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DTC Control Strategy for Doubly Fed Induction Machine

G.Naveen, P.K.S.Sarvesh, B.Rama Krishna

Abstract: This paper focuses the analysis on the control of doubly fed induction generator (DFIG) based high-power wind turbines when they operate under presence of voltage dips. The main objective of the control strategy proposed for doubly fed induction generator based wind turbines is to eliminate the necessity of the crowbar protection when low-depth voltage dips occurs. Conventional Direct Torque Control (CDTC) suffers from some drawbacks such as high torque ripple and variable switching frequency, difficulties in torque as well as flux control at very low speed. This paper is aimed to analyze DTC principles. A direct torque control strategy that provides fast dynamic response accompanies the overall control of the wind turbine. The proposed control does not totally eliminate the necessity of the typical crowbar protection for turbines it eliminates the activation of this protection during low depth voltage dips. The modeling of the complete system is done in MATLAB-SIMULINK. Simulation results show the proposed control strategythat mitigates the necessity of the crowbar protection during low depth voltage dips.

Index Terms:doubly fed induction machine (DFIM), direct torque control (DTC), crowbar protection etc.

I. INTRODUCTION

With exhausting of traditional energy resources and increasing concern of environment, renewable and clean energy is attracting more attention all over the world to overcome the increasing power demand. Out of all the renewable energy sources, wind energy and solar energy are reliable energy sources. Now a day, wind power is gaining a lot of importance because it is cost- effective, environmentally clean and safe renewable power source compared to fossil fuel and nuclear power generation.A grid connected WECS should generate power at constant electrical frequency which is determined by the grid. Generally Squirrel cage rotor induction generators are used in medium power level grid-connected systems. The induction generator runs at near synchronous speed and draws the magnetizing current from the mains when it is connected to the constant frequency network, which results in Constant Speed Constant Frequency (CSCF) operation of generator. However the power capture due to fluctuating wind speed can be substantially improved if there is flexibility in varying the shaft speed.

In such variable Speed Constant Frequency (VSCF) application rotor side control of grid-connected wound rotor induction machine is an attractive solution. In double fed induction generator, the stator is directly connected to the three phase grid and the rotor is supplied by two back-to-back converters as shown in Fig .1. Such an arrangement provides flexibility of operation at both sub-synchronous and super synchronous speeds.

In Doubly Fed Induction Generator the rotor side converter is controlled by using different control techniques like scalar control where the torque and flux have coupling effect, vector control where the torque and flux have decoupling effect and sensor-less vector control means the vector control without any speed sensor.

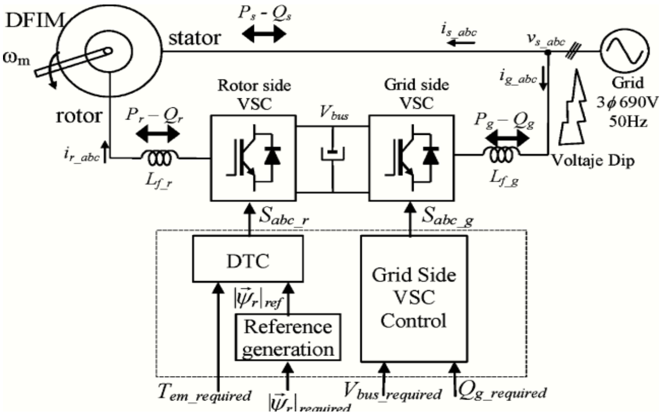

Fig 1: Wind energy generation system based on the DFIM**.**

Another scalar control technique is Direct Torque Control in which torque and flux of generator aredirectly controlled by converter voltage space vector selection through a look up table.

The technique used in the paper is to operate the DFIG through proper selection of voltage vectors.The operation of Doubly Fed Induction Generator during the voltage dips is explained by generating the three phase fault at the grid. The crowbar protection is to be eliminated in DFIG during the fault in order to reduce losses and improve the efficiency of the machine. In order to eliminate that protection, DTC is operated with rotor flux generation.

II. DIRECT TORQUE CONTROL

The Direct Torque Control (DTC) method is basically a performance enhanced scalar control method. The main features of DTC are direct control of flux and torque by the selection of optimum inverter switching vector, indirect control of stator current and voltages, approximately sinusoidal stator flux and stator currents and high dynamic performance even at standstill. The advantages of DTC are minimal torque response time, absence of coordinate transformations which are required in most of vector controlled drive implementation and absence of separate

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G.Naveen, has completed B.Tech (EEE) in 2011 and is pursuing M.Tech (PE&D) in Lakireddy BalireddyCollege of Engineering, AP., India.

Mr. P.K.S.Sarvesh, is working as Assistant Professor in Lakireddy Balireddy College of Engineering, AP. So far he has 3 years of teaching experience., India.

B.Rama Krishna, has completed B.Tech (EEE) in 2011 and is pursuing M.Tech (PE&D) in Lakireddy Balireddy College of Engineering, AP., India.

voltage modulation block which is required in vector controlled drives. The disadvantages of DTC are inherent torque and stator flux ripple and requirement for flux and torque estimators implying the consequent parameters identification.

The complete block diagram of DTC is shown in Figure 2. There are two hysteresis control loops, one for the control of torque and the other for the control of flux. The flux controller controls the machine operating flux to maintain the magnitude of the operating flux at the rated value till the rated speed and at a value decided by the field weakening block for speeds above the rated speeds. Torque control loop maintains the torque value to the torque demand. The output of these controllers together withthe instantaneous position of flux vector selects a proper voltage vector. So it is very important to estimate the stator flux and motor torque accurately.

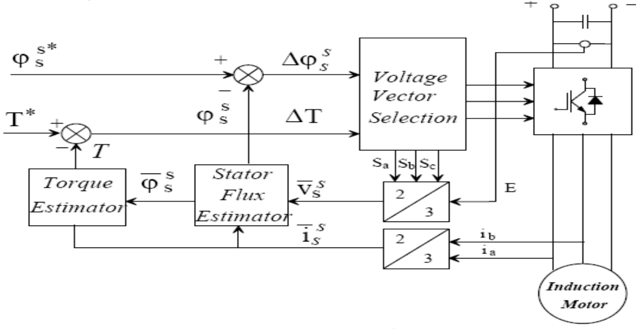


Fig 2: Block diagram of DTC

Control Of Doubly-Fed Induction Generator

Doubly-fed electric machines are electric motors or electric generators that have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system. Doubly-fed machines are useful in applications that require varying speed of the machine's shaft for a fixed power system frequency. As the penetration of large scale wind turbines into electric power grids continues to increase, electric system operators are placing greater demands on wind turbine power plants. One of the most challenging new interconnection demands for the doubly fed induction generator (DFIG) architecture is its ability to ride through a short-term low or zero voltage event at the point of common coupling (PCC), resulting from a fault on the grid. During extreme voltage sags high per unit currents and shaft torque pulsations occur unless mitigating measures are taken.

III. MATHEMATICAL ANALYSIS

When a voltage dip occurs, the stator flux evolution of the machine is imposed by the stator voltage equation

$$V_S^S = R_s i_S^S + {d\Psi_s^s}/{dt} \quad \text{……………… (1)}$$

In general, since very high stator currents are not allowed, the stator flux evolution can be approximated by the addition of a sinusoidal and an exponential term [1] (neglectingR_s)

$$\Psi_{\alpha s} = K_1 e^{-K_2 t} + K_3\cos(\omega_s t + K_4)$$
$$\Psi_{\beta s} = K_5 e^{-K_2 t} + K_3 \sin(\omega_s t + K_4) \quad \text{……….. (2)}$$

Sinusoidal currents exchange with the grid will be always preferred by the application during the fault. It means that the stator and rotor currents should be sinusoidal.

However, by checking the expressions that relate the stator and rotor currents as a function of the fluxes

$$i_S^S = \frac{L_h}{\sigma L_r L_s}\left(\frac{L_r}{L_h}\Psi_s^s - \Psi_r^s\right)$$

$$i_r^S = \frac{L_h}{\sigma L_r L_s}\left(\frac{L_s}{L_h}\Psi_r^s - \Psi_s^s\right) \quad \text{………… (3)}$$

It is appreciated that it is very hard to achieve sinusoidal currents exchange, since only the rotor flux amplitude is controlled by a DTC technique.

Consequently, as proposed in next section, a solution that reasonably cancels the exponential terms from (3) is to generate equal oscillation in the rotor flux amplitude and in the stator flux amplitude. Finally, as it will be later shown that the quality of the currents is substantially improved with this oscillatory rotor flux, rather than with constant flux.

IV.ROTOR FLUX REFERENCE GENERATION STRATEGY

As depicted in Fig 3, the proposed rotor flux amplitude reference generation strategy, adds a term ($\Delta|\Psi_r|$) to the required reference rotor flux amplitude according to the following expression:

$$\Delta|\psi_r| = |\psi_s| - \frac{|v_s|}{\omega_s}$$
$$\Psi_s = L_s i_s + L_h i_r$$
$$\Psi_r = L_r i_r + L_h i_s \quad \text{……… (4)}$$

Or

$$\psi_s = \sqrt{\psi_{ds}^2 + \psi_{qs}^2}$$
$$\psi_r = \sqrt{\psi_{dr}^2 + \psi_{qr}^2} \quad \text{……….. (5)}$$

With $|\Psi_s|$, the estimated stator flux amplitude and $|V_s|$ voltage of the grid (not affected by the dip). This voltage can be calculated by several methods, for instance, using a simple small bandwidth low-pass filter, as illustrated in Fig 4. It must be highlighted that constants K1 - K5 from (2) are not needed in the rotor flux reference generation reducing its complexity. Fig 5 shows the Simulink model of rotor flux generation strategy which depicts the actual model of proposed rotor flux amplitude reference generation strategy. Note that at steady state without dips presence, $\Delta|\Psi_r|$ the term will be zero. However, when a dip occurs, the added term to the rotor flux reference will be approximately equal to the oscillations provoked by the dip in the stator flux amplitude. For simpler understanding, the voltage drop in the stator resistance has been neglected. The magnitude of stator flux and rotor flux can be calculated by (5) by knowing the values of stator, rotor self-inductance, mutual inductance and stator, rotor currents at that instance or the values of stator and rotor flux can be calculated by taking the square root of summation of squares of direct and quadrature axis fluxes of stator and rotor respectively as mentioned in (5).

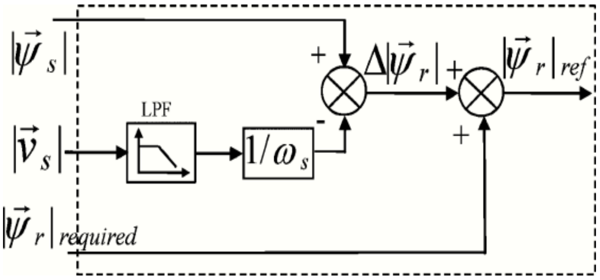


Fig 3: Rotor flux reference generation strategy

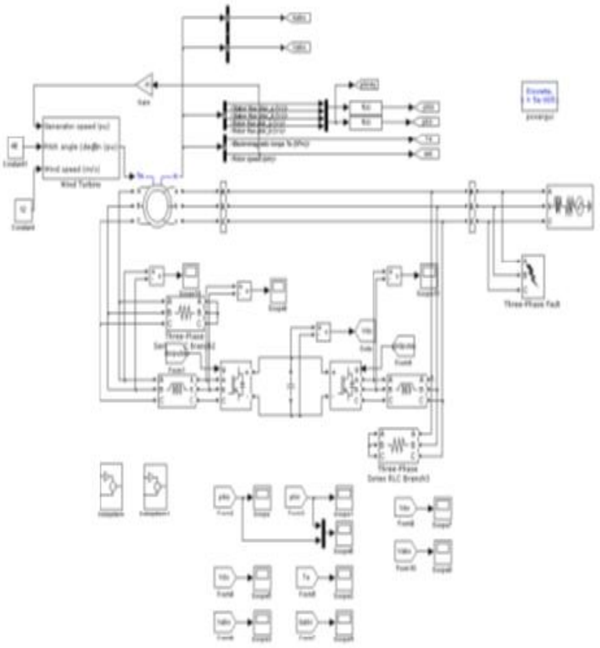


Fig 4: MATLAB/Simulink model of proposed control strategy

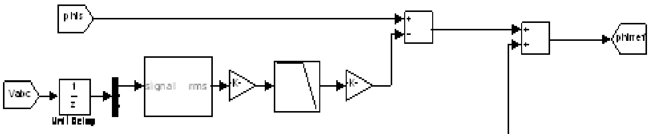


Fig 5: MATLAB/Simulink model of reference flux generation strategy.

V.RESULTS & DISCUSSIONS

The simulated wind turbine is a 2 MW, 690 V, Ns /Nr= 1/3 and two pair of poles DFIM. The main objective of this simulation validation is to show the DFIM behave or when a low depth inthis case 30%, as in symmetric voltage dip occurs with and without the proposed flux reference generation strategy and at nearly constant speed. The simulations are performed in MATLAB/Simulink. During the dip, it is desired to maintain the torque controlled to the required value (20%), allowing to eliminate mechanical the stator flux amplitude. It must be pointed out that DTC during faults is a well-suited control strategy to reach quick flux control dynamics, as well as to dominate the situation, eliminating torque perturbations and avoiding mechanical stresses. Consequently, the proposed control schema maintains the stator and rotor currents under their safety limits, avoiding high over currents, either in the voltage fall or rise stresses to the wind turbine. This issue is achieved, as shown in only if the oscillatory rotor flux is generated. For this purpose, the rotor flux is generated according to the block diagram of, generating an equivalent oscillation toHowever, as predicted in theory.It is hard to avoid a deterioration of the quality of these currents. Nevertheless, if the rotor flux is maintained constant, the currents will go further till their limit values, as, provoking in a real case, a disconnection of the wind turbine or an activation of the crowbar protection. Moreover, by mitigating the over currents of the rotor, the back-to-back converter is less affected by this perturbation, producing short dc bus voltage oscillations, as illustrated Finally, it can be said that the proposed control is useful at any operating point of the wind turbine, as well as at any type of faults (one phase, two phases, etc.). The performance will be limited only, when the rotor voltage required is higher than the available at a given dc bus voltage.

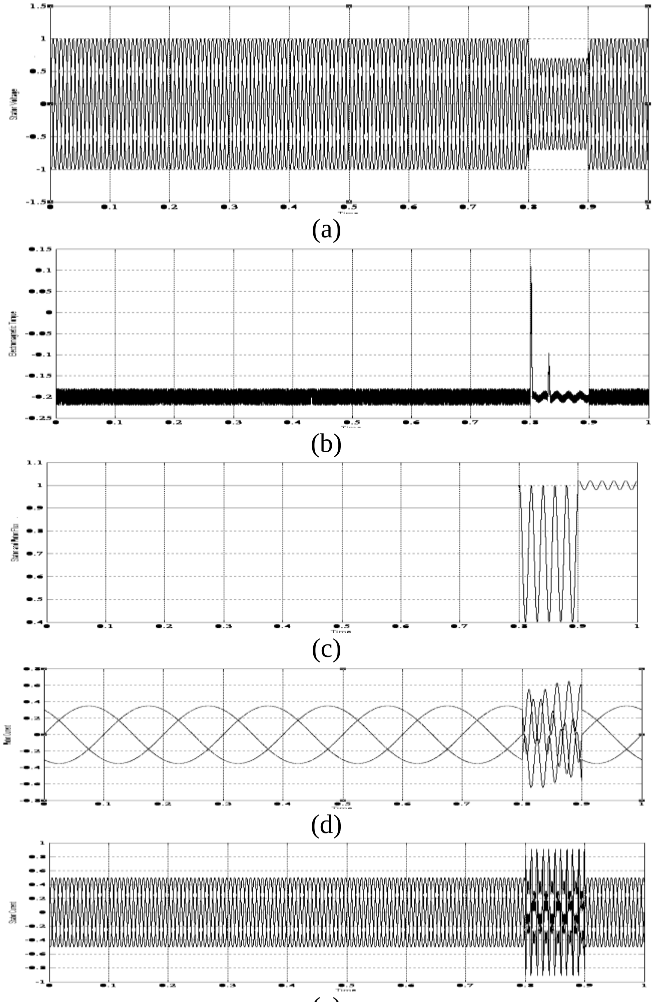
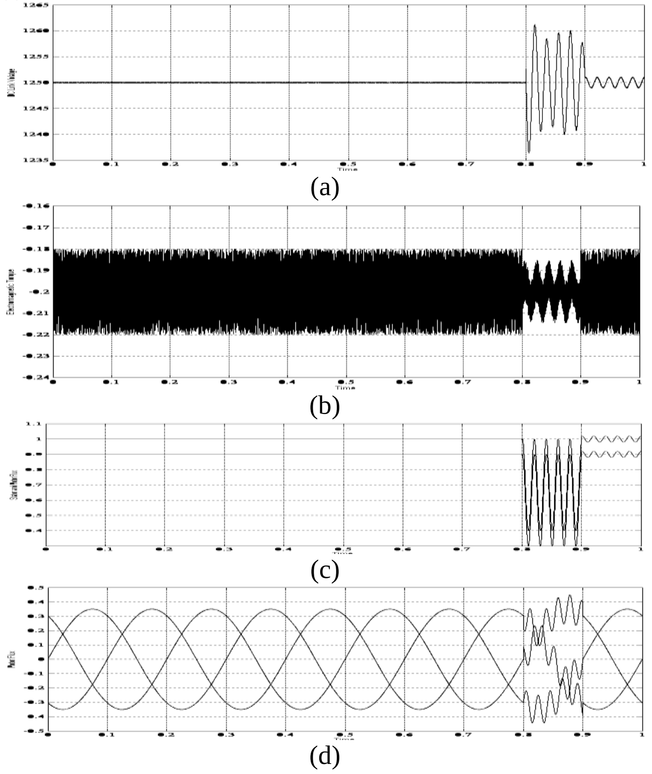
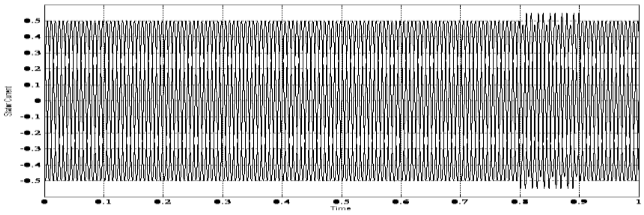


Fig 6: Simulation results of DFIM without proposed reference generation. (a) Stator voltage. (b) Torque (c) Stator and rotor fluxes (d) Rotor currents. (e) Stator currents w.r.t. time t in secs.





(e)

Fig 7: Simulation results of DFIM with proposed reference generation. (a) DC bus voltage. (b) Torque. (c) Stator and rotor fluxes. (d) Rotor currents (e) Stator currents w.r.t. time t in secs.

VI.CONCLUSION

Simulation results have shown that the proposed control strategy mitigates the necessity of the crowbar protection during low depth voltage dips. In fact, the dc bus voltage available in the back-to-back converter, determines the voltage dips depth that can be kept under control. For future work, it would be interesting to explore the possibility to generate a modified reference of rotor flux and torque, in order to be able to address deeper voltage dips without crowbar protection.

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G.Naveen has completed B.Tech (EEE) in 2011 and is pursuing M.Tech (PE&D) in Lakireddy BalireddyCollege of Engineering, AP.

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