The Harmonic Current Mitigation of DFIG under Unbalanced Grid Voltage and Non-linear Load Conditions

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Abstract

This paper presents an analysis and a novel strategy for a doubly fed induction generator (DFIG) based wind energy conversion system under unbalanced grid voltage and non-linear load conditions. A proportional-resonant (PR) current controller is applied in both grid side converter (GSC) and rotor side converter (RSC). The RSC is controlled to mitigate the stator active power and the rotor current oscillations at double supply frequency under unbalanced grid voltage while the GSC is controlled to mitigate ripples in the dc-link voltage and compensate harmonic components of the network current. Simulation results using Psim simulation program are presented for a 2 MW DFIG to confirm the effectiveness of the proposed control strategy.

Key words: DFIG, Unbalanced grid voltage, Non-linear load, GSC, RSC, Stator active power oscillation, DC-link voltage.

1. Introduction

Nowadays, variable-speed wind turbines that based on doubly-fed induction generator (DFIG) are widely used in wind generation. Under unbalanced grid voltage conditions, the main objectives are to eliminate the oscillation in stator active power, torque and the dc-link voltage [1]-[4].

This paper proposes an easy control strategy to mitigate the oscillation in the torque, stator active power, and dc-link voltage during unbalanced stator voltage conditions by using PR controllers for both RSC and GSC. Beside, this paper also investigated the ability of using GSC as statcom to compensate harmonic currents to grid under non-linear load conditions via resonant filter. The rest of the paper is organized as follows. The system behavior and operation of DFIG, the proposed control strategy, and simulation results under the voltage unbalance are presented in Section 2. Section 3 draws the conclusions.

2. Main subject

2.1 Operation of DFIG system

2.1.1 Rotor side converter

Under unbalanced stator voltage supply, the stator and rotor voltage, current and flux may all contain both positive and negative sequence components. According to [2] the stator active power can be expressed by

$$P_s = -\frac{3}{2}\mathrm{Re}\left[V_s^+ . \hat{I}_s^+\right] = P_{s0} + P_{s\sin 2}.\sin(2\theta_s) + P_{s\cos 2}.\cos(2\theta_s) \quad (1)$$

The electromagnetic power is expressed by the sum of the power outputs generated by the equivalent voltages $j\omega_s\psi_s$ and $j(\omega_s - \omega_r)\psi_r$:

$$\begin{aligned} P_e &= -\frac{3}{2}\mathrm{Re}\left[j\omega_s\psi_s^+ . \hat{I}_s^+ + j(\omega_s - \omega_r)\psi_r^+ . \hat{I}_r^+\right] \\ &= P_{e0} + P_{e\sin 2}.\sin(2\theta_s) + P_{e\cos 2}.\cos(2\theta_s) \end{aligned} \quad (2)$$

The electromagnetic torque of DFIG can be calculated as

$$T_e = \frac{P_e}{\left(\dfrac{\omega_r}{n}\right)} \quad (3)$$

In this case, the stator active power, electromagnetic power and torque will oscillate with the frequency of $2\omega_s$.

2.1.2 Grid side converter

Similar to RSC, under unbalanced grid voltage conditions, the active power output from the GSC to the network can be expressed as

$$P_g = P_{g0} + P_{g\sin 2}.\sin(2\theta_g) + P_{g\cos 2}.\cos(2\theta_g) \quad (4)$$

The dc-link voltage can be expressed by

$$\begin{aligned} C\frac{dV_{dc}}{dt}V_{dc} &= P_r - P_g = (P_e - P_s) - P_g \\ &= (P_{e0} - P_{s0} - P_{g0}) + (-P_{e\sin 2} + P_{s\sin 2} - P_{g\sin 2})\sin(2\theta_g) \\ &\quad + (-P_{e\cos 2} + P_{s\cos 2} - P_{g\cos 2})\cos(2\theta_g) \end{aligned} \quad (5)$$

Under unbalanced grid voltage conditions, the (5) is important to show that the oscillating term of the dc-link voltage is caused by the oscillating term of electromagnetic power, stator power, and grid power.

2.2 Proposed control strategy

The control objective of the RSC control is to mitigate the oscillations in the stator active power and the rotor currents during the voltage unbalance while the control objective of the GSC control is to keep the dc-link voltage constant and compensate harmonic currents in case of non-linear load.

According to (1), the stator active power oscillation can be eliminated by making $P_{ssin2} = 0$ and $P_{scos2} = 0$. Alternatively, the torque pulsation in (3) can be eliminated by ensuring $P_{esin2} = 0$ and $P_{ecos2} = 0$. Similarly, according to (5), the oscillation in dc link voltage will be eliminated by making $P_{gsin2} = -P_{esin2} + P_{ssin2} = 0$ and $P_{gcos2} = -P_{ecos2} + P_{scos2} = 0$. To achieve these controls, the PR controllers in the stationary reference frame (αβ) are used and the proposed control strategies for the RSC and the GSC are shown in Fig. 1 and Fig. 2.

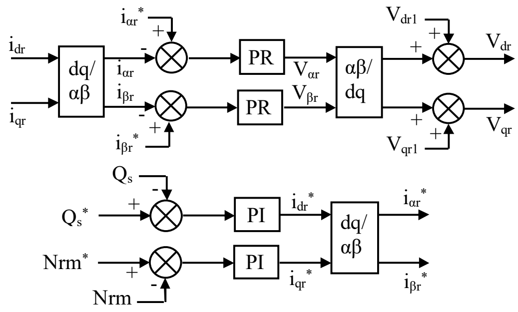

Fig 1 Proposed control strategy for RSC

Under non-linear load conditions, a resonant filter is proposed to extract the harmonic components in non-linear load currents and compensate to the network. A current control loop is added to the GSC control as Fig. 2 and the principle of harmonic compensation for non-linear load is presented as Fig. 3.

In Fig. 1 and Fig. 2, the transfer function in the block PR are $PR = K_p + K_i s/(s^2 + \omega_s^2)$; $V_{dr1} = -(\omega_s - \omega_r)\lambda_{qr}$, $V_{qr1} = (\omega_s - \omega_r)\lambda_{dr}$, $V_{dg1} = -\omega_s L_g i_{qg}$, and $V_{qg1} = \omega_s L_g i_{dg}$ are back EMF; the block filter is resonant filter of 5th, 7th harmonics.

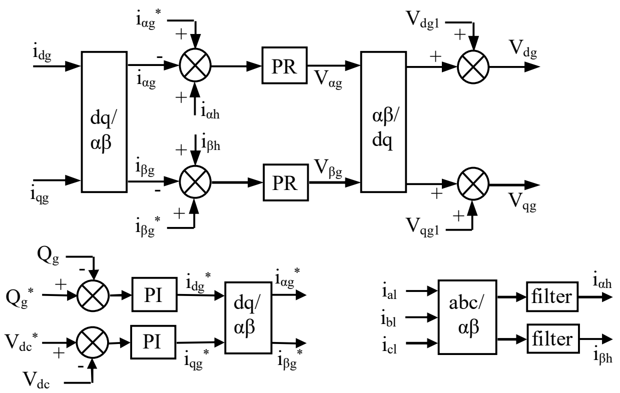

Fig 2 Proposed control strategy for GSC

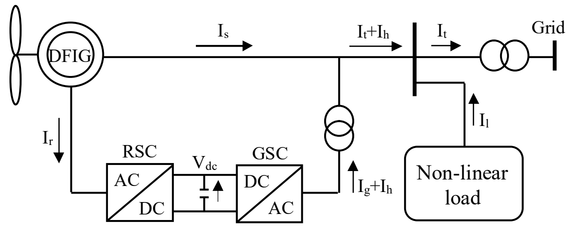

Fig 3 The principle of harmonic compensation through GSC, I_l: non-linear load current, I_h: harmonic current compensation for non-linear load

2.3 Simulation results

Simulation results with the proposed control strategy are carried out by using Psim for 2MW DFIG. The parameters of the DFIG, wind turbine and the non-linear load are given in Appendix. The non-linear load of 100 kW is applied to the grid at 3.5s and removed at 4s while the voltage unbalance of 3.5% is appeared at 5s and removed at 5.5s as Fig. 4 and Fig. 5, respectively.

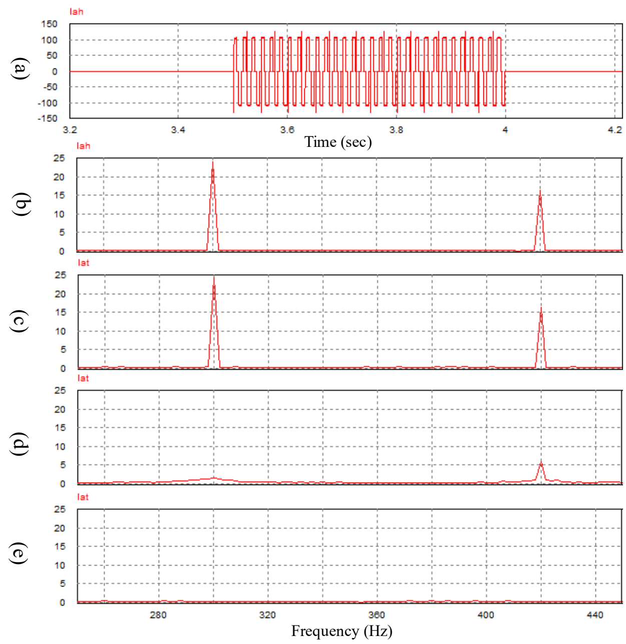

Fig 4 Dynamic responses of system under non-linear load of 100 kW (a) the non-linear load current I_{ah}, (b) the Fast Fourier Transform (FFT) of I_{ah}, (c) the FFT of network current without compensating harmonics, (d) the FFT of network current with compensating harmonics, the FFT of network current without applying non-linear load

3. Conclusions

This paper has presented coordinated control strategies for a DFIG under unbalanced grid voltage conditions and non-linear loads. The behaviors of a complete DFIG system are first analyzed. A coordinated control strategy for the RSC and GSC is proposed. The proportional-resonant (PR) current controllers in the stationary frame (αβ) are applied into both the RSC and the GSC. The main objectives are: the RSC is controlled to mitigate the oscillations in the stator active power and the rotor currents while the GSC is controlled to mitigate ripples in the dc-link voltage and compensate harmonic components in the network current by using resonant filters. Simulation results using Psim simulation program are presented to confirm the effectiveness of the proposed control strategy.

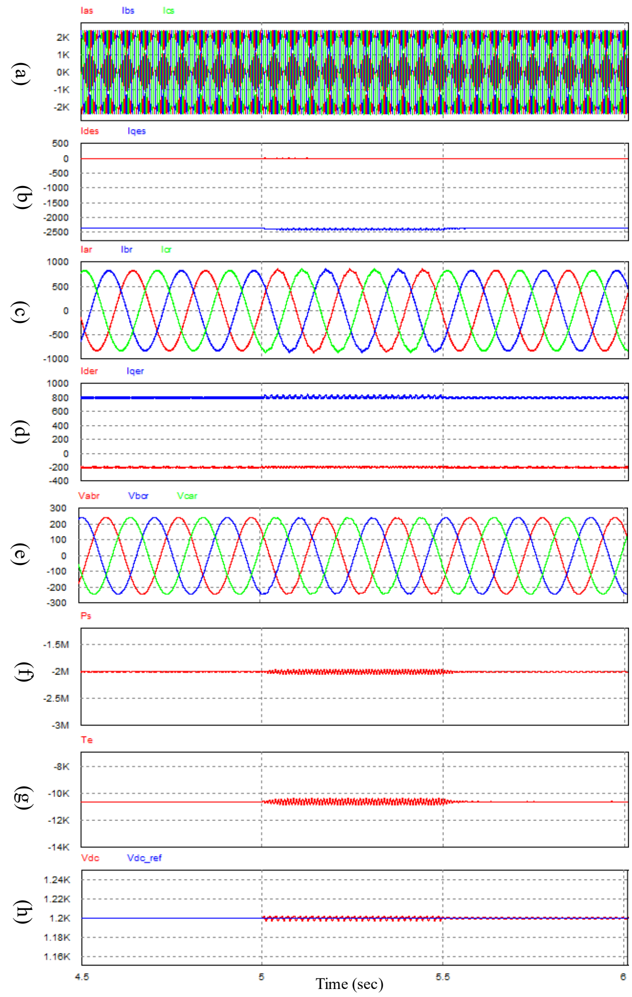

Fig 5 Simulation results under transient unbalanced grid voltage of 3 5% during 5-5 5s

References

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Appendix

DFIG parameters: P_n = 2 MW, U_n = 690 V, f = 60 Hz, p = 2, J = 98.5 Nm, R_s = 1.1616 mΩ, R_r = 1.307 mΩ , $L_{σs}$ = 0.05835 mH, $L_{σr}$ = 0.06286 mH, L_m = 2.496 mH.

Wind turbine parameters: D = 75 m, Gearbox = 93, Max.power conv.coeff = 0.4382, Opt. tip-speed ratio = 6.335, Cut-in/rated wind speed = 4 (m/s)/12 (m/s).

Non-linear load of 100kW: R_l = 8.68 Ω, L_l = 0.01 mH.