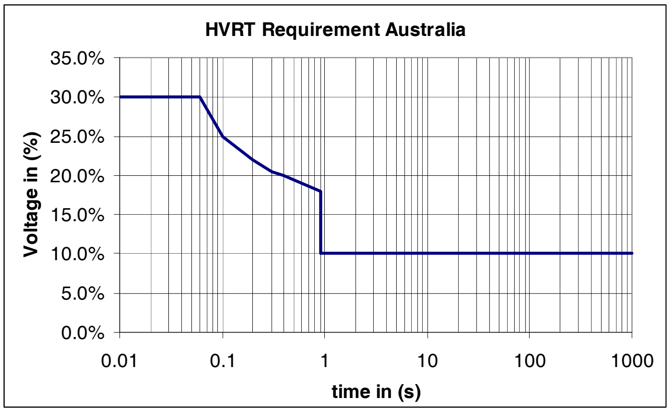


Fig. 1. HVRT Requirements in the Australian Grid Code

Overvoltages may lead to the reversal of the power flow in the line-side converter, meaning that under these conditions, current may flow from the grid into the DC-link. As a result, the DC-voltage will rise. To protect the converters, the DC-voltage has to be reduced to its rated value again. Beyond this, the current through the converter has to be limited, since IGBT's are highly sensitive to overcurrents. Possible protection measures to ensure both limitations will be presented and discussed in the paper, followed by simulation results for illustration purposes.

II. GRID CODE REQUIREMENTS

Grid Code requirements on overvoltages need to take into account overvoltages resulting from the operation of a power producer or consumer as well as overvoltages originating from the grid.

Obviously the grid needs to be protected from overvoltages which may arise as a result of abnormal system operating condition. Therefore it is common to set limits that

---

C. Feltes is with the University Duisburg-Essen, 47057 Duisburg, Germany, (e-mail: christian.feltes@uni-duisburg-essen.de).
S. Engelhardt is with Woodward SEG GmbH & Co. KG, 47906 Kempen, Germany, (e-mail: stephan.engelhardt@woodward.com).
J. Kretschmann is with Woodward SEG GmbH & Co. KG, 47906 Kempen, Germany, (e-mail: joerg.kretschmann@woodward.com).
J. Fortmann is with REpower Systems AG, 22768 Rendsburg, Germany, (e-mail: j.fortmann@repower.de).
F. Koch is with REpower Systems AG, 22768 Rendsburg, Germany, (e-mail: friedrich.koch@repower.de).
I. Erlich is with the University Duisburg-Essen, 47057 Duisburg, Germany, (e-mail: istvan.erlich@uni-duisburg-essen.de).

enforce the disconnection of a wind turbine in case the voltage exceeds a certain limit.

On the other hand, an interruption of power production resulting from transient overvoltages is not desirable. This is especially an issue of concern for transmission system operators (TSO), as the stability of the grid relies on a stable power generation. As a result, voltage control capability also of wind turbines is required by some grid operators (see Fig. 2) in order to support the voltage profile (stability). As a result the probability of disconnection of consumers and power producers in the grid can be reduced.

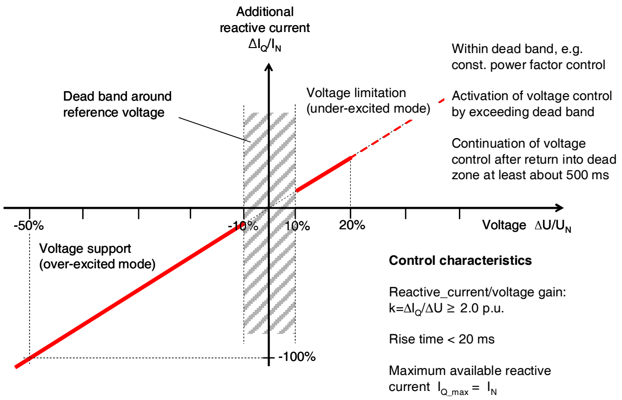


Fig. 2. Reactive power requirements of E.ON Netz [5] for HVRT.

III. WIND TURBINES

A. *Hardware System*

The most commonly used generator type in modern wind turbines is the DFIG. A typical layout of a DFIG system is shown in Fig. 3. The back-to-back frequency converter in combination with pitch control of the rotor blades enable variable speed operation, leading to higher energy yields compared to fixed speed wind turbines. Since the IGBT-converter is located in the rotor circuit, it only has to be rated to a small portion of the total generator power (typically 20-30%, depending on the desired speed range). A rotor crowbar is used to protect the rotor side converter against over-currents and the DC capacitors against over-voltages during grid faults. But a crowbar ignition means the loss of the generator controllability through the machine side converter (MSC), since the machine rotor is short-circuited through the crowbar resistors and the MSC is blocked. During this time slot the generator acts as a common induction generator and consumes reactive power, which is not desirable for LVRT. During HVRT a crowbar ignition would lead to a high generator torque and uncontrolled active and reactive power output. To avoid a crowbar ignition for most fault scenarios, a DC chopper is used to limit the DC voltage by short-circuiting the DC circuit through the chopper resistors. A line inductor and an AC filter are used at the grid side converter to improve the power quality.

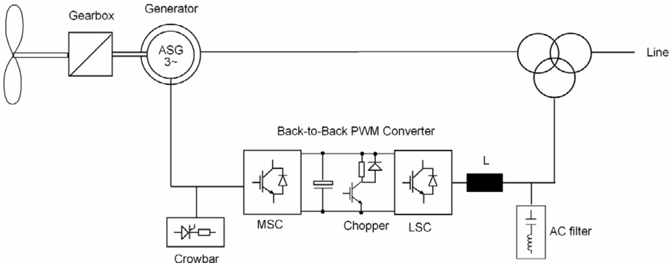


Fig. 3. System configuration of DFIG

B. *LSC control*

Fig. 4 shows the circuit diagram of the LSC. In a DFIG system the function of the LSC is to maintain the DC voltage and provide reactive current support for optimization of the reactive power sharing of MSC and LSC. During grid faults additional short-time reactive power can be fed to support the grid. Especially when the machine rotor is short circuited through the crowbar resistors, the generator consumes reactive power. This reactive power has to be compensated by the LSC.

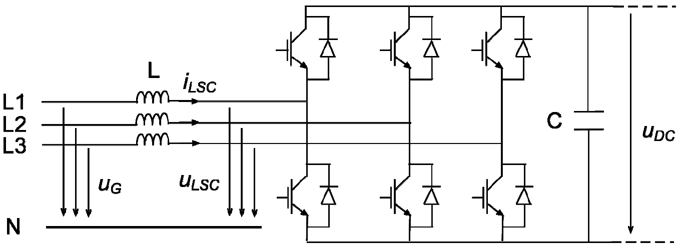


Fig. 4. LSC circuit

The control structure of the LSC is shown in Fig. 5 and Fig. 6. The outer loop of the LSC control features dc-link voltage control and reactive power control by controlling active and reactive current of the LSC [6]. The performance of the voltage controller can be enhanced by a feed-forward control of the active current of the MSC, which can be calculated via the MSC active power and the line voltage. The magnitude of the current set value is limited according to the converter rating with a priority for the active current to ensure correct dc-link voltage control.

With the voltage drop across the grid reactor considered, the resulting converter voltage is:

$$\underline{u}_{LSC}^{\angle ug} = \underline{u}_{G}^{\angle ug} - l\frac{d\underline{i}_{LSC}^{\angle ug}}{dt} - j\omega_0 l \cdot \underline{i}_{LSC}^{\angle ug} \tag{1}$$

In a voltage oriented reference frame ($u_{G,q}^{\angle ug} = 0$, $u_{G,d}^{\angle ug} = \left|\underline{u}_{G,d}^{\angle ug}\right|$) the dq-components of the LSC voltages are:

$$u_{LSC,d}^{\angle ug} = u_{G,d}^{\angle ug} - l\frac{di_{LSC,d}^{\angle ug}}{dt} + \omega_0 l \cdot i_{LSC,q}^{\angle ug} \tag{2}$$

$$u_{LSC,q}^{\angle ug} = -l\frac{di_{LSC,q}^{\angle ug}}{dt} - \omega_0 l \cdot i_{LSC,d}^{\angle ug} \tag{3}$$

From eq. (2) and (3) the inner current control loop in Fig. 6. can be easily derived. The cross-coupling terms of the voltage across the grid reactor and the grid voltage are fed forward so that the PI-controllers only have to provide a fast transition of the current to the respective set-values.

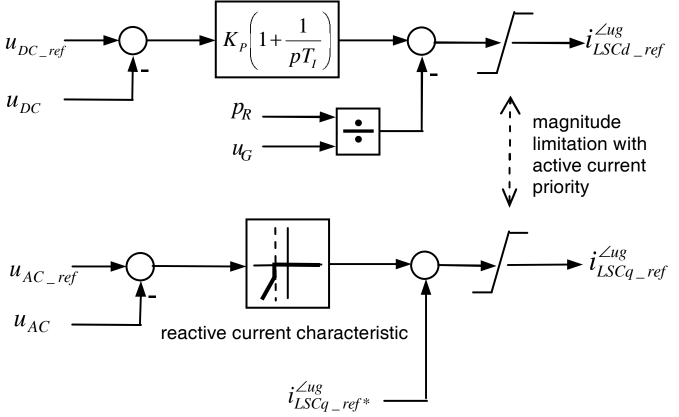


Fig. 5. DC voltage and reactive power control at LSC

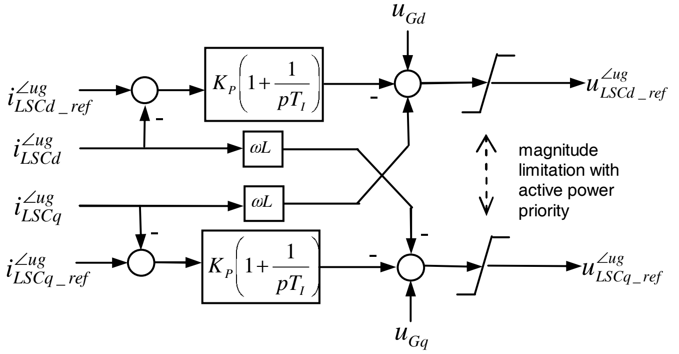


Fig. 6. LSC current control

C. MSC control

The MSC controls active and reactive power of the DFIG and follows a tracking characteristic to adjust the generator speed for optimal power generation depending on wind speed. Optionally a fast local voltage controller can be implemented. The cascaded control structure of the MSC is shown in Fig. 7 and Fig. 8 [7]. The outer power control loop of the MSC adjusts the rotor current set values of the inner rotor current loop.

The fundamental system of equations for the DFIG in the synchronous reference frame linked to the stator voltage is given by the following equations:

Voltage equations:

$$\underline{u}_S = r_S \underline{i}_S + \frac{d\underline{\psi}_S}{dt} + j\omega_S \underline{\psi}_S \tag{4}$$

$$\underline{u}_R = r_R \underline{i}_R + \frac{d\underline{\psi}_R}{dt} + j(\omega_S - \omega_R)\underline{\psi}_R \tag{5}$$

Flux equations:

$$\underline{\psi}_S = l_S \underline{i}_S + l_h \underline{i}_R \tag{6}$$

$$\underline{\psi}_R = l_h \underline{i}_S + l_R \underline{i}_R \tag{7}$$

Equation of motion:

$$\frac{d\omega_R}{dt} = \frac{1}{\theta_m}\left(\psi_{Sd} i_{Sq} - \psi_{Sq} i_{Sd} + t_m\right) \tag{8}$$

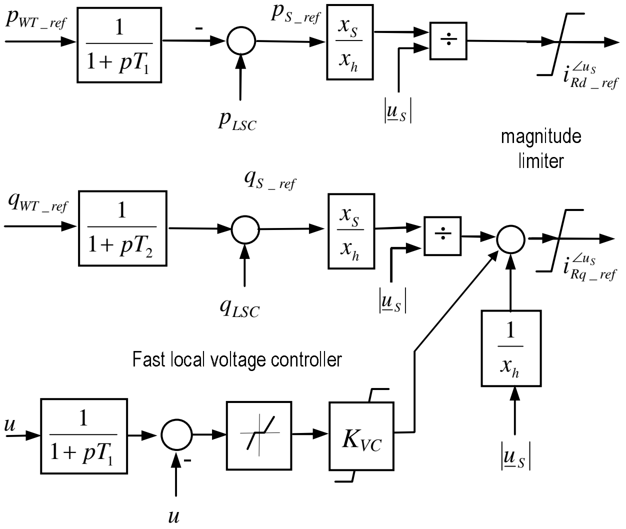


Fig. 7. Generator active and reactive power

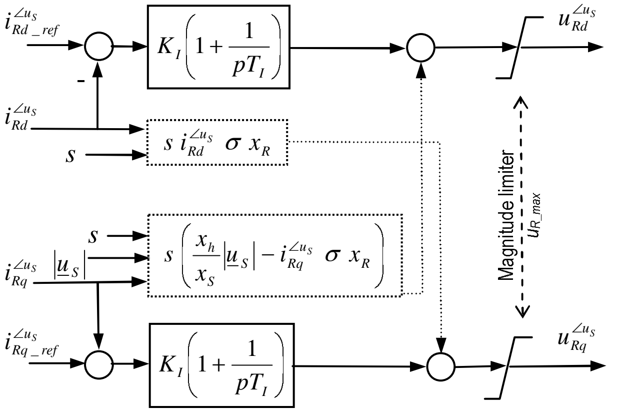


Fig. 8. MSC current control

The equations for the feed-forward current control can be derived considering steady state operation and neglecting the stator resistance:

$$\frac{d\underline{\psi}_S}{dt} = \frac{d\underline{\psi}_R}{dt} = 0 \tag{9}$$

$$r_S = 0 \tag{10}$$

After some algebraic manipulations one obtains the complex state equation for the steady state rotor voltage:

$$\underline{u}_R = s\frac{x_h}{x_S}\cdot \underline{u}_S - js\sigma x_R \underline{i}_R$$

(11)

By forwarding this voltage the parallel PI current controllers only have to put into effect the transition of the rotor currents to the set values and compensation for the stator resistance. The corresponding current control loops are shown in Fig. 8.

The equations for the power are:

$$p_{WT} = p_S + p_{LSC} \tag{12}$$

$$q_{WT} = q_S + q_{LSC} \tag{13}$$

$$p_S = \mathrm{Re}\left\{\underline{u}_S \underline{i}_S^*\right\} \tag{14}$$

$$q_S = \mathrm{Im}\left\{\underline{u}_S \underline{i}_S^*\right\} \tag{15}$$

Taking into account eq. (4),(6),(9) and (10) we receive with

$$\underline{i}_R = i_{Rd} + ji_{Rq} \tag{16}$$

$$p_S = -\frac{x_h}{x_S} |\underline{u}_S| i_{Rd} \tag{17}$$

$$q_S = \frac{1}{x_S} |\underline{u}_S|^2 + \frac{x_h}{x_S} |\underline{u}_S| i_{Rq} \tag{18}$$

From eq. (17) and (18) the feed-forward terms of the outer power control loop shown in Fig. 7 can be derived.

IV. HIGH VOLTAGE RIDE-THROUGH

To guarantee a safe operation of the WT during HVRT it has to be ensured that the converters always work in their permissible voltage range. The maximum available converter voltage, which can be modulated from the DC voltage, is:

$$u_{conv,\max} = m_{\max} \frac{\sqrt{3} \cdot U_{DC}}{2\sqrt{2} \cdot U_{LSCn}} \tag{19}$$

During HVRT different problems may arise from the increased voltages at LSC and MSC. These problems require adequate solutions in the converter control and will be discussed separately for LSC and MSC in the following.

A. HVRT with LSC

Fig. 4 can be used to elucidate the effect of an overvoltage in the grid on the LSC. During HVRT the grid voltage may exceed the maximum converter voltage.

To avoid over modulation the converter voltages have to be limited:

$$|\underline{u}_{LSC}| = \sqrt{u_{LSC,d}^2 + u_{LSC,q}^2} \le u_{conv,\max} \tag{20}$$

It has to be guaranteed that the active current can always be controlled to maintain the DC voltage. Thus, the limitation of converter output voltage has to consider a priority for active current $i_{LSCd}^{\angle ug}$ that, however, is proportional to the q-component of the LSC voltage as can be seen from Fig. 9. Therefore only the d-component of the LSC voltage has to be limited while keeping the q-component unchanged:

$$u_{LSC,d,lim}^{\angle ug} = \sqrt{u_{conv,max}^2 - u_{LSC,q}^{2\angle ug}} \tag{21}$$

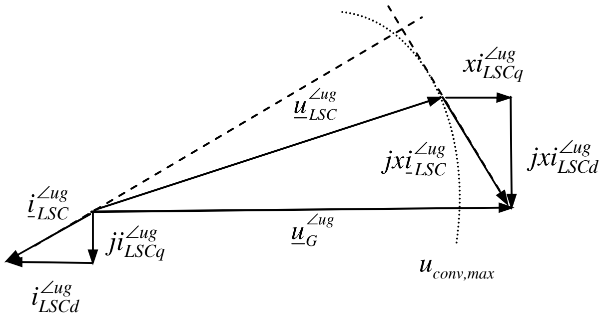


Fig. 9. Phasor diagram of LSC voltages and currents for HVRT

To avoid undesired actions of the LSC current controllers, the current due to the limitation

$$i_{LSCq\_ref*}^{\angle ug} = \frac{1}{\omega L} (u_{LSC,d,lim}^{\angle ug} - u_{G,d}^{\angle ug}) \tag{22}$$

is fed back and used as new setpoint for the q-axis current controller (Fig. 5). Additionally the controller state variables are held, when the voltage limitation is active.

With the derived converter voltage limitation the LSC control enables secure HVRT up to a voltage level, which mainly depends on the maximum converter current and the critical current of the grid reactor that may lead to saturation.

But the LSC voltage limitation derived so far can only provide good results for symmetrical HVRT, because un-symmetrical voltage components have not been considered.

To extend the LSC control for unsymmetrical overvoltages, another term representing the magnitude of the negative sequence part of the grid voltage has to be considered in the converter output voltage limitation:

$$u_{LSC,d,lim}^{\angle ug} = \sqrt{u_{conv,max}^2 - u_{LSC,q}^{2\angle ug}} - |\underline{u}_{G,2}| \tag{23}$$

This modification ensures that the negative sequence component in the measured grid voltage, which is included as feed-forward term in the LSC current control, is not shaved by the output limitation. This way the negative sequence component in the LSC currents is minimized to reduce the DC voltage ripple during unsymmetrical operation [8].

This term can be obtained from the measured grid voltage by sequence separation through coordinate transformation into a reference system rotating with the negative sequence system and filtering out the positive sequence components with a lowpass filter. It also has to be considered in the reactive current setpoint of the LSC.

B. HVRT with MSC

The requirements for the MSC are similar to those derived for the LSC. But since the MSC is not directly connected to the grid but to the rotor circuits of the generator, the voltage magnitude and frequency at the MSC during HVRT strongly depend on the operating point of the machine. To evaluate the effect of overvoltages to the MSC, the machine equations (section III. C.) have to be considered.

From eqn. (11) it is apparent, that the impact of a HVRT to the MSC not only depends on the stator voltage magnitude, but also on the machine slip. I.e., in the normal speed range of the generator the induced rotor voltage is smaller than the maximum converter voltage, even during HVRT. HVRT may only become critical for the MSC, when the generator is operated close to the speed limits.

During normal voltage operation the MSC control works with active current priority to guarantee that the generator can track the active power set points provided by the supervisory control. Usually, in this mode the voltage limitation of the MSC is not active. During fault (LVRT or HVRT) the priority is switched to the reactive current to ensure that the WT can fulfill the voltage support requirements stipulated by the grid codes. In case of HVRT this means that the generator moves to the underexcited mode. The minimum requirement in the German grid codes for the voltage controller is a proportional gain of 2.0 p.u., but for a better voltage reduction higher gains are recommended.

When the induced rotor voltage becomes bigger than the maximum converter output voltage, theMSC voltage is limited by a magnitude limiter.

In case of unsymmetrical voltages the MSC can also be used to suppress the negative sequence component in the machine currents. But the negative sequence voltage components induced through the machine are amplified from the stator to the rotor side with negative sequence slip:

$$s_{neg} = \frac{\omega_0 + \omega_R}{\omega_0} \tag{24}$$

Additionally, the turns ratio of the generator also amplifies voltages from stator to rotor side. As a result, the negative sequence control of the MSC is strongly limited.

In any case, since the MSC does not participate in DC voltage control, the only reason to implement a negative sequence control at the MSC would be to reduce oscillating torques on the drive train. But this control would adapt the negative sequence component of the stator voltage to the grid voltage, meaning that the voltage imbalance is accepted without countermeasures. Without this control the negative sequence is short circuited in the generator like in the damper winding of a synchronous generator. From grid point of view this is desirable, since the resulting negative sequence currents contribute to balancing stator voltages [9].

V. SIMULATION

All simulation studies presented in this paper have been done with MATLAB/ Simulink with use of the SimPowerSystems Toolbox. The generators are represented by a fourth-order model of the electrical circuit and the mechanical part is neglected due to the small speed deviation during the time period considered. Therefore, the simulations were carried out with constant rotor speed. The IGBT converters are modeled as ideal switches with anti-parallel diodes. Distributed parameter models are used for lines and the transformer models consider saturation effects, but no hysteresis. Circuit breaker models are ideal and open exactly at the first current zero crossing after the open command.

For the simulation scenarios a 200 MW wind farm is modeled by two equivalent wind turbines in scenario A and by one equivalent wind turbine in scenario B. In scenario A two wind turbine equivalents are used, because one is tripped after a three-phase fault while the behaviour of the other is studied during voltage recovery. The wind turbines are connected at 36kV level to a step-up transformer, whose primary side is connected to the 150 kV sea cable with a cross section of 1200 mm^2 and a length of 100 km. Shunt reactors are installed at both sides of the cable. The transmission system is connected to the extra-high voltage grid through a 150/380 kV transformer. Fig. 10 shows the observed test system.

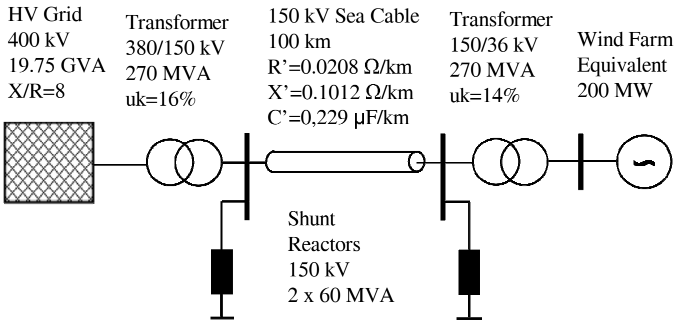


Fig. 10. Test grid

A. *Symmetrical HVRT*

In the symmetrical HVRT scenario the wind farm is operating at nominal power at a generator speed of 1.25 p.u. All generators are working in underexcited mode, when a severe three-phase fault of 200 ms duration occurs in the wind farm grid. After switching off the faulty line the voltage recovers (Fig. 11). But since 75% of the wind turbines have been tripped the voltage does not return to its pre-fault value but to a steady-state value of approx. 115% with HVRT control and to approx. 120% without HVRT control. The overshoot after fault clearing brings along a transient peak voltage of approx. 130% for both cases. From Fig. 11 it can be seen that the wind turbines support the grid voltage during and after fault through the provision of reactive power. When the fault occurs, the wind turbines change from underexcited to overexcited mode for LVRT voltage support and after voltage recovery they are operating in underexcited mode again to reduce the grid voltage in HVRT mode. The reactive power support is shared between stator and LSC to limit the LSC output voltage according to section IV. A. . During transient voltage recovery the active power at the LSC is reversed, leading to an increased DC voltage. This can be handled by a well-designed DC chopper, which limits the DC voltage to approx. 1.05 p.u.

B. *Unsymmetrical HVRT*

One situation which can lead to unsymmetrical overvoltage is a single-phase short-term interruption (STI). In the simulated case the wind farm is operating at nominal load, when a single phase short circuit occurs in the HV grid, which lasts for 100 ms and is followed by a STI at the PCC. After 200 ms the line is switched on again. Normally a STI cycle is longer, but a shorter period has been chosen here for observation.

Fig. 12 shows the simulation results. The positive sequence component of the grid voltage drops to approx. 75% during fault and recovers during STI with a dampened oscillation with a large overshoot of approx. 133%. The negative sequence voltages during STI are slightly bigger than during fault and show the same oscillations as the positive sequence components. In comparison with the negative sequence voltage at MV grid and generator stator it becomes obvious, that the generator has a balancing effect on the stator voltage. The impact of the fault and STI on the WT active power is rather small compared to symmetrical fault and the oscillations are well dampened. The oscillations in positive sequence reactive power correlate with the voltage oscillations and are small in scope. The main oscillations are in the distribution between stator and LSC reactive power. The negative sequence active and reactive power diagrams show the generator acting as a resistive inductive load for the negative sequence, which reflects the balancing effect of the generator to the stator voltages.

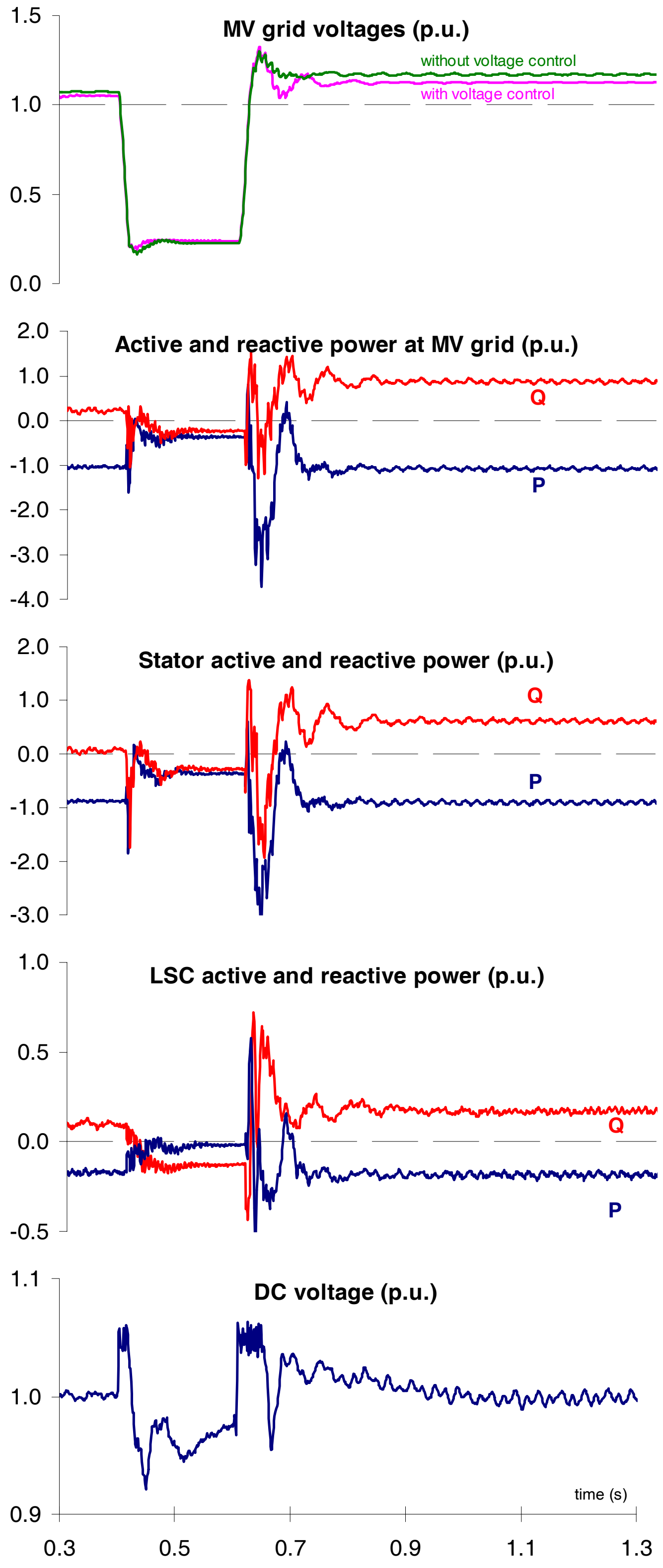
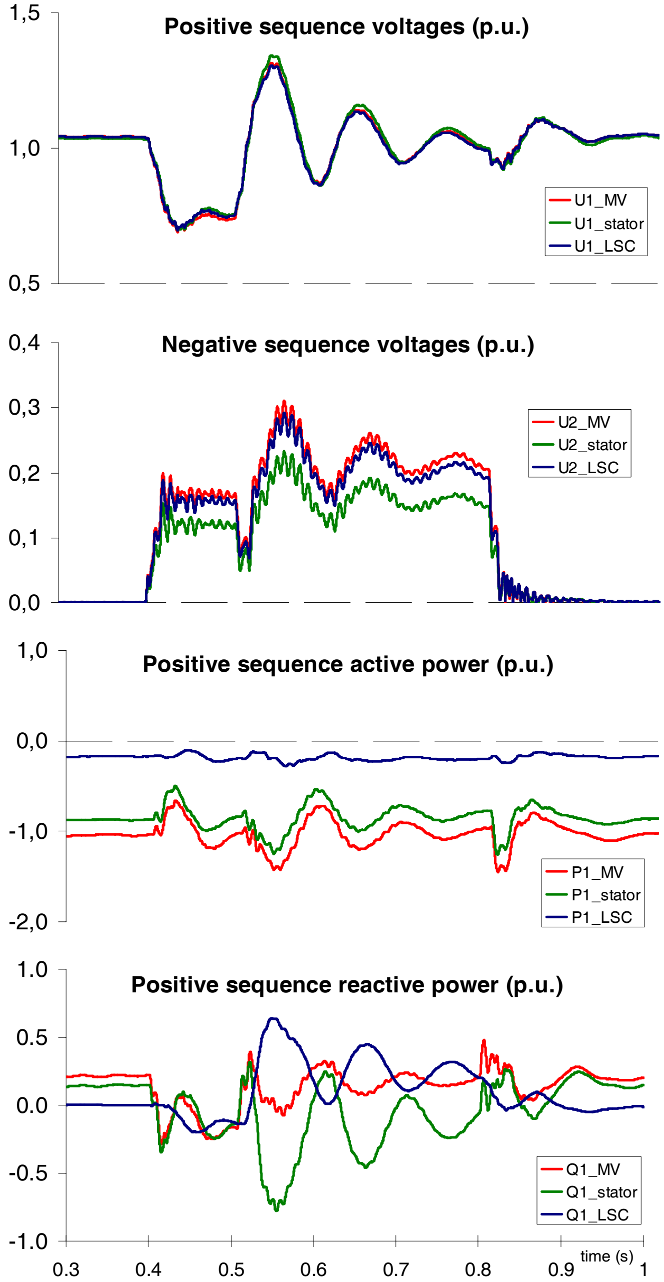


Fig. 11. Simulation results for symmetrical HVRT

In addition to positive and negative sequence components the active and reactive power also contain components oscillating with 100 Hz, which result from the interaction of positive and negative sequence components [10]. As a result of these power oscillations at MSC and LSC, there is also a 100 Hz ripple in the DC voltage. This ripple is in the allowable voltage range. When the phase with the STI is switched on again, there is a peak in the stator power and respectively in the rotor power, which leads to a small overshoot in the DC voltage, which is handled by the DC chopper.



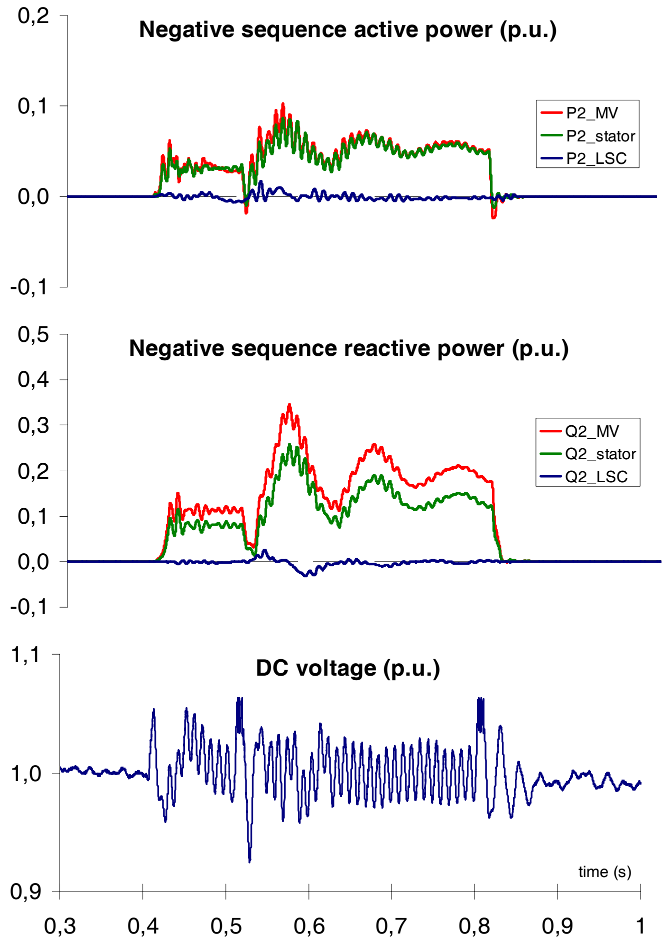


Fig. 12. Simulation results for unsymmetrical HVRT

VI. CONCLUSION

In this paper the problems, which may occur during HVRT were discussed and suitable solutions for the converter control were presented. During HVRT with the standard control the power flow at the LSC may reverse, which would lead to a fast increase of the DC voltage in the converter. With the proposed enhanced HVRT control for the LSC the power flow into the DC circuit can be reduced. This is done by a converter output voltage limitation considering active current priority, which causes the LSC to operate in underexcited mode during HVRT. With this solution the activity of the DC chopper can be reduced.

The simulation results for symmetrical HVRT show that the voltage control of the DFIG drives the generator into underexcited operation mode, leading to a reduction of the grid overvoltage. A comparison with the same scenario without the voltage control confirms this statement and shows differences in the MV voltage of approx. 5%. The voltage control presented here only acts when the fault effects a change of more than 10% of the nominal voltage. A continuous voltage control, like the one stated in the E.ON grid code, should be considered in future studies, since small voltage disturbances will also be covered.

The unsymmetrical scenario shows that the generator has a balancing effect on the stator voltages without any special countermeasures in the MSC control. It reduces the negative sequence components in the stator and grid voltages by short-circuiting the negative sequence. The torque oscillations, which occur during unsymmetrical HVRT are acceptable, since the time period of the voltage disturbance is short. The enhanced LSC control for HVRT reduces the LSC negative sequence currents to reduce the 100 Hz ripple in the DC voltage and to avoid undesired chopper actions.

From those facts it can be concluded, that the proposed control provides a good and secure solution for HVRT from both generator and grid point of view.

VII. REFERENCES

[1] Bundesverband Windenergie e.V., [online], Available: http://www.wind-energie.de

[2] I. Erlich, H. Wrede, C. Feltes, „Dynamic Behavior of DFIG-Based Wind Turbines during Grid Faults", Power Conversion Conference, IEEE 2007. PCC Nagoya '07

[3] A. Geniusz, S. Engelhardt, "Riding through Grid Faults with Modified Multiscalar Control of Doubly Fed Asynchronous Generators for Wind Power Systems", Records of the PCIM Conference, Nürnberg, 2006

[4] AEMC, "National Electricity Rules Version 13", march 2007, online: http://www.aemc.gov.au

[5] Eon Netz GmbH, "Grid Code High and Extra high voltage", online: http://www.eon-netz.com/, Bayreuth, 2006

[6] R. Pena, J. C. Clare, G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation", in *Proc. 1996 IEE Electric Power Applications*

[7] I. Erlich, J. Kretschmann, J. Fortmann, et al., "Modeling of Wind Turbines based on Doubly-Fed Induction Generators for Power System Stability Studies", presented at Power Systems Conference and Exhibition, Atlanta 2006

[8] Müller-Engelhardt, S.;Wrede, H.; Kretschmann, J.: „Leistungsregelung von Windkraftanlagen mit doppeltgespeister Asynchronmaschine bei Netzunsymmetrie." S. 489–500, VDI-Fachberichte 1963 Elektrisch-mechanische Antriebssysteme, VDIVerlag, 2006 (ISBN 3-18-091963-9)

[9] Engelhardt, S.: Regelung von Frequenzumrichtern für Windenergieanlagen mit doppelt gespeistem Asynchrongenerator, S.92-110, ISET Tagungsband Zwölftes Kasseler Symposium Energie-Systemtechnik, Regelungstechnik für dezentrale Energiesysteme, 22.-23.11.2007

[10] Hong-Seok Song, Kwanghee Nam, „Dual Current Control Scheme for PWM Converter Under Unbalanced Input Voltage Conditions", IEEE Transactions on Industrial Electronics, Vol. 46, October, 1999

VIII. BIOGRAPHIES

Christian Feltes (1979) received his Dipl.-Ing. degree in electrical engineering from University of Duisburg-Essen/Germany in 2005. Since January 2006 he is doing his Ph.D. studies in the Department of Electrical Power Systems at the same University.

His research interests are focused on wind energy generation, control, integration and dynamic interaction with electrical grid.

He is student member of IEEE.

Stephan Müller-Engelhardt (1967) received his Dipl.-Ing. degree in electrical engineering from the University Hannover, Germany, in 1997. Since 1997 he is with SEG GmbH & Co. KG, Kempen/Germany, presently manager of the group Innovation / Converter Technology and responsible for system designs and simulations, control strategies and patents. He is a member of IEEE.

Jörg Kretschmann (1958) received his Dipl.-Ing. degree in electrical engineering from the Technical University Berlin, Germany, in 1986. In the period of 1986 to 1988 he worked for engineering department of AEG-Kanis in Essen, manufacturing of synchronous generators up to 200 MVA. Since 1988 he is with SEG GmbH & Co. KG, Kempen/Germany, as a designing engineer for speed-variable applications: uninterruptible power supply, shaft alternators, DFIG for wind turbines. His main field is simulation of power converter systems, design of power components, passive grid-filter.

Jens Fortmann (1966) received his Dipl.-Ing. degree in electrical engineering from the Technical University Berlin, Germany, in 1996. From 1995 to 2002 he worked on the simulation of the electrical system and the control design of variable speed wind turbines at the German wind turbine manufacturers Suedwind and Nordex Energy. Since 2002 he is with REpower Systems AG, Germany as project manager for the simulation and implementation of new technologies for improved grid compatibility of wind turbines like voltage control and ride-through of grid faults. He is member of IEEE.

Friedrich W. Koch (1969) received his Dipl.-Ing. degree in electrical engineering from the University of Siegen, Germany in 1998. From 1998 to 2000 and 2005 to 2006 he worked as engineer, project manager and finally as head of group in the field of industrial and power plants for the SAG GmbH. In between from 2000 to 2005 he worked on his PhD in the Department of Electrical Power Systems at the University of Duisburg - Essen, Germany. Since 2006 he is with REpower Systems AG, Germany as head of the group "Grid Integration / Simulation".

Istvan Erlich (1953) received his Dipl.-Ing. degree in electrical engineering from the University of Dresden/Germany in 1976. After his studies, he worked in Hungary in the field of electrical distribution networks. From 1979 to 1991, he joined the Department of Electrical Power Systems of the University of Dresden again, where he received his PhD degree in 1983. In the period of 1991 to 1998, he worked with the consulting company EAB in Berlin and the Fraunhofer Institute IITB Dresden respectively. During this time, he also had a teaching assignment at the University of Dresden. Since 1998, he is Professor and head of the Institute of Electrical Power Systems at the University of Duisburg-Essen/Germany. His major scientific interest is focused on power system stability and control, modelling and simulation of power system dynamics including intelligent system applications. He is a member of VDE and senior member of IEEE.