UNIVERSITY OF ENGINEERING AND TECHNOLOGY LAHORE

Assignment # 2

Analysis of DFIG with Unbalanced Stator Voltage

Course Title: Control of Electric Machine Drives

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DEPARTMENT OF ELECTRICAL ENGINEERING

EE 535: Control of Electric Machine Drives

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Introduction

This case study presented DFIG sub-synchronous operation during unbalanced stator voltage conditions. Converter control was devised to mitigate unbalance effect of torque and power ripples, while making sure that no reactive power was delivered to the grid by the Stator or DC Link.

Induction Machine dq0-axis Reference Frame Model

A complex vector-based dq0-axis Reference Frame Model was built to demonstrate the dynamics of an induction machine. All variables were in per unit and the model was simulated in synchronous frame of reference. A complex vector was treated as two real variables with the q-axis leading the d-axis by 90°. The rotor speed was fixed at 0.95 p.u. DFIG control relied on stator flux-oriented reference frame, hence stator voltage and flux was aligned with the q-axis (ψ_{qs} = 0 and v_{ds} = 0).

The d-, q- and 0-axis Voltage Equations were

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{0s} \\ v_{qr} \\ v_{qr} \\ v_{0r} \end{bmatrix} = \begin{bmatrix} R_s + \frac{p}{\omega_b} X_s & \frac{\omega_s}{\omega_b} X_s & 0 & \frac{p}{\omega_b} X_m & \frac{\omega_s}{\omega_b} X_s & 0 \\ -\frac{\omega_s}{\omega_b} X_s & R_s + \frac{p}{\omega_b} X_s & 0 & -\frac{\omega_s}{\omega_b} X_m & \frac{p}{\omega_b} X_m & 0 \\ 0 & 0 & R_s + \frac{p}{\omega_b} X_{ls} & 0 & 0 & 0 \\ \frac{p}{\omega_b} X_m & \frac{\omega_s - \omega_r}{\omega_b} X_m & 0 & R_r + \frac{p}{\omega_b} X_r & \frac{\omega_s - \omega_r}{\omega_b} X_r & 0 \\ -\frac{\omega_s - \omega_r}{\omega_b} X_m & \frac{p}{\omega_b} X_m & 0 & -\frac{\omega_s - \omega_r}{\omega_b} X_r & R_r + \frac{p}{\omega_b} X_r & 0 \\ 0 & 0 & 0 & 0 & 0 & R_r + \frac{p}{\omega_b} X_{lr} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{0s} \\ i_{qr} \\ i_{dr} \\ i_{0r} \end{bmatrix}$$

DFIG Rotor Side Converter Control

1. Positive Sequence Controller

The output real power and reactive power from stator circuit was controlled via iqr and idr respectively. Feedback controllers were designed to generate the desired dq+ rotor voltages.

$$v_{qr} = r_r i_{qr} + \frac{d\psi_{qr}}{dt} + \omega_{sl}\psi_{dr} = r_r i_{qr} + \sigma L_r \frac{di_{qr}}{dt} + \omega_{sl}(\sigma L_r i_{dr} + \frac{L_m}{L_s}\psi_{ds})$$

$$v_{dr} = r_r i_{dr} + \frac{d\psi_{dr}}{dt} - \omega_{sl}\psi_{qr} = r_r i_{dr} + \sigma L_r \frac{di_{dr}}{dt} - \omega_{sl}\sigma L_r i_{qr}$$

2. Negative Sequence Controller

For a given negative-sequence stator voltage, negative sequence rotor voltage generated by the RSC was used to eliminate the negative sequence rotor current, the negative sequence stator current and the torque pulsation.

$$T_e = T_{edc} + T_{ecos}\cos(2\omega_e t) + T_{esin}\sin(2\omega_e t)$$

$$T_{edc} = \mathrm{K}(\psi_{qs}^{+}\mathrm{i}_{qr}^{+} + \psi_{ds}^{+}\mathrm{i}_{dr}^{+} + \psi_{qs}^{-}\mathrm{i}_{qr}^{-} + \psi_{ds}^{-}\mathrm{i}_{dr}^{-})$$

$$T_{ecos} = K(\psi_{qs}^{+}\mathrm{i}_{qr}^{-} + \psi_{ds}^{+}\mathrm{i}_{dr}^{-} + \psi_{qs}^{-}\mathrm{i}_{qr}^{+} + \psi_{ds}^{-}\mathrm{i}_{dr}^{+})$$

$$T_{esin} = K(\psi_{ds}^{+}\mathrm{i}_{qr}^{-} - \psi_{qs}^{+}\mathrm{i}_{dr}^{-} - \psi_{ds}^{-}\mathrm{i}_{qr}^{+} + \psi_{qs}^{-}\mathrm{i}_{dr}^{+})$$

RSC made $T_{ecos} = 0$ and $T_{esin} = 0$ by controlling $i_{qr-}$and i_{dr-}.

DFIG Grid Side Converter

1. Positive Sequence Controller

The Positive Sequence Controller tracked DC Link Voltage Reference and controlled the Power delivered to grid by GSC. Real power and reactive power were linearly related to i_{qg} and i_{dg} respectively. Hence decoupled real power and reactive power controller was designed to generate the desired grid side converter voltages:

$$v_{qg} = L_g \frac{di_{qg}}{dt} + \omega L_g i_{dg} + v_{qs}$$

$$v_{dg} = L_g \frac{di_{dg}}{dt} - \omega L_g i_{qg}$$

The GSC Filter was modeled as an inductor.

2. Negative Sequence Controller

For negative sequence compensation via GSC, the current controllers of the GSC will measure the network currents, extract the negative sequence components and generate the required negative sequence currents from the GSC for compensation. The reference values of the negative sequence currents come from the measurements of the currents to the grid.

$$i_{gq,ref}^{-} = i_{eq}^{-}$$

$$i_{gd,ref}^{-} = i_{ed}^{-}$$

DC Link Dynamics

The DC-link capacitor dynamics or the relationship between the RSC and the GSC was

$$CV_{DC0}\frac{dV_{DC}}{dt} = -P_r - P_g$$

Conclusion

The converters tracked the desired references and the DFIG continued to export power to grid during the fault. Grid Side Converter compensated the negative sequence currents required in the network during stator voltage imbalance. It also controlled DC Link Voltage and the Power delivered to grid by DC Link. Rotor Side Converter eliminated negative sequence rotor currents, negative sequence stator currents and torque pulsation. It also controlled Active and Reactive Power delivered by stator to grid.