



Performance analysis of an unbalanced DFIG WEC system

¹Sagar U. Shinde, ²K. Vadirajacharya

Department of Electrical Engineering
 Dr. Babasaheb Ambedkar Technological University, Lonere
 Email : ¹Sagar.shinde78@gmail.com, ²kvadirajacharya@dbatu.ac.in

Abstract - In this paper, an effective control strategy for the current for the operation of a doubly fed induction generator (DFIG) is presented. The proposed control scheme eliminates the rotor current errors in the following switching period. The SVM technique is used to apply identified rotor voltage. The whole control algorithm is performed in the RSC to achieve the desired control output, i.e., compensation for the stator voltage imbalance. The proposed system is verified by MATLAB simulations for 1KW DFIG feeding a grid.

Keywords –Grid connected DFIG, SVM, PCC, GSC-RSC.

I. INTRODUCTION

Doubly fed wound rotor induction machine with vector control is very effective to the high performance variable speed drive and generating applications. In variable speed drive application, the so called slip power recovery scheme is a common practice. Here the power due to the rotor slip below or above synchronous speed is recovered to or supplied from the power source resulting in a highly efficient variable speed system. This recovery of the slip is obtained by Scherbius drive for bi directional power flow. The doubly fed induction machine using an AC-AC converter in the rotor circuit (Scherbius drive) handles a fraction of (20-30%) total power. Vector-control techniques for the independent control of torque and rotor excitation current are well used to control active and reactive power drawn from the supply.

The proposed control scheme predicts an appropriate average rotor voltage vector to eliminate the rotor current errors in the following switching period. The identified rotor voltage vector is then applied to the rotor-side converter (RSC) by using space-vector modulation (SVM) with constant switching frequency. The whole control algorithm is performed in the RSC to achieve the desired control output, i.e., compensation for the stator voltage imbalance. The proposed system is verified by MATLAB simulations for 1KW DFIG feeding a grid.

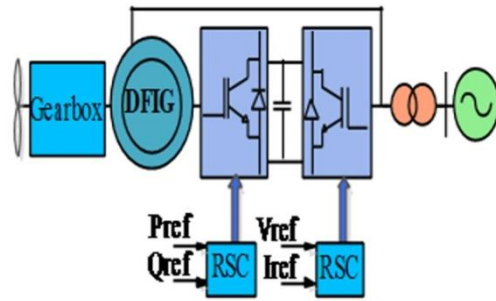


Fig. 1.DFIG system.

II. DESCRIPTION OF THE DFIG

A DFIG can supply power at constant voltage and constant frequency while its rotor rotation speed varies [3–7]. This represents an asset in providing more flexibility in power conversion and also better stability in frequency and voltage control in the power systems to which such generators are connected. A DFIG consists of a wound rotor induction generator (WRIG) with the stator windings directly connected to the three-phase grid/load and the rotor windings connected to a back-to-back partially rated [8–17] power converter. The size of the converter relates not only to the total generator power but also to the selected speed range or the slip power. PWM converters have been widely used. In this paper the cascaded H-bridge multilevel inverter is used for back to back conversion.

Use of the positive and negative reference frame rotating at the speed ω_s and $-\omega_s$ is the most common method to analyze the DFIG model. The stationary frames $\alpha_s\beta_s$ and the $\alpha_r\beta_r$ are the rotating frames rotating at the speed ω_r . The PCC method is based on the analysis of rotor voltages v_{rdq} and stator φ_{sdq} , rotor fluxes φ_{rdq} .

$$\varphi_{rd}^+ = L_r i_{rd}^+ + L_m i_{sd}^+ = \frac{L_m^2}{L_s} i_{ms}^+ + \sigma L_r i_{rd}^+ \quad (1)$$

$$\phi_{rq}^+ = L_r i_{rq}^+ + L_m i_{sq}^+ = \sigma L_r i_{rq}^+ \quad (2)$$

$$v_{rd}^+ = R_r i_{rd}^+ + \sigma L_r \frac{d}{dt} i_{rd}^+ - \omega_{sl}^+ \sigma L_r i_{rq}^+ \quad (3)$$

$$v_{rq}^+ = R_r i_{rq}^+ + \sigma L_r \frac{d}{dt} i_{rq}^+ + \omega_{sl}^+ \left(\frac{L_m^2}{L_s} i_{ms} + L_r i_{rd} \right) \quad (4)$$

Where, R_r , L_m , L_r , L_s , L_{ms} are the nominal values of rotor resistance, mutual inductance, rotor inductance, stator inductance, total leakage factor, and stator magnetizing current of the generator, respectively.

III. PROPOSED PCC FOR UNBALANCED DFIG SYSTEM

PCC forces the rotor output current follow the reference rotor current. The initial excitation for the system start up could be provided by a battery bank (not shown in the figure). The battery could be kept charged afterward using the energy flow in the dc link. Another possibility is to use a bank capacitor in the stator for the self-excitation of the machine, generating the required stator voltage. Then, the control strategy of the line side converter or, in this case, the stator-side converter, could regulate the required dc-link voltage. To compensate the load unbalance, the GSC and/or the RSC can be used. The positive & negative-sequence vector control system is oriented along the stator voltage vector. The reference rotor current is generated by an outer voltage control loop and a negative sequence component, added to compensate for stator voltage unbalances.

The rotor current in the k^{th} sampling period can be estimated based on the current values and the system model.

$$\Delta i_{rd}^+(k) = -\frac{T_s R_r}{\sigma L_r} i_{rd}^+(k) + \frac{T_s V_{rd}^+}{\sigma L_r} + T_s \omega_{sl}(k) i_{rd}^+(k) \quad (5)$$

$$\Delta i_{rq}^+(k) = -\frac{T_s R_r}{\sigma L_r} i_{rq}^+(k) + \frac{T_s V_{rq}^+}{\sigma L_r} - T_s \omega_{sl}(k) \left(i_{rd}^+(k) + \frac{L_m \sigma L_r L_{ms}}{L_s} \right) \quad (6)$$

$$\bar{V}_{rd}^+(k) = R_r i_{rd}^+(k) + \frac{\sigma L_r}{T_s} \Delta i_{rd}^+(k) - \omega_{sl} \sigma L_r i_{rq}^+(k) \quad (7)$$

$$\bar{V}_{rd}^+(k) = R_r i_{rd}^+(k) + \frac{\sigma L_r}{T_s} \Delta i_{rd}^+(k) + \omega_{sl} \left(\frac{L_m^2}{L_s} i_{ms}(k) + \sigma L_r i_{rd}^+(k) \right) \quad (8)$$

In order to regulate the output rotor current to follow its reference at the end of the next switching period, the average required output rotor voltages $\bar{v}_{rdq}^+(k)$ should be precisely predicted in the next switching period; and they are shown in the discrete basis as (7) and (8). These predicted rotor voltages are then applied into the RSC to force the rotor current error to zero. The compensation method for such time delay should be adopted to avoid large overshoot and oscillations in the rotor current. To increase the control performance in terms of low distortion and low current ripple, the required rotor voltage is then controlled using SVPWM technique.

V. IMPLEMENTATION OF SVPWM FOR CONVERTERS

By comparing the stationary frame d-q components of the reference voltage vector, the sector where the reference voltage vector is located is identified. Using the d-q components of the reference voltage vector, a sine loop voltage and a dc-link voltage information, the effective times T_1 , T_2 are calculated. Instead of the sine table, to reduce the calculation time, another look-up table which contains the corresponding to each sector number may be used. Using the corresponding sector information the actual switching time for each inverter leg is generated from the combination of effective times and zero sequence time.

$$(|V_{sr}| \cos \alpha) * T_s = V_{dc} * T_1 + (V_{dc} \cos 60^\circ) * T_s \quad (9)$$

Equating volt-seconds along the β axis:

$$(|V_{sr}| \sin \alpha) * T_s = (V_{dc} \sin 60^\circ) * T_2 \quad (10)$$

Solving the above two simultaneous equations, one gets:

$$T_1 = \frac{|V_{sr}| T_s \sin(\frac{\pi}{3} - \alpha)}{V_{dc} \sin(\frac{\pi}{3})} \quad T_2 = \frac{|V_{sr}| T_s \sin(\alpha)}{V_{dc} \sin(\frac{\pi}{3})} \quad (11)$$

$|V_{sr}|$ represents the length of the reference Vector and α is measured from the start of the vector.

$$T_1 = \frac{2T_s [V_\alpha \sin(\frac{\pi}{3}) - V_\beta \cos(\frac{\pi}{3})]}{\sqrt{3}V_{dc}} \quad T_2 = \frac{2T_s V_\beta}{\sqrt{3}V_{dc}} \quad (12)$$

Substituting,

$$V_\alpha = \frac{3}{2} V_a^* V_\beta = \frac{\sqrt{3}}{2} (V_b^* - V_c^*) \quad (13)$$

$$T_1 = \frac{T_s(V_a^* - V_b^*)}{V_{dc}} \quad T_2 = \frac{T_s(V_b^* - V_c^*)}{V_{dc}} \quad (14)$$

The imaginary switching periods T_{as} , T_{bs} and T_{cs} are defined as:

$$T_{as} = \left(\frac{T_s}{V_{dc}}\right) V_a^*; \quad T_{bs} = \left(\frac{T_s}{V_{dc}}\right) V_b^*; \quad T_{cs} = \left(\frac{T_s}{V_{dc}}\right) V_c^* \quad (15)$$

The active vector switching times T_1 and T_2 in sector1 may be expressed as:

$$T_1 = T_{as} - T_{bs}; \quad T_2 = T_{bs} - T_{cs} \quad (16)$$

Extending this procedure, for the other sectors, the active vector switching times (T_1 and T_2) and for the respective sectors may be expressed in terms of the imaginary switching times (T_{as} , T_{bs} and T_{cs}) for a particular sampling interval. The effective time T_{eff} is the time during which the active vectors are switched in a sector and is given by ($T_1 + T_2$). This may be determined as the difference between the maximum and minimum values among T_{as} , T_{bs} and T_{cs} . Hence, $T_0 = T_s - T_{eff}$.

$$T_{eff} = \max\{T_{as}, T_{bs}, T_{cs}\} - \min\{T_{as}, T_{bs}, T_{cs}\} \\ = T_{max} - T_{min}$$

The offset time, T_{offset} required to distribute the zero voltage symmetrically during one sampling period is given by:

$$T_{offset} = \frac{T_0}{2} - T_{min} \quad (17)$$

The actual switching times for each the inverter leg can be obtained by the time shifting operation as follows:

$$T_{ga} = T_{as} + T_{offset}; \quad T_{gb} = T_{bs} + T_{offset}; \quad T_{gc} = T_{cs} + T_{offset} \quad (18)$$

V. SIMULATION RESULTS

The MATLAB Simulation has been performed for the following system parameters:

DFIG Parameters:

1 KW, 460V, 6 pole, 50 Hz.

Stator resistance, inductance [R_s , L_s] (p.u.) = 0.016, 0.06;

Rotor resistance, inductance [R_r' , L_r'] (p.u.) = 0.015, 0.06;

Mutual inductance L_m (pu) = 3.5;

Grid Voltage = 7.5KV.

Back to back converters: 3 level svpwm cascaded H-bridge converter.

Battery Parameters: 325V.

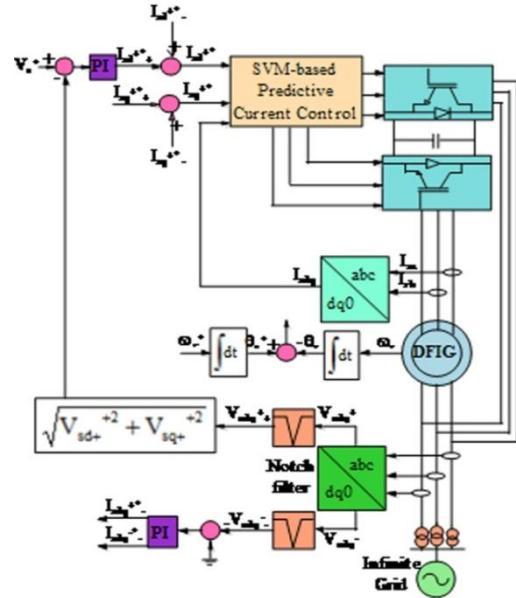


Fig.2. 1KW DFIG WEC system Simulation diagram

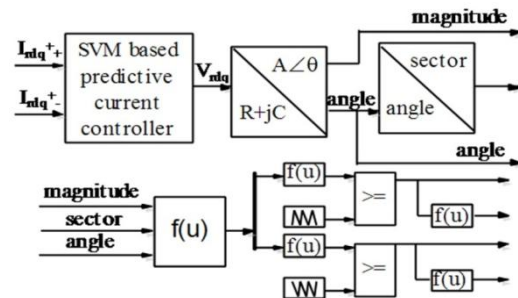


Fig.3. SVPWM-based Predictive current control circuit

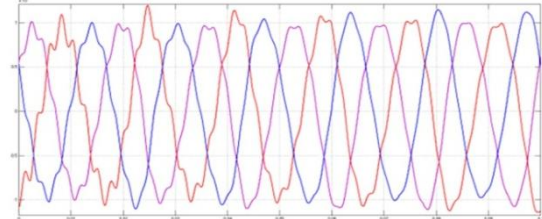


Fig.4. stator voltages

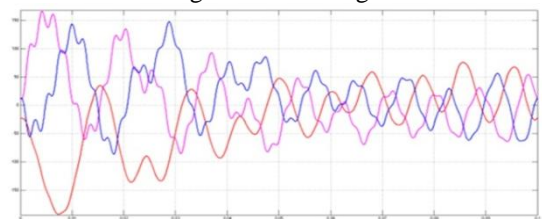


Fig.5. Stator currents

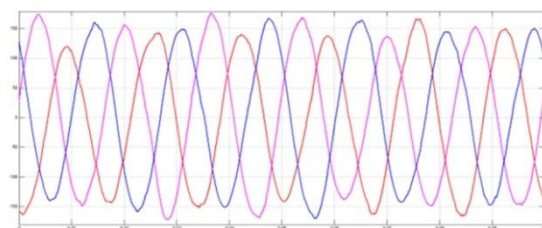


Fig.6. rotor voltages

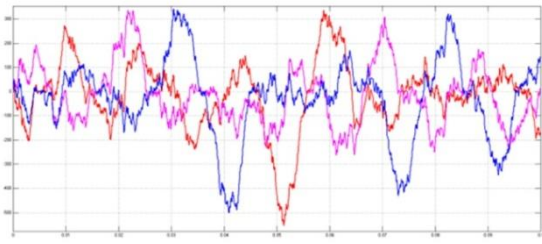


Fig.7. rotor currents

V. CONCLUSION

An improved PCC method for an unbalanced stand-alone DFIG system has been proposed in this paper and the combined voltages from stator and rotor side converter is calculated. Simulation results shows that the control is simple to implement and very effective at compensating for the torque pulsations, reactive power pulsations, and unbalanced stator current that normally occur when stator voltage is unbalanced. This greatly reduces the wear on the mechanical components, such as the shaft, gear box, and blade assembly, and also improves the quality of the power fed into the grid.

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