

Advanced Control Strategy of DFIG during Symmetrical Grid Fault.

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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 of the stator of DFIG is connected directly to the grid, second the abrupt variation of the wind velocity causes the fluctuations of the WT output power. In order to improve the behavior of the DFIG, to protect the power converter and to smooth the output power fluctuations of the DFIG under faults, an adequate control of SMES is proposed, The simulations are conducted using the proposed control strategy and the traditional control strategy based on MATLAB/Simulink, The results show the effectiveness of the proposed control.

Key-Words: - Wind power generation, Doubly fed induction generator (DFIG), Superconducting magnet energy storage (SMES), voltage sag, Power fluctuation.

1 Introduction

As you can see for the title of the paper you must use 16pt, Centered, Bold, Times New Roman. Leave one blank line and then type AUTHORS' NAMES (in Capital, 12pt Times New Roman, centered), Department (in 12pt Times New Roman, centered), University (in 12pt Times New Roman, centered), Address (in 12pt Times New Roman, centered), COUNTRY (in Capital, 12pt Times New Roman, centered). Then you must type your e-mail address and your Web Site address (both in 12pt Times New Roman, centered).

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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 (DTC), direct control of power (DPC), and controls vector (VC) [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].

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 converter [8][9].

The SMES is controlled to level the wind power fluctuation, and 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.

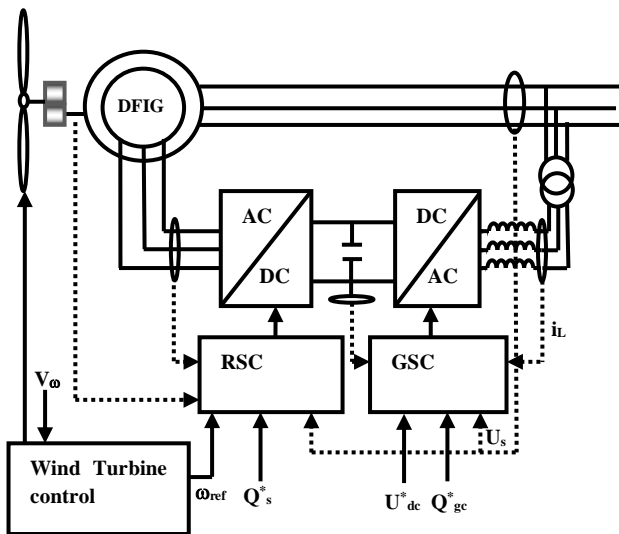


Fig.1.Configuration of a DFIG wind turbine system

2 DFIG Model Under Grid Fault

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:

$$\vec{v}_s = R_s \vec{i}_s + \frac{d}{dt} \vec{\psi}_s \tag{1}$$

$$\vec{v}_r = R_r \vec{i}_r + \frac{d}{dt} \vec{\psi}_r - j\omega \vec{\psi}_s \tag{2}$$

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:

$$\vec{\psi}_s = L_s \vec{i}_s + L_m \vec{i}_r \tag{3}$$

$$\vec{\psi}_r = L_r \vec{i}_r + L_m \vec{i}_s \tag{4}$$

Where L_m 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):

$$\vec{\psi}_r = \frac{L_m}{L_s} \vec{\psi}_s + \sigma L_r \vec{i}_r, \quad \sigma = 1 - \frac{L_m^2}{L_s L_r} \tag{5}$$

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

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

$$\vec{v}_r = \frac{L_m}{L_s} \frac{d\vec{\psi}_s^r}{dt} - (R_r \vec{i}_r + \sigma L_r \frac{d\vec{i}_r}{dt}) \tag{6}$$

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 .

Behaviour under Grid Fault

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

$$\vec{\psi}_s^s = \frac{V_s}{j\omega_s} e^{j\omega_s t} \tag{7}$$

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

$$\vec{e}_r = \frac{L_m}{L_s} \frac{d}{dt} \vec{\psi}_s^r = \frac{L_m}{L_s} s V_s e^{j\omega_{sr} t} \tag{8}$$

Where s is the slip, and ω_{sr} is slip angular frequency. The amplitude of the EMF e_r is $sV_s L_m/L_s$, 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].

$$\vec{\psi}_s^s = \frac{V_s(1-p)}{j\omega_s} e^{j\omega_s t} + \frac{V_s p}{j\omega_s} e^{-\frac{t}{\tau_s}} \tag{9}$$

Where p is the depth of voltage dip, and τ_s 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 τ_s . Then according to (6), the EMF under symmetrical faults can be given by:

$$\vec{e}_r = \frac{L_m}{L_s} \left[sV_s(1-p)e^{j\omega_r t} - V_s p(1-s)e^{-j\omega_r t} e^{\frac{-t}{\tau_s}} \right] \quad (10)$$

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].

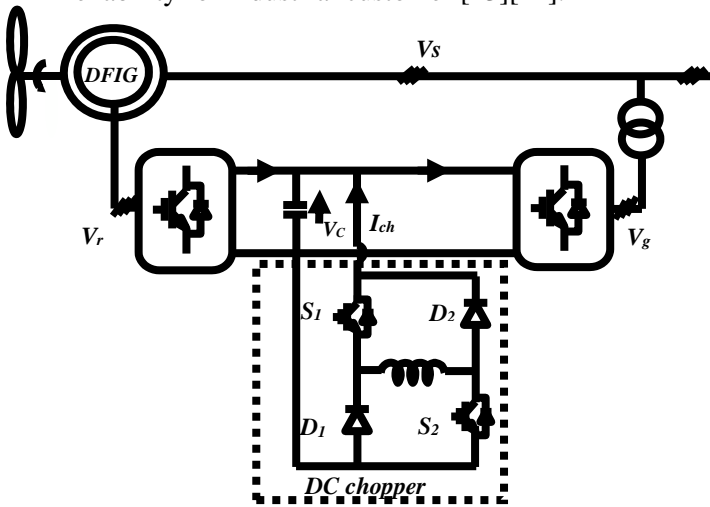


Fig 2 : The main circuit of DFIG wind power system based on SMES.

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.

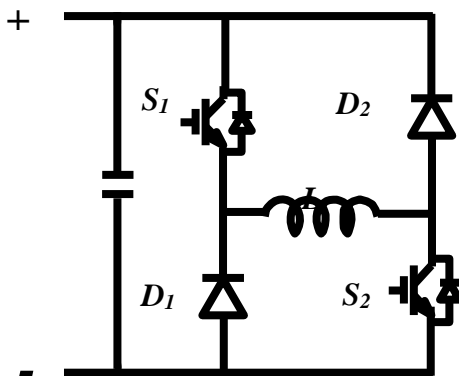


Fig.3. The DC-DC converter connecting the SMES to the DC-link

In the process of voltage compensation, the DCchopper is utilized to control energy transfer of

the superconducting magnet. The DC chopper has two basic operation modes[16][17].

Charging mode. The DC chopper absorbs active power from AC side and charge the superconducting magnet. In this mode, G₁ is on at all times, and G₂ is alternately on and off during each chopper cycle. When G₂ is on for (duty cycle) per unit time, the magnet is charged from the DC link through G₁ and G₂ in series. When G₂ is off, the magnet current is bypassed through G₁ and D₁.

2) Discharge mode. The DC chopper delivers active power to AC side and discharge the superconducting magnet. In this mode, G₁ is off at all times, and G₂ is alternately on and off during each chopper cycle. When G₂ is on for per unit time, the magnet current is bypassed through G₂ and D₂. When G₂ is off, the magnet discharges to the DC link through D₁ and D₂ in series.

3.2 DC voltage Control

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

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

The analysis of the dc link voltage regulators is carried out with reference to the control scheme represented in fig 4.

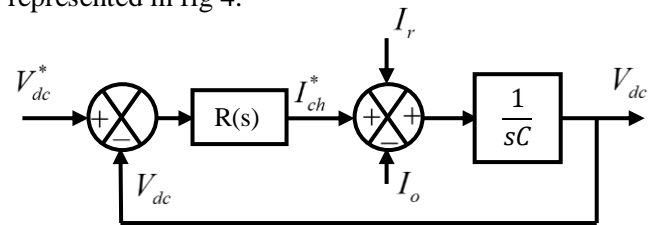


Fig.4. Block diagram of the dc-link voltage control. The input of the regulator PI is the dc-link voltage error, the output is the reference value of the chopper current I^{*}_{ch}.

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

(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

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

Introducing (12) in (11) leads to

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

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

TABLE I.

Specifications Used For The Simulation:

Components	Part name	Rating values
DFIGs	Rated Generator Power	6×1,5 MW
V _s	Rated Terminal stator voltage	690 V
f	Rated frequency	50 Hz
R _s	Stator Resistance	0.0048 mΩ
L _s	Stator leakage inductance	0.1386 mH
R _r	Rotor Resistance	0.00549 mΩ
L _r	Rotor leakage inductance	0.1493 mH
V _{dc}	Rated DC-link Voltage	1150 V
C _d	Input Capacitance	10μF
L	SC Inductor	2.5 H
f _s	Switching Frequency	10 KHZ
K _p	Proportional coefficient	0.1128
T _i	Integral coefficient	0.12

Results et discussions

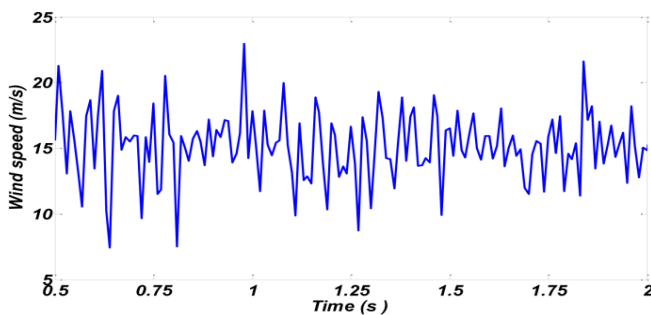


Fig.5. Wind speed evolution

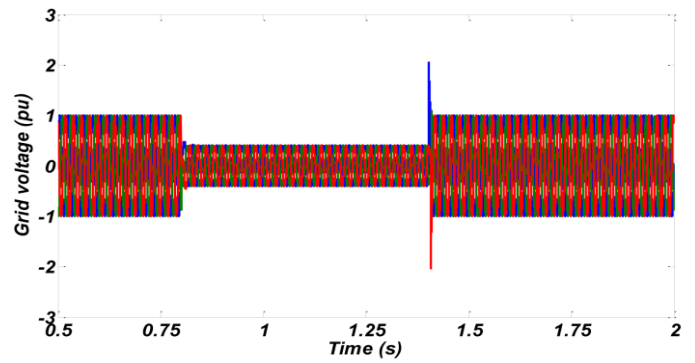


Fig.6. Grid voltage

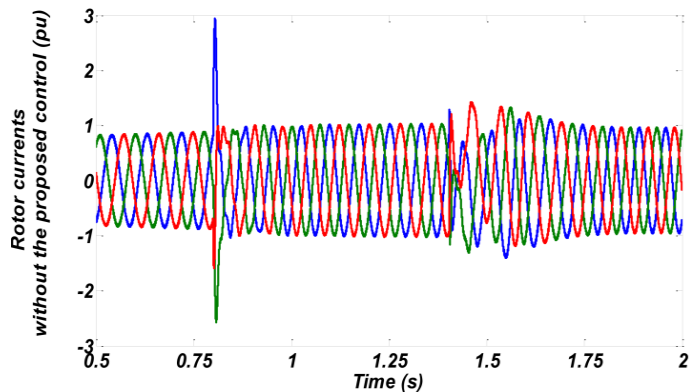


Fig.7. Rotor current without the proposed control

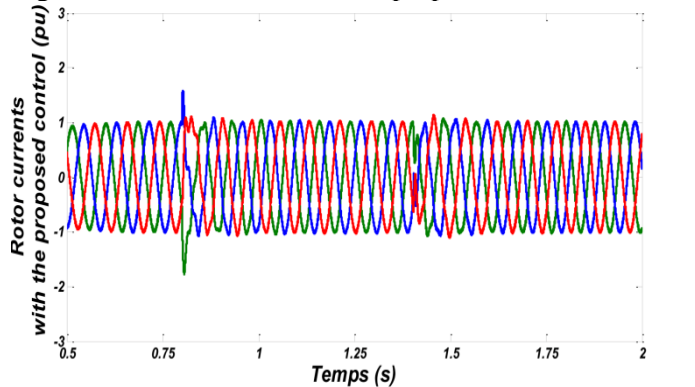


Fig.8. Rotor current with the proposed control

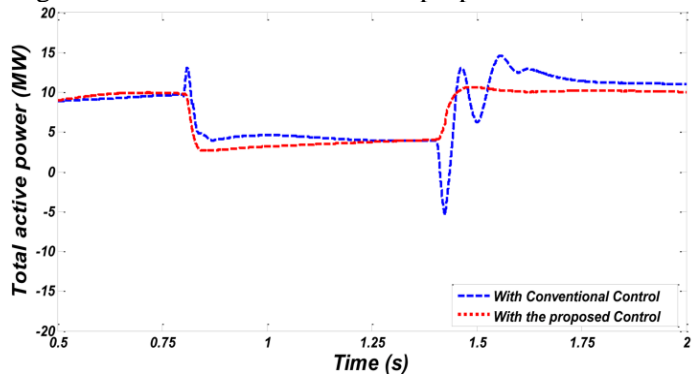


Fig.9. Output active power

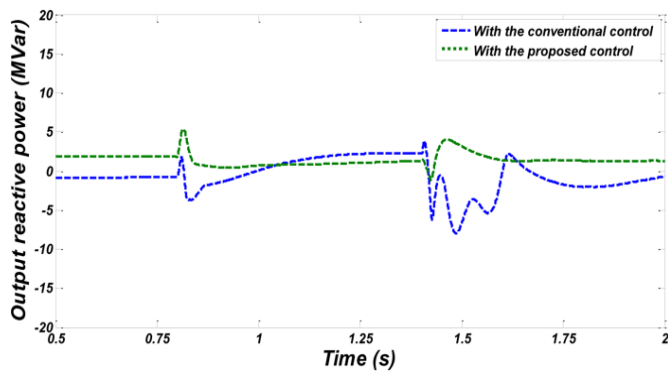


Fig.10. Output reactive power

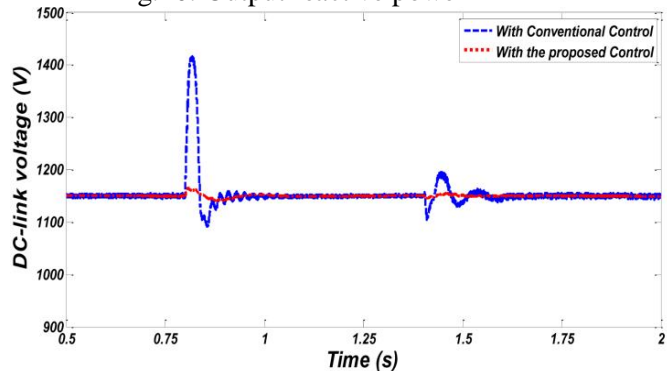


Fig.11. DC-link voltage

4 SIMULATION RESULTS

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. 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 $t_i=0.8s$ and $t_f=1.4s$

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.

5 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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