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Abstract

Owing to the problems associated with the global warming every country around the world is looking into the options of alternative energy sources like renewable energy. The wind power is prominent in renewable energy throughout the world. The doubly fed induction generator (DFIG) based wind turbines are mostly used in wind power generation. But the sensitivity of DFIG wind turbine towards the grid disturbance is a serious issue. This may result in impairment of power converters connected to the grid, and consequently the DFIG is disconnected from the grid. Thereupon the power quality of the grid cannot be maintained. In order to lower this complication, the DFIG wind turbine is connected to super capacitor energy storage (SCES) thus compensating reactive power and thereby improving the voltage profile. By using a static synchronous compensator (STATCOM) along with SCES further improves the voltage profile. Simulation results can be examined in MATLAB/Simulink for a DFIG Wind turbine without SCES, with
SCES and both SCES and STATCOM. The enrichment of fault ride-through (FRT) shall be observed in a system along with STATCOM and SCES together.

Key Words and Phrases: Doubly fed induction generator (DFIG), STATCOM, low voltage ride through (LVRT), super capacitor energy storage.

1 Introduction

As compared to all other renewable energy sources the wind power is the more favored source of renewable energy because of its immense efficiency, less service and low contamination. Wind turbine is straightly linked to the rotor and the stator of the DFIG is coupled straightly to the grid. Whenever the fault takes place in between wind turbine and grid, the voltage profile of the grid reduces. To satisfy the grid codes STATCOM and SCES are used. STATCOM and SCES inject voltage into the grid whenever fault occurs. For this purpose several flexible AC transmission (FACT) devices like STATCOM, static VAR compensator and energy storage systems like Superconducting Magnetic Energy Storage (SMES), Battery Energy Storage System (BESS) and SCES can be used. In this paper we introduce a blend of SCES and STATCOM to minimize the impact of fault in the DFIG connected grid. FRT capability can be improved using STATCOM and SCES. This combination will improve the voltage instability and it will follow the world wide grid code requirements [1]. The super capacitors have strong potential for applications that need a combination of excessive power, less charging time, more stability, and longer self-existence. Therefore, super capacitors may appear as the solution for more applications in power systems. Particularly, there has been high concern in developing super capacitors for electric vehicle hybrid systems as well as back-up and emergency power requirement. A few techniques have been utilized as a part of upgrading the FRT capacity of the DFIG. These techniques experience the ill effects of the messy control circuit line and a few of them have to actuate the crowbar under substantial voltage plunges. Also the techniques based on additional devices incorporate the utilization of superconducting current limiter, SMES, arrangement of dynamic breaking resistor, dynamic voltage restorer [2], STATCOM, etc. However, usage of these devices adds cost to the system with no additional advantage other than improving the FRT capacity. In recent time, devices for energy storage are utilized to moderate the effect of wind variations in the power system. BESS, SMES, super capacitor (SC) and flywheel are a few devices for energy storage available for wind turbine establishments. Operation of batteries and super
capacitor with wind turbines have been analyzed and it was found that the super capacitor has the benefits of a lower capital cost, higher power thickness and elongated life time contrasting rest of the devices for energy storage.

**System Configuration**

### 2.1. DFIG Based Wind Turbine with STATCOM and Super Capacitor

Representation of DFIG-based wind turbine linked with SCES is seen in Fig.1. The stator rotor pair is connected to the power grid. While the stator of DFIG is linked to power grid directly, the rotor terminals are connected to the power grid via two converters. The two converters which are connected back to back via a DC link are AC-DC rotor-side converter (RSC) and a DC-AC grid-side converter (GSC). To maintain reactive power flow the supercapacitor is connected across the DC link through an intermediate DC-DC converter. The DFIG wind turbine supplies active and reactive power, thus maintaining a voltage magnitude. RSC, regulate the active and reactive power on the stator side while the GSC regulate the reactive power exchanged between grid and DFIG[3-5].

![Figure 1: Test system of DFIG-based wind turbine equipped with super capacitor energy storage and STATCOM.](image)

### 2.2 DFIG-based Wind turbine model

Doubly fed electrical generators look similar to AC generators. Unlike AC electrical generators DFIG runs at speeds slightly over and below synchronous speed. The DFIG has both rotor and stator. As the stator is connected to the grid directly, the rotor is linked to the converters through DC link. Whenever the fault develops in the transmission line the wind turbine detaches from the grid. In order to reduce this problem STATCOM and SCES is used. When a grid fault is identified, the rotor side converter of the DFIG may be cut-off to
insulate it from extensive current transients in rotor circuit. In this paper vector control is employed for both grid side as well as rotor-side grid side converters. Equations [1-4] represent the voltage equations in the d-q reference frame of the DFIG are expressed as follows

\[ v_{ds} = R_i i_d - \omega_s \lambda_{qs} + \frac{d \lambda_{ds}}{dt} \]  
(1)

\[ v_{qs} = R_i i_q + \omega_s \lambda_{ds} + \frac{d \lambda_{qs}}{dt} \]  
(2)

\[ v_{db} = R_i i_d - (\omega_s - \omega_r) \lambda_{qs} + \frac{d \lambda_{dr}}{dt} \]  
(3)

\[ v_{qf} = R_i i_q - (\omega_s - \omega_r) \lambda_{ds} + \frac{d \lambda_{qr}}{dt} \]  
(4)

Where resistance per phase is referred as R, \( \omega \) refers the precise frequency, the flux interface is referred as \( \lambda \), the subscripts ‘d’ and ‘q’ indicate direct and quadrature axes respectively, while the subscripts ‘s’ and ‘r’ refers stator and rotor of the wind turbine.

2.3. Super capacitor model and control scheme

The resistance \( R_{sc} \) in series with a capacitor of capacitance \( C_{sc} \) represents the supercapacitor model[6]. The resistive loss in capacitor is \( R_{sc} \) while \( C_{sc} \) is estimated based on energy \( E \) needed to consume and distribute to the DFIG. The capacitance \( C_{sc} \) is calculated using Equation 5.

\[ C_{sc} = \frac{2E}{V_{sc}^2} \]  
(5)

Where \( C_{sc} \) = Super capacitor capacitance in farad
\( V_{sc} \) = Voltage across the super capacitor
\( E \) = energy stored in the super capacitor to absorb or deliver to DFIG

2.3. STATCOM model and control scheme

STATCOM is linked to the bus via transformer and voltage source converter with DC output voltage to improve the voltage profile during fault and increase the reactive power. During transients STATCOM is used in a transmission line to enhance the transmittable power. This is achieved by enlarging (shrinking) the capability of power transfer as the machine angle boosts (lessens). Just as the DC capacitor voltage rises from its normal value, the STATCOM is ‘overexcited’ and yield reactive power. The STATCOM is ‘under
excited’ when the DC capacitor bank voltage diminishes below the normal value and consume reactive power from the system. Currently, STATCOM is one of the most powerful devices used in solving voltage sag problems[7]. However, cost and installation constraints have limited its implementation to where there is prominent necessity for a stable voltage supply. In auxiliary systems, STATCOM are established at certain points to meet the following requirement: 1. Voltage profile improvement 2. Voltage variation and mitigation of flicker 3. Improve transient stability of the power system.

2 Simulation Results

The current work is simulated and executed using MATLAB/SIMULINK for the doubly fed induction generator based wind turbine whose installed capacity is 1.5MW and the estimated voltage is 0.69kV. The wind speed of the DFIG-based wind turbine is set at 9.5 m/s and is linked to the grid of 0.69/20 kV through a three-phase step-up transformer. A 20 kV power grid is connected to the single DFIG using RSC, DC link capacitor and GSC. A super capacitor with capacitance $C_{sc}$ equal to 8F along with a 0.2Ω resistance $R_{sc}$ in series is used in the model. To appraise the performance of the proposed arrangement of DFIG based wind turbine with a super capacitor to check the effectiveness of fault ride through capability, a balanced three-phase short-circuit is induced in the transmission line at time $t = 2$ to 2.1 sec. After 0.1 sec the fault is rectified. The simulation was done for three cases: (i) In the absence of supercapacitor (ii) having a supercapacitor amid RSC and GSC placed at the DC link terminals (iii) with both STATCOM and SCES[7]. The results of the simulation are verified with worldwide grid codes to justify the usage of STATCOM and super capacitor in improving the competence of fault ride through of the DFIG. By using super capacitor at the dc link side, the voltage profile of the transmission is found to have improved to 0.45p.u. These outcomes affirm the aspect of the supercapacitor in boosting the voltage profile of the DFIG. Further by using STATCOM and super capacitor the voltage profile of DFIG wind turbine can be improved up to 0.55p.u thereby supporting the grid under the fault period. Symmetrical three phase short circuit is induced at the high voltage terminals of the three phase transformer from time $t=2$ to 2.1 sec Fault clearing time is 0.1 sec.

3.1 DFIG without Super capacitor for Terminal Voltage and stator current
As seen from Fig.3 the stator current is initially constant (i.e. 590A at 1.8s) before the occurrence of fault. When the fault occurs at t=2s the line current increases to nearly 1750A at 2.1s and comes to its original value. At the generator terminal the RMS voltage without supercapacitor during a three-phase fault at start is as shown in Fig.2. As the turbine is connected to the grid the voltage increases from 0 and the reference signal is set as 1 and at that point the voltage is maintained constant. After the fault has occurred at t=2s a reduction in voltage drop is found from 1.0v to 0.1v. 0.1V lies below the minimum voltage level stated by most worldwide grid codes. At this juncture the grid must have disconnected from turbine. Despite this, the maximum drop in voltage at the generator terminals is minimized and the turbine remains connected to the grid during fault conditions. Fig. 2 depicts the stator voltage at the DFIG terminals during fault condition when the supercapacitor is not used. After the fault is cleared in 0.1sec (i.e...2 to 2.1s) the voltage raises to its original position (1.0V) and it is maintained constant.

![Figure 2: DFIG terminal voltage during a three-phase fault without supercapacitor](image)

![Figure 3: Stator current during a three phase fault in the DFIG without Supercapacitor](image)

### 3.2. DFIG without Super capacitor for Active and Reactive power:

When the fault occurred at t=2s the turbine absorbs some amount of active power. As the fault is cleared at 0.1s the active power is absorbed to resume to its normal value of 0.6p.u. The reactive power is maintained constant at 0 (Fig.5).
3.3 DFIG with Super capacitor Stator current and Terminal Voltage:

By connecting supercapacitor, the voltage drop is reduced to 0.45p.u during the fault clearing time and after the fault it comes to its original position as shown in Fig.6. When supercapacitor is connected, the line current decreases to 1600A during the fault and after the fault is cleared, it tends to reach its normal value as noticed in Fig.7.

3.4. DFIG with Super capacitor Active power and Reactive power:

Analyzing Fig.8 there seems to be no significant effect on the profile of active power with the usage of supercapacitor except the active power returns to its initial value after fault clearance. Using supercapacitor, the amount of absorbed reactive power is less i.e (0.1p.u) and absorbs reactive power to regain to its normal position (Fig.12).
3.5 DFIG with STATCOM and Super capacitor for Terminal Voltage and stator current:

After the fault has occurred at t=2s there is a voltage drop reduction from 1.0 v to 0.55v. After the fault is cleared in 0.1s (i.e., 2 to 2.1s) the voltage raises to its original position (1.0) and it will maintain constant as long as fault remains. Stator current: Initially the stator current is constant (i.e., 200A at 1.8s) before fault (Fig.11). When the fault occurs at t=2s the line current increases to nearly 1000A at 2.1s and comes to its original value.

3.6. DFIG with STATCOM and Super capacitor for Active power & Reactive Power

As detailed in Fig.12, before the fault occurred the generated active
power was 0.6p.u. When the fault occurred at t=2s the turbine absorbs some amount of active power as the turbine is not disconnected from the grid and is maintained constant and when fault is cleared in 0.1s the active power is absorbed to resume to its normal position (i.e 0.6p.u) and power fluctuations are reduced. The reactive power is maintained constant at 0 before the fault as detailed in Fig.13.

**Figure 12:** Response of active power of DFIG under three phase fault using STATCOM and super capacitor

**Figure 13:** Response of reactive power of DFIG under three phase fault using STATCOM with Super Capacitor

## 4. Conclusion

In this paper, the increasing efficacy of using supercapacitor along with wind turbine and with improved FRT capability of DFIG wind turbine is presented. The voltage profile is verified when supercapacitor is connected to the DFIG wind turbine across the DC link by using simulation from MATLAB/Simulink Software. By using STATCOM the enhancement of LVRT capability is increased and voltage drop, stator currents and the reactive power absorption are reduced.

<table>
<thead>
<tr>
<th>Method</th>
<th>Voltage profile</th>
<th>Stator current</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFIG Wind turbine without Supercapacitor</td>
<td>0.1</td>
<td>1750</td>
</tr>
<tr>
<td>DFIG Wind turbine with Supercapacitor</td>
<td>0.45</td>
<td>1500</td>
</tr>
<tr>
<td>DFIG Wind turbine with STATCOM And Supercapacitor</td>
<td>0.55</td>
<td>1000</td>
</tr>
</tbody>
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Table 2: Simulation results of Stator terminal voltage of DFIG Wind Turbine
From TABLE 2 it can be seen that the STATCOM and super Capacitor is thus found to be the most effective technique to enhance the low voltage ride through capability for DFIG-based wind turbine connected to the grid.

References


