Control of Wind Power Plant for Cooperation with Conventional Power Generation Unit and HVDC Classic Link

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Abstract: This paper focuses on the control of wind power plant equipped with doubly-fed induction generators (DFIG) for its cooperation with conventional generation unit and HVDC classic link. DFIG wind turbine and wind power plant voltage control are presented in detail. Also their influences on power system voltage stability are analyzed. Besides DFIG wind power plant, synchronous generators and monopolar HVDC classic link are also considered. For synchronous generator, conventional controllers are employed: governor, exciter and power system stabilizer (PSS). For the HVDC classic converters, the *V-I* controllers are applied. In this paper, the capability of DFIG wind power plant to improve power system dynamic behavior is presented. Simulation results show that the DFIG wind power plant and wind turbine voltage control strategy will reinforce the power system voltage stability.

Keywords: Doubly-fed induction generator, wind turbine control, wind power plant control, synchronous generator control, converter control, HVDC classic

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1. INTRODUCTION

Since the wind energy is renewable and environmental natural resource, the utilization of wind power plant increased quickly. Wind power constitutes the renewable generation technology which has experienced the fastest growing among all types of renewable generation technologies currently investigated (Erlich, I. Winter, W. and Dittrich, A. (2006), Rueda, J.L. and Shewarega, F. (2009)).

With the development of the doubly-fed induction generator (DFIG) technology, large scale DFIG wind power plants are integrating into power systems increasingly. The DFIG machines are collectively referred to as variable speed machines and they possess important advantages such as reactive power control capabilities, smaller and cheaper converter compared with a full size one (Rueda, J.L. and Shewarega, F. (2009)).

Since the increasingly integration of large DFIG wind power plants, their influences on power system dynamic behavior must be considered. Especially, their impacts on power system static and dynamic voltage stability must be analyzed. Also, their interaction with conventional power plants must be taken into consideration.

This paper focuses on the contribution of DFIG wind power plants with continuous voltage control on power system voltage stability. Besides DFIG, synchronous generators and monopolar HVDC classic link are also simulated. Furthermore, the control functions of DFIG wind power plants and their capability in improving power system dynamic behavior will be analyzed theoretically. The structure of the power system is given in Fig. 1.

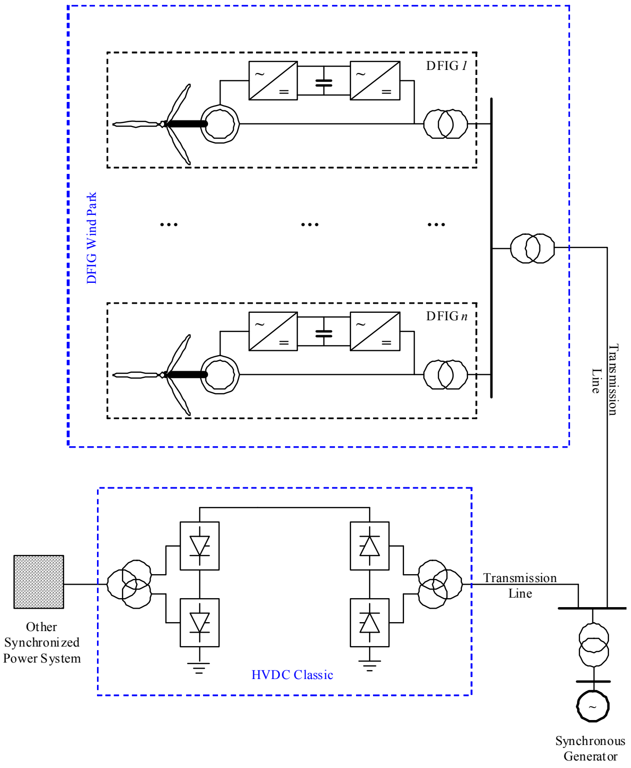

Fig. 1. Power system structure.

This paper is organized as follows: following the introduction, the wind power plant and wind turbine voltage controls will be introduced in section 2. In section 3, the synchronous generator voltage control and HVDC classic control will be illustrated. Then in section 4, simulation results will be given. Finally, brief conclusions are deduced.

2. WIND POWER PLANT VOLTAGE CONTROL

The basic example structure of DFIG is shown in Fig. 2. As a general approach, the space-phasor coordinates with orthogonal direct (*d*) and quadrature (*q*) axes are used. The choice of the stator voltage as the reference frame enables the decoupled control of *P* (active power, *d* control channel) and *Q* (reactive power, *q* control channel) (Erlich, I. Winter, W. and Dittrich, A. (2006), Rueda, J.L. and Shewarega, F. (2009)).

According to Grid Codes, active and reactive power should be controlled at the point of common coupling (PCC), which is usually located at medium or high voltage side of the wind power plant transformer. Therefore the wind power plant controller can be installed at the PCC, as shown in Fig. 3 (Bluhm, R. and Fortmann, J. (2010)).

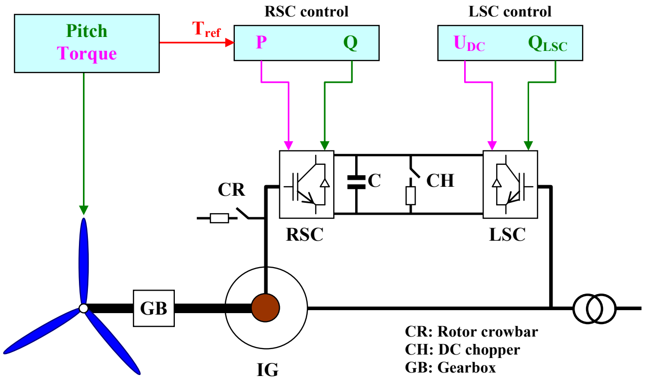

Fig. 2. DFIG control.

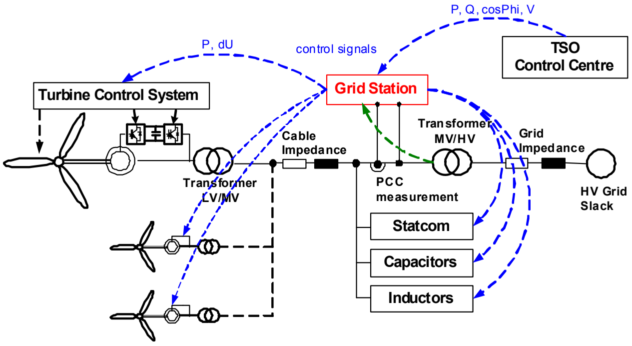

Fig. 3. Wind power plant control.

The wind power plant controller can receive active and reactive power setpoints from the Control Centre of the system operator. A classical control mode is a power factor setpoint at the PCC controlled by the wind power plant controller sending reactive power setpoints to all turbines of inside the plant. In case of voltage control, there is a voltage setpoint at the PCC.

This paper employs voltage control method at PCC in combination with local voltage control at the wind turbine level (Bluhm, R. and Fortmann, J. (2010)). Optionally, external reactive power compensation can be connected to the PCC and can be controlled by the wind power plant controller. This is only necessary, if the reactive power range of the wind turbine is not sufficient to fulfill the requirements at the PCC.

The basic function of a voltage controller is to calculate the setpoint for reactive power depending on the voltage. A general block diagram for a proportional characteristic is shown in Fig. 4. The voltage measurement (*U_meas*) is subtracted from the voltage setpoint (*U_set*) to calculate the voltage deviation (ΔU). This deviation is multiplied by the proportional control factor *KVC* to calculate the reactive power setpoint (*Q_set*). Depending on the desired control characteristic, a reactive current setpoint (*Iq_set*) can also be used (Bluhm, R. and Fortmann, J. (2010)).

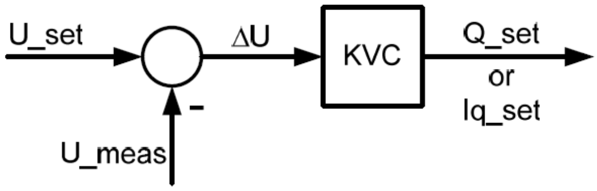

Fig. 4. Proportional voltage control block diagram.

The voltage control can be implemented in both turbine level (local) and the wind power plant level (central) and the detailed description can be found in (Bluhm, R. and Fortmann, J. (2010)). A combination of the central and local voltage control can combine their favorable characteristics with benefit for grid stability. The continous voltage control at the turbine level delivers a very fast response to deep voltage drops and also to small voltage deviations inside the standard operation range (Bluhm, R. and Fortmann, J. (2010)).

The combination with voltage control at the wind power plant level ensures an exact adjustment of the required reactive power value at the grid connection point. A stable control of the combined controller can be guaranteed because the time constant of the subordinate local control is more than 10 times faster than the time constant of the wind power plant controller. Settings such as slope or response time of the combined voltage control can be easily adapted to achieve the desired characteristics required at different connection points or in different countries (Bluhm, R. and Fortmann, J. (2010)).

The above mentioned wind power plant voltage control characteristic will be applied for analyzing its influence on the power system voltage stability.

3. SYNCHRONOUS GENERATOR AND HVDC CLASSIC CONTROLS

3.1 Synchronous generator and its controls

In this paper, the synchronous generator is equipped with governor, exciters and PSS. The description of these conventional controllers can be found in (Kundur, P. (1993), Rogers, G. (1999), Cai, L.J. (2004)).

3.2 HVDC-classic system

The basic configuration of a typical monopolar HVDC classic link is given in Fig. 5. It uses one conductor, usually of negative polarity and the return path is provided by ground or water. Cost considerations often lead to the use of such systems, particularly for cable transmission. This type of configuration may also be the first stage in the development of a bipolar system (Kundur, P. (1993), Rogers, G. (1999)).

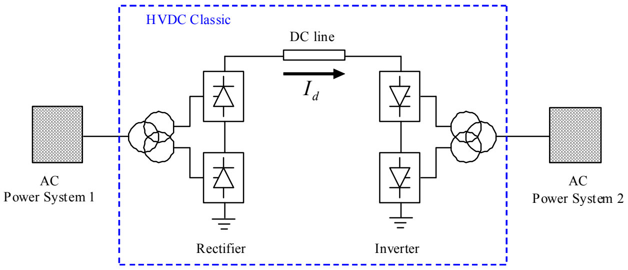

Fig. 5. Monopolar HVDC link.

Also the following components associated with the HVDC system are considered in this paper (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)):

1. Smoothing reactors: large reactors connected in series with each pole of each converter station.

2. Harmonic filters: Converters generate harmonic voltages and currents on both AC and DC sides. These harmonics may cause overheating of capacitors and nearby generators, and interference with telecommunication systems. Filters are therefore necessary on both AC and DC sides (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)). Since the system RMS behavior is considered in this paper, only the AC side harmonic filters are simulated.

3. Reactive power supplies: DC converters inherently absorb reactive power. In steady-state, the reactive power consumed is about 50% of active power transferred. Under transient conditions, the consumption of reactive power may be much higher. Reactive power sources are therefore provided on the AC sides of converters. The capacitors associated with the AC filters also provide part of the reactive power required (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)).

3.3 HVDC-classic control selection

An HVDC transmission system is highly controllable. Its effective use depends on appropriate utilization of this controllability to ensure desired performance of the power system. With the objectives of providing efficient and stable operation and maximizing flexibility of power control without compromising the safety of equipment, various levels of control are used in a hierarchical manner (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)).

Consider the HVDC link shown in Fig. 5. It represents a monopolar link or one pole of a bipolar link. The corresponding equivalent circuit is shown in Fig. 6.

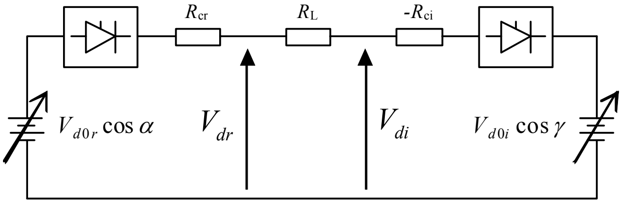

Fig. 6. Equivalent circuit of a monopolar HVDC link

The direct current flowing from the rectifier to the inverter is:

$$I_d = \frac{V_{d0r}\cos\alpha - V_{d0i}\cos\gamma}{R_{cr} + R_L - R_{ci}}$$

The power at the rectifier terminals and the inverter terminal are:

$$P_{dr} = V_{dr} I_d$$

$$P_{di} = V_{di} I_d = P_{dr} - R_L I_d^2$$

The DC voltage at any point on the line and the current (or power) can be controlled by (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)):

1. controlling the internal voltages ($V_{d0r}\cos(\alpha)$) and ($V_{d0i}\cos(\gamma)$). This is accomplished by grid/gate control of the valve ignition angle or

2. control of the AC voltage through tap changing of the converter transformer.

The voltage control speeds are:

1. Grid/gate control is rapid: 1 to 10ms. It is always used for rapid action and dynamic control.

2. tap changing is slow 5 to 6s per step. It is always used for slow action and steady state control.

For the selection of the HVDC classic control, following considerations influence the selection of control characteristics (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)):

1. Prevention of large fluctuations in direct current due to variations in AC system voltage.

2. Maintaining direct voltage near rated value.

3. Maintaining power factors at the sending and receiving end that are as high as possible.

4. Prevention of commutation failure in inverters.

3.4 HVDC classic control characteristics

a) Ideal control characteristics:

Under normal operation, the rectifier maintains constant current (CC), and the inverter operates with constant extinction angle (CEA), maintaining adequate commutation margin. This control concept is shown in Fig. 7 using the steady state voltage-current (*V-I*) characteristics (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)).

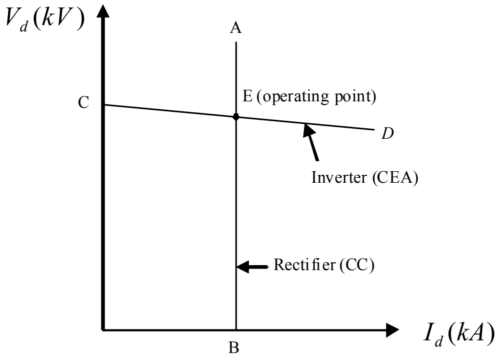

Fig. 7. Ideal V-I control of HVDC link

b) Actual control characteristics:

In practice, there are restrictions on the ignition angle α, the extinction angle γ and the system voltage. Consider these restrictions, the actual control characteristics are shown in Fig. 8. The explanation of different segments can be found in (Kundur, P. (1993), Hingorani, N.G. and Gyugyi, L.(2000)).

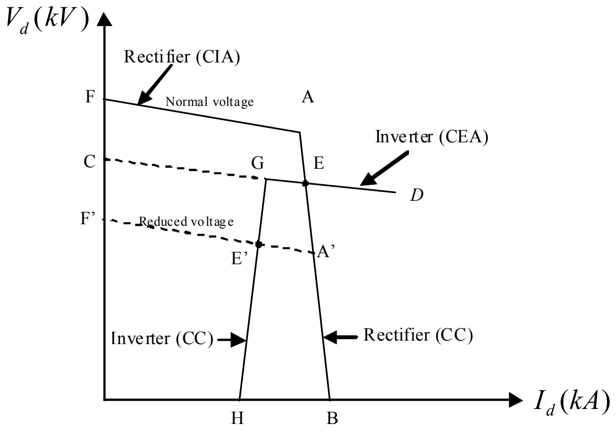

Fig. 8. Actual V-I control of HVDC link

In this paper, following controls are employed:

1. the rectifier maintains constant current by changing α.

2. the inverter operates with constant extinction angle γ for maintaining adequate commutation margin and voltage.

4 SYSTEM STUDIES

In order to evaluate the effects of the wind power plant voltage control on the power system voltage stability, different simulations are carried out. Two cases are employed to verify the contribution of wind power plant voltage control:

Case 1. Only with the wind turbine/wind power plant voltage controller.

Case 2. With the wind turbine/wind power plant voltage controller and synchronous generator voltage controller

In the two cases, the rectifier maintains constant current and the inverter operates with constant extinction angle for maintaining adequate commutation margin. The values in the following figures are illustrated in per unit (base voltage = component nominal voltage).

4.1 Three phase short circuit at wind power plant PCC (WP_PCC)

A three phase short circuit of 150ms (on t=0.5s) at wind power plant PCC (node WP_PCC, as shown in Fig. 1.) is simulated. Voltages at different buses are employed to demonstrate the system voltage behavior.

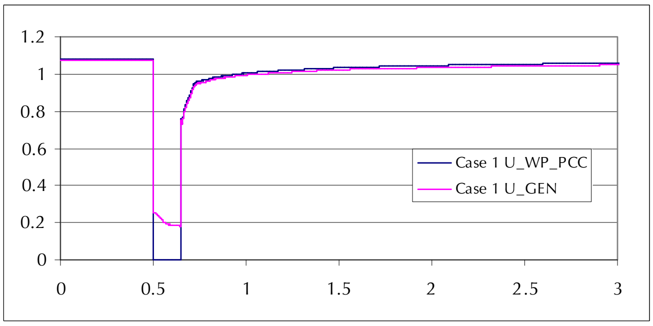

Fig. 9. Case 1: WP_PCC and Generator voltages

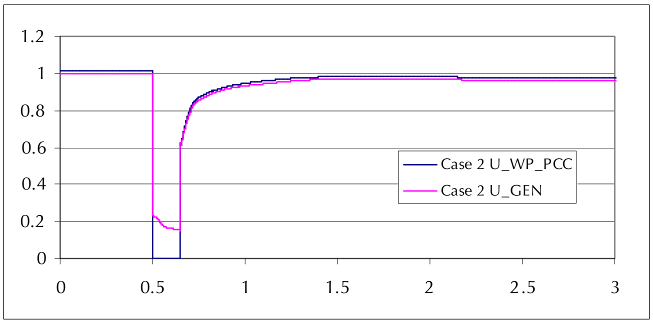

Fig. 10. Case 2: WP_PCC and Generator voltages

In Fig. 9 and 10, the voltages at nodes WP_PCC and GEN are illustrated. It is clear that the wind turbine voltage controller will reinforce the power system voltage control and thus enhance the system voltage stability.

From Fig. 11 to 14, the voltages on the HVDC classic link are given. It is obvious that the wind turbine voltage controller can also reinforce the HVDC classic voltage control and thus enhance the overall system voltage stability. The negative value of the voltage in Fig. 13 and 14 is because of the base value of the converter bridge is only the half DC nominal voltage.

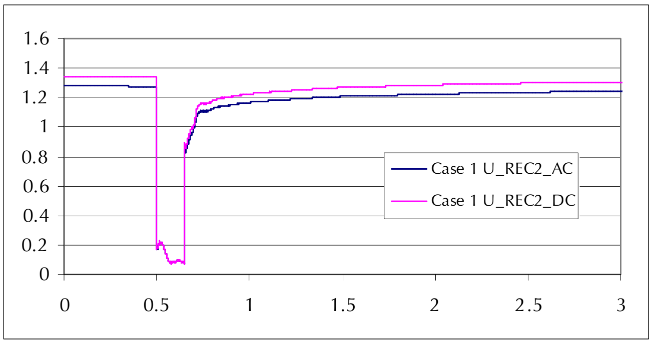

Fig. 11. Case 1: HVDC voltages (Node REC2)

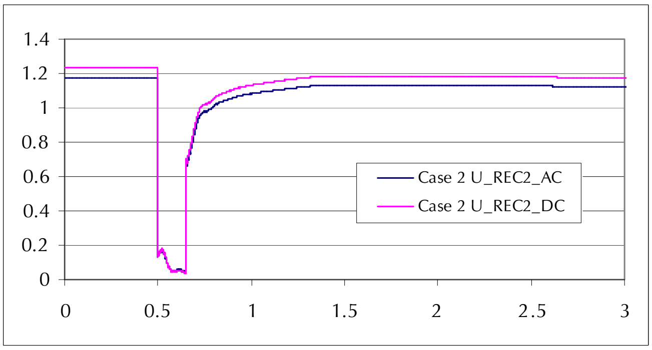

Fig. 12. Case 2: HVDC voltages (Node REC2)

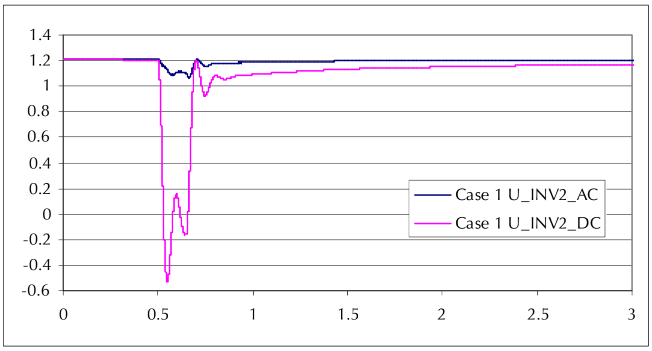

Fig. 13. Case 1: HVDC voltages (Node INV2)

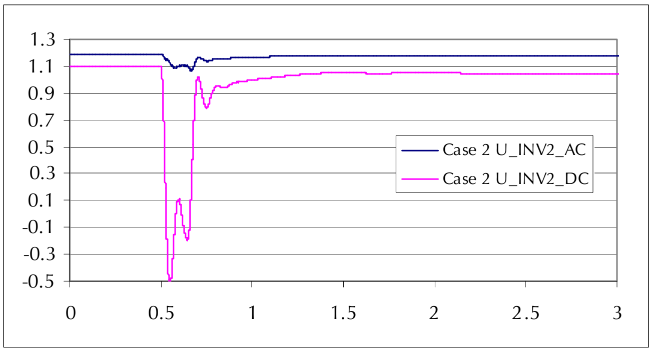

Fig. 14. Case 2: HVDC voltages (Node INV2)

4.2 Three phase short circuit at HVDC classic link (converter node REC_AC)

In order to prove the contribution of wind turbine voltage controller on the HVDC classic system, a three phase short circuit of 150ms is simulated at converter node REC_AC, as defined in Fig. 1. In order to prevent commutation failure, a short circuit reactance is applied ($Z_{\text{short\_circuit}}$=1Ω). Voltages at different buses are used to demonstrate the system behavior.

Fig. 15 and 16 show the voltages at nodes WP_PCC and GEN. It can be seen that the wind turbine voltage controller will keep the system voltage in a stable range and thus enhance the system voltage stability.

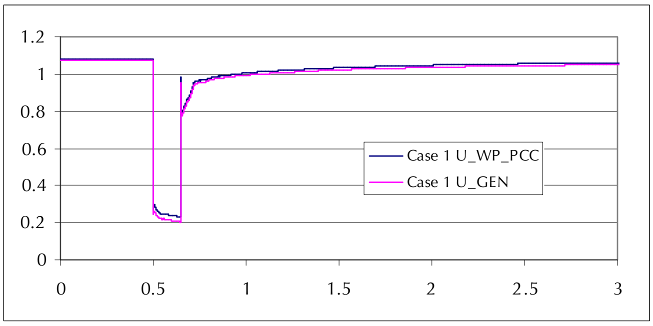

Fig. 15. Case 1: WP_PCC and Generator voltages

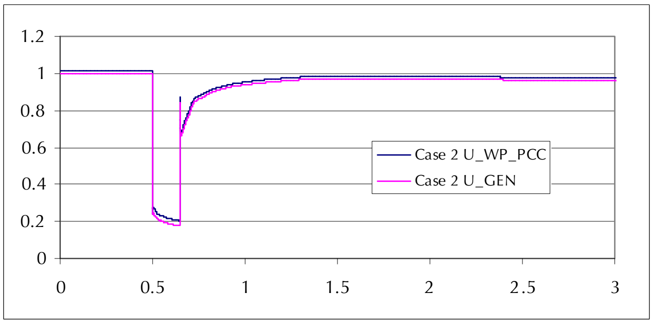

Fig. 16. Case 2: WP_PCC and Generator voltages

Fig. 17 to 20 demonstrate the voltages on the HVDC classic link. From the simulation results, it is obvious that the wind turbine voltage controller can also support the HVDC classic voltage control and then enhance the overall system voltage stability. The negative value of the voltage in Fig. 19 and 20 is also because of the base value of the converter bridge is only the half DC nominal voltage.

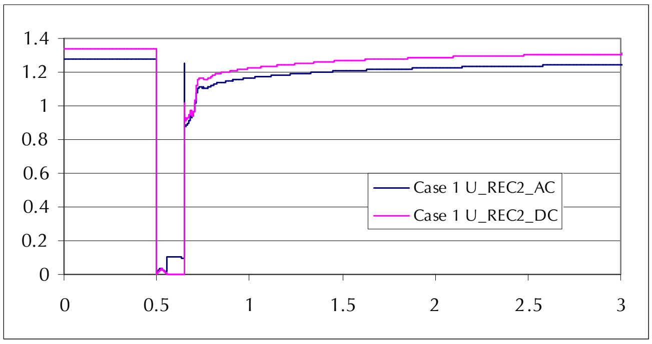

Fig. 17. Case 1: HVDC voltages (Node REC2)

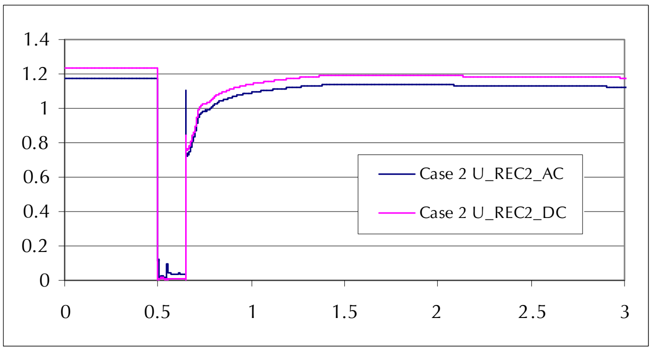

Fig. 18. Case 2: HVDC voltages (Node REC2)

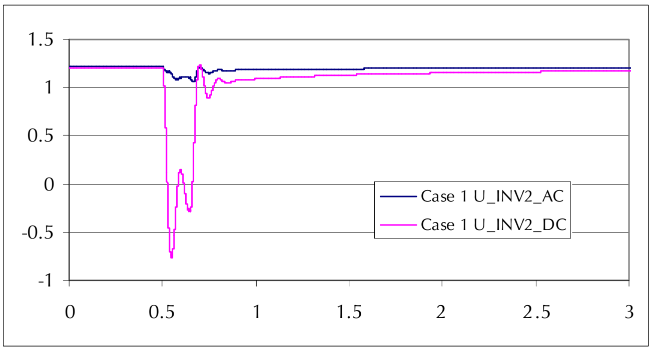

Fig. 19. Case 1: HVDC voltages (Node INV2)

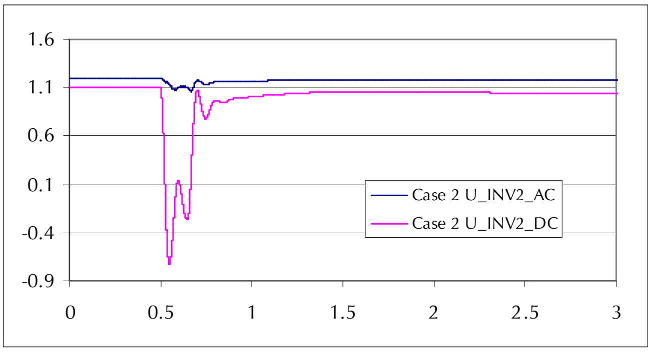

Fig. 20. Case 2: HVDC voltages (Node INV2)

5 CONCLUSIONS

This paper analyzes the contribution of DFIG wind power plants voltage control on power system voltage stability. Power system equipped with synchronous generators and monopolar HVDC classic link is simulated, where conventional controllers are applied to the generator and HVDC classic link. Simulation results show that the wind turbine and wind power plant voltage control approach can reinforce power system voltage stability. Also the HVDC classic voltage behavior can also be improved by means of the proposed voltage control strategy.

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