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IMPROVED DFIG SYSTEM BEHAVIOR WITH SMES SYSTEM DURING VOLTAGE SAG

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ABSTRACT

This paper proposes a system using a Superconducting Magnetic Energy Storage (SMES) for smoothen the fluctuation power of the wind turbine (WT) injected to electrical grid, and to enhance the behavior of a WT system during the fault. The Doubly Fed Induction generator (DFIG) has two main problems; first, it is very sensitive to voltage variation, because the stator of DFIG is connected directly to the grid, second is the abrupt variation of the wind velocity causes the fluctuations of the WT output power injected into electrical grid. In order to improve the behavior of the DFIG, to protect the power converter and to smooth the output power fluctuations under faults, an adequate SMES system and it's control are proposed, The simulations are conducted using the proposed control strategy and the traditional control strategy based on MATLAB/Simulink, The results shown the effectiveness of the proposed control.

Keywords: *Wind power generation; Doubly fed induction generator (DFIG); Superconducting magnet energy storage (SMES); voltage sag, Power fluctuation.*

1. INTRODUCTION

Wind energy is one of the intermittent resources most advanced like means of fighting against environmental degradation due to the CO2 emissions of the traditional power stations.

The integration of the wind turbine in the electrical grid has appreciably increased during the last decade. The wind turbines equipped with the doubly fed induction generator (DFIG) dominated the installations of wind turbine. The DFIG shown in figure 1 is the most used in the wind energy exceeding 1 MW, thanks to these advantages; operation at variable speed, decoupled control of active and reactive power, the powers converters are dimensioned only 25% - 30% of the rated power of the DFIG [1] - [2].

The stator of DFIG is connected directly to the electrical grid, the rotor is connected to the grid via two converters; the rotor side converter (RSC) and the grid side converter (GSC), and these two last devices are connected together by a DC bus. The RSC is used to control the decoupled active power (or couple) and reactive power (or flow) based on the concept of the orientation of field or of the control of vector, the GSC is controlled in order to stabilize the tension of DC bus and to order the reactive power injected by the GSC. Several classical strategies of controls were employed to order DFIGs; direct control of couple, direct control of power , and controls vector [3] [4].

When a fault occurs on the power grid, it is requesting that the DFIG should remain connected to the power grid and contribute to the stability of the power systems. An abrupt low stator voltage due to grid fault produces a dc component in the stator flux. In this case the DFIG is found faced of two major's problem 1) the large transient current that appears in the rotor winding 2) the overvoltage in the DC bus which causes degradation of the DFIG performance, The former problem can damage the power converters [5][6].

With the increased penetration of wind power in power systems, wind turbine performance under the grid faults and fluctuations of the output power injected in the grid become important issues to be addressed [7].

The existing solutions which are presented to improve the behavior of the DFIG under symmetrical faults can be mainly classified into two categories: improved control strategies and auxiliary solutions. Improved control strategies like demagnetization control [18], stator current feedback control [19] and inductance emulating control [20] are only suitable for moderate voltage sags. Meanwhile, hardware solutions such as crowbar protection circuit which is used to bypass the RSC by using a series of resistance [21] can

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only solve part of the LVRT problems; Other hardware solutions like static synchronous compensator [22], dynamic voltage restorer [23] and series grid side converter [24] have good effect on enhancing LVRT capacity. However, all of the LVRT methods mentioned above are unavailable to simultaneously sustain the unsteady power of the DFIG under variable wind speed during normal operations.

An additional energy storage system for doubly-fed induction generator based wind turbine systems is controlled. Superconducting magnetic energy storage (SMES), which is characterized by highly efficient energy storage, quick response and power controllability, is introduced to the DC link of the back-to-back power converters of the DFIG through a bi-directional DC/DC power electronic converters [8][9].

The SMES is controlled to smooth the output wind power fluctuation, to protect the powers converters and to improve fault ride-through capability for the grid-connected wind farms.

Using MATLAB SIMULINK, the model of the SMES system for DFIG is developed, and the simulation tests are performed to validate our proposed control.

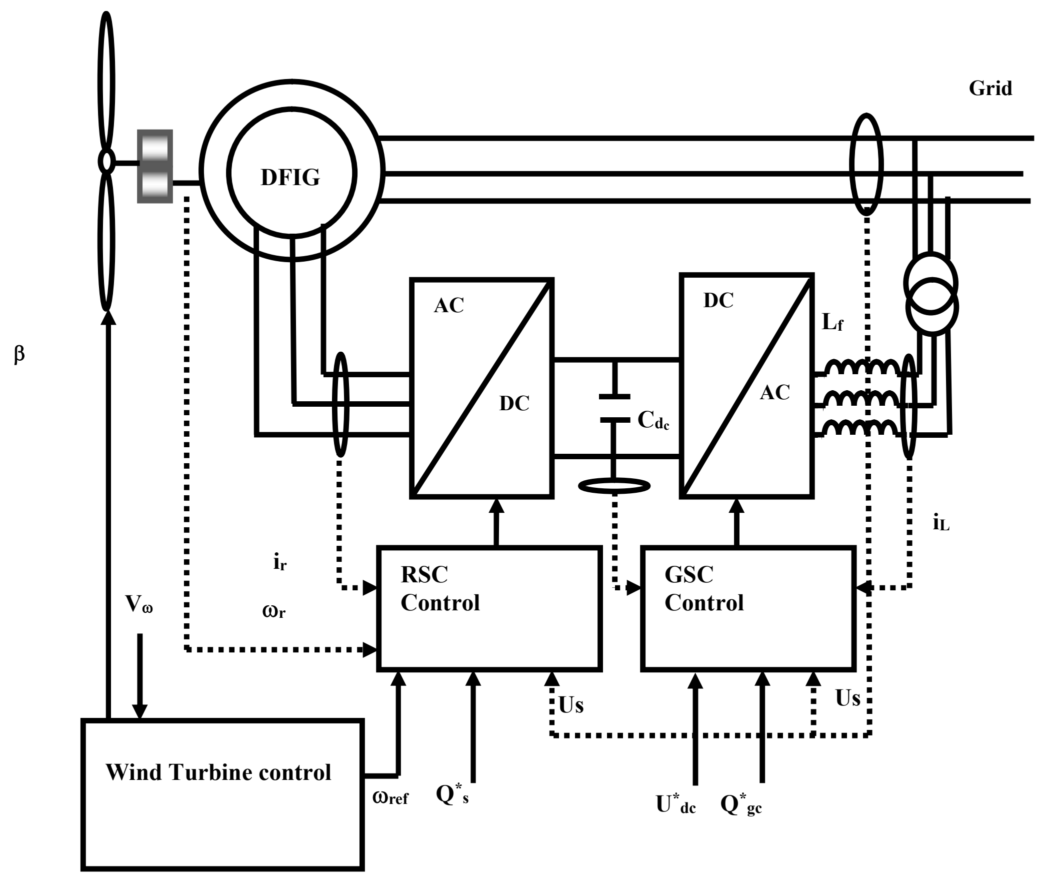

Figure.1.Configuration Of A DFIG Wind Turbine System

2. DFIG MODEL UNDER GRID FAULT

2.1 THE MODEL OF DFIG

The model generally used for the DFIG is the Park's model [10]. For the simplification of the study, the rotor variables will be referred to as the stator:

$$\vec{v}_s = R_s.\vec{i_s} + \frac{d}{dt}\vec{\psi}_s \quad (1)$$

$$\vec{v}_r = R_r.\vec{i_r} + \frac{d}{dt}\vec{\psi}_r - j\omega\vec{\psi} \quad (2)$$

Where i represents the current, v the voltage, ψ the magnetic flux, ω the rotor electrical speed and R the resistance. The subscripts r and s indicate rotor and stator variables.

In the case of DFIG, the stator windings are directly connected to the grid, which means that the stator voltage v_s is determined by the grid. The rotor voltage v_r is controlled by rotor side converter and used to perform the machine control. The stator and rotor fluxes are given by:

$$\overrightarrow{\psi}_s = L_s\overrightarrow{i_s} + L_m\overrightarrow{i_r} \quad (3)$$

$$\overrightarrow{\psi}_r = L_r\overrightarrow{i_r} + L_m\overrightarrow{i_s} \quad (4)$$

Where Lm represents the magnetizing inductance, L_s and L_r represents the stator and rotor inductance, respectively. The rotor voltage is one of the most important variables for the converter. This voltage is induced by the variation of the rotor flux, which can be calculated from (3) and (4):

$$\overrightarrow{\psi}_r = \frac{L_m}{L_s}\overrightarrow{\psi}_s + \sigma L_r.\vec{i}_r,\quad \sigma = 1 - \frac{L_m{}^2}{L_s L_r}$$

(5)

σ being the leakage factor and σLr the rotor transient inductance.

From (2) and (5), the following expression is obtained:

$$\vec{v}_r = \frac{L_m}{L_s}\frac{d\overrightarrow{\psi}_s^r}{dt} - (R_r\vec{i}_r + \sigma L_r\frac{d\vec{i}_r}{dt})$$

(6)

The rotor voltage given by (6) can be divided into two items. The first will be referred to as EMF it is induced by the stator flux and the second item is the voltage drop caused by the rotor current in both rotor transient inductance σL_r and the rotor resistance R_r.

2.2 Behavior under Grid Fault

During normal operation, neglecting the stator resistance Rs, the stator flux linkage can be expressed as [11],[12].

$$\overrightarrow{\psi}_s^s = \frac{V_s}{j\omega_s}e^{j\omega_s t} \quad (7)$$

Where ωs is the stator angular frequency, Vs is the amplitude of stator voltage. Then the EMF induced by the stator flux linkage during normal condition can be calculated according to (6)

$$\vec{e}_r = \frac{L_m}{L_s}\frac{d}{dt}\overrightarrow{\psi}_s^r = \frac{L_m}{L_s}sV_s e^{j\omega_{srt}} \quad (8)$$

Where s is the slip, and ωsr is slip angular frequency. The amplitude of the EMF er is sVsLm/Ls, which is proportional to the slip s. Typically, s is variable between -0.3 and 0.3, so the EMF under normal condition is relatively small.

Under symmetrical fault occurs, the stator flux linkage would contain DC component, and can be expressed as [12],[13].

$$\overrightarrow{\psi}_s^s = \frac{V_s(1-p)}{j\omega_s}e^{j\omega_s t} + \frac{V_s p}{j\omega_s}e^{\frac{-t}{\tau_s}}$$

(9)

Where p is the depth of voltage dip, and τs is the time constant of the stator flux linkage. The first item is the positive sequence component of the stator flux linkage, and the second item is the DC component, which decays with the time constant τs. Then according to (6), the EMF under symmetrical faults can be given by:

$$\vec{e}_r = \frac{L_m}{L_s}(sVs(1-p)e^{j\omega_{sr}t} - V_s p(1-s)e^{-j\omega_r t}e^{\frac{-t}{\tau_s}}) \quad (10)$$

3. SMES CONTROL APPROACHES

The main circuit of the SMES system used for doubly-fed induction generator is shown in Fig. 2. The DC link system is composed of RSC, GSC, DC chopper, and SMES. The energy stored in the SMES enables an exchange of active power with the system for a short period of time (few seconds). This controller could be used to improve the regulation of the real power flow of a wind farm. Also, SMES have previously been used to improve the power supply reliability for industrial customer [13][14].

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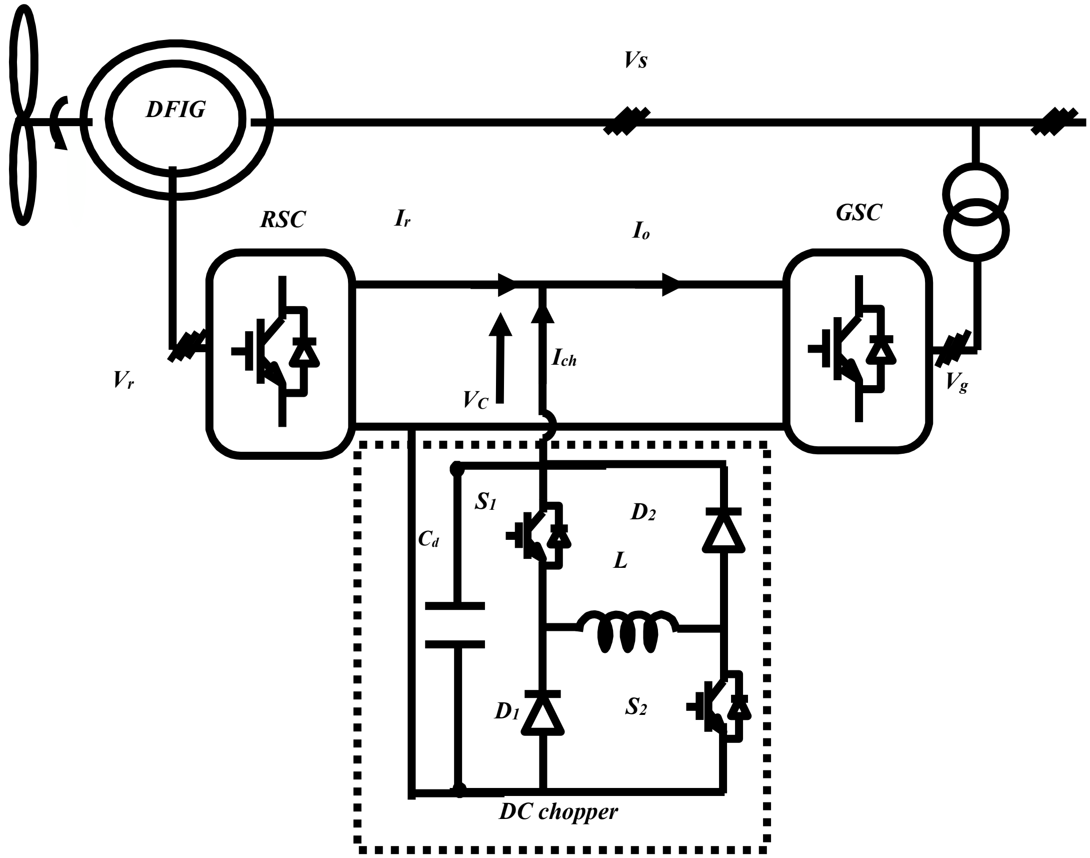

Figure 2 : The main circuit of DFIG wind power system based on SMES.

3.1 SMES energy control transfer

The DC-DC converter which has been used is the chopper shown in Fig. 3 [15]. This converter has been studied using.

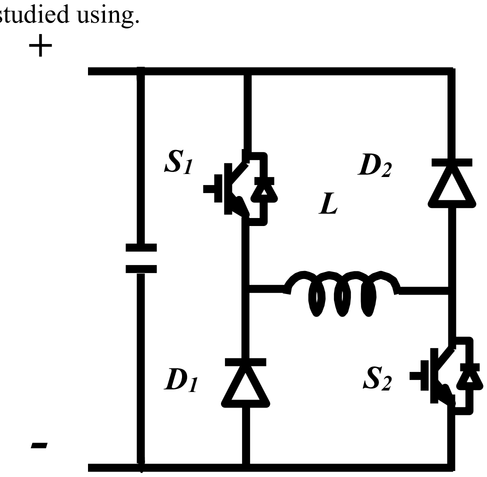

Figure 3. The DC-DC converter connecting the SMES to the DC-link

In the process of voltage compensation, the DC chopper is utilized to control energy transfer of the superconducting magnet. The DC chopper has two basic operation modes[16][17].

1) Charging mode. The DC chopper absorbs active power from AC side and charge the superconducting magnet. In this mode, G_1 is on at all times, and G_2 is alternately on and off during each chopper cycle. When G_2 is on for (duty cycle) per unit time, the magnet is charged from the DC link through G_1 and G_2 in series. When G_2 is off, the magnet current is bypassed through G_1 and D_1.

2) Discharge mode. The DC chopper delivers active power to AC side and discharge the superconducting magnet. In this mode, G_1 is off at all times, and G_2 is alternately on and off during each chopper cycle. When G_2 is on for per unit time, the magnet current is bypassed through G_2 and D_2. When G_2 is off, the magnet discharges to the DC link through D_1 and D_2 in series

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3.2 DC voltage Control

The dc circuit can be expressed using the current balancing equation as :

$$I_r + I_{ch} = I_o + C\frac{dV_{dc}}{dt} \qquad (11)$$

Where I_r is the RSC current Io is the output current and I_{ch} is the SMES Current The analysis of the dc link voltage regulators is carried out with reference to the control scheme represented in fig 4.

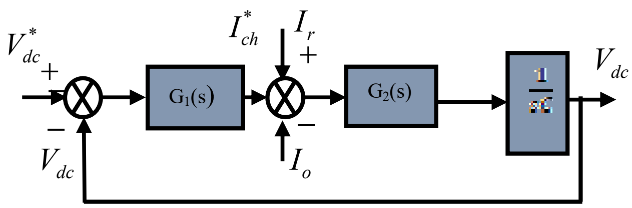

Figure . 4. Block diagram of the dc-link voltage control.

The input of the regulator PI is the dc-link voltage error, the output is the reference value of the chopper current I^*_{ch}. With the transfer function of regulator P is $G_2(s)=1$ the V_{dc} can be expressed :

$$V_{DC} = \frac{G_1(s)}{sC+G_1(s)}V_{DC}^* + \frac{1}{sC+G_1(s)}I_r - \frac{1}{sC+G_1(s)}I_o \qquad (12)$$

In this case, the dc-link voltage must be regulated to its reference value to ensure a correct operation of grid side converter. Then, a PI regulator is chosen for R(s) to accomplish the system requirement yielding

$$G_1(s) = K_p\left(1+\frac{1}{T_i s}\right) = K_p\frac{1+T_i s}{T_i s} \qquad (13)$$

Introducing (12) in (11) leads to

$$V_{DC} = \frac{\omega_n^2(1+T_i s)}{s^2+2\delta\omega_n s+\omega_n^2}V_{DC}^* + \frac{\frac{T_i}{K_p}\omega_n^2 s}{s^2+2\delta\omega_n s+\omega_n^2}I_r - \frac{\frac{T_i}{K_p}\omega_n^2 s}{s^2+2\delta\omega_n s+\omega_n^2}I_o \qquad (14)$$

Where $\omega_n = \sqrt{\frac{K_p}{T_i C}}$ and $\delta = \frac{1}{2}\sqrt{\frac{T_i K_p}{C}}$

4. SIMULATIONS RESULTS

TABLE 1 : Specifications Used For The Simulation:

Components	Part name	Rating values
DFIGs	Rated Generator Power	6×1,5 MW
Vs	Rated Terminal stator voltage	690 V
f	Rated frequency	50 Hz
Rs	Stator Resistance	0.0048 mΩ
Ls	Stator leakage inductance	0.1386 mH
Rr	Rotor Resistance	0.00549 mΩ
Lr	Rotor leakage inductance	0.1493 mH
Vdc	Rated DC-link Voltage	1150 V
Cd	Input Capacitance	10µF
L	SC Innductor	2.5 H
fs	Switching Frequency	10 KHZ
Kp	Proportional coefficient	0.1128
Ti	Integral coefficient	0.12

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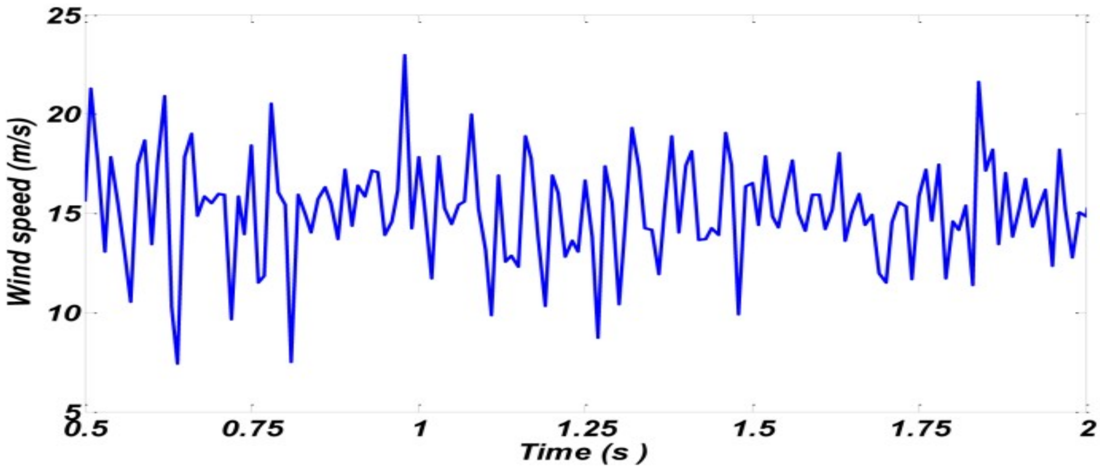

Figure 5. Wind evolution

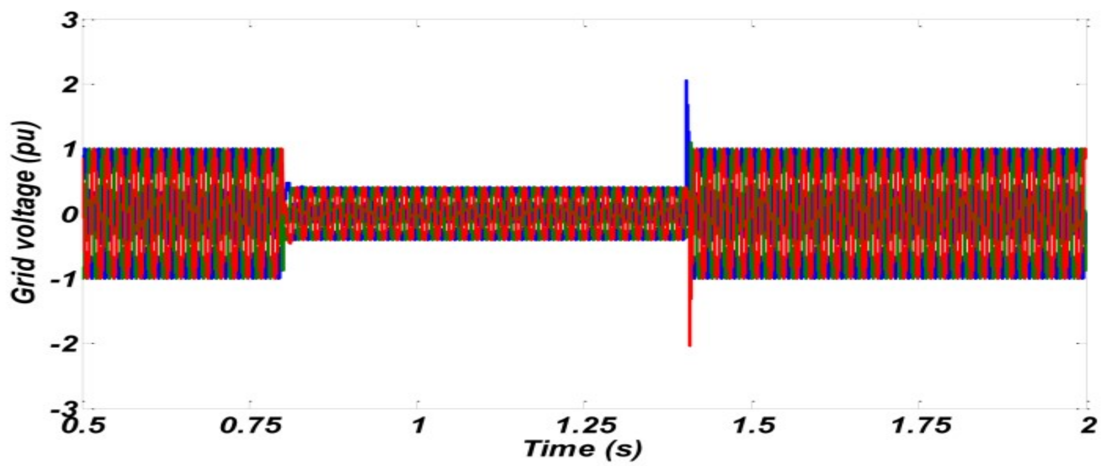

Figure.6. Grid voltage

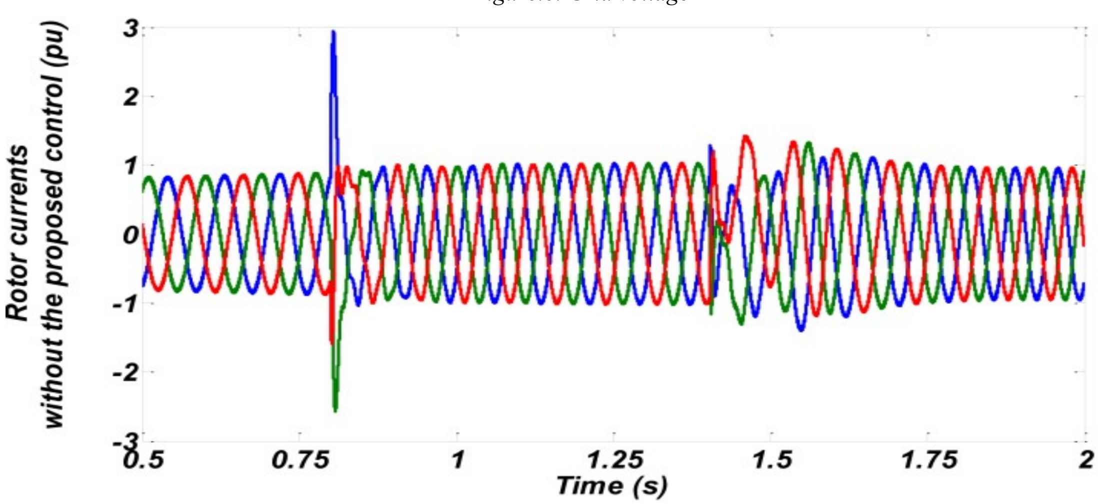

Figure.7. Rotor current without proposed control

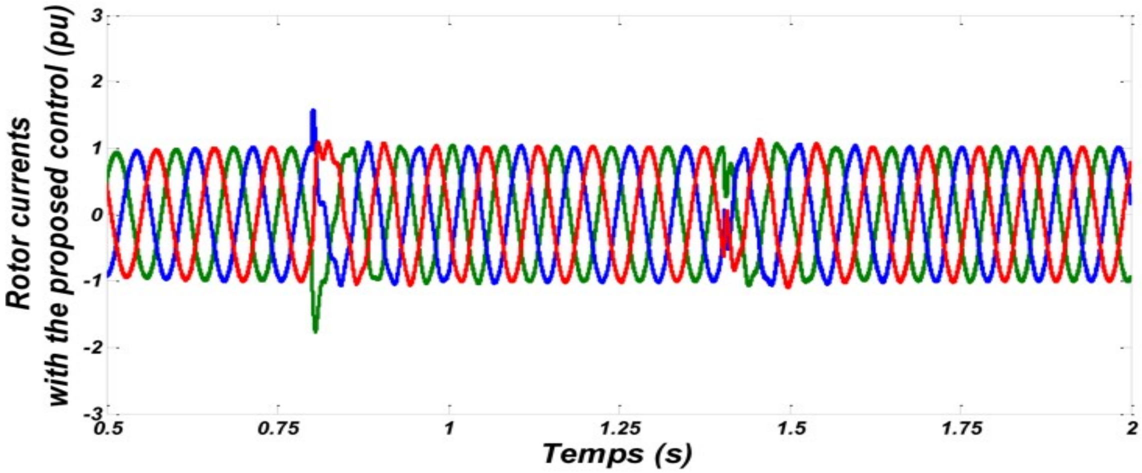

Figure.8. Rotor current with the proposed control

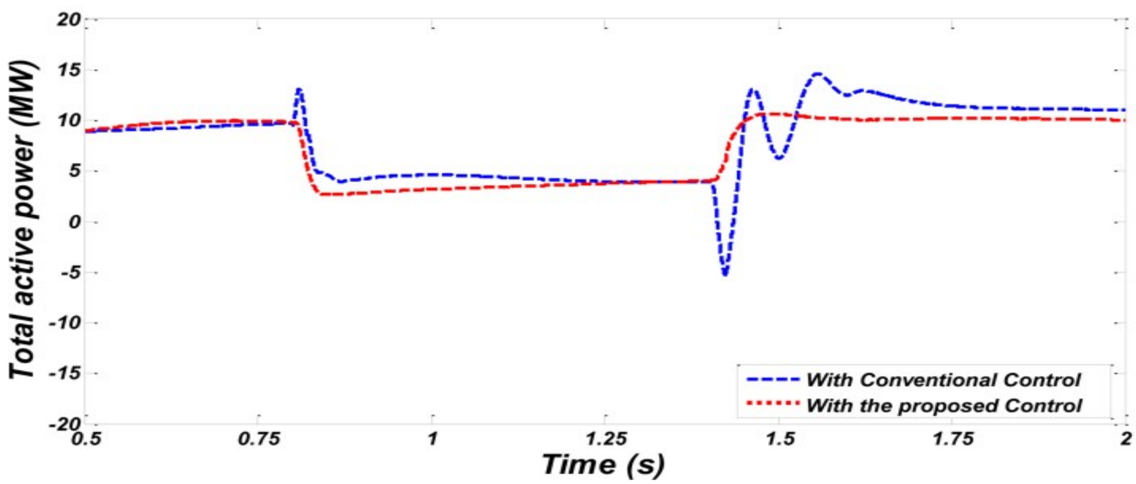

Figure.9. Output active power

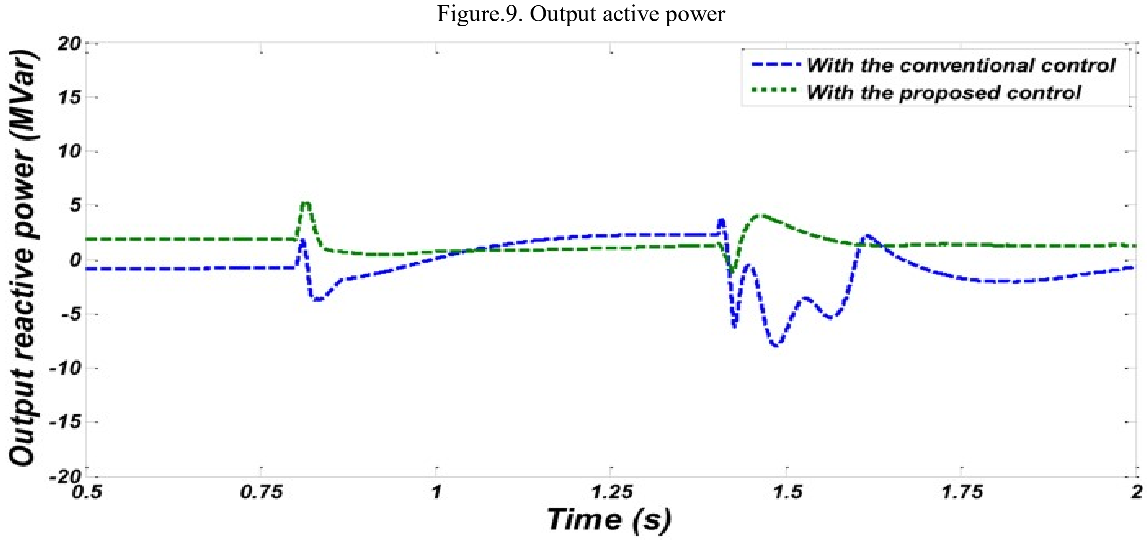

Figure.10. Output reactive power

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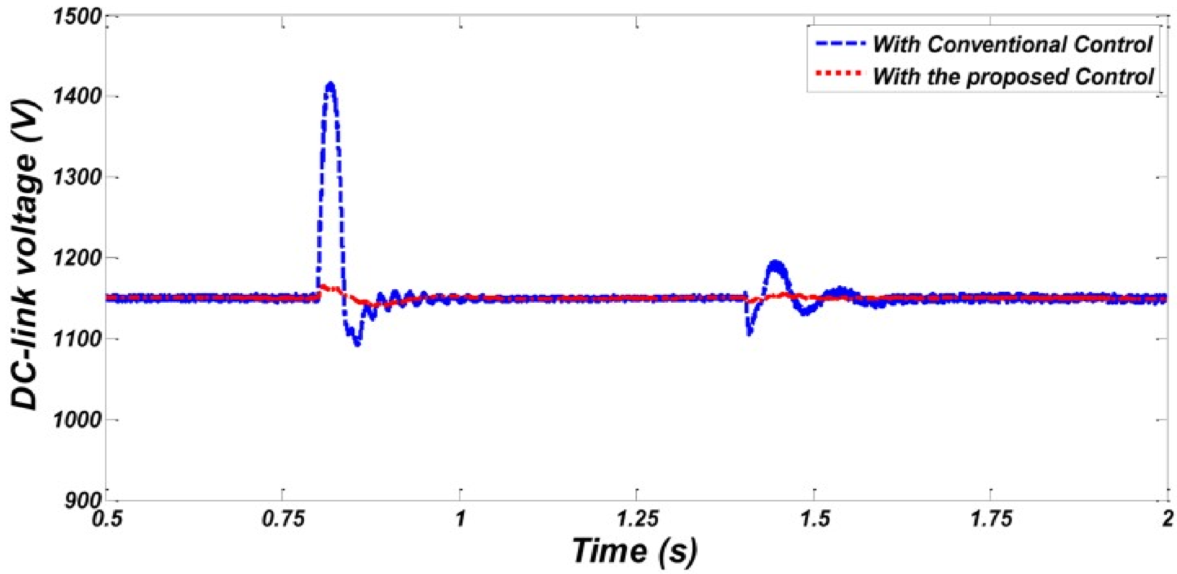

Figure 11. DC link voltage

5. RESULTS ANALYSE

To evaluate the system performance, the model of the SMES based excitation system for DFIG is established using MATLAB SIMULINK. The model contains a six DFIG wind turbine. According to the system parameters of the electric power system dynamic simulation laboratory, the parameters DFIG are designed as shown in Table I.

Fig.7 represents the rotor current of DFIG with the conventional control under faults without SMES. Fig. 8 show the reduced peak of the rotor current with the proposed control. By introducing the SMES into the excitation system of DFIG, the active power which is delivered to the power grid can be smoothen as shown with fig. 9, the fluctuation is smoothed precisely between ti=0.8s and tf=1.4s

Fig.10 represents the reactive power of DFIG with the conventional control and with the proposed control. we can see that it is kept around zero. Fig.11. shows the fluctuations of the DC bus voltage with conventional control which could reach 1425 V; this may destroy the power converters and destabilizes the dynamic performance of DFIG. With the proposed control the DC bus voltage become more stable with slight fluctuations compared to overshoot of the DC bus voltage observed with conventional control.

6. CONCLUSION

A new control scheme for wind turbine based DFIG systems, in which a SMES is employed to obtain high energy storage capability, has been analyzed in this paper. The use of a two-quadrant dc chopper, connecting the SMES to the dc- side of the voltage source inverter, allows frequent charging and discharging cycles of the superconducting coil. The control scheme has been tested by numerical simulations;

The simulation results show that the energy storage system can smooth very quickly to the active and reactive power fluctuations of DFIG.

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