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# Design and control of DFIG with SMES storage under symmetrical grid fault

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**ABSTRACT**

This paper presents a novel design and robust control for wind conversion systems using DFIG. The system is designed to reduce the problems related to the sudden variation of the wind speed and to improve the sensitivity of the DFIG to grid faults to avoid disconnection of the wind system from the electrical grid. To enhance the DFIG behavior, power fluctuation and to protect power devices under symmetrical faults, a specific superconducting magnetic energy storage (SMES) scheme and its control are proposed. To validate this study, the control structure and strategies were implemented in the MATLAB/Simulink environment. The results obtained by simulation were compared with those using traditional control strategies, they highlight an improvement in the functioning of wind conversion systems of this type, showing the rigor and effectiveness of the proposed strategy.



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## 1. INTRODUCTION

Wind energy is a clean energy, which has made remarkable progress today in dealing with the environmental degradation caused by the conventional power resources. Technological progress and the development of wind systems have encouraged their integration into the electrical system [1]. This considerable integration of the wind turbine into grid especially wind systems equipped with doubly feed induction generators (DFIG) [2], [3]. This dominance of DFIG is due to its advantages which are variable speed operation, the converters used are only sized at a fraction 25-30% of the DFIG power rated and the decoupled active and the reactive power control [4]–[8].

The stator of the DFIG shown in Figure 1 is connected directly to the electrical grid but the rotor is connected to grid via two power devices; the first device is a rotor side converter (RSC) is placed after the rotor, the other device is a grid side converter (GSC) is placed before the grid, these two power device systems are linked together by a DC bus. The RSC is controlled for decoupling of the active and reactive powers. The GSC is controlled to stabilize the voltage of DC link and keep the reactive power around zero. The advanced strategies were used for the optimal DFIG functioning under normal conditions; direct torque control (DTC), direct power control (DPC), adaptive fuzzy power control and vector control (VC) [9]–[12]. In the event of a disturbed network regime, the DFIG must contribute to the electrical grid stability while remaining connected to the network.

The operation of the DFIG is braked by two obstacles [13]–[15]; i) sudden and random change in wind speed; causes fluctuating power output; and ii) fault in the electrical network causes; overcurrent in winding of the rotor and an overvoltage in DC link which can impacts the performance of the WT based DFIG, and can damage the power device.

In the literature, we find two categories of solutions; first is the contribution in command algorithm, the second is use of an additional equipment [8]. In this paper, we will be presented of a novel strategy that can ensure; improving the behavior of the DFIG system, protection of the electronics power device of the DFIG system, and participate in system services; this proposal is a new design of an additional energy magnetic storage system (SMES), and its robust control. This proposed system ensures a highly efficient energy storage, optimal time response and power flow regulation [16], [17]. The SMES is used to sustain the wind system during the grid disturbed regime, keep the DFIG connected to the electrical system and smooth power output. In the MATLAB/Simulink environment, the model in question has been developed, and the simulations obtained validate the effectiveness of our model.

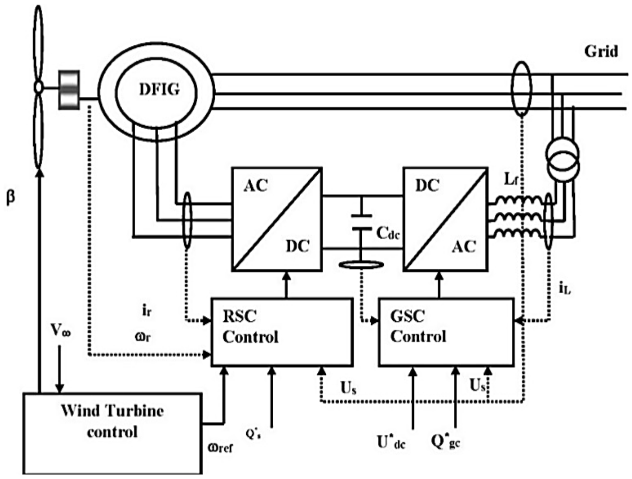


Figure 1. DFIG system

By applying the park model to the DFIG we will have the equation system below [8], [18]. Where v represents voltage and i the current, the resistance is represented by R, ω the rotor electrical speed and ψ the flux. The indexes s and r design stator and rotor variables.

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

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

The fluxes of the rotor and stator are identified by:

$$\vec{\psi}_s = L_s\vec{\iota_s} + L_m\vec{\iota_r} \qquad (3)$$

and

$$\vec{\psi}_r = L_r\vec{\iota_r} + L_m\vec{\iota_s} \qquad (4)$$

Ls, Lr and Lm describe respectively the inductors of the stator, the rotor and the magnetizing.
From (3) and (4) the rotor flux is:

$$\vec{\psi}_r = \frac{L_m}{L_s}\vec{\psi}_s + \sigma L_r.\vec{\iota}_r \quad \text{with } \sigma = 1 - \frac{{L_m}^2}{L_s L_r} \qquad (5)$$

Where: σ: leakage factor, and σLr: rotor transient inductance.
The rotor voltage is identified by (2) and (5), as follow:

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

The voltage of the rotor (6) is composed of two terms. The electromagnetic force is the first terms and the voltage drop is the second.
– Behavior under grid fault

Under normal operation, where Rs equal to zero, the stator flux is equal to zero [19], [20]:

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

where the stator frequency is expressed by ωs, the stator voltage is denoted by Vs.

The EMF can be calculated according to (6).

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

s: the slip, $\omega_{sr}$: slip frequency angular. sVsLm/Ls is the EMF amplitude. Under voltage dip, the stator flux includes a DC component, and can be identified by [20], [21].

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

τs is the constant time of the flux in the stator, p is the depth of voltage dip. The first term is the positive sequence of the stator flux, and the second term is the DC component. Then according with (6), the EMF is by (10).

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

## 2. SMES DESIGN

The DFIG system with SMES device is presented in Figure 2. The SMES system is a very efficient storage system, among the advantages it has are: the charging and discharging is done as quickly as possible, the energy density is high and the longevity of its life cycle and it also allows the exchange of power quickly while regulating the flow of power [21], [22].

### 2.1. SMES control

The chopper shown in Figure 3. The DC DC converter is utilized to control power flow. The mode operating of the DC chopper [23], [24]:

- Charging sequence: The DC converter stores excess power from DC link in the superconducting magnet.
- Discharge sequence: The DC converter injects the power from superconducting magnet to DC link. In this mode.

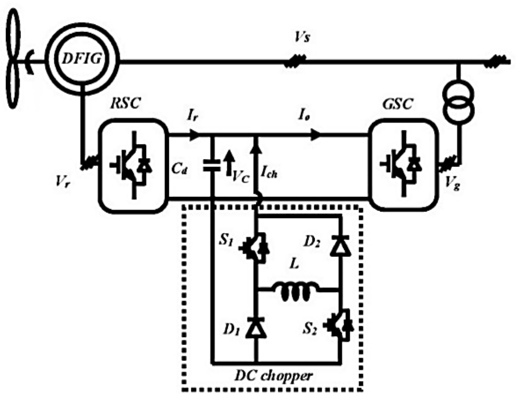

Figure 2. The DFIG system with SMES design

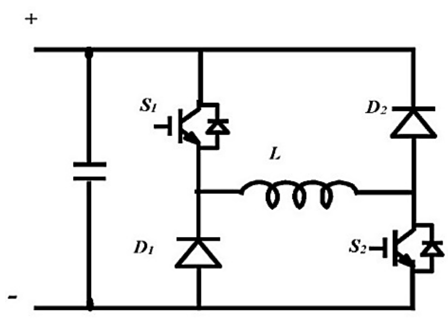

Figure 3. The SMES system circuit

### 2.2. Output power control

The active power P is given by (11) where Im represent current through the magnet and Vd is voltage across the magnet:

$$P = V_d . L_m \tag{11}$$

$$E = \frac{1}{2} L . I_m^2 \tag{12}$$

The current Im in the magnet coil changes in consonance with stored energy E given in (12). The voltage reference across the coil is indicate by P and $I_m$. The voltage ripple will be abated with the proposed circuit and the current will be controllable which allows us to have a large control region. Current regulation increases the control margin. in our case the output power is controlled by the current coil and the voltage is kept constant.

## 3. SMES CURRENT CONTROL

The traditional SMES control without observation of the voltage is shown in Figure 4 with the assumption follow:
- Magnet coil represented of a small resistance $R_B$ and a large self-inductance $L_B$
- Voltage drop $V_{drO}$ and voltage vdl generated by another device is considered as disturbances
- Converter response $\tau_{d0}$

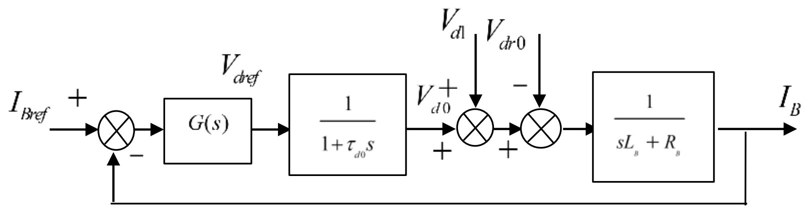


Figure 4. SMES Block diagram control

Gc(s) is proportional corrector with his gain Kp. The transfer function is described as (3).

$$G(s)=\frac{I_B}{I_{Bref}}=\frac{K_P}{(sL_B+R_B)(1+\tau_{d0}s)+K_P}$$

$$G(s)=\frac{K_P}{K_P+R_B}.\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$$

Were

$$\zeta=\frac{L_B+\tau_{d0}R_B}{2\sqrt{\tau_{d0}L_B(K_P+R_B)}}\,,\ \omega_n=\sqrt{\frac{K_P+R_B}{\tau_{d0}L_B}}$$

With the suitable ζ is given, we can determine Kp. The corrector PI is also used but it has no benefit compared to the corrector P:
- Proportional corrector with observing voltage

The high value of the voltage supplied by another converter may affect the current of the SMES. This value can be introduced into the regulation to control the current $I_B$ in the coil Figure 5 shows the block diagram of the buffer side with observation of the voltage and G2(s) controller.

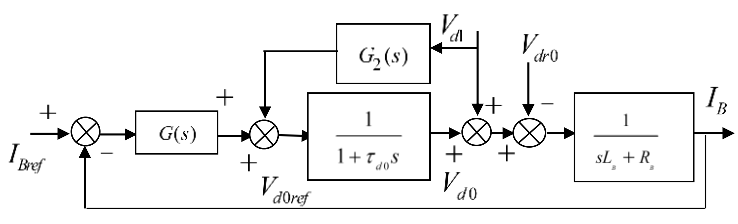


Figure 5. Block diagram of coil with voltage observations

## 4. RESULTS AND DISCUSSIONS

The Table 1 presents the parameters of the generator used in the wind farm composed of six turbines, so that we can start our command we have chosen two scenarios. The first will be between the instant 0.8 s and 1.4 s, this is the duration of a fault that occurs on the network. The fault occurs at t0=0.8 s. The second scenario between 1.4 s and 2 s the duration of the normal operation, this is the duration where there is no fault on the network show Figure 6 The moment of the recovery voltage is tf=1.4 s, it's two scenarios will be well under a variable wind speed between 6 m/s and 24 m/s, what is true in most cases see [25] shown in Figure 7. The validation of the performance of the new SMES design is done by developing a model under the MATLAB/Simulink environment. the proposed model is applied to a wind farm composed of six DFIG wind turbines. the wind system parameters are described in Table 1.

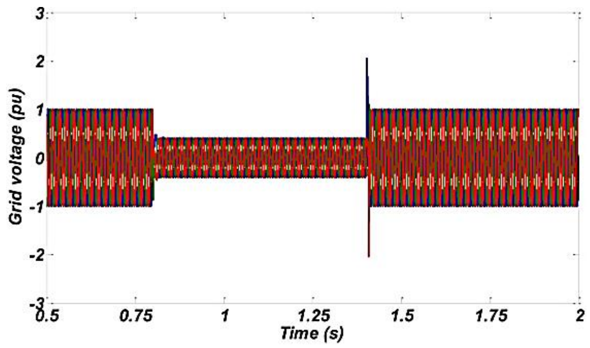


Figure 6. Grid voltage

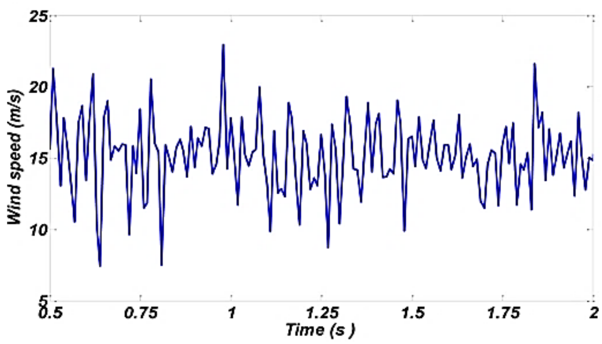


Figure 7. Wind speed

Table 1. Simulation parameter values

| Parameters | Rating values | Parameters | Rating values |
|---|---|---|---|
| P: DFIGs generator power | 6×1.5 MW | Cd: Input capacitance | 10 µF |
| Terminal stator voltage: Vs | 690 V | Lsc: SC inductor | 2.5 H |
| F: Frequency: f | 50 Hz | fs: Switching frequency | 10 KHZ |
| Rs: Stator resistance | 0.0048 mΩ | Kp: Proportional coefficient | 0.1128 |
| Ls: Stator leakage inductance | 0.1386 mH | $L_B$ Self inductance | 0.31 H |
| Rr: Rotor resistance | 0.00549 mΩ | $R_B$: Resistance of coil | 10 mΩ |
| Lr: Rotor leakage inductance | 0.1493 mH | τd0: Dealy time response of SMES | 5 msec |
| Vdc: DC-link voltage | 1150 V | Ti: Integral coefficient | 0.12 |

The current in rotor winding with the conventional control is showed in Figure 8. the impact of the proposed command on the overcurrent is illustrated in Figure 9. The addition of the SMES in the system has enables the wind system to generate smooth active and reactive power. The active power is illustrated in Figure 10. The blue curve shows the active power with the traditional control where one can clearly see the fluctuations due to the fault of the electrical network, the red curve represents the active power obtained by using the proposed control whose fluctuations are attenuated.

In Figure 11, we see a reactive power under the traditional method and the proposed method. The comparison between the two curves, the one in blue and the one in green obtained by the proposed method, shows that it is less fluctuated. Finally, the curve of Figure 12 aims to highlight the overshot of the DC bus voltage noticed using the traditional method on the blue curve and the loss attenuated by the proposed method that is illustrated by the red figure.

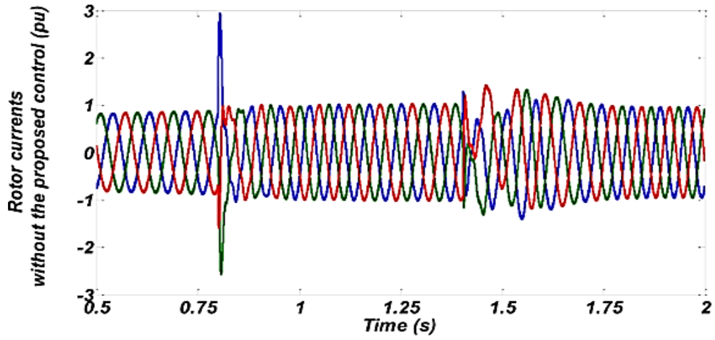


Figure 8. current with traditional control in rotor winding

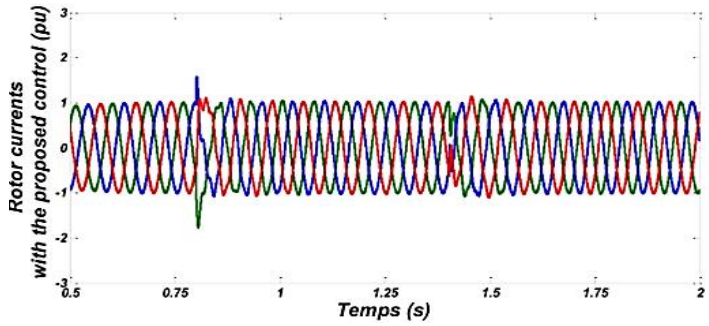


Figure 9. Current with the suggested control in rotor winding

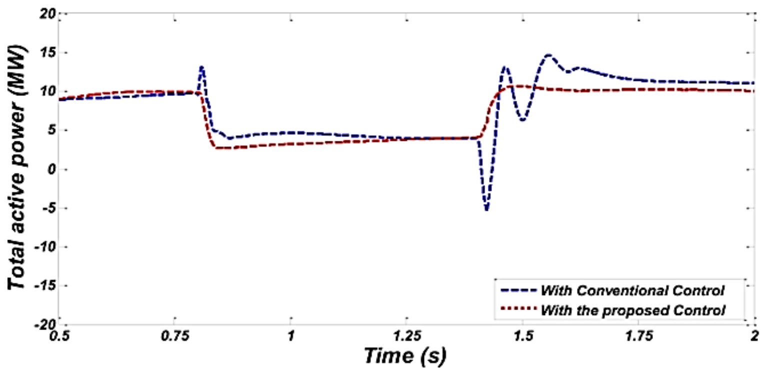


Figure 10. Active power

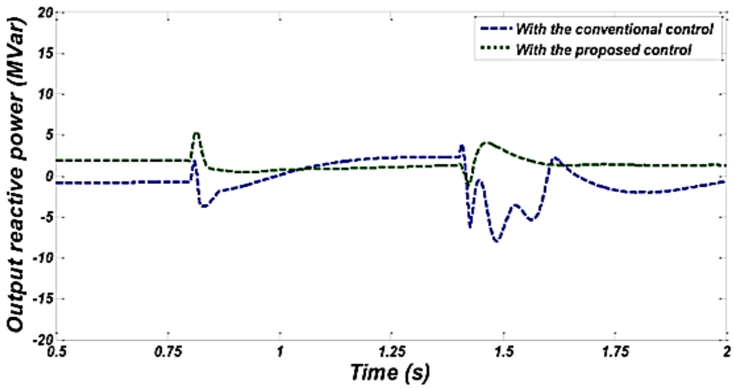


Figure 11. Reactive power

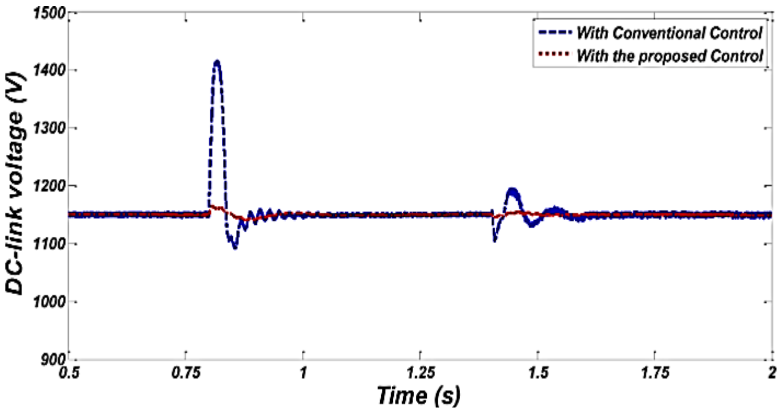


Figure 12. DC-bus voltage

## 5. CONCLUSION

A new design strategy is studied for wind system based DFIG connected to the network. using the magnetic storage system SMES. This strategy is especially particularly beneficial for reducing two inconveniences that could disturb the normal operation of wind turbines based DFIG, such as the random variation of wind speed and disconnection of wind turbines during symmetrical grid faults. The proposed control system effectively improves the power production during the rapid and random variations of the wind resource, maintains the power production during the symmetrical fault, and at the same time, can participate in the improvement of the electric system services.

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