Controlling Of DFIG Wind Turbine Under Unbalanced Grid Fault Condition

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NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>vsd, vsq</td>
<td>Stator d and q winding voltage.</td>
</tr>
<tr>
<td>isd, isq</td>
<td>Stator d and q winding current.</td>
</tr>
<tr>
<td>vrd, vrq</td>
<td>Rotor d and q winding voltage.</td>
</tr>
<tr>
<td>ird, irq</td>
<td>Rotor d and q winding current.</td>
</tr>
<tr>
<td>λsd, λsq</td>
<td>Stator d and q winding flux linkage.</td>
</tr>
<tr>
<td>λrd, λrq</td>
<td>Rotor d and q winding flux linkage.</td>
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<tr>
<td>T</td>
<td>Generator torque.</td>
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<tr>
<td>Qs</td>
<td>Stator reactive power.</td>
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<tr>
<td>Lm</td>
<td>Generator magnetizing inductance.</td>
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<tr>
<td>Ls, Lr</td>
<td>Stator and rotor per phase winding inductance.</td>
</tr>
<tr>
<td>Lls, Llr</td>
<td>Stator and rotor per phase leakage inductance.</td>
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<tr>
<td>Rs, Rr</td>
<td>Stator and rotor per phase winding resistance.</td>
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<tr>
<td>p</td>
<td>Number of generator poles.</td>
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<tr>
<td>n</td>
<td>Rotor/stator turns ratio.</td>
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<tr>
<td>J</td>
<td>System moment of inertia.</td>
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<tr>
<td>B</td>
<td>System frictional constant.</td>
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<tr>
<td>oωd</td>
<td>dq-axes frame rotational speed with respect to the stator.</td>
</tr>
<tr>
<td>oωA</td>
<td>dq-axes frame rotational speed with respect to the rotor.</td>
</tr>
<tr>
<td>qwsyn</td>
<td>Synchronous rotational speed (50 Hz).</td>
</tr>
<tr>
<td>qmech</td>
<td>Rotor mechanical speed.</td>
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ABSTRACT

A wind electrical generation system is the most cost competitive of all the environmentally clean and safe renewable energy sources in world. In induction wind generators, unbalanced three-phase stator voltages cause a number of problems, such as unbalanced currents, reactive power pulsations, and stress on the mechanical components. Sometimes, induction wind generators are switched out of the network, beyond a certain amount of unbalance. This can further weaken the grid and affects the overall system. In this analysis doubly fed induction generator (DFIG), is used to control the rotor currents. The controlling of rotor currents allows the controlling of reactive power and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds. The controlling of DFIG, variable speed wind turbine under network fault is studied using simulation developed in MATLAB/SIMULINK. This paper presents a DFIG control strategy that enhances the standard speed and reactive power control with controllers that can compensate for the problems caused by an unbalanced grid. This strategy involves balancing of the stator currents and eliminating torque and reactive power pulsations.

Keywords: DFIG, reactive power control, torque control, variable speed drive, wind energy.

1. INTRODUCTION

The global electrical energy consumption is rising and there is steady increase of the demand on power generation. So in addition to conventional power generation units a large no. of renewable energy units is being integrated into the power system. A wind electrical generation system is the most cost clean and safe renewable energy sources in world. The recent evolution of power semiconductors and variable frequency drive technology has aided the acceptance of variable speed generation systems. Both fixed-speed squirrel-cage induction generator and variable speed doubly fed induction generator are used in wind turbine generation technology. A special type of induction generator, called a doubly fed induction generator (DFIG), is used extensively for high-power wind applications. A double fed induction generator is a standard, wound rotor induction machine with its stator windings is directly connected to grid and its rotor windings is connected to the grid through an AC/DC/AC converter. AC/DC converter connected to rotor winding is called rotor side converter and another DC/AC is grid side converter. DFIG’s ability to control rotor currents allows for reactive power control and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds. In this analysis we use a control method of DFIG to compensate the problems caused by an unbalanced grid. This will allow...
DFIGs to stay connected to the grid under conditions in which they would normally be disconnected for their own protection. Rotor side converter control is only considered.

**Figure 1** Doubly Fed Induction Generator

**2. CONTROLLER DESIGN**

For the proposed control, hysteresis control is used. The control structure is shown in Figs. 2 and 3. The control topology is standard except for the addition of the $Cd_{comp}$ and $Cq_{comp}$ controllers, which supplement the $d$- and $q$-axis rotor voltage. These feedback controllers shown gives the loops a very high gain at the known disturbance frequency (100 Hz). Further, the controllers compensate the torque and reactive power pulsations that arise when the stator voltage is unbalanced. Reducing the reactive power pulsation dramatically improves the unbalance of stator current.

**Figure 2** d-Axis control topology

**Figure 3** q-Axis control topology

For symmetrical components, compensation for torque and reactive power pulsations is analogous to a controller injecting a negative sequence into the rotor circuit in such a manner as to compensate for the negative sequence in the stator circuit. It results into reduction of torque pulsations, reactive power pulsations, and stator-current unbalance under unbalanced grid voltage conditions.

**2.1 Design of Cird and Cirq**

The inner loop $ird$ and $irq$ current controllers, $Cird$ and $Cirq$, were designed using linearized state equations. This is done by substituting the generator flux linkages (1) through (3) into the generator voltage equation (4) [6]. After obtaining the generator currents as a state equation relating the voltage and current in the $dq$ frame, as shown in (5). From this form, the transfer functions relating current to voltage are easily obtained, assuming $o_dA$ is constant.

\[
\begin{bmatrix}
\lambda_{sd} \\
\lambda_{sq} \\
\lambda_{rd}
\end{bmatrix} =
\begin{bmatrix}
L_s & 0 & nL_m & 0 \\
0 & L_s & 0 & nL_m \\
nL_m & 0 & L_r & 0
\end{bmatrix}
\begin{bmatrix}
i_{sd} \\
i_{sq} \\
i_{rd}
\end{bmatrix}
\]

\[
\begin{align*}
\lambda_{sd} &= L_{ls} + L_{rm} \\
\lambda_{sq} &= nL_{rm} \\
\lambda_{rd} &= L_r
\end{align*}
\]
From the linearized state equations (5), *ird/vrd*(s) and *irq/vrq*(s) are determined.

2.2 Design of *Cω_mech*

For the design of speed controller, the *ω_mech/ird*(s) transfer function must be determined.

Since *imq* is large negative and *imd* is very small. Therefore, the torque can be approximated as

\[ T' \approx \frac{P}{2} \left( L_m n i_{mq} i_{rd} \right) \]

\[ T' (s) = \frac{P}{2} L_m n i_{mq} i_{rd} . \]

A fast speed loop will respond more quickly to changes in the load and a slow speed loop will allow the generator to accelerate or decelerate as the wind changes.

2.3 Design of *CQs*

The reactive power outer loop is designed by relating stator reactive power *Qs* to *irq*. 

\[ \omega_mech \frac{T}{i_{rd}} (s) = \frac{P}{2} \frac{L_m n i_{mq}}{sJ + L3} . \]
The magnetizing current $i_{mq}$ can be approximated as constant. Equation (13), then, can be written as

$$\frac{Q_s}{i_{rq}}(s) = mv_{sd}. \quad (13)$$

A PLL controller is used.

2.4 Design of Unbalance Compensation Controllers $C_d,\text{comp}$ and $C_q,\text{comp}$

The $C_d,\text{comp}$ and $C_q,\text{comp}$ controllers shown in Figs. 2 and 3. The $C_d,\text{comp}$ and $C_q,\text{comp}$ controllers are designed to have a large gain at the known disturbance frequency but also to have a negligible effect at all other frequencies. This is done by using a high-$Q$, second order resonant filter. Also removing the second harmonic from $ird$ and $irq$ will not completely remove the second harmonic from the torque and reactive power, although it can reduce it.

3. SIMULATION RESULTS
4. CONCLUSION
A control methodology for DFIG wind turbine under unbalanced grid fault condition is presented. Controlling helps to compensate the torque pulsations, reactive power pulsations, and unbalanced stator current that normally occur when stator voltage is unbalanced. This improves the quality of the power fed into the grid by reducing the wear on the mechanical components.

References