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A new approach for power quality improvement of DFIG based wind farms connected to weak utility grid

Hossein Mahvash, Seyed Abbas Taher *, Mohsen Rahimi

Department of Electrical Engineering, University of Kashan, Kashan, Iran

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Stator voltage orientation control (SVOC);
Flicker mitigation

Abstract Most of power quality problems for grid connected doubly fed induction generators (DFIGs) with wind turbine include flicker, variations of voltage RMS profile, and injected harmonics due to switching in DFIG converters. Flicker phenomenon is the most important problem in wind power systems. This paper described an effective method for mitigating flicker emission and power quality improvement for a fairly weak grid connected to a wind farm with DFIGs. The method was applied in the rotor side converter (RSC) of the DFIG to control the output reactive power. q axis reference current was directly derived according to the mathematical relation between rotor q axis current and DFIG output reactive power without using PI controller. To extract the reference reactive power, the stator voltage control loop with the droop coefficient was proposed to regulate the grid voltage level in each operational condition. The DFIG output active power was separately controlled in d axis considering the stator voltage orientation control (SVOC). Different simulations were carried out on the test system and the flicker short term severity index (P_{st}) was calculated for each case study using the discrete flickermeter model according to IEC 61400 standard. The obtained results validated flicker mitigation and power quality enhancement for the grid.

1. Introduction

Using wind energy as the most important source of renewable energies is increasing every day and the operational capacity of wind power plants is expected to reach 425 GW by the end of 2015 [1]. Power quality improvement in the grids connected to wind farms leads to consumers' satisfaction, damage reduction of the sensitive equipment, and development of wind power plants. Due to the inherent aerodynamic effects of wind speed such as speed continuous variations, turbulence, and gusty

* Corresponding author at: Department of Electrical Engineering, University of Kashan, Kashan 87317-51167, Iran. Tel./fax: +98 3155511131.
E-mail address: sataher@kashanu.ac.ir (S.A. Taher).
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Nomenclature

P_{st} short term flicker severity index
ω_r, ω_t generator and turbine speed
T_e, T_m generator and turbine torque
H_g, H_t generator and turbine inertia constant
D_{tg}, k_{seq} equivalent torsial damping and torsial spring constant
θ_{sh} angular position between generator and turbine
f_s stator steady state frequency
ω_b base angular speed (selected equal to $2\pi f_s$)
V_{sd}, V_{sq}, I_{sd}, I_{sq}, ψ_{sd}, ψ_{sq} stator d and q axes voltages, currents, and fluxes
V_{rd}, V_{rq}, I_{rd}, I_{rq}, ψ_{rd}, ψ_{rq} rotor d and q axes voltages, currents, and fluxes
ω_s, ω_r stator and rotor electrical speed
R_s, R_r, L_s, L_r stator and rotor resistance and self-inductance
L_m, $L_{\sigma r}$ mutual magnetizing inductance and rotor leakage inductance
S DFIG slip
I^*_{rd}, I^*_{rq} rotor d and q axes reference currents
K_P, K_I proportional and integrator coefficients of PI controller
α bandwidth of internal loops of rotor current control
α_p bandwidth of external loop of active power control
P_s, P_{s_inject}, Q_s, Q_{s_inject} stator absorbed and injected active and reactive power
$|V_{sd}|$ stator phase-neutral peak voltage (equal to 1 pu)
P^*_s, Q^*_s stator reference active and reactive power
$|V_{PCC}|$, $|V^*_{PCC}|$ PCC voltage amplitude and reference voltage amplitude
X_s, K, S_n stator mutual reactance, droop coefficient, and wind farm apparent power
It should be noted that rotor quantities refer to the stator side.

wind, wind farm output power is fluctuated and thus the grid voltage will be varied. These variations cause power quality problems, especially flicker emission [2]. Turbulence means that wind speed at a certain value is not at this value exactly and continually has a percentage of variations (typically between 10 and 20%). Turbulence intensity is calculated via wind speed deviation divided by mean wind speed. Gusty wind is the sudden increase of wind speed that causes severe changes in the output active power.

The flicker frequency range is 0.5–42 Hz [3] due to the dynamic and continuous voltage changes between 0.9 and 1.1 pu. The most sensitive frequency of the glimmering of luminous lamps that annoys human eyes is around 8.8 Hz [4]. The flicker severity is measured by two short- and long-term statistical indexes and calculated in 10 min and 2 h via the discrete flickermeter model according to IEC 61400 standard [3–5]. The most important grid parameter affecting the flicker severity is the short circuit capacity (SCC). By increasing the SCC, the grid will be stronger and power quality problems will be reduced. The grid X/R ratio affects the flicker emission, too; but its effect is not as much as the SCC. In rural and remote regions, grids are usually weak and thus power quality problems are higher.

Doubly fed induction generators (DFIGs) are widely used in wind power plants because of controllable abilities [6] and cause lower power quality disturbances for the grid. Due to the wind speed variations and consequently turbine speed variations, DFIG performs in super and subsynchronous and even synchronous modes; but, in all of these modes, the generator can produce the active power for the grid, which is a remarkable ability for the DFIG. Block diagram of the DFIG is shown in Fig. 1. The flicker emission can be reduced by applying control loops with PI controllers in rotor side converter (RSC), grid side converter (GSC), and also the pitch angle control system of the DFIG which have an effective role in improving the power quality characteristics. In special cases, power quality equipment is used as well; however, using them forces high expenses. This equipment often works according to the reactive power control [7]. Static synchronous compensator (STATCOM) is one of the most famous facilities in this regard which is applied in wind farms with DFIGs [8,9].

Flicker mitigation methods in DFIGs are generally divided into three groups [10,11]. These methods are often used in RSC based on reactive power control. One of these procedures that has been presented in different versions is called fixed power factor; according to this method, generator power factor is

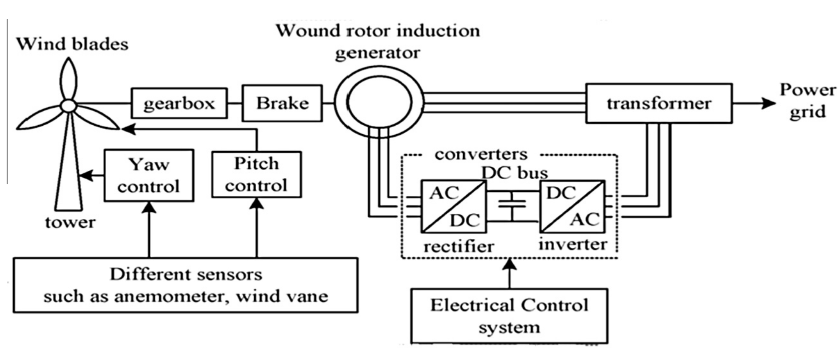

Fig. 1 Block diagram of DFIG.