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A Detailed Investigation and Testing of Grid Voltage Oriented Sliding Mode Control for DFIG (Doubly Fed Induction Generator)

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ABSTRACT

Doubly Fed Induction mills (DFIGs) are widely utilized in variable-velocity wind mills in spite of the nicely frequent overall performance of DFIGs, those mills are particularly realistic to grid faults. Therefore, the presence of grid faults ought to be taken into consideration inside the layout of any manage device to be deployed on DFIGs. Sliding Mode manage (SMC) is a beneficial alternative for electric powered equipment manipulate because SMC offers rapid dynamic reaction and less sensitivity to parameter versions and disturbances.

KEYWORDS: *DFIG, SMC, AC, IRD*

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I. INTRODUCTION

DFIG offers great performance in restrained variety pace programs with the main benefit of partly rated strength converter, but this gadget is particularly touchy to voltage variations for the reason that stator is hooked up at once to the electric grid. While mutual flux is altered, torque oscillations can also appear critically affecting blades shaft and transmission machine. If the rotor-side controller isn't always appropriate for running under disturbances, the stator currents may additionally turn out to be non-sinusoidal compromising stability of the electric grid. . In several countries, fault experience-thru functionality has become obligatory within the interconnection of new era devices. The better the penetration of wind generators the stricter the technical standards for mills interconnection have to be. Those necessities, called grid codes, cowl voltage operating range, electricity component regulation, frequency operating variety, grid aid functionality and low fault trip via functionality. For DFIG, an abrupt voltage variation reasons a natural flux in the stator that could set off over-voltages inside the rotor windings that might have an effect on or even spoil the electricity converter. Therefore, the use of crowbar or another safety device is vital for excessive voltage dips. However, as soon as the modern has decreased, the injection of demagnetizing current can be used for restoring quicker the stator flux to its imperative position and hold with reactive energy contribution to the grid, improving temporary reaction of the generator underneath natural flux. Feedback manage is a useful opportunity to improve the overall performance of DFIG turbines in presence of electric faults due to the fact that it's far feasible to face low intensity faults without disconnecting the generator from the grid. SMC is a strong technique capable of offering insensitivity in opposition to bounded disturbance/uncertainties and finite-time convergence. Furthermore, the discontinuous nature of SMC suits with the direct manipulate of energy electronics (inverters) used on DFIG heading off modulation of the manipulate sign. Doubly-fed electric powered machines also slip-ring turbines are electric motors or electric mills, where both the sector magnet windings and armature windings are one by one linked to device out of doors the machine. By way of feeding adjustable frequency AC power to the field windings, the magnetic discipline can be made to rotate, allowing version in motor or generator pace. That is useful, for instance, for generators utilized in wind generators.

II. RESEARCH OBJECTIVES

- To model a grid voltage-oriented SMC controlling directly torque and stator reactive power.

- To validate SMC via simulations considering balanced and unbalanced voltage dips faults.
- To modify the torque and reactive power references to inject a demagnetizing current for restoring stator flux

III. RESEARCH METHODOLOGY

This research work will adopt a research methodology that combines the theory model with empirical evaluation and refinement of the proposed scheme on MATLAB simulation tool. MATLAB is a useful high-level development environment for systems which require mathematical modelling, numerical computations, data analysis, and optimization methods. This is because MATLAB consists of various toolboxes, specific components, and graphical design environment that help to model different applications and build custom models easier. Moreover, the visualization and debugging features of MATLAB are simple. The basic scheme of the system is presented in figure 1.1, the stator is immediately related to the electric grid, while the rotor needs a bidirectional power go with the flow among the grid and electric system, and therefore, lower back-to-lower back energy converter is used normally, the nominal energy of the returned-to-again converter is 30% of the generator nominal energy.

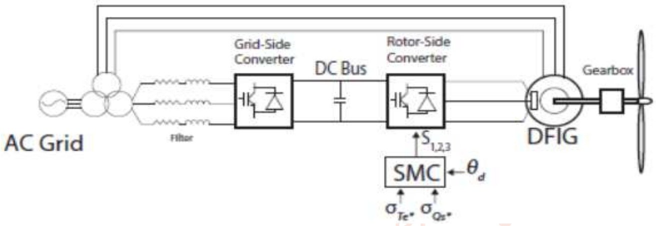


Figure 1.1: Wind Turbine Scheme with DFIG.

The electric machine model refereed to a synchronous rotating reference frame can be summarized using the following set of equations shown below:

$$\vec{v}_s = \frac{d\vec{\lambda}_s}{dt} + R_s\vec{\imath}_s + jw_s\vec{\lambda}_s \tag{1}$$

$$\vec{v}_r = \frac{d\vec{\lambda}_r}{dt} + R_r\vec{\imath}_r + jw_r\vec{\lambda}_r \tag{2}$$

$$\vec{\lambda}_s = L_s\vec{\imath}_s + L_r\vec{\imath}_r \tag{3}$$

$$\vec{\lambda}_r = L_r\vec{\imath}_r + L_m\vec{\imath}_s \tag{4}$$

For DFIG it's far handy to orient the gadget model in a synchronous velocity rotating reference frame. Neglecting voltage drop due to stator resistance, the stator voltage phasor will lead the stator flux phasor by means of ninety degrees beneath ordinary operation, therefore orienting the d axis inside the stator flux vector route will decouple lively and reactive power ($\boldsymbol{\lambda_{sq}}$= 0 and $\boldsymbol{\lambda_{sd}}$ = 0):

$$\tau_e = \frac{3PL_m}{2L_s}\left(i_{rd}\lambda_{sq} - i_{rq}\lambda_{sd}\right) \tag{5}$$

$$\tau_{e,normal} = \frac{-3PL_m}{2L_s}\left(i_{rq}\lambda_{sd}\right) \tag{6}$$

$$Q_s = \frac{3L_m}{2L_s}\left(v_{sd}i_{rq} - v_{sq}i_{rd}\right) + \frac{3L_m}{2L_s}\left(\lambda_{sd}v_{sq} - \lambda_{sq}v_{sd}\right) \tag{7}$$

$$Q_{s,normL} = \frac{-3L_m}{2L_s}\left(v_{sq}i_{rd}\right) + \frac{3}{2L_s}\left(\lambda_{sd}v_{sq}\right) \tag{8}$$

Where P is the number of pole pairs of the electric machine.

The torque is controlled by the quadrature axis rotor current, while the reactive power is controlled by the direct axis rotor current.

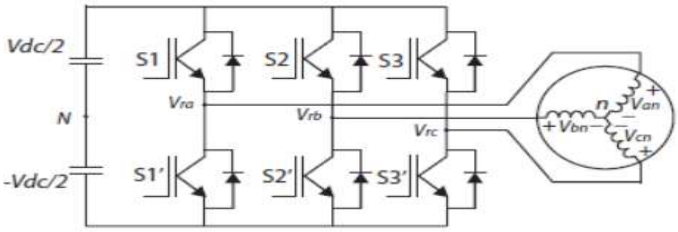


Figure 1.2: Two Level Inverter.

The output voltage of a power converter seen from the neutral of the DFIG rotor is:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} \tag{9}$$

In which Vdc is the DC link voltage, S1; S2 and S3 are the switch states of each leg of the strength converter. Each leg can most effectively have legitimate switching states (0 or one). The voltage can be measured with recognize to an imaginary reference factor inside the middle of the DC link (see determine 2), the output voltage could be in that case a sign characteristic with a benefit same to Vdc=2. because the basic output of SMC is a sign feature, it may be used for direct switching of electricity electronic gadgets if a courting between d; q and a; b; c quantities is hooked up.

$$\begin{bmatrix} V_{aN} \\ V_{bN} \\ V_{cN} \end{bmatrix} = \frac{V_{dc}}{2}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} sign(S_1 - 0.5) \\ sign(S_2 - 0.5) \\ sign(S_3 - 0.5) \end{bmatrix} \tag{10}$$

The sign function is defined as follows:

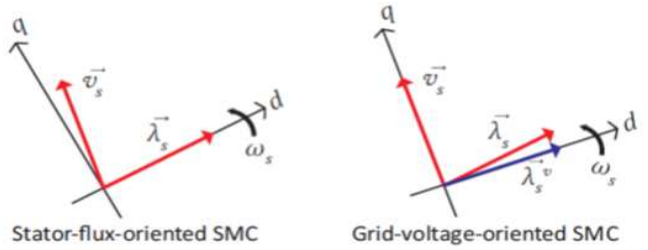
$$sign(x) := \begin{cases} -1, x < 0 \\ \ \ 1, x > 0 \end{cases} \tag{11}$$

GRID VOLTAGE ORIENTED CONTROLLED DESIGN:

For decoupling energetic and reactive strength, a synchronous pace reference frame is used. There are alternatives: stator flux and grid voltage orientation. it is convenient to pick the grid voltage orientation when you consider that $\boldsymbol{i_{rd}}$ is at once related with reactive energy. Consequently, the offered controller is oriented inside the grid-voltage course for ensuring balance independently on operational conditions. In determine 3 it is displayed the contrast among stator flux and grid voltage orientation. Where $\boldsymbol{\vec{\lambda}_s^v}$ is the virtual stator flux defined as:

$$\vec{\lambda}_s^v = \frac{\vec{v}_s}{jw_s} \tag{12}$$

Grid-voltage orientation will ensure that $\boldsymbol{v_{sd}}$ = 0 and a constant change in the evolution of the reference frame rotational angle ($\frac{d\vec{\lambda}_s}{dt}$), however, the stator flux will have components in both reference axis direction, for unbalanced conditions $\boldsymbol{v_{sq}}$ will have a sinusoidal behaviour centred in zero while $\boldsymbol{v_{sd}}$ will be sinusoidal as well with An offset. The dynamics of the rotor current are obtained from Equations (2) to (4):



Stator-flux-oriented SMC Grid-voltage-oriented SMC

Figure: 1.3: Comparison Between Reference Frame Orientations.

$$\frac{di_{rd}}{dt} = \frac{1}{L'_r}\left(v_{rd} - R_r i_{rd} - \frac{L_m}{L_s}\frac{d\lambda_{sd}}{dt} + w_r L'_r i_{rq} + \frac{L_m}{L_s} w_r \lambda_{sq}\right)$$
(13)

$$\frac{di_{rd}}{dt} = \frac{1}{L'_r}\left(v_{rq} - R_r i_{rq} - \frac{L_m}{L_s}\frac{d\lambda_{sq}}{dt} + w_r L'_r i_{rd} + \frac{L_m}{L_s} w_r \lambda_{sd}\right)$$
(14)

The main control objective of variable-speed turbines is to maintain the power coefficient of the turbine at the optimal value that can be achieved indirectly by controlling the electromagnetic torque of the machine. On the other hand, reactive power control is required for fault recovery support, therefore, the following sliding surfaces are selected:

$$\sigma_{\tau_e} = \tau_e - \tau_e^* \qquad (15)$$

$$\sigma_{Q_e} = Q_e - Q_e^* \qquad (16)$$

The dynamics of the sliding surfaces are:

$$\dot{\sigma}_{\tau_e} = \tau_e - \tau_e^* \qquad (17)$$

$$\dot{\sigma}_{Q_e} = Q_e - Q_e^* \qquad (18)$$

Where derivative of equations (5) and (7) results:

$$\dot{\tau}_e = \frac{-3PL_m}{2L_s}\left(i_{rq}\lambda_{sd} + i_{rq}\dot{\lambda}_{sd} - i_{rd}\lambda_{sq} - i_{rd}\dot{\lambda}_{sq}\right) \qquad (19)$$

$$\dot{Q}_s = \frac{-3L_m}{2L_s}\left(\dot{v}_{sd} i_{rq} + v_{sq} i_{rd}\right) + \frac{3}{2L_s}\left(\dot{\lambda}_{sd} v_{sq} + \lambda_{sq}\dot{v}_{sd}\right) \, (20)$$

Under normal conditions the terms $\boldsymbol{v_{sq}}$, $\boldsymbol{\lambda_{sq}}$and $\boldsymbol{\dot{\lambda}_{sq}}$are equal to zero, however when a fault in the stator voltage occurs, the mathematical expressions depending on the mentioned can be seen as perturbations (P$\boldsymbol{\dot{\tau}_e}$and P$\boldsymbol{\dot{Q}_s}$). On the other hand, let's consider that the torque and reactive power references are much slower than the rest of system dynamics.

$$\dot{\sigma}_{\tau_e} = \overbrace{k\lambda_{sd}\left(R_r i_{rq} + \frac{L_m}{L_s} w_r \lambda_{sd} + w_r L'_r i_{rd}\right)}^{F_{\tau e}} \underbrace{-k\lambda_{sd}}_{d_{\tau_e}} v_{rq} + P_{\tau_e}$$

(21)

NATURAL FLUX AND DEMAGNETIZING CURRENT:

The dynamic behaviour of DFIG underneath voltage dips is studied in element. The natural flux is part appearing due to immediate voltage dips, since the stator flux can't trade abruptly. The herbal flux induces a massive voltage inside the rotor and can motive loss of manipulate of the electrical gadget. Consequently, the concept of demagnetizing modern is used to be able to counteract the natural flux and return the electrical system to a strong nation, preventing in addition deformation of stator and rotor currents.

$$\frac{d\vec{\lambda}_s}{dt} = \vec{v}_{s\,fault} - \frac{R_s}{L_s}\vec{\lambda}_s + \frac{L_m}{L_s} R_s \vec{i}_r$$

$$\vec{\lambda}_s(t) = \vec{\lambda}_{sn}(0) e^{\frac{-R_s}{L_s}t} + \frac{\vec{v}_s}{jw_s} e^{jw_s t} - \frac{\vec{v}_s}{jw_s} e^{-jw_s t}$$

The primary time period is the natural flux which decays exponentially if the rotor present day is omitted. however, the forced flux due to the ultimate voltage carried out to the stator has two components, one rotating in synchronous pace due to the advantageous sequence element of the faulted voltage and the other one rotating in the contrary route due to the terrible collection component of voltage.

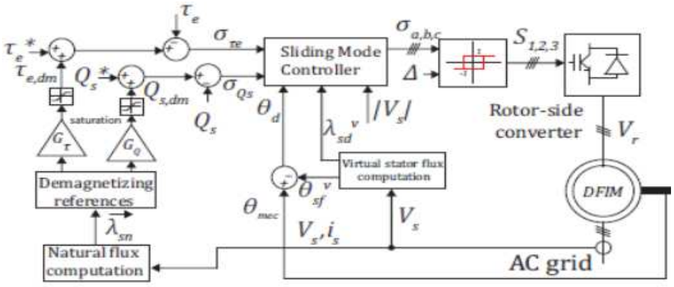


Figure 1.4: The circuit diagram

The main disadvantage of demagnetizing modern-day strategy is the want of herbal flux calculation. Normally band skip filters are used for decoupling wonderful, negative and natural fluxes. Since the stator resistance is negligible especially for big electric powered machines, the herbal flux can be effortlessly computed if the voltage collection components are known. On this paper a fast convergence not on time sign cancellation method is used for stator voltage series decomposition, then the symmetrical additives are subtracted from the full stator flux and the natural flux component is obtained.

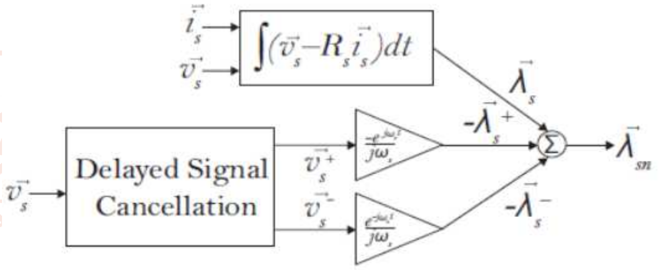


Figure 1.5: Natural Flux Estimation Using Delayed Signal Cancellation.

IV. RESULTS AND DISCUSSION

The results obtained during the simulation of this research work are described below:

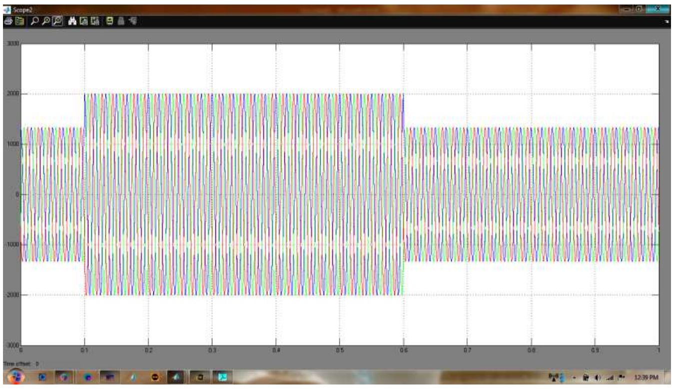


Figure 1.6: The graph showing current

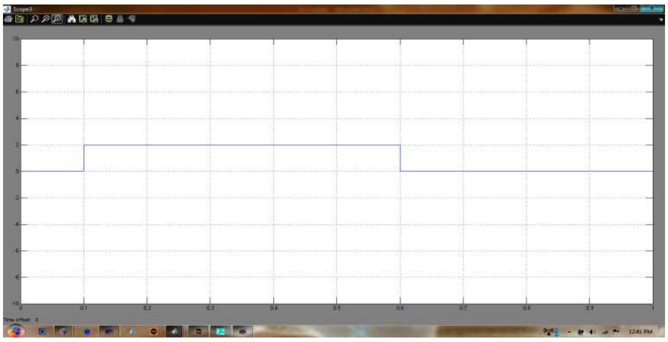


Figure 1.7: The Qs related graph

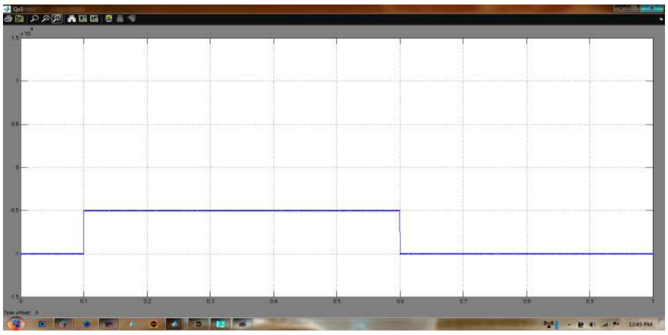


Figure 1.8: The Torque related graph

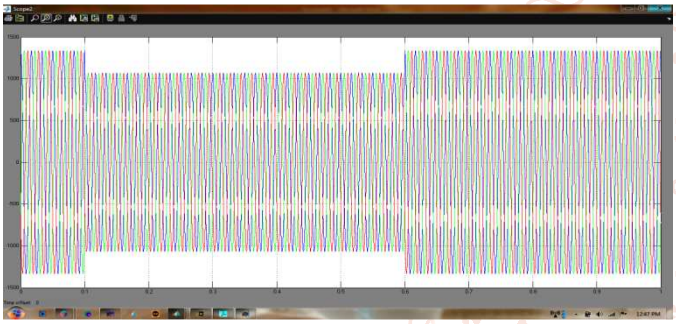


Figure 1.9: The Voltage presenting graph

V. CONCLUSION

The paper is about a grid-voltage-oriented sliding mode control for DFIG and its testing under voltage dips. The controller has the main advantages of simple structure, no dependence on system parameters and switching of power electronic devices directly from the controller output signals. The controller is able to track torque and stator reactive power even under voltage distortion of the grid without sequence decomposition of rotor current without further modification of the original controller. However, the natural stator flux component may affect stator current and active power oscillations, therefore a transient demagnetizing reference is included to the original scheme in order to eliminate natural flux component enhancing fault ride through capability of the controller.

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