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STATCOM based mitigation of Voltage Sag in DFIG based Wind connected System

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Abstract—

Due to the change in the nature and environmental condition, the power which is being generated from a renewable supply of energy continually fluctuates. Similarly, by injection of wind power into the electrical grid, some power quality problems may rise because of the unsteady nature of wind and relatively new types of induction generators. For usingthe Doubly Fed Induction Generators (DFIGs) as the primary power supply in an isolated system, they are supposed to be ready for regulating the voltage and frequency of the system with Fault Ride-Through (FRT) capability.

Voltage stability becoming an important criteria to maintain the DFIG-based wind turbine functioning during disturbances. This paper proposes a new control strategy for riding through the symmetrical faults for a DFIG operating in an isolated power system which is done by a Static Synchronous Compensator (STATCOM).When it is integrated in a power system with conventional synchronous generators, the Fault Ride-Through capability of a DFIG is much improved by the proposed control strategy while providing voltage support and frequency balance to the system throughout the fault duration. Thus, the stability in the transient condition of the power system is significantly improved. The developed system is simulated and analyzed in MATLAB/Simulink software.

KEYWORDS:
Wind Turbine; DFIG; Modeling; Voltage Sag; STATCOM; Voltage Mitigation.

I. INTRODUCTION

As a result of global warming, the impact of fossil fuel and non-renewable power generation on the environment became a priority for scientist. Due to these all issues, we are focussing on non-conventional and clean energy such as wind, solar and other such energies [1]. During the last decades wind energy has received a huge boost and determined as the most promising alternative source of energy because of its availability and cheapness in comparison with other resources. One of the most vital renewable energy sources are Wind Turbine Generators (WTGs), which are very much used in the power islanded networks and/or individual loads. DFIGs are fairly used in various WTG types due to their back-to-back partially rated power converter system and variable speed operation with their relatively simple control.

With the increase in wind turbines technology, the demand for this non-conventional wind energy has also increased drastically. Due to uneven nature of the wind, power extracted from the nature by wind turbines are also fluctuating. So, the wind generator output induced to the power grid may cause some power quality issues [2].The most important challenge for the DFIGs is their operation during voltage sags.

In this paper, wind turbine, drive train, DFIG and the converter model is connected to a grid. During a three-phase fault, the system is analysed and the voltage sag thus occurred is mitigated by using STATCOM. The method used here for wind energy system transient analysis is implemented in MATLAB/SIMULINK.

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II. MATHEMATICAL MODELS

The mathematical model of Wind Turbine will be provided in this section. The DFIG configurationhere whichis based on wind energy conversion system (WECS) is shown in Fig. 1.

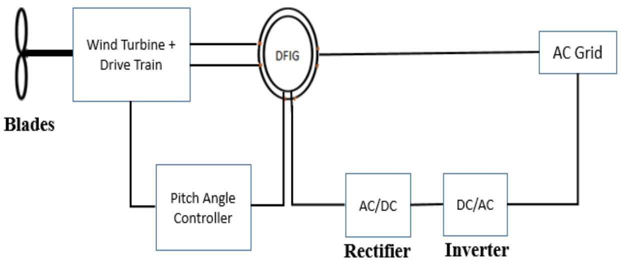

Fig. 1 DFIG based on wind energy conversion system

A. *Wind Turbine and Drive Train System*

In steady state, the mechanical power P_m which is extracted from the wind turbine can be expressed by [3]

$$P_m = \frac{1}{2} * \rho * A * C_p(\lambda,\beta) * \upsilon^3 \quad \dots(1)$$

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right) e^{-C5/\lambda i} + C_6\lambda \quad \dots(2)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \quad \dots(3)$$

$$C_{pmax} = C_{pnom} \quad \dots(4)$$

$$\lambda_{inom} = \frac{1}{\frac{1}{\lambda nom} - 0.035} \dots(5)$$

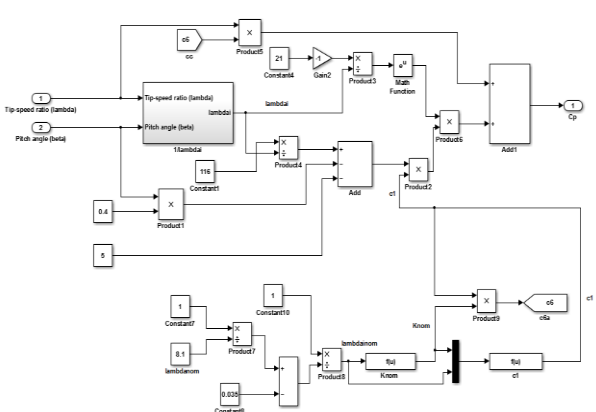

Fig. 2C_p Model

$$K_{nom} = \frac{-(C_2 * C_5/\lambda_{inom} - C_4 * C_5 - C_2).\ e^{-C5/\lambda inom}}{(\lambda_{nom})^2} \quad \dots(6)$$

$$C_1 = \frac{C_{pnom}}{\left(\frac{C_2}{\lambda_{inom}} - C_4\right) * e^{-(C5/\lambda inom)} + (K_{nom} * \lambda_{nom})} \quad \dots(7)$$

$$C_6 = K_{nom} * C_1 \quad \dots(8)$$

$$\lambda = \frac{\omega R}{\upsilon} \quad \dots(9)$$

Where $C_p(\lambda,\beta)$, A, β, υ are power coefficient, sweep area, pitch angle and wind speed respectively. C_1-C_6 are the turbine constants, C_{pnom} and C_{pmax} are the rated and maximum value of Cp respectively whileλ is the requiredtip speed ratio of the rotor blade tip speed to wind speed, λ_i is the initial value of λ and λ_{nom} is the rated value of λ. K_{nom} refers to the nominal value of pitch.

Mechanical torque $T_m$referred to as the ratio of mechanical power to turbine speed as given by [4]

$$T_m = \frac{P_m}{\omega} \quad \dots(10)$$

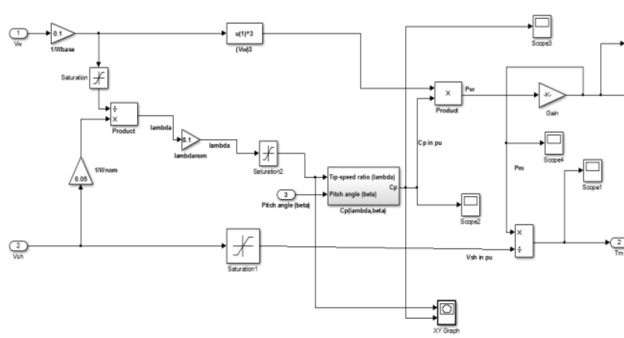

Fig. 3 Wind Turbine Model

The wind turbine power can be controlled via changing the power coefficient. Naturally, it is controlled by adjusting the pitch angle to maintain the power from wind turbine.As shown in Fig. 4, C_P function has the highest value of C_{Pmax} = 0.48 where the pitch angle β = 0 . For capturing the maximum wind power generated, β should be equal to zero.

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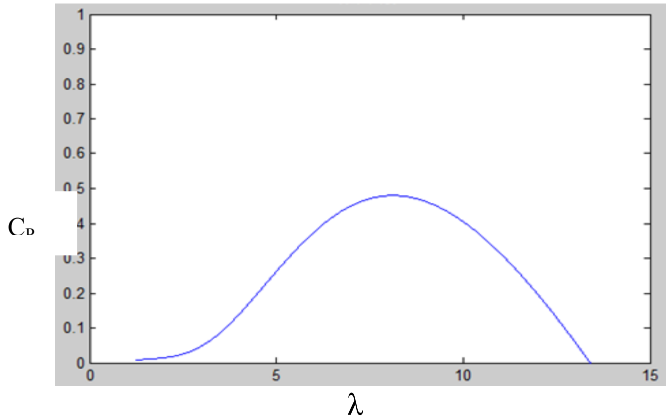

Fig. 4Curve of C_P for $\beta = 0$

Shaft and gearbox together makes the drive train system. Here, two-mass model of the drive train system is used which is given by [5]

$$T_t - T_{sh} = 2*H_t*\frac{d\omega t}{dt} \quad \ldots(11)$$

$$\frac{d\theta sta}{dt} = \frac{\omega t-\omega r}{Webase} \quad \ldots(12)$$

$$T_{sh} = [\theta_{sta} *K_{ss} + K_d *(W_t\text{-}W_r)] \quad \ldots(13)$$

$$T_{base} = \frac{Pnom}{Webase} \ldots(14)$$

$$T_m = T_{base}* T_{sh} \quad \ldots(15)$$

Where T_t and $T_{sh}$are output torque of the turbine and shaft torque respectively. H_t is turbine inertia constant.$\theta_{sta}$is shaft twist angle and $K_{ss,}$ ω_t are shaft stiffness coefficient and angular speed of the wind turbine respectively.P_{nom} refers to the rated mechanical power of wind energy system, W_{ebase}refers the electrical base speed and T_{base} as the base torque of wind turbine.

Simulink model of the Drive Train is shown in the figure below.

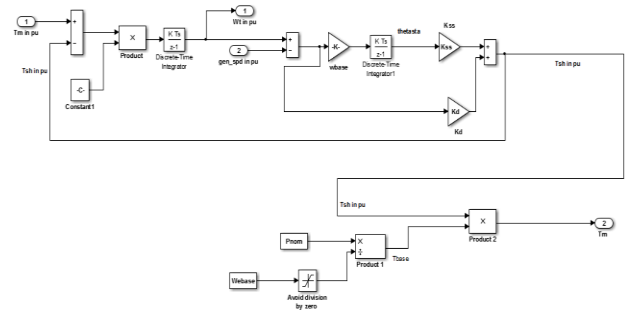

Fig. 5 Drive Train Model

B. Pitch Angle Controller

The pitch angle controller model as shown in Fig5, is useful when wind speed is high and the generator speed can no longer be controlled by increasing the generated power because of capacity constraints of generator and converters/inverters. Therefore the blade pitch angle is adjusted to limit the aerodynamic efficiency of the rotor. This prevents the rotor speed becoming too high. The pitch angle should be varied to balance the electrical and mechanical power [6].

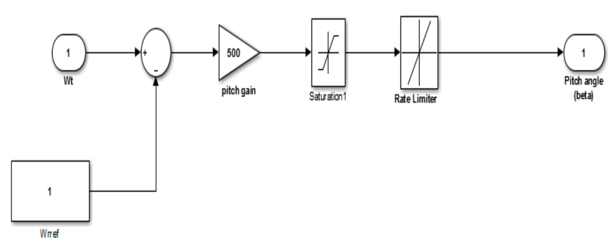

Fig. 6 Pitch Angle Controller Model

Doubly-Fed Induction Generator (DFIG) is connected to the grid via its two converters which is the Rotor Side Converter (RSC) and Grid Side Converter (GSC).DFIG stator is connected to the grid directly while the rotor is connected via the converters to the grid.Pulse Width Modulation (PWM) generator is used for generating and supplying the pulse into the convertors. Choke is used here in order to limit the high starting current from the generator.

The Simulink model thus drawn for the purpose is shown in Fig. 7.

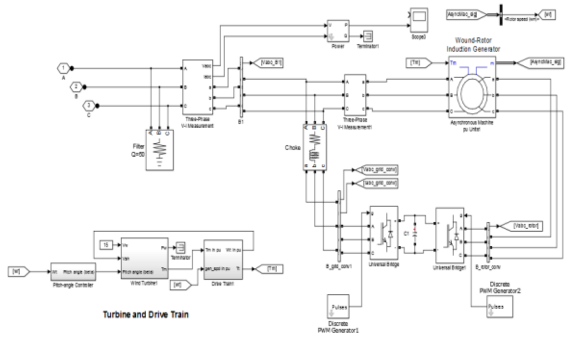

Fig. 7 DFIG with its converters

III. MODEL OF THE POWER GRID

The single line diagram of test system used in this study is illustrated in Figure 3. The grid model consist of a 33 kV, 60 Hz, grid supply point, feeding a 25 kV distribution system through a 1000 MVA, 33/25 kV step down transformer, which is fed into a 460V system through 1000 MVA, 25kV/460V step down transformer. There is astatic load of 500 MW at B460 bus. The line of 25 kV, 30kilometres is shown as a nominal-Π line. The DFIG based wind turbine is of 1.5 MW.The speed of the wind is variable with gradual increase in slope [7].

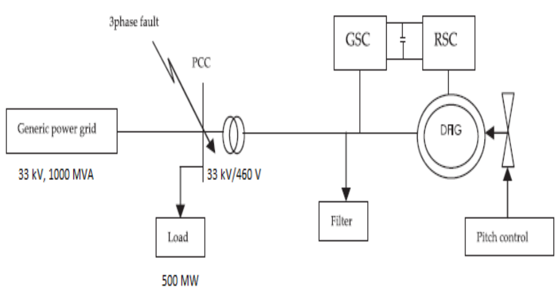

Fig. 8 Single line diagram for the system

The DC link voltage of the DFIG is taken as 1000 mF. The system is studied for 0.4secs. For providing voltage sag compensation, a DVR is connected as a series device for voltage compensation at the sending end bus (460 V). Here in this model, a nominal Pi-Line of 30 km is used.

The DFIG is thus connected to the power grid via the Point of Common Coupling (PCC) and a three phase or symmetrical fault is created in the load side.The Simulink model is shown in Fig. 9.

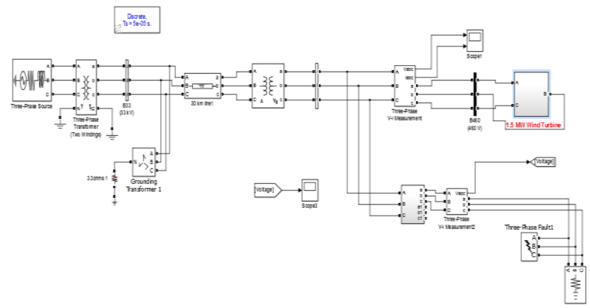

Fig. 9 DFIG connected to the grid

IV. STATIC SYNCHRONOUS COMPENSATOR

Static Synchronous Compensator (STATCOM) is a FACTS device consisting of a coupling transformer, Voltage Source Converter (VSC) and a dc energy storage device connected in shunt via the coupling transformer to the distribution network. DC energy source which is present is converted into three phase AC output voltage by VSC across the storage device. It is used for generating and absorbing the reactive power by continuously varying the amplitude ofthe converter voltage. With respect to the line bus voltage, a controlled current flows in between the tie reactance which is between the STATCOM and the distribution network enabling the STATCOM to mitigate the fluctuations in voltage such as swells, sags, transient disturbances etc and for providing smooth voltage regulation.

Here in this paper, a 3-level cascaded multilevel converter based STATCOM is used for mitigating the voltage sag [8].

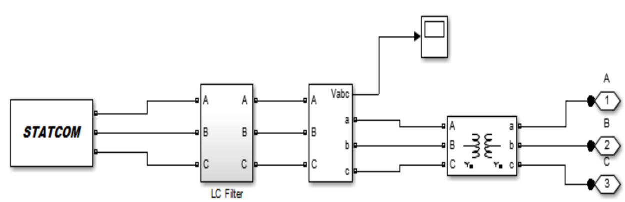

Fig. 10 STATCOM Model

A LC filter is connected in series with the system for removing any harmonic distortions if present. Inside the STATCOM, three multilevel inverter is used for three phases. Four switches are used in each of the multilevel inverter as shown in Fig. 11. PWM generator is used for generating the pulses.

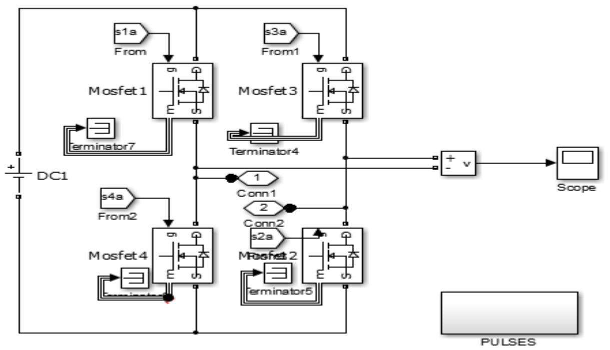

Fig. 11 Multilevel Inverter

The STATCOM model [9] thus generated is integrated to the existing model in the load side for voltage mitigation purpose. The model thus produced is as shown in Fig. 12.

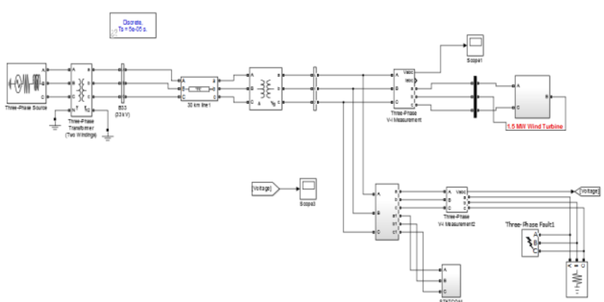

Fig. 12 Grid connected DFIG with STATCOM

V. SIMULATION RESULTS AND DISCUSSION

The DFIG based system is connected to the grid and the real and reactive power of the system isas shownbelow. The system is analysedunder 3-phase fault and in not going to affect the DFIG active power output, the initial fluctuations of the DFIG as shown in figure 13 is due to the wind speed variations and at 1.5 MW,its becoming almost constant.

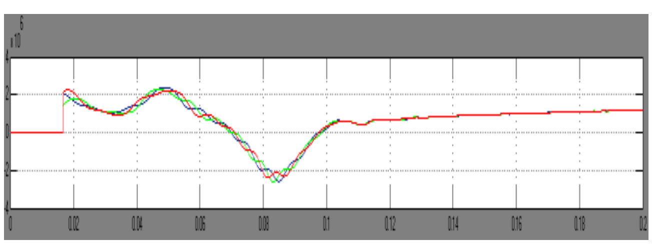

Fig. 13 Active power output of DFIG

Reactive power as shown in Fig. 14 is almost equal to zero, thus making it a free flowing system and the power factor closely equals to 1.

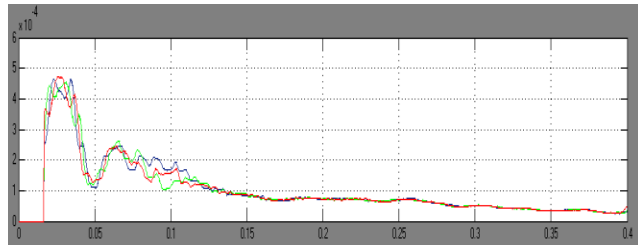

Fig. 14 Reactive power output of DFIG

Fig. 15 and Fig. 16 shows the Stator voltage and current, Rotor voltage and current respectively.

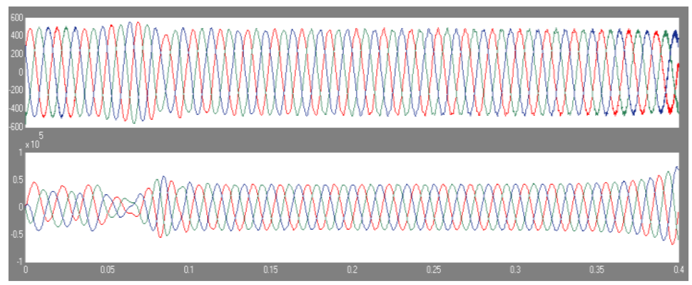

Fig. 15 Stator voltage and current waveform

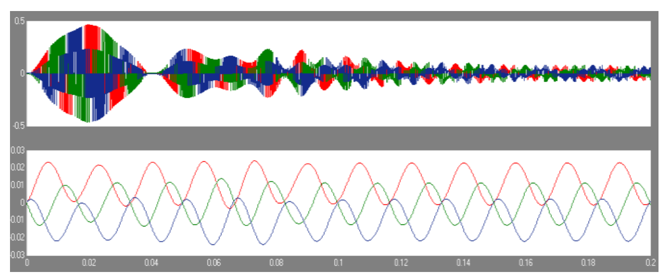

Fig. 16 Rotor voltage and current waveform

A 3-phase fault is created for atransition time of 0.1secsto 0.2secs. Voltage sag is thus created for that interval, which is about 50% of the normal voltage. System during the voltage sag is as shown below [10].

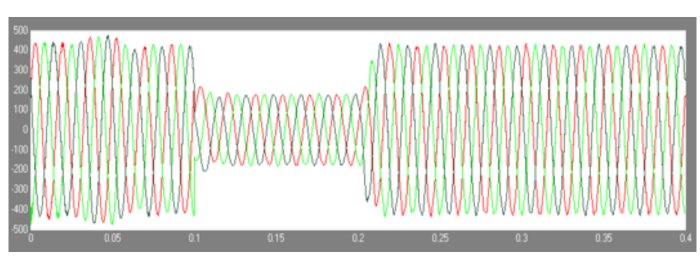

Fig. 17 System during 3-phase fault

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A STATCOM is connected at the load end and it compensates for the voltage needed for the sag compensation and the obtained result is given below.

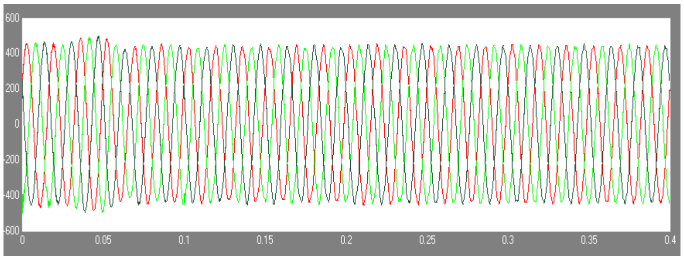

Fig. 18 System after voltage mitigation

STATCOM is thus injecting the voltage needed for restoring the system to the normal operating condition.

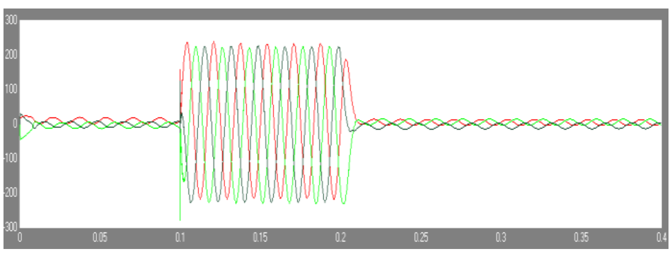

Fig. 19 STATCOM voltage injected into the system

VI. CONCLUSION

This paper presents the Low Voltage sag Ride-Through (LVRT) capability of wind turbine. One of the most simplest and successful method for voltage sag compensation is to integrate the DFIG-based wind turbine to the power grid for the duration of grid disturbances. The application of STATCOM indetailed investigated and studied in this paper to achieve uninterrupted operation of DFIG-based wind turbine during three phase or symmetrical fault conditions.

Without using STATCOM, the voltage at Point of Common Coupling (PCC) is dropping about 50% of the system voltage.So for improving the voltage profile, STATCOM is implemented in the paper.

However, varying wind speed is considered here. Different constant wind speed can be considered and the results obtained can thus be compared for future references.Maximum Power Point Tracking (MPPT) Technique can be implemented for best efficiency from the system.

APPENDIX

- DFIG

Nominal power: 1.5 MVA
Nominal voltage (LL): 460 V
Nominal Frequency: 60 Hz
Pair of poles: 2
Stator resistance and inductance: 0.01965, 0.0397pu
Rotor resistance and inductance: 0.01909 0.0397pu
Dc link capacitance: 1000 mF

- TRANSFORMER

Nominal power: 1000 MVA
Nominal Frequency: 60 Hz
Ratio: 25000/460 V, Δ/Y

- GRID

Nominal power: 1000 MVA
Nominal voltage (LL): 25 kV
Nominal Frequency: 60 Hz
Source Impedance: 0.0001 Ω

- TURBINE CONSTANTS

C_1 : 0.5176, C_2: 116, C_3 : 0.4, C_4 : 5,
C_5 : 21, C_6 : 0.0068, C_7 : 0.08

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