Application of STATCOM for Enhancing Steady and Dynamic Performance of Distribution System with DFIG Wind Power Generation

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Abstract— *The paper presents the application of Static Synchronous Compensator (STATCOM) for enhancing steady and dynamic performance of distribution system with Doubly Fed Induction Generator (DFIG) wind power generation. The mathematical models of STATCOM, wind energy conversion system such as wind, wind turbine, drive train, DFIG, and converter are systematically derived. The dynamic behavior of the power system with STATCOM controller is also investigated by using MATLAB/Simulink. It was found in the simulation results that the STATCOM can improve the dynamic behavior of the system.*

Keywords— STATCOM, Wind Energy, Double Fed Induction Generator, Power System Dynamic.

I. INTRODUCTION

Because of the global warming concerns, government around the world is implemented to use the energy that kind of clean and environmental-friendly energy. Renewable energy such as ocean energy, solar energy, and wind energy are suggested to decrease the use of fossil fuels [1-2]. Wind power generation is continuously increased in the last few years. Wind energy conversion system consists of wind turbine, drive train, and generator. Wind turbine converts the kinetic energy to the mechanical power which is coupled to the generator [3]. The drive train includes low speed shaft, high speed shaft and gearbox. With many kinds of generator, variable speed application is used Permanent Magnet Synchronous Generator (PMSG) and Double Fed Induction Generator (DFIG). The variable speed application with DFIG has gained to use because of more flexible to control real and reactive power flow. It has a wide range of dynamic speed control depending on the size of the converter. Moreover, with the less rating of converter, it cause in lightweight mechanism structure and cost. The largest wind power plant in North America is used DFIG [4-5].

The modeling and simulation DFIG based on variable speed wind energy conversion system play very important role to study wind, wind turbine, drive train, DFIG and converter dynamic, it can help us to investigate the dynamic behaviors, design and improve the converter and pitch controller before installation for maximum performance [6].

For many years, Flexible AC Transmission System has been applied for improving steady state and dynamic of power system. There are various kinds of FACTS devices such as Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), etc [7].

This paper presents the STATCOM, wind energy conversion, wind turbine, drive train, DFIG, and converter model connected to grid. The presented model of variable speed wind energy conversion system dynamic analysis is implemented in MATLAB/SIMULINK. The study of dynamic behaviors when a temporary three phase to ground fault occurrence with DFIG based on wind energy conversion system was investigated in this paper.

II. MATHEMATICAL MODEL

This Section will provide the mathematical models of STATCOM and DFIG based on wind energy conversion system.

STATCOM

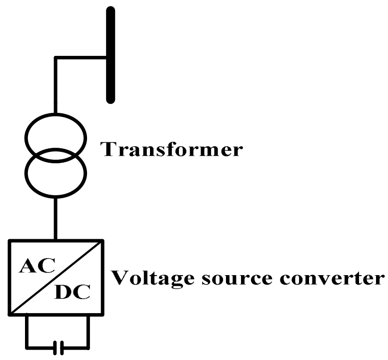

Fig. 1: STATCOM

Static Synchronous Compensator (STATCOM) consists of a solid-state voltage source converter with advanced high-power electronics switching, dc capacitor and transformer as shown in Fig. 1. The converter is used to convert dc voltage into ac voltage. The ac voltage can be controlled both magnitude and angle. The STATCOM is able to absorb and supply reactive power by regulating voltage angle same as line voltage.

Wind Turbine and Drive Train System

In steady state, the mechanical power which is extracted from the wind turbine is described by following equation. Mechanical power of wind turbine is expressed by [8]

$$P_m = c_p(\lambda,\beta)\frac{\rho A}{2}v^3 \quad (1)$$

$$c_p(\lambda,\beta) = c_1(\frac{c_2}{\lambda_i} - c_5\beta - c_4)e^{-c_5/\lambda_i} + c_6\lambda \quad (2)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + c_7\beta} - \frac{c_8}{\beta^3+1} \quad (3)$$

$$\lambda = \frac{R\omega}{v} \quad (4)$$

Where $c_p(\lambda,\beta), A, v, \beta$ are power coefficient, sweep area, wind speed and pitch angle, respectively.

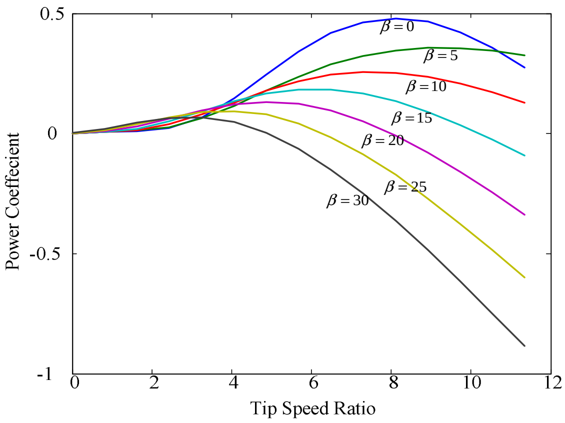

Fig. 1: Wind turbine characteristic

Mechanical torque T_m is the ratio of mechanical power to turbine speed as given by

$$T_m = \frac{P_m}{\omega} \quad (5)$$

The power from the wind turbine can be controlled via the power coefficient. In practical, it is controlled by adjusting a pitch angle (β) to maintain a power from wind turbine. Fig. 2 shows the characteristic of wind turbine for various pitch angles.

A drive train system consists of shaft and gearbox. The dynamic of the drive train system is described by [9]

$$2H_t\frac{d\omega_t}{dt} = T_m + T_t \quad (6)$$

$$2H_g\frac{d\omega_g}{dt} = T_e - T_t - F\omega_g \quad (7)$$

$$T_t = -[D_e(\omega_t - \omega_g) + K_e\theta_t] \quad (8)$$

$$\frac{d\theta_t}{dt} = \omega_t\omega_b \quad (9)$$

$$\frac{d\theta_t}{dt} = \omega_t\omega_b \quad (10)$$

Where H_t, H_g, ω_t, ω_g, K_e, F and D_e are turbine inertia, generator inertia, turbine speed, generator speed, stiffness, DFIG damping, equivalent damping coefficient, respectively.

Doubly Fed Induction Generator (DFIG)

Doubly Fed Induction Generator (DFIG) is a wound rotor induction machine which includes stator and rotor winding. This fifth order of DFIG in d-q model is used in this paper [10].

The d-q stator voltage (u_{ds}, u_{qs}) are described by

$$u_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{\omega_b dt} - \omega_s\varphi_{qs} \quad (11)$$

$$u_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{\omega_b dt} - \omega_s\varphi_{ds} \quad (12)$$

The d-q rotor voltage (u_{dr}, u_{qr}) are described by

$$u_{dr} = R_r i_{dr} + \frac{d\varphi_{dr}}{\omega_b dt} - (\omega_s - \omega_r)\varphi_{qr} \quad (13)$$

$$u_{qr} = R_r i_{qr} + \frac{d\varphi_{qr}}{\omega_b dt} - (\omega_s - \omega_r)\varphi_{dr} \quad (14)$$

Where i_{dr} , i_{qs} are direct and quadrature axis stator current. R_s , R_r are stator and rotor resistance. The ω_s , ω_r are synchronous and DFIG speed.

The d-q stator flux ($\varphi_{ds}, \varphi_{qs}$) include self and mutual flux linkage are described by

$$\varphi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (15)$$

$$\varphi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (16)$$

The d-q rotor flux ($\varphi_{dr}, \varphi_{qr}$ $\varphi_{dr}, \varphi_{qr}$) include self and mutual flux linkage are expressed as

$$\varphi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (17)$$

$$\varphi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (18)$$

Where L_s, L_r, and L_m are stator, rotor and mutual inductance, respectively.

The electromagnetic torque T_e is expressed as

$$T_e = (\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}) \quad (19)$$

Converter

DFIG converter system as shown in Fig. 1 is a back-to-back converter connected via a DC link capacitor. It consists of Rotor Side Converter (RSC) and Grid Side Converter (GSC) .The RSC is controlled voltage source by injecting the ac voltage at slip frequency to the rotor. The GSC is controlled voltage source as generates the ac voltage. It maintains the DC link voltage to be constant value. The converter is expressed as [11]

$$P_r = P_g + P_{dc} \quad (20)$$

Where P_r, P_g and P_{dc} are RSC, GSC and DC link real power, expressed by following

$$P_r = v_{dr} i_{dr} + v_{qr} i_{qr} \quad (21)$$

$$P_g = v_{dg} i_{dg} + v_{qg} i_{qg} \quad (22)$$

$$P_{dc} = v_{dc} i_{dc} = C v_{dc\_nom} \frac{dv_{dc}}{dt} \quad (23)$$

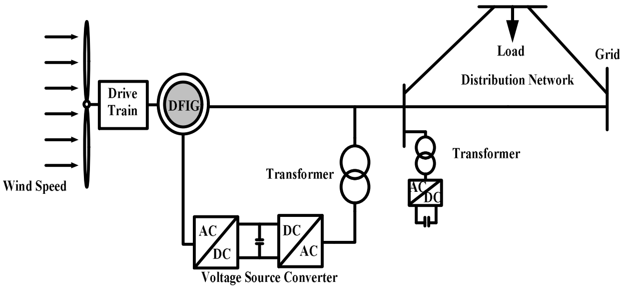

Fig. 2: Sample System

III. SIMULATION RESULTS

The presented mathematical model of STATACOM and DFIG based on wind energy conversion system is tested on a sample system as shown in Fig.2. A temporary three-phase to ground fault occurs at load bus and the fault is cleared after 100 msec. It can be observed from Fig. 3 that STATCOM can improve system voltage both steady and dynamic state.

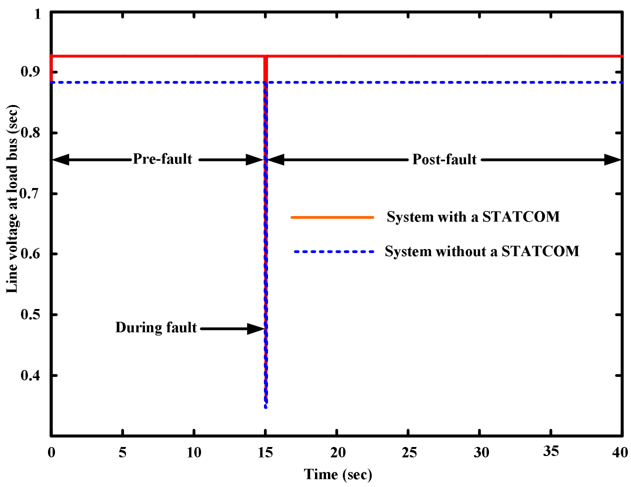

Fig. 3: Comparison of the voltage at load bus of the system with and without STATCOM

IV. CONCLUSION

This paper investigated the effect of Static Synchronous Compensator (STATCOM) on steady and dynamic state of the system connected with Doubly Fed Induction Generator (DFIG) wind power generation. Their mathematical models are systematically derived. The simulation results are tested on MATLAB/Simulink. The simulation results indicated that STATCOM can improve both steady and dynamic performance of the system.

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