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Analysis of DFIG Fed WECS under Different Fault Conditions

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Abstract:
This paper gives study of DFIG based wind turbine power generation system. The proposed system reliability connected to grid under fault conditions is demonstrated in MATLAB/Simulink software. A wound type rotor based induction generator and back-to-back IGBT based converter used for design of DFIG. The proposed system has capability of generating maximum energy under low speed wind conditions. The control system was designed for pitch angle control, wind turbine power, DC bus voltage, grid voltage and reactive power control.

I. INTRODUCTION

Wind energy systems are the rapid expanding and greater rising sustainable energy source between them due to financially feasible. In India, which is the colossal greenhouse gas releasing country after the US and China, renewable energy at present achieves for about 16% of the total established size of 315,426MW. Various applications of wind power can be found in a wide power range from a few kilowatts to several megawatts in small scale off-grid standalone systems or large scale grid-connected wind farms.

Doubly-fed induction machines are receiving increasing attention for wind energy conversion system during such situation, because the main advantage of such machines is that, if the rotor current is governed applying field orientation control-carried out using commercial double sided PWM inverters, decoupled control of stator side active and reactive power results and the power processed by the power converter is only a small fraction of the total system power [1].

With increasing penetration of wind-derived power in interconnected power systems, it has become necessary to model the complete wind energy systems in order to study their impact and also to study wind power plant control [5]. Through the model developed in this paper can be used for simulating all types of induction generator configurations. The choice of synchronous rotating reference frame makes it particularly favorable for the simulation of doubly-fed configuration in transient conditions. A complete simulation model is developed for such machine using MATLAB Simulink software [2].

II. WIND-TURBINE DOUBLY-FED INDUCTION GENERATOR

The wind turbine and the doubly-fed induction generator are shown in Fig. 1. The AC/DC/AC converter is divided into two components: the rotor-side converter and the grid-side converter. C_{rotor} and C_{grid} are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source [3].

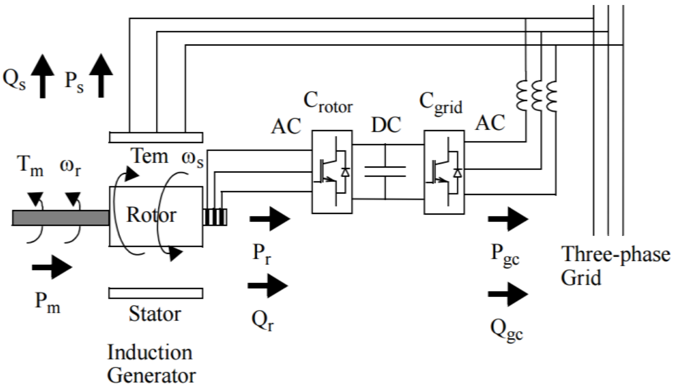

Fig 1: The wind turbine and the DFIG system (Power Flow)

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The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals V_r and V_{gc} for C_{rotor} and C_{grid} respectively in order to control the power of the wind turbine, the DC bus voltage and the voltage at the grid terminals [4].

The power flow, illustrated in Fig. 1, is used to describe the operating principle. The mechanical power and the stator electrical power output are computed as follows:

$$Pm = Tm*\omega r$$

$$Ps = Tem*\omega s$$

For a lossless generator the mechanical equation is:

$$J(d\omega r/dt) = Tm*Tem$$

In steady-state at fixed speed for a lossless generator

$$Tm = Tem \text{ and } Pm = Ps + Pr$$

It follows that:

$$Pr = Pm - Ps = Tm*\omega r - Tem*\omega s = -sPs$$

where s = (ωs-ωr)/ωs is defined as the slip of the generator.

III RSC and GSC control systems

Rotor side converter control system

The rotor-side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The actual speed of the turbine ωr is measured and the corresponding mechanical power of the tracking characteristic is used as the reference power for the power control loop. The power control strategy is depicted in Fig. 2. For the rotor-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with air-gap flux.

The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses and is compared with the reference power obtained from the tracking characteristic. A PI controller is used to compensate the power error to zero. The output of this controller is the reference rotor current Iqr_ref that must be injected in the rotor by converter C_{rotor} [6].

This is the current component that produces the electromagnetic torque Tem. The actual Iqr component is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by C_{rotor}. The current regulator is assisted by feed forward terms which predict Vqr.

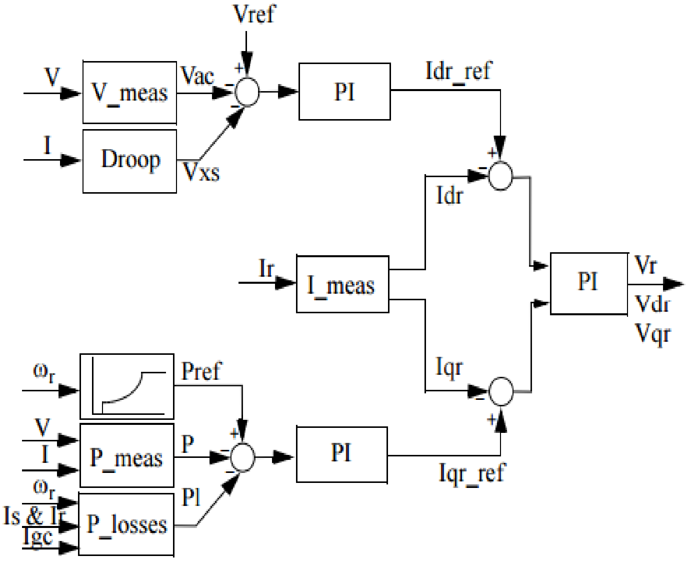

Fig 2: Rotor side converter control system

The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter Crotor. The reactive power is exchanged between Crotor and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sent to the grid or to Crotor.

Grid side converter control system

The grid side converter is used to control the DC bus capacitor voltage. The control system is figured in Fig 3. The grid-side controller is designed as the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. The GSC controller is having of measurement of AC currents dq parameters to be controlled and Vdc. The GSC voltage magnitude and phase was controlled by inner current controller by using reference current signal from DC voltage regulator [7].

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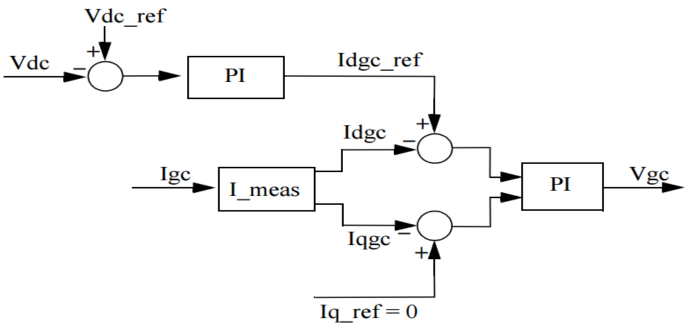

Fig 3: Grid side converter control system

Pitch angle controller

A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value [8]. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value. The control system is given in fig 4.

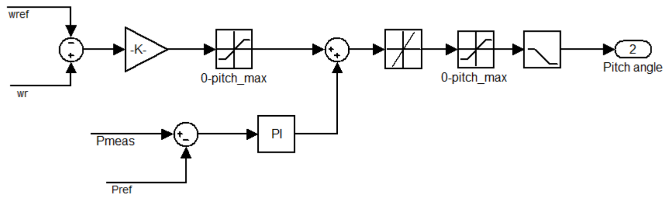

Fig 4: Pitch angle controller

IV. SIMULATION RESULTS

The simulation was done on 10 MW DFIG wind turbine. The DFIG based wind turbine is interconnected to grid of 120 kv system through 25kv distribution line. A wound rotor type asynchronous generator and back-to-back converters are used to design Doubly Fed Induction Generator. Stator winding of induction generator is connected to grid through distribution line. And rotor winding is connected to PWM converters. The DFIG has advantage of generating maximum power under oscillating conditions. The simulation design of proposed model is shown in fig 5. The system is simulated under constant wind speed of 15 m/s. The electromagnetic torque controller is used to maintain speed at constant value. The output power of wind turbine is 1 pu at rated speed for wind speed of 15 m/s.

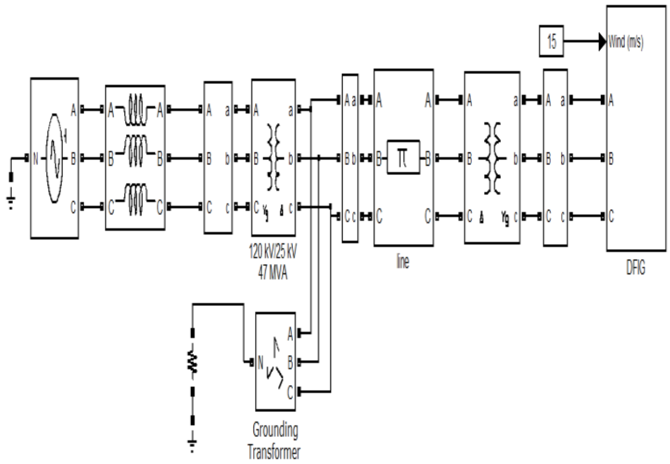

Fig 5: Simulation circuit of DFIG based WECS.

Initially the system starts with steady-state condition by generating 9 MW. The dynamic response of the system verified by creating fault in interconnected grid. The amplitude of the voltage source is reduced to half of its actual value from 0.2 to 0.3 sec in grid.

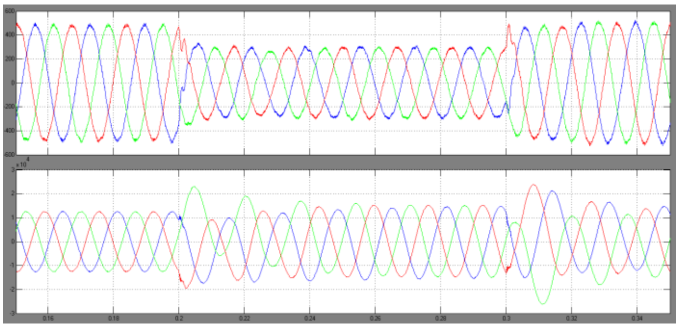

Fig 6: DFIG voltage and current

From fig 6 it is observed that at simulation time 0.2 sec the magnitude of voltage has decreased to 300 V from initial peak value of 500 V. But the system has started to recover oscillations from 0.25 sec.

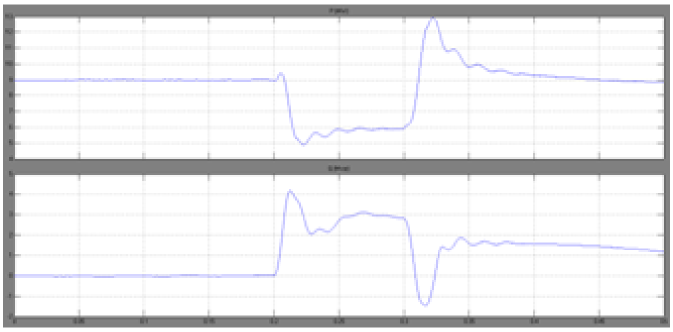

Fig 7: Active and reactive power

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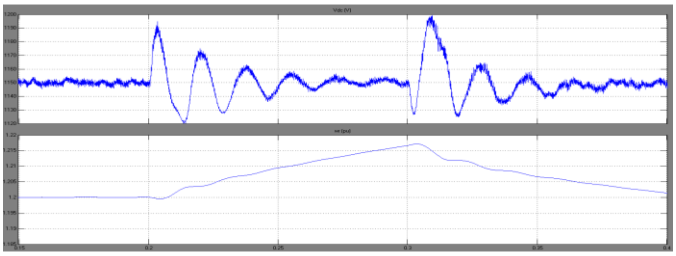

Fig 8: DC link voltage and rotor speed

DC link voltage of the PWM converters was shown in figure 8. It is clearly showing that DC voltage is constant up to 0.2 sec at value of 1150 V. It can be observed that the dc link voltage started getting oscillating from 0.2sec due decreasing of grid voltage requirement to half of the amplitude. But after four cycles the DC voltage is balanced to its normal value due DC voltage controller in Grid Side Converter controller (see Fig 3). The rotor speed is increased to 1.22 pu during fault time between 0.2-0.3sec by pitch controller (see fig 4).

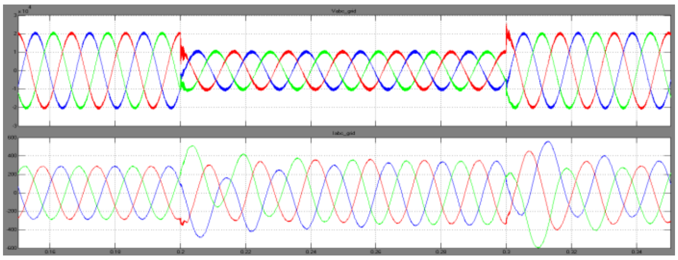

Fig 9: Distribution line voltage and current (25 kv line)

It can be clearly seen that the feeder voltage is constant through-out fault time 0.2-0.3sec. But the current is getting fluctuation up to four cycles then after it is balanced to initial steady-state conditions.

FFT Analysis of DFIG Voltage and current

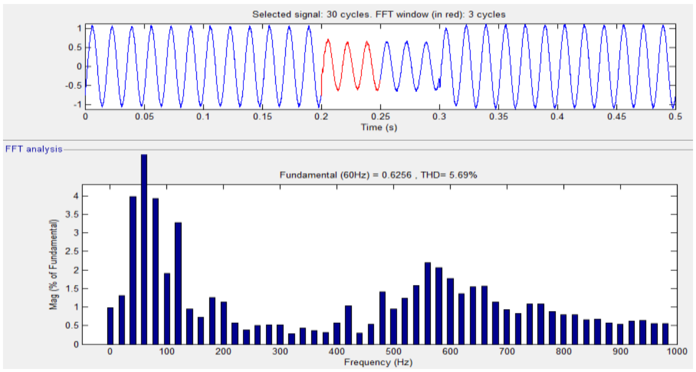

Fig 10: FFT analysis of DFIG voltage between (0.2-0.25) sec (5.69%)

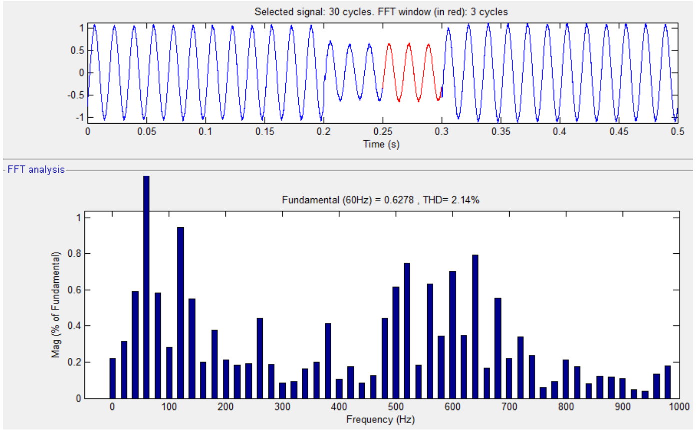

Fig 11: FFT analysis of DFIG voltage between (0.25-0.3) sec (2.14%)

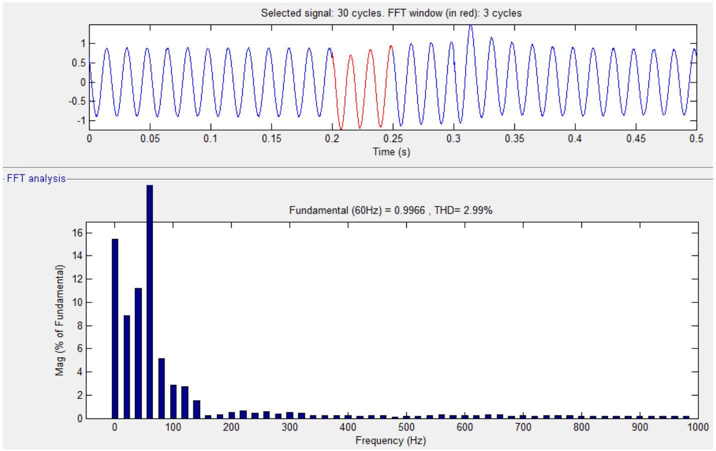

Fig 12: FFT analysis of DFIG current between (0.2-0.25) sec (2.99%)

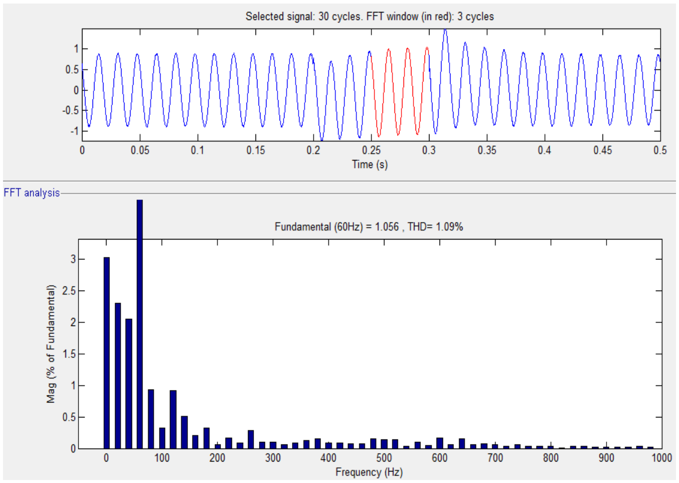

Fig 13: FFT analysis of DFIG current between (0.25-0.3) sec (1.09%)

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From figures 10, 11, 12 and 13, FFT analysis of DFIG voltage and currents showing that the Total Harmonic Distortion (THD) is decreased from first three cycles to second three cycles during fault condition of 0.2 to 0.3 sec.

FFT analysis of feeder voltage during fault

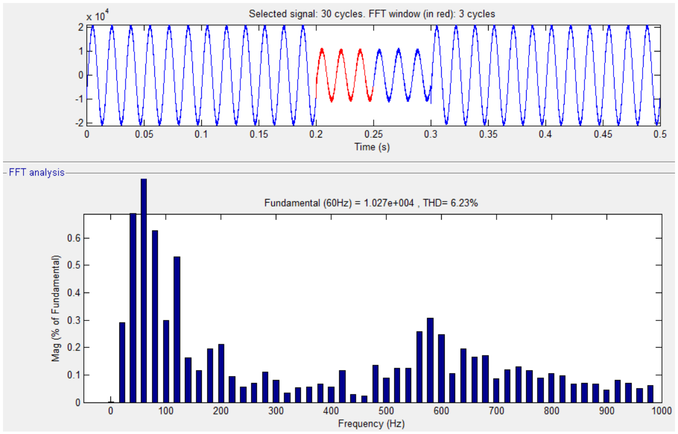

Fig 13: FFT analysis of feeder voltage between (0.2-0.25) sec (6.23%)

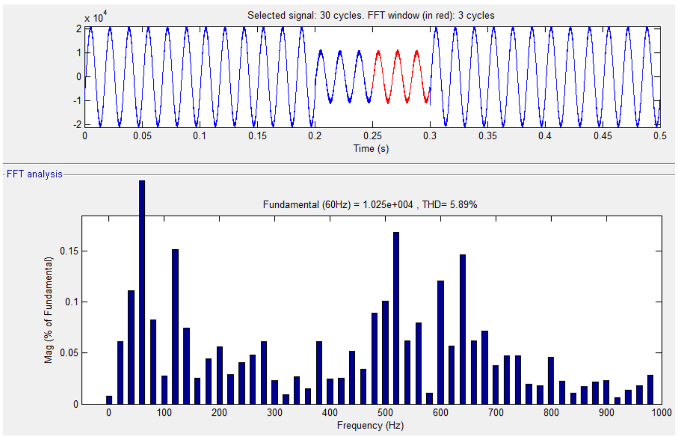

Fig 13: FFT analysis of feeder voltage between (0.25-0.3) sec (5.89%)

CONCLUSION

The modeling and simulation analysis of Doubly Fed Induction Generator has carried in this paper. The dynamic modeling of DFIG based wind turbine was described in section 2. DC link voltage balancing was achieved by DC voltage controller. Steady-state and dynamic performances of DFIG interconnected to grid were mentioned using FFT analysis of DFIG voltage and currents and distribution line voltage. The performance analysis of proposed technique was done in MATLAB/Simulink simpowersystems software.

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