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Low Voltage Ride Through (LVRT) Capability Improvement of Wind Power Generator by Using STATCOM

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Abstract

Nowadays asynchronous wind turbines are widely used in renewable energy to produce electricity. However, the asynchronous wind turbine which used in home and abroad doesn't have enough LVRT capability. If any faults occur in the wind turbine and voltage fall down, then the induction generator become in unstable position and it requires to be shut down the power system. But a shut sown of large wind farm can have a serious effect on power system operation.

So this paper proposes a method to improve the LVRT capability of fixed speed induction generator (FSIG) based on wind farm using static synchronous compensator (STATCOM). And this paper establishes the simulation model of asynchronous wind generator based wind farm and STATCOM in Matlab/Simulink environment. The research results show that the STATCOM device can improve asynchronous wind farm LVRT capability and keep working and reducing the adverse effects of power grid.

Keywords: LVRT capability improvement, superconducting magnetic energy storage (SMES), voltage source converter (VSC), wind energy conversion systems (WECS), pulse width modulation (PWM).

I. Introduction

Recently, the generation of electricity using wind power has received much interest and considerable attention all over the world. One of the simplest methods of operating a wind generation system is to use an induction generator connected directly to the power grid, because an induction generator is the most cost-effective and robust machine for wind energy conversion. However, fixed speed wind generator system with the induction generator requires reactive power support [1] for voltage regulation and improvement of low voltage ride-through (LVRT) capabilities. As wind speed continuously changes, the voltage at the point of common coupling (PCC) also fluctuates. One of the effective methods to improve this situation is by using STATCOM. There are various type of STATCOM, SMES is one of them. SMES has the ability to provide both active and reactive power simultaneously and quickly.

When a fault occurs, the voltage at the WECS terminal drops. Thus the generated active power falls, while the mechanical power does not change and so the induction generator accelerates. After faults clearance, the reactive power consumption increases resulting in reduced voltages near the generator unit. Thus the induction generator voltage does not recover immediately after the fault. As a consequence, the generator continues to accelerate, resulting in rotor speed instability [2]. Then the WECS requires to be disconnected from the power system. But shutdown of a wind farm during and after a network disturbance is not acceptable and not desirable by transmission system owners (TSO). So, the recent trend is to decrease the shut down operation, because a shut down of large wind farm can have a serious effect on the power system operation. As for example, in Germany the wind generator shut down phenomenon has been reduced by adopting the LVRT requirement from German grid operator named E.ON Netz [3]. But due to the recent increase of large wind farms, in many countries [4] the new grid codes have been developed to ensure secure power system operation. Therefore, it is important to investigate a suitable method to enhance the LVRT capability of fixed speed wind generators.

Many authors have discussed the application of FACTs controllers like SVC to improve the LVRT capability of induction generators. However, these devices cannot provide active power control [5-7]. Also results are not compared with the grid code. Therefore in this study effectiveness of the proposed system have been compared with the grid code.

The SMES is a well-known system [1] where energy is stored within a magnet that is capable of quickly releasing megawatt amounts of power. The ability of injecting/absorbing real or reactive power independently enhances the controllability and provides operation flexibility to a power system. Therefore, the SMES system can augments the transient stability as well as LVRT capability of wind farm. The proposed SMES can provide not only the reactive power support to enhance the LVRT capability and voltage regulation but also active power support to enhance the transient stability of wind farms. Therefore SMES is used in this study.

II.1 Model System for Simulation Analyses [1]

The model system as shown in Fig. 1 has been used for the simulation of wind generator stabilization in this work. The model system consists of one synchronous generator (100 MVA), SG, and one wind turbine generator (50 MVA induction generator, IG), which are delivering power to an infinite bus through a transmission line with two circuits. Though a wind power station is composed of many generators practically, it is considered to be composed of a single generator with the total power capacity in this paper. There is a local transmission line with one circuit between the main transmission line and a transformer at the wind power station. A single squirrel-cage induction machine model, which is represented by a steady state equivalent circuit shown in Fig. 2 where s denotes a rotational slip, is used for the wind generator. To establish the rotating magnetic field of the stator, reactive power is needed to be supplied from the network to the stator winding of the induction generator. So to compensate the reactive power demand at steady state, a capacitor bank is inserted at the terminal of IG [8]. The value of the capacitor C is so chosen that the power factor of the wind power station becomes unity when it is operating in the rated condition (V=1.0, P=0.5)**.** The SMES unit is located at the induction generator terminal bus. Generator parameters are shown in Table I. The system base power is 100 MVA.

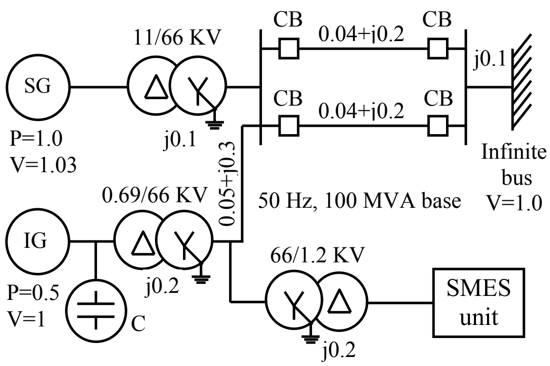

Fig.1. Power system model [1]

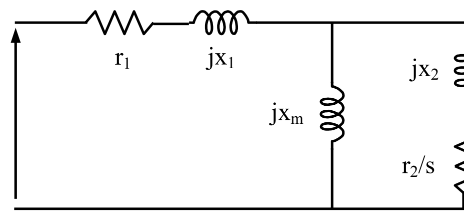

Fig.2 Steady state equivalent circuit of single squirrel-case induction generator [1]

Table I
Generator parameters

SG		IG	
MVA	100	MVA	50
Ra(pu)	0.003	r1(pu)	0.01
Xa(pu)	0.13	x1(pu)	0.18
Xd(pu)	1.2	Xmu(pu)	10
Xq(pu)	0.7	r2 (pu)	0.015
Xd′(pu)	0.3	x2(pu)	0.12
Xq′(pu)	0.22	H(sec)	1.5
Xd″(pu)	0.22		
Xq″(pu)	0.25		
Td0′(sec)	5.0		
Td0″(sec)	0.04		
Tq0″(sec)	0.05		
H(sec)	2.5		

II.2. Two-mass Drive Train Model

In case of conventional WECS model, accurate results are obtained by increasing the number of masses, springs and damper which are used to represent the physical characteristics of the actual system. It has been proved that the two-mass model for WECS representation is fairly accurate [1]. Thus this approach is adopted here and is shown in Fig. 3. As shown in the Fig. 3, the wind turbine and the generator rotor are modeled as two masses and the wind mill shafts as spring element. The dynamic equations of the two-mass representation are given by [1],

$$\frac{d\omega_t}{dt} = \frac{T_t - K_s\delta}{2H_t} \quad (1)$$

$$\frac{d\omega_e}{dt} = \frac{K_s\delta - T_e}{2H_e} \quad (2)$$

$$\frac{d\delta}{dt} = 2\pi f\left(\omega_t - \omega_e\right) \quad (3)$$

where T is the torque, δ is the angular displacement between the two ends of the shaft, ω is the angular speed, H is the inertia constant and K_s is shaft stiffness.
The indexes t and e stand for wind turbine and generator parameters, respectively.

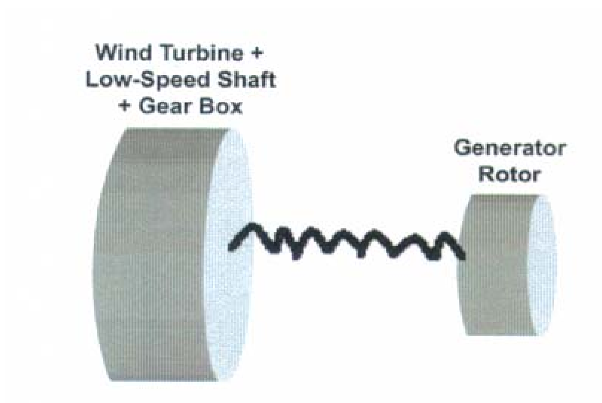

Fig. 3. The simplified two-mass model [1]

III. Modeling of Wind Turbine

The model of wind turbine rotor is complicated. According to the blade element theory [1], modeling of blade and shaft needs complicated and lengthy computations. More over, it also needs detailed and accurate information about rotor geometry. For that reason, considering only the electrical behavior of the system, a simplified method of modeling of the wind turbine blade and shaft is normally used. The mathematical relation for the mechanical power extraction from the wind can be expressed as follows:

$$P_W = 0.5\rho\pi R^2 V_W^3 Cp(\beta,\lambda) \quad (4)$$

Where, P_w, is the extracted power from the wind, ρ is the air density [kg/m^3], R is the blade radius [m] and C_p is the power coefficient which is a function of both tip speed ratio, λ, and blade pitch angle, β[deg]. The C_p equation can be written as:

$$\lambda = \frac{V_W}{\omega_B} \quad (5)$$

$$C_p = \frac{1}{2}\left(\lambda - 0.022\beta^2 - 5.6\right)e^{-0.17\lambda} \quad (6)$$

Where, ω_B is the rotational speed of turbine hub [rad/s]. Here wind speed, V_w, is in mile/hr. The C_p-λ curves are shown in Fig.4 for different values of β.

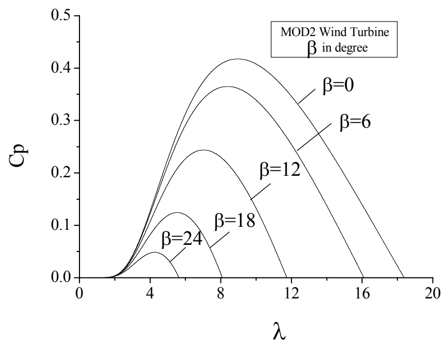

Fig. 4. C_P- λ curves for different pitch angles

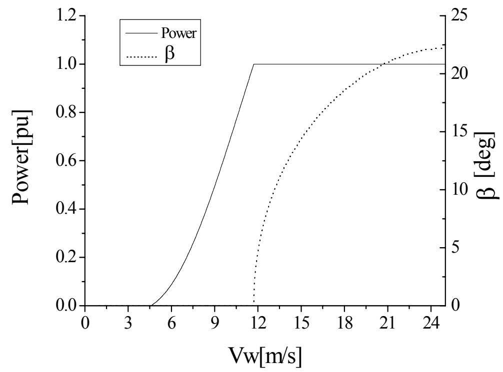

Fig.5 Output power versus wind speed and pitch angle versus wind speed characteristics

Power versus wind speed characteristic is also shown in Fig.5. When the wind velocity exceeds the rated speed, then the pitch angle of the blade needs to be controlled to maintain the output at the rated level. Fig. 5 also shows the control of pitch angle with the variation of wind velocity to control the output power nearly constant at rated capacity. Now the turbine torque, Tw, can be calculated from eq. (4).

$$T_W = 0.5\rho\pi R^2 V_W^2 Cp(\beta,\lambda)/\lambda \quad (7)$$

IV. Control System of SMES

A. Brief Overview of SMES System

The SMES system used in this paper consists of a Wye-Delta transformer, a 6-pulse PWM voltage source converter using IGBT, a DC link capacitor, a two-quadrant DC-DC chopper using IGBT, and a superconducting coil or inductor of 0.5 H. The VSC and the DC-DC chopper are linked by a DC link capacitor of 50 mF.

B. PWM Voltage Source Converter

The PWM voltage source converter provides a power electronic interface between AC power system and superconducting coil. DC link voltage V_{dc} and grid point voltage V_G are maintained as constant by the VSC. We consider here the simplified VSC single-phase equivalent circuit shown in Fig. 6, where V_{ac} and V_{conv} are the rms values of the ac system line voltage and VSC output ac voltage respectively, and R and X are the converter transformer resistance and leakage reactance respectively. With positive directions specified for real power, P, and reactive power, Q, as well as the current, I, as shown in the figure, we have the following equations, where V_d and V_q indicate real and imaginary components of the VSC output ac voltage respectively, $\bar{I}$ is a phasor of the current flowing from ac system side to the converter side, and I_d and I_q are the real and imaginary components of $\bar{I}$ respectively.

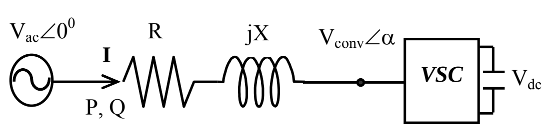

Fig. 6 VSC single phage equivalent circuit

$$\bar{I} = \frac{V_{ac} - (V_d + jV_q)}{R + jX} \quad (8)$$

$$I_d = \frac{1}{R^2 + X^2}\left[R(V_{ac} - V_d) - XV_q\right] \quad (9)$$

$$I_q = \frac{-1}{R^2 + X^2}\left[X(V_{ac} - V_d) + RV_q\right] \quad (10)$$

$$P=\mathrm{Re}\left(V_{ac}\bar{I}^*\right)=V_{ac}I_d \quad (11)$$

$$Q=\mathrm{Im}\left(V_{ac}\bar{I}^*\right)=V_{ac}I_q \quad (12)$$

From eqs. (13) and (14), it can be shown that

$$P\propto I_d \quad \text{and} \quad Q\propto I_q$$

Again, if R is very small, then from eqs. (11) and (12) it can be shown that

$$I_d \propto V_q \quad \text{and} \quad I_q\propto V_d$$

Therefore, it can be said that

$$P \propto V_q \quad \text{and} \quad Q \propto V_d$$

i.e, active and reactive power of SMES are proportional to the d- and q-axis currents and thus also to the q- and d-axis voltages.

Based on this concept, the control system of the VSC is constructed. The control system of the VSC is shown in Fig. 7. The PWM signal is generated for IGBT switching by comparing reference signal, which is converted to 3-phase sinusoidal wave with the triangular carrier signal. The frequency of the triangular carrier signal is chosen 450 Hz. The DC voltage across the capacitor is 2000 Volt, which is kept constant throughout by the 6-pulse PWM converter.

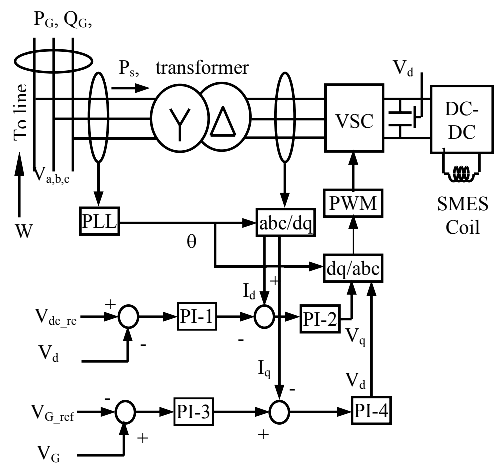

Fig. 7. The control system of the

V. Simulation Results

To verify the effectiveness of the proposed system the wind speed is considered as constant. The wind farm compatible grid code is more or less similar. The wind farm terminal voltage, for example, has to return to 90% of the nominal voltage within 3s after the starting of voltage drop [4]. Shutdown of a wind farm during and after a network disturbance is not acceptable. In order to enhance the LVRT capability, the system with high response speed for both active and reactive power compensation is needed. This paper shows a control methodology to overcome the voltage dip of wind farm during a network disturbance in power system.

The symmetrical 3LG fault in the transmission line connected to SG as shown in Fig.1 is considered as network disturbance. For analyzing the transient stability, it is considered that a 3LG fault occurs at 0.1 s and circuit breakers (CB) on the faulted line are opened at 0.2 s and finally, at 1.0s the CBs are reclosed. The time step and simulation time have been chosen as 0.00001 and 10.0 s, respectively.

Terminal voltage responses of the wind farm for 3LG fault without and with SMES considered are shown in Fig. 8. In the case without SMES, when network disturbance occurs in the system, the wind farm terminal voltage drops quickly but it cannot return back to 90% of the nominal voltage within 3 s after the beginning of the voltage drop. Thus it does not satisfy the grid code shown in fig [10] . But when the proposed SMES is used, since the necessary reactive power is supplied from the SMES properly according to the error signals, the wind farm terminal voltage returns back to its pre-fault value in less than 1 s. IG rotor speed also return back to original value as soon as possible when SMES is used. Shown in Fig: 9.

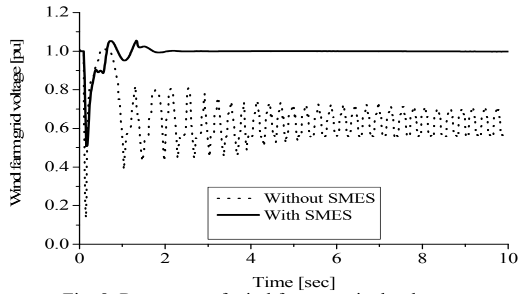

Fig. 8. Responses of wind farm terminal voltages

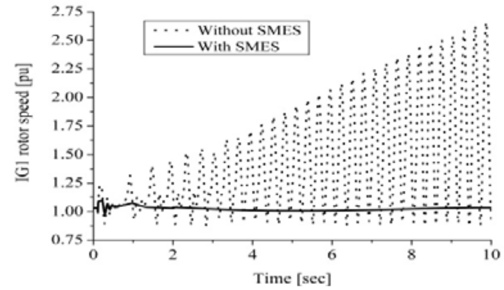

Fig. 9. Responses of IG1 rotor speed

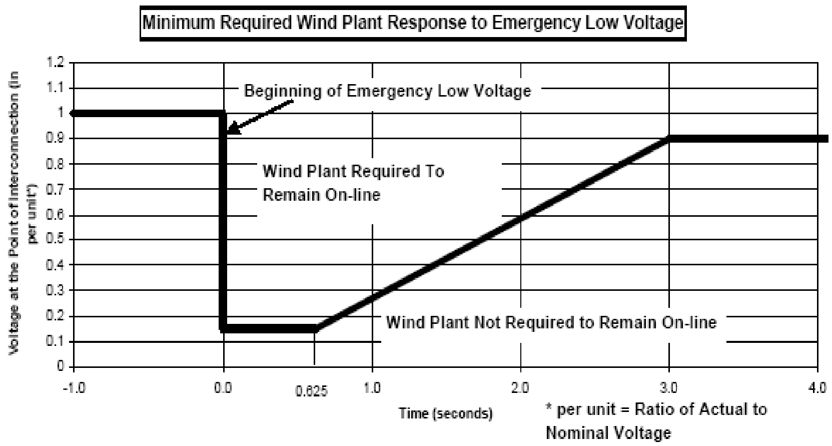

Fig. 10. Low voltage ride through standard set by FERC, U.S. [3]

6. Conclusions

In this paper, STATCOM is proposed to enhance the transient stability of wind farm integrated power system. The proposed STATCOM is able to stabilize the wind farm during a fault in the grid. The STATCOM is very effective to damp out the rotor speed oscillations. Moreover, LVRT capability of the wind farm can be enhanced by using the proposed STATCOM. Therefore, it is concluded that the integration of the proposed STATCOM to wind farm can be an effective means to improve the stability and LVRT capability of the wind farm.

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