ENHANCEMENT OF LOW VOLTAGE RIDE THROUGH CAPABILITY OF FIXED SPEED WIND FARMS

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Abstract— High penetration level of wind power affects the generation profile of the power system. As per the grid code regulations of different countries Low Voltage Ride Through (LVRT) capability is essential requirement of wind farm to avoid a disconnection during the voltage dip. This paper present the enhancement in LVRT capability of wind farm based on fixed speed induction generator (FSIG) by the use of Static Synchronous Compensator (STATCOM). A control strategy applied to STATCOM will regulate the reactive power requirement at different operating condition as per the requirement and will also enhance the transient stability of the wind farm during grid disturbances. LVRT is investigated based on German E-ON Netz grid code.

Index Terms — Critical Clearing Time, Fixed Speed Induction Generator, Low Voltage Ride Through, Static Synchronous compensator.

I. INTRODUCTION

The burning of fossil fuels is having a significant influence on the global climate. Effective mitigation of climate change will require deep reductions in greenhouse gas emissions. Therefore an alternative to the nuclear and fossil fuel power is renewable energy technologies (hydro, wind, solar, biomass, geothermal, and ocean). As a green renewable resources wind have substitution potential to conventional fossil fuels. The cost of electricity generated by wind energy has been continuously decreasing during the last decade due to advancement in technology and mass production.

The simplicity in working and construction makes the FSIG a very robust, reliable, and cost effective machine. Hence it is widely used for wind energy conversion system (WECS).FSIG are highly sensitive to voltage sag due to the direct connection to the grid. In case of voltage drops due to the fault, electromagnetic torque decrease significantly whereas mechanical torque is still applied, this unbalanced torque accelerates the rotor which may result in instability. FSIG absorbs reactive power from the grid during its normal operation and during the voltage dip it will consume more reactive power from the grid to recover the air gap flux. If voltage profile is not recovered fast, the rotor may continue to accelerate and the generator absorbs huge reactive power which may further reduce voltage and induction generator becomes unstable. In order to overcome this problem grid connection code called LVRT Capability is established. LVRT refers wind turbine should have the ability to remain connected during faults and the voltage dip condition within certain limit [1]. The LVRT capability can be enhanced by providing additional reactive power support using STATCOM. The main advantage of STATCOM is its capability to inject controllable reactive current independently on the grid voltage and thus the compensating current is not reduced as the voltage drops [2, 3].

This paper is organized in six sections. Section II describes the proposed test system. Section III deals with STACOM operation and control scheme. Section IV explains LVRT Requirements as per German E.ON NETZ grid code. Section V presents results and discussion. Section VI concludes the result of the work.

II. TEST SYSTEM

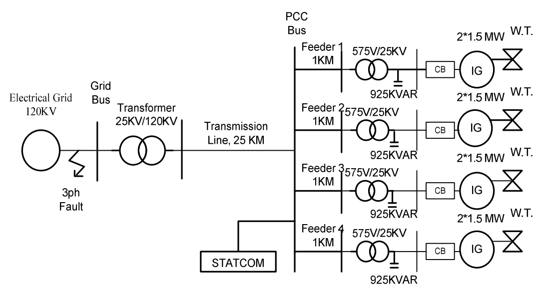


Fig.1 Schematic diagram of grid connected wind farm

In a FSIG based wind power plant, the rotor of squirrel cage induction generator is driven by a wind turbine to capture mechanical power and the stator winding is connected directly to the grid to transmit the electrical power.

Fig.1. shows the schematic diagram of the fixed speed induction generator based WECS. A simulation model of 12 MW consisting of four FSIG wind turbine is investigated. Each unit generates a low voltage of 575 V. A transformer step ups the voltage to 25 KV in the distribution stage. A second transformer further raises the medium voltage to 120 KV grid through 25 Km long 25 KV transmission line. A 925 KVAR delta connected capacitor bank is connected at the terminal of induction generator. Additional reactive power is provided by the STATCOM during three phase short circuit fault at the grid. The parameters of the test system are given in Appendix.

III. STATCOM AS REACTIVE POWER COMPENSATION DEVICE

The STATCOM is design using a power electronics voltage source converter (VSC). The function of VSC is a fully controllable voltage source matching the system voltage in phase, frequency and with amplitude which can be continuously controlled. Since STATCOM is a controlled reactive-power source it can be used for voltage regulation in a power system and can increase the transmission power capacity. Thus the incorporation of STATCOM results in improvements of steady-state characteristics and enhancement of the overall system stability. STATCOM is used to maintain certain voltage level at Point of Common Coupling (PCC) under heavy loading condition [4]. A STATCOM provides the desired reactive power by exchanging the instantaneous reactive power among the phases of the ac system. The difference between the converter output voltage and the PCC bus voltage basically determine the flow of reactive power through the coupling to or from the system [5].

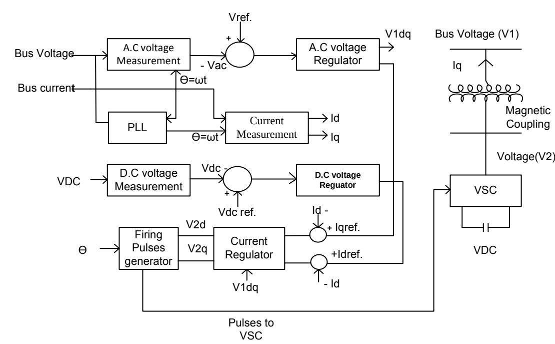


Fig.2 Control strategy of STATCOM

The control strategy for STATCOM is established in Fig.2. A Phase Locked Loop (PLL) with synchronizes on the positive sequence component of the bus voltage. The output of the PLL angle θ is used to compute the V_d, V_q, I_d and I_q. Measuring system measures d and q components of voltage and current to be controlled. The current regulator controls the magnitude and phase of the voltage generated by the PWM converter (V_{2d} V_{2q}) from the I_{dref} and I_{qref} reference currents produced respectively by the DC voltage regulator and the AC voltage regulator. The current regulator is assisted by a feed forward type regulator which predicts the V_2 voltage output (V_{2d} V_{2q}) from the V_1 measurement (V_{1d} V_{1q}) and the transformer leakage reactance. PWM modulator is generating pulses according to V_{2d} and V_{2q} for voltage source converter.

IV. LVRT REQUIREMENTS

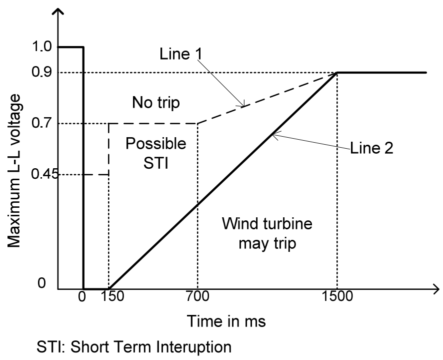


Fig.3 LVRT requirement for WTs according to E.ON Netz

A LVRT capability is its ability to survive transient voltage dip without tripping. This capability means that all generation plants, including wind generator should have the ability to stay connected during faults and voltage dip conditions within certain limit [6]. In order to prevent the disconnection of wind farm during network disturbance, many countries impose grid code requirement for LVRT.

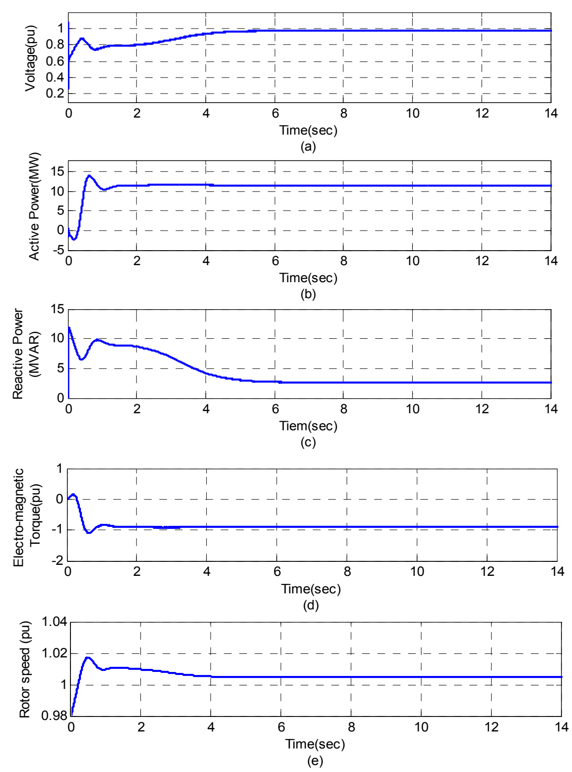
One such grid code LVRT requirement according to German E.ON Netz grid code is shown in the Fig.3. The LVRT restrictions given by the German grid code establish two different border lines that the WTG must accomplish to interconnect with the grid (see Fig.3). As shown in Fig. 3 above Line 2, all generating facilities must pass through the fault without being disconnected from the network. In the area between the Line 1 and Line 2, wind turbines may disconnect shortly with agreement from ENE. If the measured voltage is below the limit line 2 wind turbines allowed to trip. Wind turbines are also expected to have reactive power and voltage support capabilities during and after fault event [7].

V. RESULTS AND DISCUSSION

A. Steady State Results

When induction generator accelerated above synchronous speed via a step-up gear, the induced current and the torque in the rotor reverse their direction, converting the mechanical power of the turbine in to the electrical power. The circuit breaker is closed and the generator is directly connected to the grid. The simulated waveforms for the wind farm are shown in Fig.4, where the system is simulated at the rated wind speed 9 m/sec.

The results shown in Fig.4 revels that after the direct connection to the grid, the active power will exceed its nominal value and reach its maximum limit. Fig.4 (a) shows the steady state voltage 0.9933 p. u. The wind turbines generate active power of 11.56MW in steady state and absorb reactive power of 2.62MVAR from the grid as shown in Fig.4 (b) and (c) respectively. The results of electromagnetic torque and rotor speed are described in Fig.4 (d) and (e) respectively.

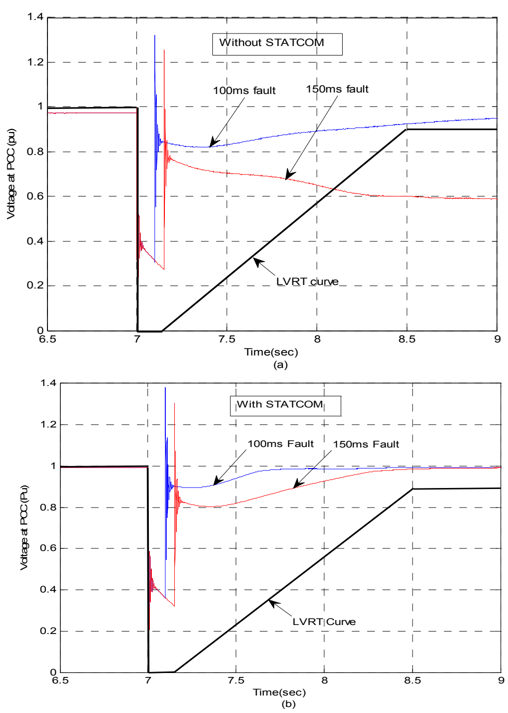


(a) Voltage at PCC , (b) Active Power(MW), (c)Reactive Power(MVAR),(d) Electromagnetic Torque, (e) Rotor speed(pu)

Fig.4 Operation of 12MW wind farm at rated wind speed

B. Results during Three phase fault

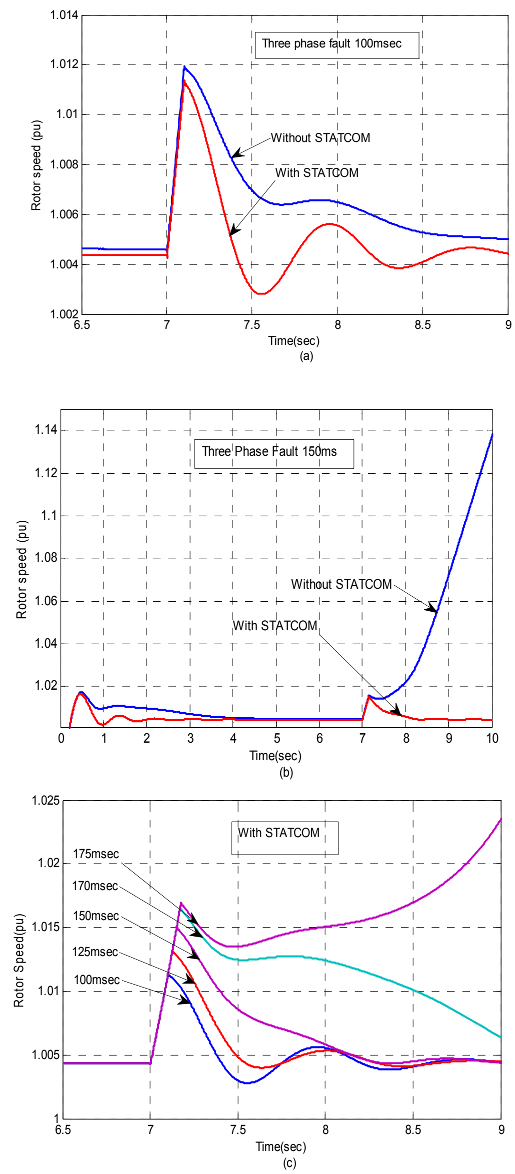
Simulation is carried out to study and analyses the effect of STATCOM as additional reactive power compensating device under abnormal condition. Thereby the operation of wind farm is monitored for two cases, with and without STATCOM. Three phase fault is created at grid side at time of 7 sec. and cleared after 100 ms and 150 ms. Fig5 (a) shows the voltage variation at PCC during fault condition without STATCOM. For fault period 150 ms the PCC voltage does not restore quickly as per the grid code requirement. Fig5 (b) shows that the voltage variation at PCC during fault condition with STATCOM. For fault duration 150 ms the voltage profile quickly restores 90 percent within 1.5 sec after fault clearance as per the grid code requirement. Comparing the voltage variation with the LVRT curve indicates that the wind turbines with STATCOM could continue to operate as the PCC remain above the LVRT curve. Thus it satisfies grid code requirement incorporation of as per Fig.3.



(a) Without STATCOM (b) With STATCOM

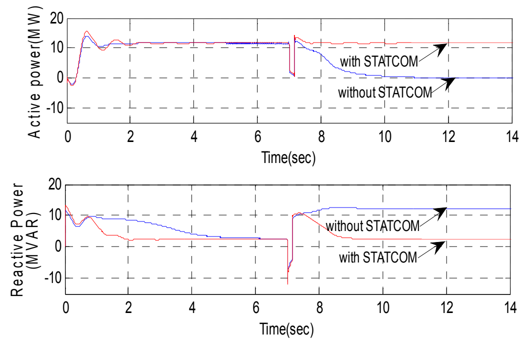
Fig. 5 Voltage variation at PCC of wind farm

Fig.6 shows the variation in rotor speed of wind turbines during three phase fault with and without STATCOM. Fig.6(a) shows with 100 ms fault clearing time, the rotor speed is less accelerate and more damped for wind farm with STATCOM.fig.6 (b) show the rotor speed of turbines to three phase fault with clearing time of 150 ms. The critical clearing time reach a value of 128 ms without STATCOM. If fault persist more than critical clearing time (128 ms), the rotor will continue to accelerate and wind turbines become unstable. The speed of the wind turbines ramps up gradually and it will be disconnected from the grid due to over speed protection. As per the LVRT requirements shown in Fig.3, winds turbines remain connected for at least 150 ms. Therefore by installing the STATCOM the critical clearing time is increased to up to172 ms. This is consistent with the simulation results and represent the additional margin 44ms for using STATCOM in wind farm. It has been clear that wind turbines remains stable even for 150 ms. Fig.6(c) shows the variation in rotor speed at different fault clearing time. After critical clearing time 172 ms rotor speed will continue to accelerate and it will disconnect form the grid.



(a) With 100ms fault clearing time
(b)With 150ms fault clearing time
(c) Rotor speed at different clearing time

Fig.6 Rotor Speed wind turbine



(a) Active power(MW) (b)Reactive power (MVAR)

Fig.7 Fixed speed wind farm during 150ms grid fault with and without STATCOM

Fig.7 shows that without STATCOM total generated active power from the wind farm during fault period is decreased and falls to zero, while with STATCOM active power is return back to its rated value after the fault clearance. Wind farm is disconnected due to lack of reactive power support during falut. While connecting STACOM as additional reactive power supporting device wind farm has the ability to stay connected to the grid during fault.

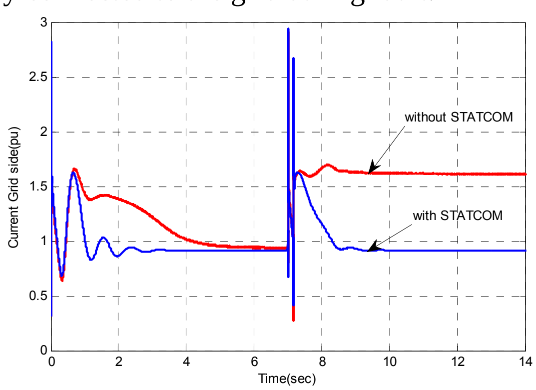
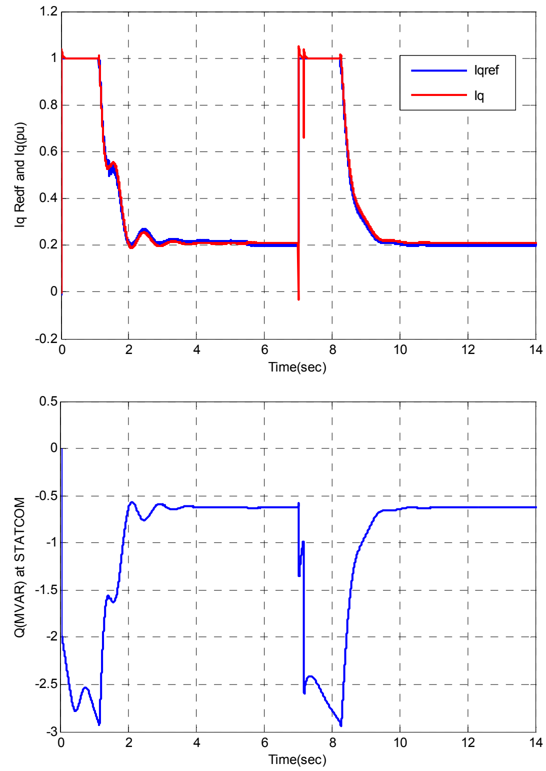


Fig.8 current grid side with and without STATCOM

The fault current waveform is shown in Fig.8, The transient current can be observed, which overlapped the short circuit current from the grid side during the fault and directly after its clearing by over current protection. The fault current from the grid side is reduced from 1.6pu to 0.91 pu by installing STATCOM. It is clear from the fig.6 that over all the value of the fault current from wind farm side with STATCOM is less than the case without STATCOM.



(a)Current Iqref and Iq (b)Reactive power of STATCOM

Fig.9 STATCOM variable

Fig.9 (a) shows the variation in result reveals that Iq follows Iqref. that means high sensitivity and high response of applied current technique. Fig.9 (b) shows STACOM is generating reactive power during the fault period for improvement the voltage profile. A Negative value indicates capacitive operation.

VI. CONCLUSION

The steady state and transient operation of FSIG based wind farm is successfully demonstrated in the present paper. The enhancement in LVRT capability of FSIG based wind farm by using STATCOM is shown as per German E.ON Netz grid code the test system satisfied the requirement. By using STATCOM reactive power requirement, voltage profile, and wind farm stability should be solved. The critical clearing time of the generator is also increased.

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APPENDIX

Fixed speed induction Parameters	
Rated power (MW)	3
Rated voltage (V)	575
Rated frequency (Hz)	60
Stator resistance (pu)	0.004843
Rotor resistance (pu)	0.004377
Stator leakage inductance (pu)	0.1248
Rotor leakage inductance (pu)	0.1791
Mutual inductance (pu)	6.77

Transmission line parameters	
Positive sequence resistance (ohm/km)	0.1153
Zero sequence resistance (ohm/km)	0.413
Positive sequence inductance (henries/km)	0.00105
Zero sequence inductance (henries/km)	0.00332
Positive sequence capacitance (farads/km)	11.33e-9
Zero sequence capacitance (farads/km)	5.01e-9

STATCOM DATA	
STATCOM rating	3 MVA
DC-link capacitance	375 μF
DC link Voltage	4000 V