Improving Fault Ride-Through Capability of Fixed Speed Wind Turbine by using Simultaneously Series Braking Resistor and STATCOM

M. Ferdosian
Email: ferdosian_m@yahoo.com

H. Keshavarz
Email: eng.keshavarze@gmail.com

H. Abdi
Email: hamdiabdi@gmail.com

B. Sabouri
Email: sabouri_behzad@yahoo.com

J. Mikaeili
Email: mikaili1351@yahoo.com

A. Kashiha
Email: kashiha_ali@yahoo.com

Abstract **– Fault ride-through (FRT) is required for wind turbines connected to the grid, which is steadily increasing in recent years. This paper presents a solution for wind energy conversion system based on use series braking resistor (BR) and STATCOM simultaneously for improving FRT. The wind energy conversion system (WECS) is considered as a fixed-speed system, equipped with a squirrel-cage induction generator. The drive-train is represented by two-mass model. The analytical and simulation studies of the BR and STATCOM for improving FRT capability are presented and compared with the impact of only the application of the STATCOM. The simulation results show that simultaneously STATCOM and BR effectively improve the FRT capability of WECS compare to STATCOM. PSCAD/EMTDC software is used for simulation.**

Keywords **– Braking Resistor (BR), Fault Ride Through (FRT), Fixed Speed Wind Turbines, STATCOM.**

I. INTRODUCTION

Voltage control is important for the interaction of wind turbine generation system (WTGS) to grid [1]. Interaction WTGS to grid need two main requirements as fallow:

- Reactive power control during normal operating condition
- FRT capability during fault condition.

The FRT requirement ensures that wind turbine generators must remain connected to the grid in fault condition. To achieve the optimum efficiency in conversion from kinetic energy of wind to the electrical energy, modern variable speed wind turbines (VSWT) are able to vary their speed, by means of power electronic converters. With an adequate control, the converters can be used to provide voltage support at the level of grid interface [2], [3].

However, modern VSWT are not the only ones installed in wind farms. There are important amounts of fixed speed wind turbine (FSWT) still in use. The FSWT exhibits poor FRT performance during fault condition as the induction generator draws reactive power during fault. When, fault occurs, the terminal voltage of IG drops. Therefore, the electrical torque abruptly deceases to zero due to the terminal IG voltage and the rotor speed starts to increase. After fault clearance, the reactive power consumption increases resulting in reduced voltage of IG. Thus, the induction generator voltage does not recover immediately after fault, but a transient period follows. Therefore, the generator continues to accelerate and the generator becomes unstable [4]–[6]. Thus, by providing the needed reactive power not only improves voltage regulation; but also helps to damp the rotor speed oscillations. Many papers have been discussed the using of shunt FACTS controllers like SVC and STATCOM to improve the Fault ride-through of WECS [6]–[7]. But they are able only injected reactive power after fault clearing. In this paper, series BR and STATCOM simultaneously is used for solving FRT problems of the interaction of wind energy conversion system (WECS) and power grid. The series BR prevent dip voltage drop during fault. On the other hand, the STATCOM aims to restore the voltage at the terminals of the generator and thereby mitigate the destabilizing electrical torque and power after fault clearing.

II. BRAKING RESISTOR

The series BR concept aims to contribute directly to the balance of active power during a short circuit fault. It does this by dynamically inserting a resistor in the generation circuit, increasing the voltage at the terminals of the generator and thereby mitigating the destabilizing depression of electrical torque and power during the fault period. The general schematic arrangement of series BR is shown in Fig. 1[8].

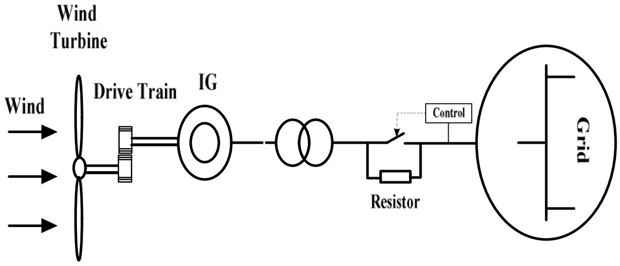

Fig.1. Schematic diagram of series BR in system

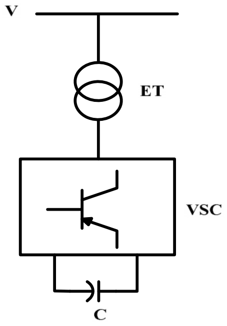

Fig.2. Schematic diagram of basic STATCOM

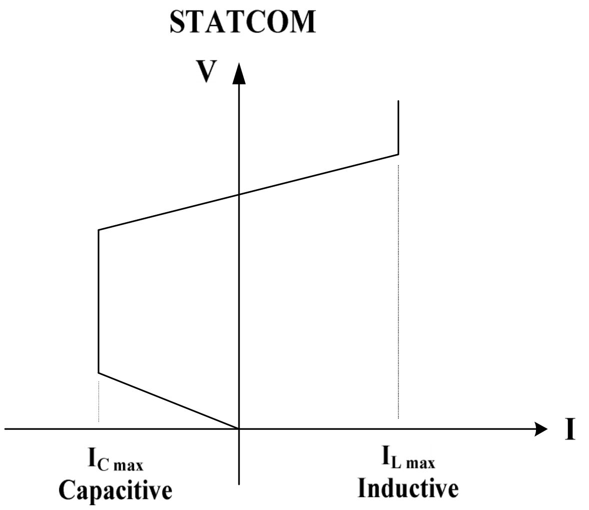

Fig.3. V–I characteristics of STATCOM

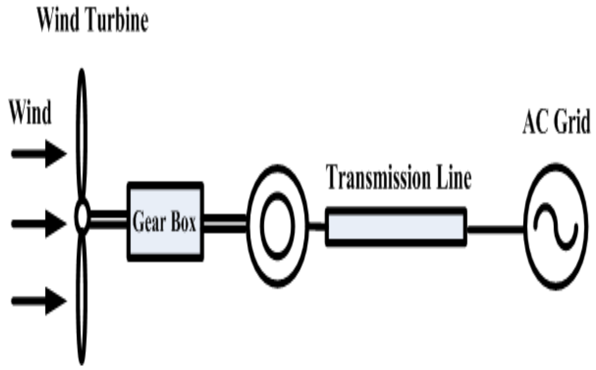

Fig.4. Schematic diagram of typical WECS

III. STATCOM

The basic configuration of the STATCOM adopted in this work is shown in Fig. 2. The voltage-sourced converter (VSC) is the basic electronic part of a STATCOM, which converts the dc voltage into a three-phase set of output voltages with desired amplitude, frequency, and phase. Fig. 3 shows the V–I characteristic of STATCOM [9].

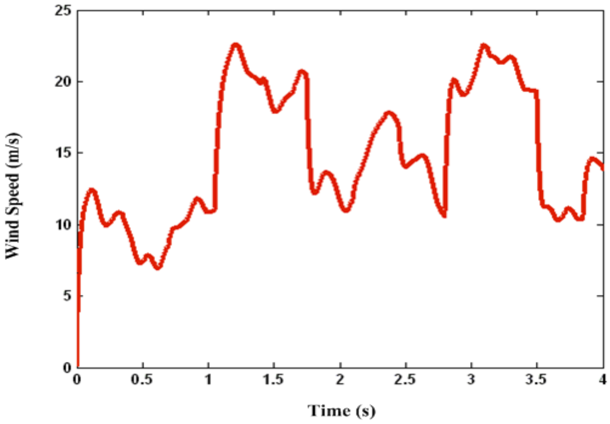

Fig.5. Wind Speed Model

As it can be seen the STATCOM can operate with its rated current even at reduced voltages. Hence, the injected reactive power varies linearly with the voltage. The effect of the STATCOM in this problem is to inject reactive power into the grid when voltage drops, as a result of a network short-circuit.

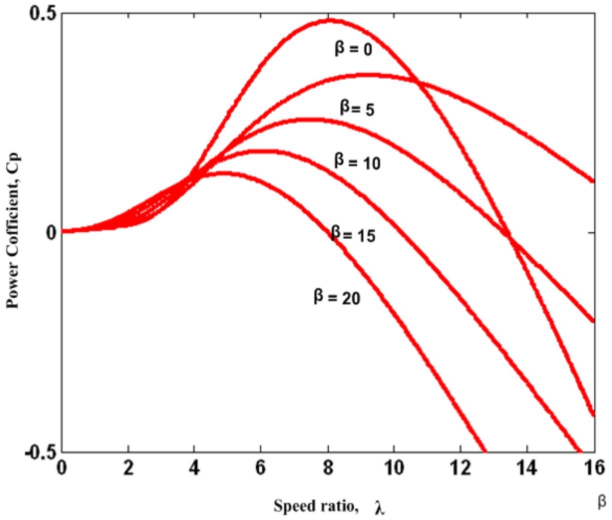

Fig.6. C_P- λ curves for different pitch angles

IV. FIXED SPEED WIND TURBINE

Fig. 4 shows the schematic diagram of a typical WECS. The wind speed model, the model of wind turbine, the mechanical model of the drive-train and induction generator is described in the following sections [10]–[11].

A. Wind Speed Model

As shown in Fig. 5, wind speed is modeled as the sum of following component:

- Base wind speed,
- Gust wind speed,
- Ramp wind speed, and
- Noise wind speed [10].

The Steady wind speed to the turbine is 15 m/s.

A. Wind Turbine Model

In general, the relation between wind speed and mechanical power extracted from the wind can be described, as follow [10]–[11]:

$$P_{WT} = \frac{\rho}{2} A_{wt}\, C_p(\lambda,\beta)\vartheta_{\omega}^{3} \qquad (1)$$

where, P_{wt} is the power extracted from the wind, ρ is the air density, v_w is the wind speed, CP is the performance coefficient or power coefficient, λ is the tip speed ration, A_{wt} is the area covered by the wind turbine rotor. Fig. 6 shows the C_p–λ curve. The performance coefficient is different for each turbine and is relative to the tip speed ratio λ and pitch angle β. In this paper, the C_p is as follows [11]:

$$C_P = \frac{1}{2}(\lambda - .022\beta^2 - 5.6)e^{-0.17\lambda} \qquad (2)$$

B. Shaft Model/Drive Train System

The shaft model of the wind turbine is described by the two-mass model as shown in Fig. 7 and defined by the following equation [10]–[11]:

$$\frac{\partial\theta_s}{\partial t} = \omega_t - \omega_g \tag{3}$$

$$\frac{\partial\omega_t}{\partial t} = \frac{1}{2H_t}(T_t - K_s\theta_s + D(\omega_g - \omega_t)) \tag{4}$$

$$\frac{\partial\omega_g}{\partial t} = \frac{1}{2H_g}(-T_e + K_s\theta_s - D(\omega_g - \omega_t)) \tag{5}$$

Where, T_t is the mechanical torque referred to the generator side; T_e the electromagnetic torque; H_t and H_g are the equivalent turbine-blade inertia and the generator inertia, respectively; ω_t and ω_g are the turbine's rotational speed and the generator's rotational speed, respectively; K and D are the shaft stiffness and the damping constant, respectively; θ_s is the angular displacement between the ends of the shaft.

IV. EFFECT OF SERIES BR AND STATCOM DURING FAULT

The electrical torque, T_e can be calculated, as follows:

$$T_e = \frac{R_r}{s}I_r^2 = \frac{R_r}{s}\frac{V_{th}^2}{(R_{th}+R_r/s)^2+(X_{th}+X_r)^2} \tag{6}$$

Where, R_r, R_s, *and* R_{th} are the rotor, stator, and thevenin resistance, respectively; X_r, X_s, X_m, *and* X_{th} are the rotor, stator, magnetizing, and thevenin reactance, respectively. Also, V_t *and* V_{th} are the terminal and thevenin voltages, respectively; I_r *and* I_s are the rotor and stator currents, respectively. In (6), $s\ (\omega_s-\omega_r)\ \omega_s$ is the rotor slip, where ω_s and ω_r are the synchronous and rotor speeds, respectively. When the induction machine operates as a generator, the mechanical torque is negative. Therefore, the electrical-mechanical equilibrium equation of an induction generator can be written, as follows:

$$\frac{d\omega_r}{dt} = \frac{(T_e - T_m)}{2H} \tag{7}$$

During fault condition, the large fault currents would flow during a downstream fault before the opening of a circuit breaker. This will cause the voltage at PCC to drop, which would affect operation of STATCOM. Therefore, the electrical torque abruptly deceases to zero due to the terminal IG voltage and the rotor speed starts to increase and the generator will become unstable.

By using simultaneously series BR and STATCOM dip voltage sag is prevented at the terminal voltage of induction generator According to (6), the electrical torque is proportional to the square of the terminal voltage. Therefore, BR prevents from the decreasing electrical torque and accelerating the induction generator. On the other hand, the STATCOM aims to increase the voltage at the terminals of the WECS and thereby mitigate the destabilizing electrical torque and power during the fault.

V. SIMULATION RESULTS

A single line diagram of the simulated power system with series BR and STATCOM is shown in Fig. 8. The parameters of this system are listed in appendix A. A three phase short circuit fault is simulated on the middle of line B, which starts at t□10 s. After 0.2 s, the circuit breaker isolated the faulted line. The simulations have been carried out by PSCAD/EMTDC for Three cases, as follows:

Case A) Without using any series BR and STATCOM,
Case B) Only by using STATCOM,
Case C) By using simultaneously series BR and STATCOM.

Fig. 9 shows the rms value of the terminal voltage of IG for three cases. It can be observed that terminal voltage of IG decreases to zero in cases B and A, approximately during fault and in case A cannot be restored to pre-fault level. The series BR not only decreases the voltage sag to 0.6 per-unit, but also the voltage at PCC can be restored quickly after the fault compare to case B.

Fig. 10 shows the rotor speed of the induction generator for three cases, respectively. As shown in Fig. 10, the variation of the rotor speed is reduced in both cases B and C, and returned in pre-fault value; but the rotor speed in case A is unstable. But, the using series BR and STATCOM is very effective in suppressing the variations of the swings fault clearing.

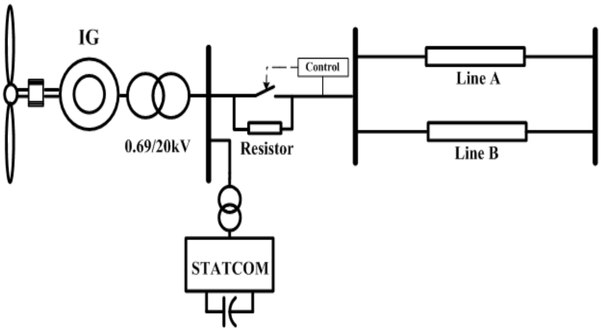

Fig.8. Simulated power system with series BR and STATCOM

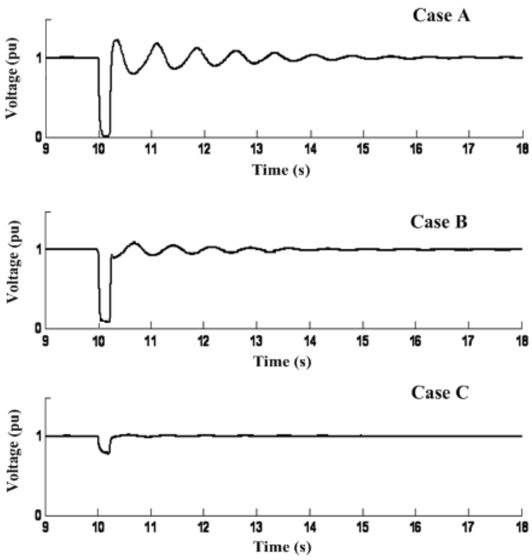

Fig.9. Terminal voltage during fault

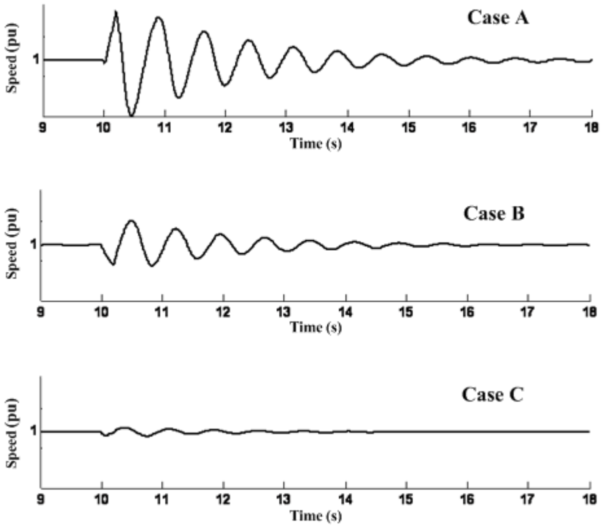

Fig.10. Rotor speed of induction generator during fault

VI. CONCLUSION

In this paper, the effect of simultaneously using the series BR and STATCOM in the performance of fixed speed turbines has been studied based simulation by PSCAD/EMTDC. The simulation results show that simultaneously using the series BR and STATCOM not only suppresses the voltage drop but also improves generator speed and the voltage stability of power grid integrated with WECS. Also, the comparison with STATCOM shows that the simultaneously using of the series BR and STATCOM is more effective for enhancement of FRT capability than STATCOM.

APPENDIX

Table I : Grid Parameters

Supply	20 kV
Frequency	50Hz
Step down	.69kV/20 kV
Transformer	10 MVA
X/R ratio	8

Table II: Induction Generator Parameters

Number of poles	4
Slip	1.8%
Power factor	0.9
Stator resistance	0.0577 Ω
Rotor resistance	0.0161 Ω
Stator reactance	0.0782 Ω
Rotor reactance	0.012 Ω
Magnetizing reactance	2.43 Ω

REFERENCES

[1] J. M. Rodriguez, and J. L. Fernandez, “Incidence on power system dynamics of high penetration of fixed speed and doubly fed wind energy systems: study of the Spanish case,” *IEEE Trans. Power Syst.*, vol. 17, no. 4, pp. 1089–1095, Nov. 2002.

[2] J. G. Slootweg, S. W. D. de Haan, H. Polinder, and W. L. Kling, “General model for representing variable speed wind turbines in power system dynamics simulations,” *IEEE Trans. Power Syst.*, vol. 18, no.1, pp. 144–151, Feb. 2003.

[3] H. S. Ko, G. G. Yoon, and W. P. Hong, “Active use DFIG-based variable-speed wind-turbine for voltage control in power system operation,” *J. Elect. Eng. Technol.*, vol. 3, no. 2, pp. 254–262, Jun. 2008.

[4] M. Aten, J. Martinez, and P. J. Cartwright,“Fault recovery of a wind farm with fixed speed induction generators using a STATCOM,” *Wind Eng.*, vol. 29, no. 4, pp. 365–375, 2005.

[5] P. M. Anderson, and Anjan Bose, “Stability Simulation of Wind Turbine Systems,” *IEEE Trans. Power App. Syst.*, vol. PAS-102, no.12, pp.3791–3795, Dec. 1983.

[6] S. M. Muyeen, M. A. Mannan, M. H. Ali, R. Takahashi, T. Murata, and J. Tamura, “Stabilization of wind turbine generator system by STATCOM,” *IEEJ Trans. Power Energy*, vol. 126, no. 10, Oct. 2006.

[7] H. Gaztanaga, I. E. Otadui, D. Ocnasu, and S. Bacha, “Real-time analysis of the transient response improvement of fixed-speed wind farms by using a reduced-scale STATCOM prototype,” *IEEE Trans. Power Syst.*, vol. 22, no. 2, pp. 658–666, May 2007.

[8] W. Freitas, A. Morelato, and W. Xu, “Improvement of induction generator stability using braking resistors,” IEEE *Trans. Power Syst.*, vol. 19, no.2, pp. 1247–1249, May. 2004.

[9] W. Freitas, A. Morelato, W. Xu, and F. Sato, “Impacts of ac generators and DSTATCOM devices on the dynamic performance of distribution systems,” *IEEE Trans. Power Del.*, vol. 20, no. 2, pp. 1493–1501, Apr. 2005.

[10] P. M. Anderson, and Anjan Bose, “Stability simulation of wind turbine systems,” *IEEE Trans. Power App. Syst.*, vol. PAS-102, no.12, pp. 3791–3795, Dec. 1983.

[11] B. Adkins, and R. G. Harley, *The General Theory of Alternating Current Machines*. London, UK: Chapman & Hall, 1975.

AUTHOR'S PROFILE

M. Ferdosian

was born in Abadeh, Iran, on Sep 9, 1985. He received the B.S. degree in electrical control engineering from Malek Ashtar University, Isfahan, Iran, in 2007 and the M.S. degree in electrical power engineering from Azad University of Science and Research branch, Iran, in 2011.

His research interests are flexible AC transmission system (FACTS), static series/parallel compensators, and renewable energy.

H. keshavarz ziarani

was born in Abyek, Iran, on july 6, 1982. He received the B.S. degree in Electronic Engineering from Department of Electronic and Computer Engineering, Qazvin Azad University, Qazvin, Iran, in 2007 and the M.S. degree in electrical power engineering from Azad University of Science and Research branch, Iran, in 2005.

His research interests are Power electronics applications in power system and electrical drives Study and modeling of FACTD devices Power system dynamic.

H. Abdi

was born in Paveh, Kermanshah, Iran, on July 1973. He received his B.Sc. degree from Tabriz University, Tabriz, Iran in 1995; M.Sc., and Ph.D. degrees from Tarbiat Modares University, Tehran, Iran, in 1999 and 2006, all in Electrical Engineering. Currently, he is an assistant professor in the Department of Electrical Engineering, Razi University, Kermanshah, Iran.

His research interests include power system optimization, operation and planning, restructuring and market design, transmission expansion planning, renewable energies, and design of electrical and control systems for industrial plant.

B. Sabouri
was born in Tehran, Iran, on Sep 8, 1971. He received the B.S. degree in electrical electronic engineering from Azad University, Garmsar, Iran, in 1996.
His research interests are flexible AC transmission system (FACTS), static series/parallel compensators.

Jamal Mikaeili
was born in Kermanshah, Iran, on Sep 21, 1972. He received the B.S. degree in electrical power engineering from Islamic Azad University, Yazad, Iran, in 2000 and the M.S. degree in electrical power engineering from Azad University of pardis Science and Research branch, Hamedan, Iran, in 2013.
His research interests are flexible AC transmission system (FACTS).