Performance Enhancement of Doubly Fed Induction Generator-Based Wind Farm for Grid Voltage Dip and Harmonics Mitigation

Snehal Joshi¹
PG student , Indus University , Ahmedabad

Shefali Talati²
Manager , Electrical Research & Development Association , Vadodara.

Abstract

Electricity generation from renewable energy sources has rapidly increased for the last few decades worldwide. Solar and wind energy are the most frequently used technologies in the field. However, integration of these sources to the grid requires more attention and additional devices to improve power quality and maintain voltage stability.

This paper presents an improved control strategy for grid connected Doubly Fed Induction Generator (DFIG) wind turbines system to enhance Low Voltage Ride Through (LVRT) capacity and power quality. The proposed scheme uses Grid Side Converter (GSC) for reactive power compensation and for active harmonics filtering. Simulations performed in MATLAB/Simulink verify the effectiveness of the proposed control strategy.

Keywords: DFIG, Grid Side Converter, LVRT, Harmonics mitigation.

Introduction

In last few decades a number of reasons have led the capacity of the Renewable Energy Sources (RES) to continuously increase. In many countries RES targets to have 20% to 50% of all electricity generation due to the concerns of CO2 emissions, fossil fuel costs, and energy efficiency. In order to maintain sustainable and reliable operation of the power system for these targets, transmission system operators (TSOs) have revised the grid code requirements. TSOs are planning the future development of the power system with even more penetration from Renewable Energy Converters (RECs), to integrate more power according to their grid codes. In this scenario with high RECs penetration the power quality aspect of the grid need supreme attention as all the RECs uses power electronics devices which are the major contributors of poor power quality. Moreover, recent grid standards as IEEE 1547-2003 require the wind turbine to provide some reactive power in order to ride through fault (LVRT)[1], during grid disturbance. As a result of that various technical issues regarding impact on system operational security, ensuring stability, voltage regulation, and power quality need to be taken in to consideration before these plants can be connected to the electricity grid.

The objective of this paper is to analyze the performance of Grid Side Inverter as LVRT circuit and to reduce amount of Harmonics produced by DFIG.

The structure of paper is as follow: in section – I: Modeling of the DFIG generator model is presented, in section II – an improved scheme of using GSC for LVRT and power quality is presented, in section III – Simulation and results of the test system are presented and section IV – presents conclusion based on the results obtained from simulation model.

I. MODELING AND CONTROL OF THE GENERATOR

A. Modeling of Wind turbine generator (DFIG)

The modeling of DFIG is expressed in the d-q reference using Parks transformation.

Stator and rotor side voltages of wind energy system are described by below equations[1],[2].

\[ V_{ds} = R_s i_{ds} - \omega q_s + \frac{d\phi_{ds}}{dt} \]
\[ V_{qs} = R_{siqs} - \omega \phi_{ds} + \frac{d \phi_{qs}}{dt} \]
\[ V_{dr} = R_{ridr} - (\omega - \alpha r) \phi_{qr} + \frac{d \phi_{dr}}{dt} \]
\[ V_{qr} = R_{riqr} - (\omega - \alpha r) \phi_{dr} + \frac{d \phi_{qr}}{dt} \]

The electromagnetic torque is given by
\[ T_{em} = \frac{3P}{4} (i_{qs} \phi_{ds} - i_{ds} \phi_{qs}) \]

Where,
\[ V_{ds}, V_{qs} = \text{d- and q-axis stator voltages} \]
\[ V_{dr}, V_{qr} = \text{d- and q-axis rotor voltages} \]
\[ I_{ds}, I_{qs} = \text{d- and q-axis stator current} \]
\[ I_{dr}, I_{qr} = \text{d- and q-axis rotor current} \]
\[ R_{s}, R_{r} = \text{Per-phase stator and rotor resistances referred to the stator} \]
\[ \phi_{ds}, \phi_{qs} = \text{d- and q-axis stator flux linkages} \]
\[ \phi_{dr}, \phi_{qr} = \text{d- and q-axis rotor flux linkages} \]
\[ \omega = \text{Speed of rotation of the rotor} \]
\[ \omega_r = \text{Rotor electrical angular velocity.} \]

B. Fault ride through capacity [LVRT]

Over the years various techniques have been developed to improve LVRT capacity of the wind turbine generators[5],[6],[8]. In [1],[4] it has been shown that DFIG have ability to improve the power quality by injecting some amount of reactive power during grid voltage disturbances. The main reason for providing LVRT capacity is that all the RECs are very sensitive to grid voltage variations. Also, because of uncontrolled source of their generation all RECs have characteristics of weak disturbance rejection.

With higher power generation from wind turbines, it has become necessary that the wind turbines remains in operation during the event of grid voltage variations. For these reasons grid codes [10] demands that the wind farms must withstand a certain percentage of voltage dips for a specified period. The overall required fault behavior of a wind farm can be summarized by four main points,

- For the faults that last up to 160ms, the wind farm has to remain connected to the network
- During the voltage sag the wind farm has to supply maximum reactive current in order to support the grid voltages, without exceeding the transient limit of the plant
- For system faults that last up to 160ms upon therestoration of voltage to 90% of nominal a wind farm has to supply active power to at least 90% of its prefaultvalue within 0.5 sec
- The restoration voltage of the wind turbine must follow the graph shown in Figure:1

![Figure:1-Required LVRT characteristics as per Indian electricity grid codes](image1)

In this paper the required LVRT characteristics has been simulated in MATLAB. The simulation logic circuit is presented in Figure:2. Reactive power compensation has been achieved by providing 2% reactive current for each % drop in voltage.

![Figure:2- Simulation circuit – LVRT](image2)
PLL is tuned in such a way that it provides leading current during faults in order to support the grid recovering voltages. The simulated results are presented in section-III.

C. Harmonics mitigation

With increased REC penetration, and with increase in non-linear loads, the power quality of the grid has become an issue of prime importance. Various research works [7],[11],[12] show that interconnection of REC with power system injects certain amount of harmonics at Point of Common Coupling (PCC). However, the number of solutions that can mitigate this is increasing and new techniques are being formulated and classical ones being reformulated or improved. In [7] review of such mitigation techniques is presented.

The main purpose of such power quality enhancement techniques is to reduce the electromagnetic interface produced due to presence of unnecessary signals, so called harmonics, in the grid. These signals can cause power system devices to malfunction frequently. To make sure all the system equipment functions as intended, these signals need to be compensated.[7]. There are three main way of compensating these signals:

- By reducing harmonics emission of the equipment
- By increasing the harmonics withstand capacity of the equipment
- By reducing the exchange of disturbances between grid and the source of disturbances

First two compensating methods require physical alteration of the grid. However, the compensation method presented in this paper concentrates on reducing the exchange of disturbances.

II. PROPOSED DFIG - GSC CONTROL CIRCUIT

Figure:3 shows the functional control scheme of Grid Side Converter (GSC) of DFIG. The GSC is essentially a shunt converter which is capable of injecting current in shunt to the load. Hence, the GSC can be used for reactive power exchange between generator and grid by regulating the DC bus voltages and keeping it to a constant value. However, due to small rating of GSC the controlling capacity is limited.

![Functional control system of GSC– DFIG](image)

For active harmonics filtering, an additional current control loop is added to the GSC converter control system.

III. SIMULATION OF TEST SYSTEM

I. SYSTEM DESCRIPTION

A simple test system was built to accurately evaluate the performance of system with and without DFIG, shown in Figure:4. The test system also include a large synchronous generator unit which represents the main AC system. Here 2.1MW DFIG is considered so total generation from DFIG is approx. 20% of overall load requirement. Model data of DFIG are shown in Table:1.
Here DFIG is connected to main grid through a transmission network of different line length. The generated power from DFIG is stepped up and delivered to Point of Common Coupling (PCC). PCC is a 220KV bus which further transmits the power to lumped load of 500MW combination of static load and dynamic load. All efforts have been made to simulate the closest approximate model to existing utility grid. In order to understand operation of GSC, for LVRT and active filtering, and to evaluate its behavior with power quality issues the performance evaluation has been made with a simulation model using MATLAB.

### Table: 1-DFIG modeling data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal electrical power [P]</td>
<td>2100 kW</td>
</tr>
<tr>
<td>Nominal system voltage [V]</td>
<td>690 V</td>
</tr>
<tr>
<td>System frequency [f]</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Stator resistance [Rs]</td>
<td>0.1748 Ω</td>
</tr>
<tr>
<td>Rotor resistance [Rr]</td>
<td>0.0325 Ω</td>
</tr>
<tr>
<td>Stator leakage inductance [Ls]</td>
<td>0.0259 H</td>
</tr>
<tr>
<td>Rotor leakage inductance [Lr]</td>
<td>0.026 H</td>
</tr>
<tr>
<td>Mutual Inductance [Lm]</td>
<td>0.0249 H</td>
</tr>
<tr>
<td>Number of poles [p]</td>
<td>6</td>
</tr>
<tr>
<td>Moment of inertia [J]</td>
<td>139 Kg m^2</td>
</tr>
<tr>
<td>Rated wind velocity [Vm]</td>
<td>12 m/s</td>
</tr>
</tbody>
</table>

**II. SIMULATION MODEL AND RESULTS**
A. Analysis of fault ride through capacity [LVRT]

To analyze the fault behaviour of the system a three phase fault has been created at t=0.2sec:

It is shown in Figure:7 and Figure:8 that for the fault at t=0.2sec the grid voltages drops and current drawn from grid increases. As a result of that the active and reactive power generation of DFIG also decreases. Figure:9 and Figure:10 shows the results of boosted voltage by using GSC for LVRT capacity as proposed in section-II. It is shown that DFIG injects reactive current in to the grid and causes voltage recovers on 220KV HV bus. Due to recovery of the grid voltages the reactive current supplied by DFIG decreases gradually.

B. Analysis of active filtering by GSC.

Figure:11 presents FFT analysis of the system at 220KV generator side bus with synchronous generator only. Figure:12 also shows results at the same bus but with interconnection of DFIG and grid. It is clearly seen that DFIG injects considerable amount of harmonics components in the grid as the THD increased to 4.05 % from 1.57 %.
In this paper, the simulation has been carried out to demonstrate the effect of grid voltage drop on DFIG. It also shows impact of DFIG generation on harmonics level of the power system. The transmission line parameters have been first calculated and then simulated with as per proper reference standards. The results show that power generation from the DFIG reduces with drop in grid voltage. It also shows that DFIG injects certain amount of harmonics in the grid which can cause power quality problems.

The results also show that the proposed GSC system can provide solution for both the LVRT and harmonics generation. With this system, the DFIG can inject reactive current in to grid during grid faults and contribute to the recovery of the system voltages. The GSC circuit can also be used as active harmonics filtering circuit to reduce the harmonics generated from DFIG itself and from the grid. However, the filtering capacity is limited to only 15% to 20% of the DFIG rating because of the lower rating of the GSC circuit.

IV- CONCLUSION

Reference:
[10] Indian Electricity grid codes