Annals of Electrical and Electronic Engineering, 1(2) 2018, Pages: 7-12

Published by IASE

Annals of Electrical and Electronic Engineering

Journal homepage: www.aeeej.org

On the performance of network during a transient

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ARTICLE INFO

Article history:
Received 2 October 2017
Received in revised form
7 January 2018
Accepted 21 January 2018

Keywords:
Doubly fed induced generator
DC link
Harmonic range
Torque
Voltage fault

ABSTRACT

Three control strategies are represented in this study which is compared with each other based on transient modes. In this study, simulation is done by MATLAB software. During voltage faults, the reaction of stator makes the charge of electricity induced in a rotor; so, the harmonic range goes up in the rotor and causes the ripple in torque and DC link voltage. On the other hand, the transferred power from the rotor to grid decreases which causes immediate voltage increase in DC link. This study represents a new method for improving the performance of wind turbines using doubly fed induction generator during grid fault and prevents the destruction of different sections.

1. Introduction

Fixed-speed wind turbines have some advantages such as simplicity, high reliability and low production and operating costs. Their main disadvantage is their low efficiency in nearly fixed velocity. In order to solve this problem, variable speed turbines have been designed which absorb the highest level of power in a specific range by adjusting the rotation speed (Ackermann, 2005; Akhmatov, 2005; Erlich et al., 2007). Two common types of these turbines are convertor wind turbines with full capacity and doubly fed induction generator (DFIG) (Thenmozhi and Srimathi, 2015; Kasem et al., 2008).

The most prevalent installed turbine in recent years has been variable speed wind turbines using DFIG. This generator has a high efficiency because of the variable speed; moreover, the power of electronic convertor is nearly 30% of the generator power. This generator has some problems such as using brushes and slippery loops which reduce its reliability and increase its maintenance costs. This issue is especially important in case of turbines installed in the sea or far distances. Fig. 1 shows the schema of this generator (Foster et al., 2010; Peng et al., 2009; Salles et al., 2009).

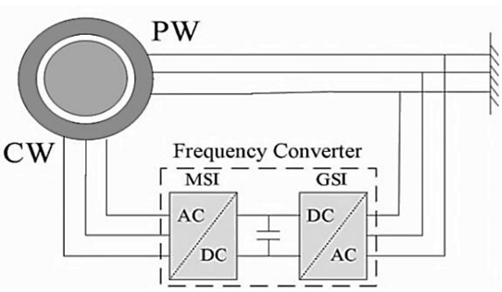

Fig. 1. Scheme of DFIG.

The main advantage of wind turbines using doubly fed induction generator is the fact that, power electronic equipment should work only within a fraction of the whole system power (20-30%) meaning that, in this case, the loss of electronic power decrease in comparison with the wastes of power equipment for direct drive synchronous generator. Moreover, using a smaller invertor reduces the cost. However, the protection and control of power electronic equipment should be considered, so different methods have been represented. The controlling methods which have been introduced for achieving the highest efficiency in variable speeds track the goal of maximum power. Protective methods and strategies protect different equipment against the disturbance of network (Sangeetha and Ravikumar, 2015; Meegahapola et al., 2010).

Here, the protection of DC link plays a key role. Usually the voltage of DC link is determined in specified level. In other words, the relation between two invertors and received power from rotor and the sending power to farm are based on DC link voltage. During voltage drop, the DC link voltage increases due to decrease in power injection and its saving in reservoir. This voltage increase damages to insulators of this section and destroys power electronic equipment. Different methods have been proposed to prevent this event such as using chopper in DC link or using crowbar in the rotor invertor (Xiang et al., 2006; Rathi and Mohan, 2005; Hansen and Michalke, 2007; Lopez et al., 2007; Xu and Cartwright, 2006). These methods protect the power equipment well but cause disturbance from farm to network. This study represents a new method to improve this performance. This paper consists of different sections. In the second section, the modeling of wind turbine using doubly fed induction generator is shown. The suggested method is presented in the third section and the fourth section is devoted to simulation and discussion followed by conclusion at the end.

2. Wind turbine

Some of the existing power is transformed to active mechanical power in the shaft of wind turbine by rotor blades. For calculating the stable state of mechanical power of wind turbine, $C_p(\lambda, \beta)$ curve is used (Rahimi and Parniani, 2010; Lima et al., 2010; Liang et al., 2010; Yao et al., 2008). The mechanical power P_{mech} is calculated as following:

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https://doi.org/10.21833/AEEE.2018.02.002

$$P_{mech} = \frac{1}{2}\rho A_r C_p(\lambda, \beta)\omega^3 \tag{1}$$
$$\lambda = \frac{\Omega_r r_r}{\omega} \tag{2}$$

Cp is power coefficient and β is pitch angle, λ is speed ratio, ω is wind speed and Ωr is rotor speed. The radius of rotor surface is rr, p is air density and Ar is the swept surface by the rotor. Fig. 2 shows the $C_p(\lambda, \beta)$ curve as a function of wind speed in rotor rated speed (fixed-speed wind turbine). The goal of power control is to calculate the speed of the tip where the highest amount of mechanical power or torque of wind turbine is received by generator.

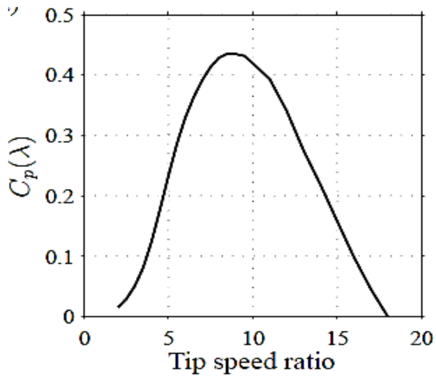

Fig. 2. Power coefficient, Cp based on λ.

Fig. 3 shows the mechanical power caused by $C_p(\lambda, \beta)$ curve and the change of rotor speed caused by wind speed for variable speed wind turbines. The rotor speed in areas of variable speed is controlled, so the ratio of optimized speed is kept. In other words, as far as speed or power is under the rated amounts, the Cp maximum is kept. When the turbine reaches rated power, the pitch angle in high speeds is controlled for confining the entry power to turbine. In Fig. 3, in 13m/s wind speed, the turbine reaches to 1pu rated power.

It should be noted that the rotor radius can be optimized for fixing the positions with different speeds. For example, if the radius of r_r rotor increases, the output power of the turbine also increases according to Eq. 2. It means that for lower wind speed, a rated peed will result. However the increase in rotor radius predicates that, in high speeds the output power should be confined more so as not to pass generator rated power. So, there is often a compromise between rotor radius and generator rated power. This selection depends highly on average speed of the site.

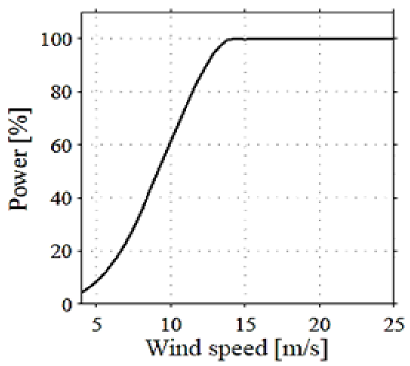

Fig. 3. The power of wind turbine based on wind speed.

The equivalent circuit of doubly fed induction generator and magnetic loss are shown in Fig. 4 which is acceptable as a single-phase Y circuit in stable state. If DFIG is Δ connector, the machine can also be represented as Y equivalent.

Using the Kirchhoff voltage rule in the circuit, the following is resulted:

$$V_s = R_s I_s + j\omega_1 L_{s\lambda} I_s + j\omega_1 L_m (I_s + I_r + I_{R_m}) \tag{3}$$
$$\frac{V_s}{s} = \frac{R_r}{s} I_r + j\omega_1 L_{r\lambda} I_r + j\omega_1 L_m (I_s + I_r + I_{R_m})$$
$$0 = R_m I_{R_m} + j\omega_1 L_m (I_s + I_r + I_{R_m})$$

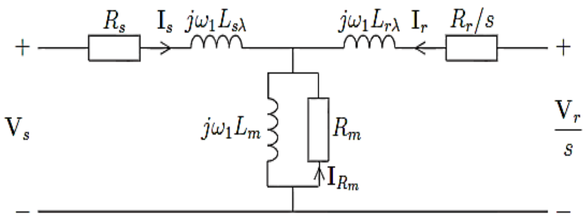

Fig. 4. Equivalent circuit of DFIG.

here, Vs is stator voltage, Rs is stator resistance, Vr is rotor voltage, Rr is rotor resistance, Is is stator current, Rm is the magnetizing resistance, Ir is rotor current, Lsλ is stator leakage inductance, Irm is the magnetized resistance current, ω_1 is stator frequency, Lsλ is rotor leakage inductance, S is slip and Lm is inductance magnetizing where S equals:

$$S = \frac{\omega_1 - \omega_r}{\omega_1} = \frac{\omega_2}{\omega_1} \tag{4}$$

ωr is rotor speed and $\omega 2$ is slip frequency. Moreover, if the flux of aerial distance and stator flux and rotor flux are defined as following:

$$\Psi_m = L_m (I_s + I_r + I_{R_m}) \tag{5}$$
$$\Psi_s = L_{s\lambda} I_s + L_m (I_s + I_r + I_{R_m}) = L_{s\lambda} I_s + \Psi_m \tag{6}$$
$$\Psi_r = L_{r\lambda} I_r + L_m (I_s + I_r + I_{R_m}) = L_{r\lambda} I_r + \Psi_m \tag{7}$$

The described equations in equivalent circuit of (3) and (7) are written as following:

$$V_s = R_s I_s + j\omega_1 \Psi_s \tag{8}$$
$$\frac{V_s}{s} = \frac{R_r}{s} I_r + j\omega_1 \Psi_r$$
$$0 = R_m I_{R_m} + j\omega_1 \Psi_m.$$

The ohmic losses equals:

$$P_{loss} = 3\left(R_s |I_s|^2 + R_r |I_r|^2 + R_m \left|I_{R_m}\right|^2\right), \tag{9}$$

and Te electromechanical torque is calculated:

$$T_e = 3n_p Im[\Psi_m I_r^*] = 3n_p Im[\Psi_r I_r^*], \tag{10}$$

where n_p is the number of the pairs of the poles.

3. The suggested method

In this section, the suggested methods for controlling and protecting DC link are represented. In order to compare different methods with the present one, first the previous methods are reviewed and then the suggested method is shown in two parts. Finally, three strategies will be introduced.

3.1. Strategy A

In this strategy that is suggested from previous methods, DC link voltage is protected by chopper and controlling crowbar. Fig. 5 shows the position of chopper and crowbar. In this strategy, during grid and voltage drop, the crowbar enters the circuit, consumes the power and prevents sending power to rotor invertor. In this position, if DC voltage link goes beyond a certain level, the chopper enters the circuit and discharges DC link capacitor by a resistance.

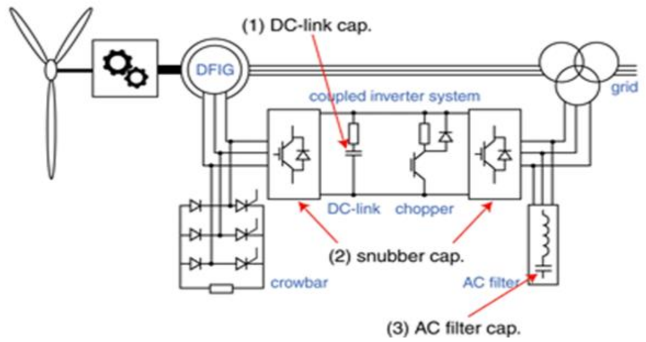

Fig. 5. Wind system diagram using chopper and crowbar (rotor converter-grid converter-crowbar-grid).

In this case, rotor side control algorithm is shown in Fig. 6 and grid side control algorithm is shown in Fig. 7. Controlling signals are produced based on reference values by using PI controller.

3.2. Strategies B and C

In this case, for improving the performance of wind turbines from grid perspective, it is needed to put the electronic power section out of the circuit during the fault because grid voltage has dropped and the grid is not receiving any power. So, the capacitor of DC link should not receive any power and the value of reference control algorithm should change so as not to receive any voltage from grid. Hence, according to the suggested method, control algorithm changes to Fig. 8 during fault (strategy B). Moreover, control algorithm of grid will change. As shown in Fig. 7, the amount of power that is sent to the grid depends on DC link. If the DC link voltage goes beyond the reference value, the power should be injected to grid which is based on the voltage of DC link. During this fault, the amount of power sent to the grid should increase in accordance with voltage drop (strategy C).

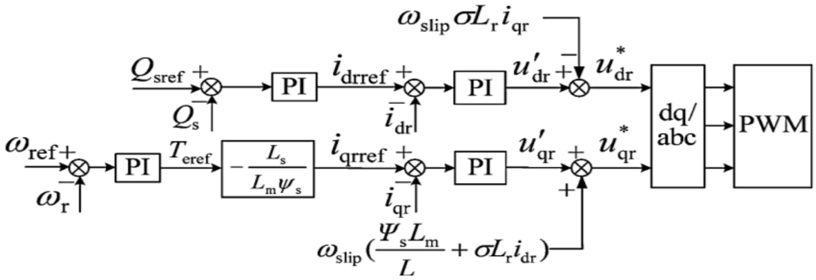

Fig. 6. Control algorithm of rotor in normal mode.

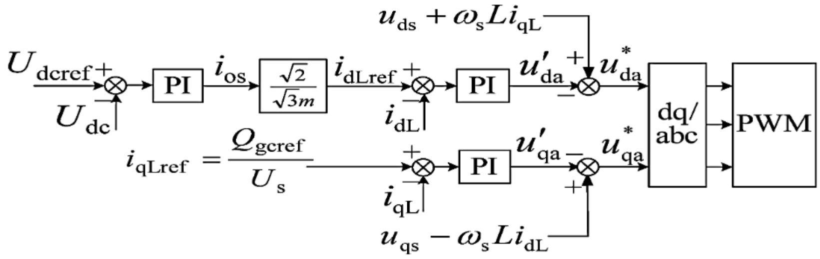

Fig. 7. Control algorithm of grid in normal mode.

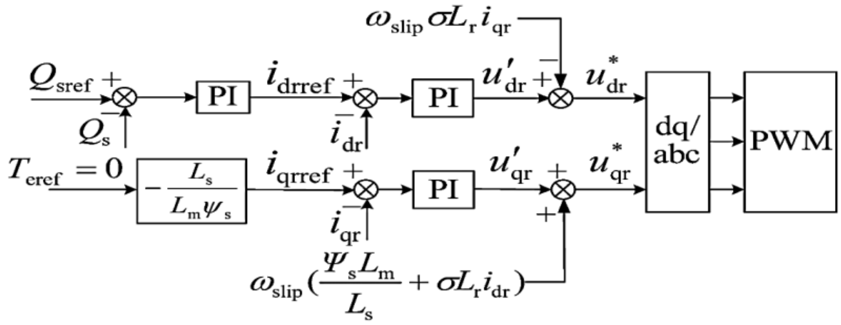

Fig. 8. Control algorithm of rotor in fault mode.

4. Simulation

In this section, three mentioned strategies for controlling the voltage of doubly fed induction generator are simulated and the results of the implementation of all three strategies are considered. As mentioned before, the power produced by rotor is sent to grid. If a fault happens in grid or a voltage drop is imposed on the grid due to disturbance, the received power decreases and consequently leads to immediate increase in the voltage of capacitor.

In order to prevent this event, A, B and C strategies are considered. Finally, a grid like what is shown Fig. 9 is designed in MATLAB simulator software.

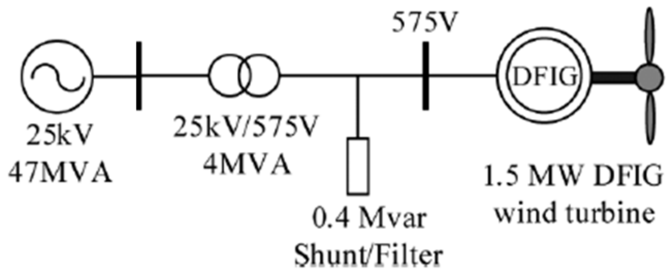

Fig. 9. Linear diagram of studied system.

In Figs. 10-13, the effect of voltage drop in 2/1-2/3 Seconds on wind turbines are observed. In order to control this effect, three strategies are used and the results are shown in Figs. 10-12.

They are compared with each other based on transient modes.

4.1. Simulation of control strategy A

In this strategy, when the voltage goes more than 1160, the chopper switch is connected and the extra power is lost in resistance. The performance of crowbar is very effective and prevents the sent power to reach converter and DC link. The sent power goes to the crowbar and if the voltage goes higher than 1160, it will go to resistance through walls and will be discharged in the walls. In this strategy, the highest power is received from rotor. The result of this strategy is shown in Fig. 10.

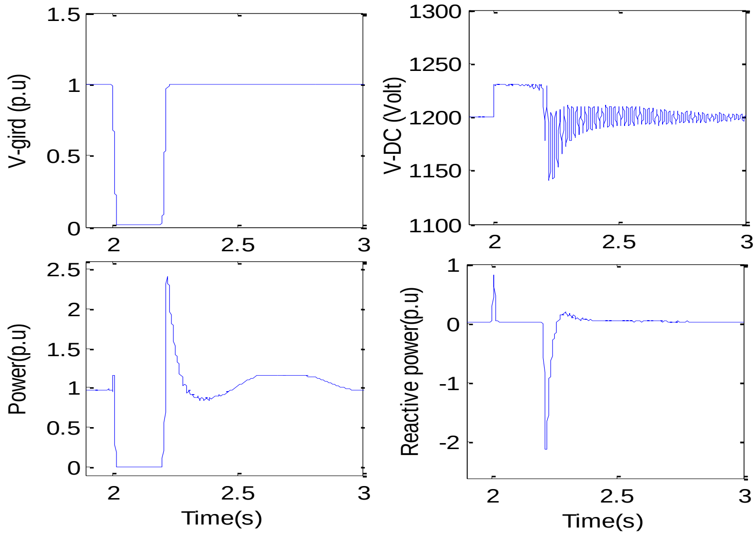

Fig. 10. Grid voltage, DC link voltage, active and reactive power (control strategy A).

4.2. Simulation of control strategy B

Strategy B prevents the extreme and immediate increase in the voltage of capacitor by controlling the rotor inverter. During the fault, the torque value becomes zero to make the received power zero. Making the reference torque zero will make the reference current and also reference voltage zero. So, the rotor inverter will not receive any power from rotor. The result is shown in Fig. 11.

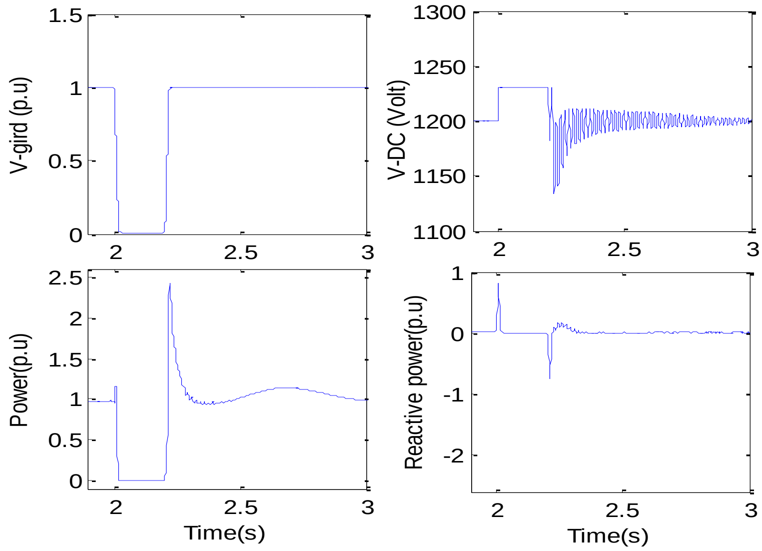

Fig. 11. Grid voltage, DC link voltage, active and reactive power (control strategy B).

4.3. Simulation of control strategy C

In this mode, during the fault, the amount of producing signal of grid reference current is added a little which comes up with increase in transferred power from DC link to the grid and consequently prevents the increase in DC link voltage. This mode acts like capacitor discharging and the voltage decreases through this strategy. The result is shown in Fig.12.

5. Comparison of proposed strategies (A, B, C)

As it was mentioned completely, in strategy A, the highest power is received form rotor but in strategy B, any power is received from rotor. In strategy C, the highest power is taken from DC link and by increasing the transferred power from DC link to grid, the increase in Dc link voltage is prevented. In t=2.1s, a voltage drop of 200 milliseconds occurs in power distribution grid. Fig. 13 shows wind turbine equipped with DFIG in 12m/s using strategy A, B, C. As shown in this figure, through using strategy B, DC link voltage fluctuation is not adequately conductive.

Controlling the rotor current can be affected by the fluctuations of DC link voltage, the sudden performance of active power and rotor current which is controlled by strategy B is far worse than strategy C. in strategy C, due to using control plan of grid, DC link voltage is reduced significantly and a better performance is seen in comparison with strategy B because when the wind speed is 12m/s which is more than the speed limit, the generator acts in accordance with the speed limit of the rotor. The high speed of the wind turbine which is due to the suggested control strategy of the rotor converter can be controlled by the blade step. Controlling the blade step can limit converting electrical energy to kinetic energy. So, when controlling of blade step is activated, identifying the voltage drop of grid can help decreasing voltage fluctuations in DC bus. Consequently, the existence of grid converter in the suggested control strategy for reducing the voltage is justified. Now these three strategies of wind turbines using DFIG in 12m/s are explained. During the fault, increase in rotor speed resulted by controlling strategy C is much more than strategy A. Increase in rotor speed gained in strategy C can transform the extra energy to kinetic energy. Thereby, the fluctuations of active power, reactive power, rotor current and DC link voltage will decrease significantly in comparison with strategy A. Moreover, through using control strategy C, the doubly fed induction generator can remain connected to grid even for a long time.

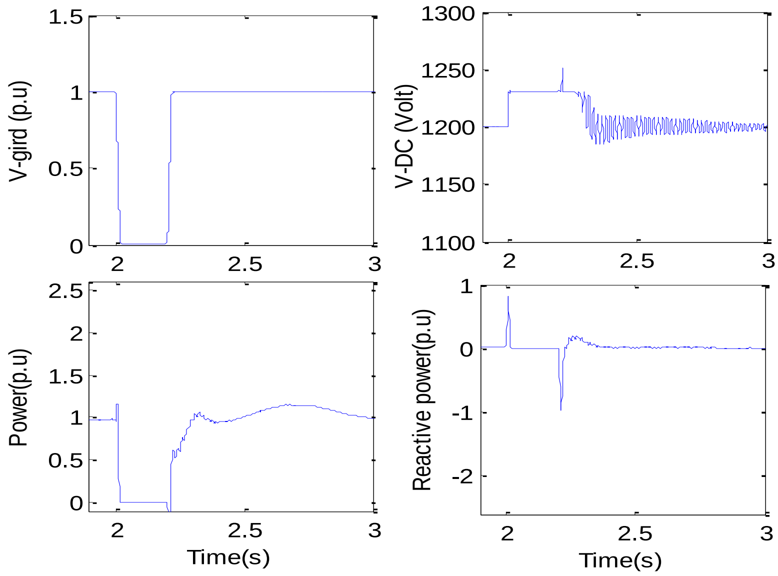

Fig. 12. Grid voltage, DC link voltage, active and reactive power (control strategy C).

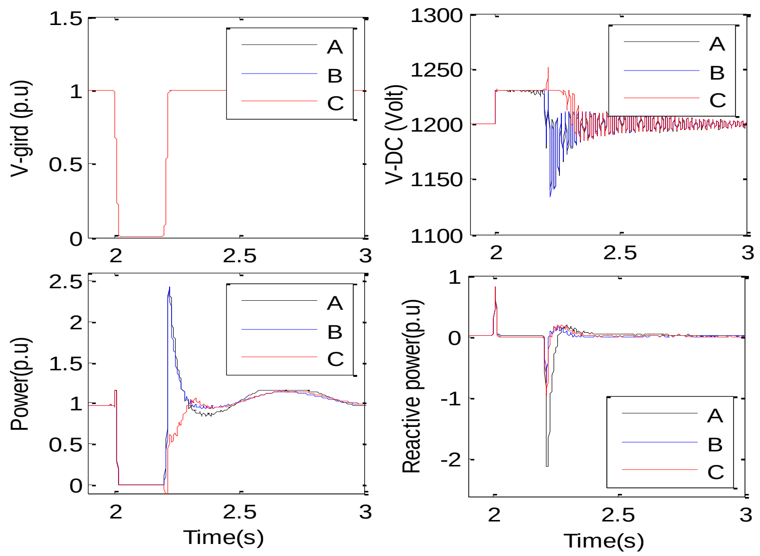

Fig. 13. Comparison of these three strategies (A, B, C).

6. Conclusion

The prevalent use of wind turbines makes a significant challenge for finding the most reliable operation of power systems. Wind turbines should be protected during disturbances in order to support the grid performance for ensuring the supply of electricity produced by wind power.

This paper suggests a new and efficient strategy for controlling rotor and grid converter to improve the capability of wind turbines equipped with doubly fed induction generator. The new suggested strategy enables the doubly fed induction generator to produce electricity and temporarily to absorb enormous energy by increasing the rotor speed; for example, when a fault happens. Moreover, the new strategy introduces the “compensation” item to reduce the extra voltage of DC link during grid fault. The results of simulation showed that the suggested control strategy can effectively reduce the transient mode of rotor current and DC link voltage. Comparing with strategy A using crowbar, this strategy showed a better transient mode for doubly fed induction generator in a short time during disturbance. This new control strategy leads to reduction of mechanical effects on wind turbines and brings the crowbar disturbance to minimum level.

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