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Study on Key Factors of Dynamic Reactive Power Support of Mega Kilowatt Wind Power Base Consist of Doubly-fed Induction Generator

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Abstract. According to GB/T 19963-2011< Technical rule for connecting wind farm to power system >, taking a mega kilowatt wind power base as an example, study the factors that impacts dynamic reactive power support of wind farms consist of DFIG (Doubly-Fed Induction Generator), such as different types of reactive power compensation devices, performance behavior of wind turbines, and tap position of transformer. Study requirement of dynamic reactive power support of wind turbine. The simulation results indicates that performance behavior of wind turbine is very important for dynamic reactive power supporting capability of wind farms, it is very useful for improving dynamic reactive power support of wind farms by choosing the right type of reactive power compensation devices and the right tap position of transformers. And at the end, reasonable dynamic reactive power support strategy is proposed.

Introduction

In recent years, wind power develops rapidly in China, especially wind power capacity accounted for the proportion of the total installed capacity in the grid is more and more high in north China, northeast, northwest, the northeast. Wind power has become the second largest power supply in north China, northeast[1]. Wind power capacity is far beyond the local load or the capacity of the local power grid to accept wind power in some areas. Wind power safe and stable operation will directly affect the normal operation of the local power grid. In recent years, China's "Three North" region of the large-scale wind power off grid accidents result in voltage substantial fluctuations, greatly reduce of frequency, loss of large load and other serious consequences to the regional power grid [2-3]. The accidents were caused by cable short circuit of wind farms, the main reasons are wind turbine without low/high voltage ride through, insufficient reactive power compensation equipment capacity, insufficient adjustment capacity of reactive power compensation[4]. It is the fundamental problem of reactive power and voltage. Now, wind turbines almost are provided with LVRT(Low Voltage Ride Through). But the problems of reactive power and voltage still exist in the process of LVRT.

According to GB/T 19963-2011< Technical rule for connecting wind farm to power system >, the paper study on dynamic reactive power support of wind farm when fault occurs in grid. Factors that impacts dynamic reactive power support of wind farms consist of DFIG is analyzed. In order to meet requirement of standard, reasonable dynamic reactive power support strategy is proposed based on wind turbine, reactive power compensation devices and tap position of transformers. Study dynamic reactive power control strategy of wind farm during fault and after fault, for achieving the function of wind farm low voltage ride through. The strategy can support reactive power and transient stability of power system.

The Requirement of National Standard

The requirement of LVRT and dynamic reactive power support in GB/T 19963-2011< Technical rule for connecting wind farm to power system > [5]as follow.

LVRT Capability of Wind Farm

(a) When the voltage of point of connection of wind farm drops to 20% nominal voltage, the wind turbines in the wind farm should ensure the continuous operation for 625ms without tripping off. (b) The voltage of point of connection of wind farm can recover to 90% nominal voltage in 2s after voltage drop, the wind turbines in the wind farm should ensure the continuous operation without tripping off.

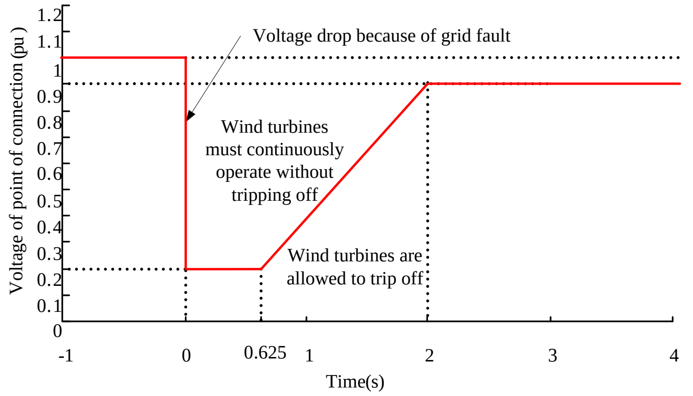


Fig. 1 Requirement on Low Voltage Ride through of Wind Farm

Capability of Dynamic Reactive Power Support

For wind farm group that total installed capacity is mega kilowatt class and above, when voltage drops because of three-phase short circuit fault of power system, every wind farm should have dynamic reactive power support capability in LVRT process as follows.

When the voltage of point of connection of wind farm is in the interval of 20%~90% nominal voltage, wind farm should support voltage recovery by output reactive power current; from the time of the voltage drop of point of connection of wind farm, response time of dynamic reactive current control is less than 75ms, continuous time should not be less than 550ms. Dynamic reactive current injected to power system from wind farm

$$I_T \geq 1.5 \times (0.9 - U_T) I_N, \ (0.2 \leq U_T \leq 0.9) \tag{1}$$

where: U_T ---voltage per unit value of point of connection of wind farm; I_N ---Rated current of wind farm.

According to requirements above, the paper studies dynamic reactive power support of wind farms in mega kilowatt wind power base.

Key Factors of Wind Farm Dynamic Reactive Power Support

The elements that affect dynamic reactive power support of wind farm include wind turbine, reactive power compensation device and transformer.

Wind Turbine

Wind turbine is the main dynamic reactive power supply in LVRT process of wind farm. Wind turbine can operate as current source type reactive power supply, and output reactive current. Decoupling control of active power and reactive power can be achieved for DFIG. Reactive current can be controlled by dynamic reactive power support control system of DFIG, as shown in Fig. 2.

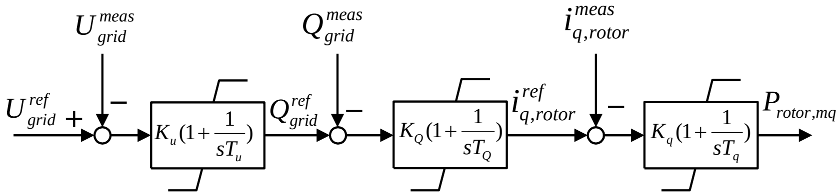


Fig. 2 Dynamic Reactive Power Support Control System of DFIG

DFIG is involved in transient voltage control of power system by outputting reactive power in the process of voltage drop and voltage recovery. Comparing the given voltage reference U_{grid}^{ref} with actually measured voltage, the control signal is gotten, and dealt with PI controller. And then, gain reactive power reference Q_{grid}^{ref} that control system need output. Actual reactive power output of DFIG is adjusted by current control of inner loop. Dynamic reactive power support of DFIG is realized.

Reactive Power Compensation Device

Reactive power compensation device includes current type and voltage type. Reactive power of current type of reactive power compensation device is proportional to the voltage; reactive power of voltage type of reactive power compensation device is proportional to the square of the voltage. Reactive power characteristics of current type is better than voltage type. When voltage drops, current type of reactive power compensation device can output more reactive power than voltage type.

Transformer

There are many main transformers and box transformers in mega kilowatt wind power base. The transformer can't output reactive power, but the different tap positions mean different impendence and voltage ratios of transformer, that affects dynamic reactive power support capability of wind farm in process of LVRT.

Below, taking a mega kilowatt wind power base as an example, the paper will analyze dynamic reactive power support capability of wind farm.

Dynamic Reactive Power Support Capability Analysis

In order to meet the dynamic reactive power support requirement of national standard, the factors that impact dynamic reactive power support capability of wind farm.

Simulation Model

Based on actual grid, the paper establishes mega kilowatt wind power base model, as shown in Fig. 3. There are two 750MVA transformers in 500kV substation A, and two 220kV substations as 220kV substation B and 220kV substation C. The installed capacity of the wind power base is 1600MW, where two wind farms(total 400MW) connected to substation A, five wind farms(total 550MW) connected to substation B, three wind farms(total 650MW) connected to substation C. All wind turbines of the wind power base is assumed as DFIG. The length of LA-B connecting substation A and substation B is 70km, its type is 4 ×LGJ-400. The length of LB-C connecting substation B and substation C is 110km, its type is 2 ×LGJ-630. The length of line connecting Wind farm 3 and substation B is 100km, where L3-1 is 35km, 2 ×LGJ-300; L3-2 is 65km, 2 ×LGJ-630.

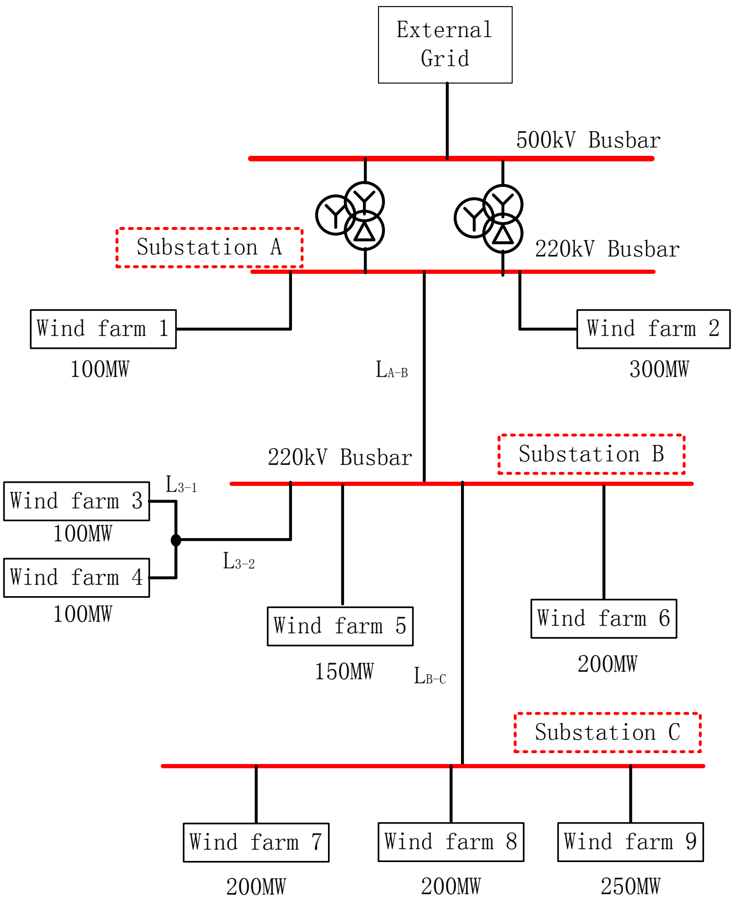


Fig. 3 Mega Kilowatt Wind Power Base Case

The paper takes wind farm 3(100MW) as an example to analyze dynamic reactive power support capability. Electrical parameters of main elements in wind farm as follows: the type of six collection lines is YJY23H-26/35kV-3×185, the length of every collection line is 2km; the capacity of main transformer is 100MVA, voltage ratio is 220±8×1.25%/35kV, short-circuit voltage is 13%; the capacity of box transformer is 1.6MVA, voltage ratio is 35±8×1.25%/0.69kV, short-circuit voltage is 6.5%.

Typical type electrical elements are chosen for the wind farm. Wind turbines is assumed with LVRT capability, that meet requirement of national standard. SVC and STATCOM taken as two types of reactive power compensation devices are compared.

Simulation setting as follows:

(1) Set three phase short circuit on line, resulting in voltage of point of connection of wind farm drops to 0.2pu. Clear the fault 0.625s later.

(2) Wind turbines are set three operation situations as consume reactive power, power factor is 1, and output reactive power. Reactive current of wind turbine is the same as Eq. 1.

(3) Considering effect of tap position of transformer in wind farm, tap positions are set as follows: main transformer -8, box transformer +2; main transformer 0, box transformer 0; main transformer +8, box transformer -2.

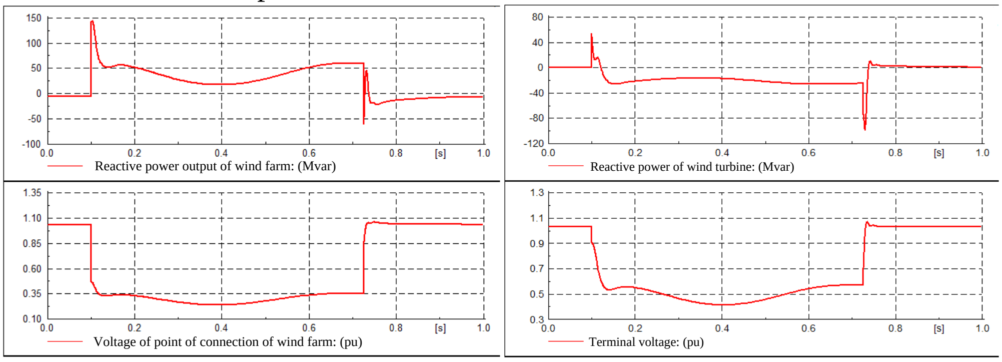
Wind Turbine Operation Situation

The tap positions of transformers are set as main transformer 0, box transformer 0. STATCOM as dynamic reactive power compensation device is provided in wind farm. STATCOM can output dynamic reactive current, and realize dynamic reactive power support[6-7]. In order to meet requirement of national standard, with different operation situation of wind turbine, STATCOM capacity demanded of wind farm is as shown in Tab. 1. The simulation results indicate that, when tap position of transformer is fix, if wind farm outputs reactive current as requirement of national standard, STATCOM capacity demanded of wind farm is mainly affected by operation situation of wind turbine.

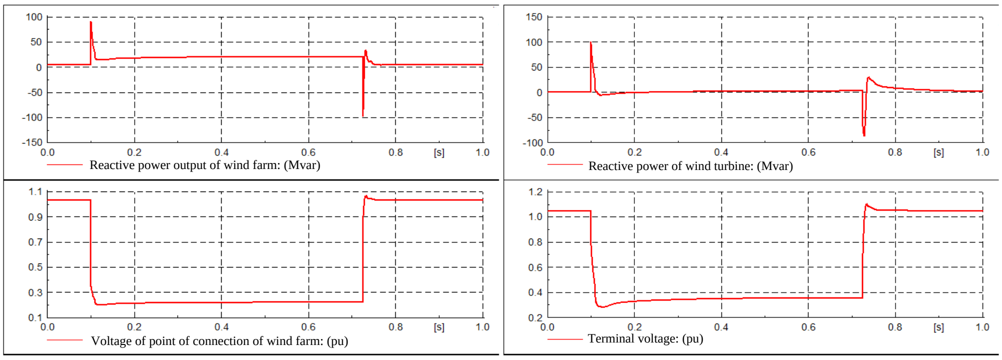
Table 1 Statcom quantity demanded of wind farm

operation situation of wind turbine	STATCOM [Mvar]
consume reactive power	265*
power factor is 1.0	100
output reactive power	25

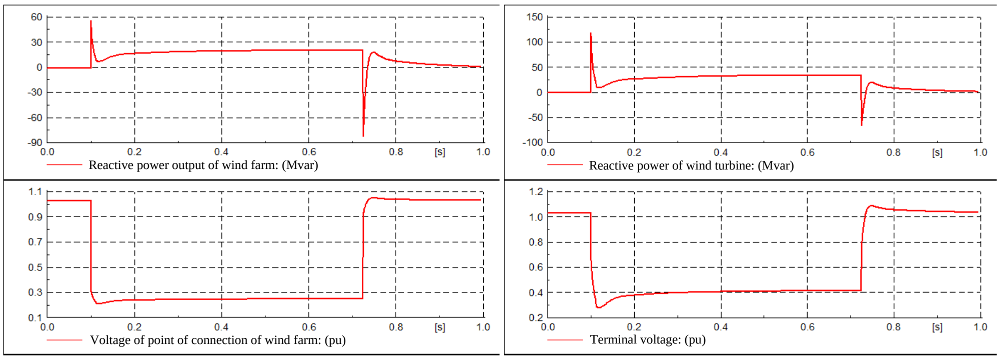
Note: Expresses reactive power capacity limit for wind farm, the number is reactive power inflection point of wind farm. That means reactive current of wind farm can't meet requirement of national standard, if wind turbine consumes reactive power.



(a) DFIG consumes reactive power



(b) The power factor of DFIG is 1.0



(c) DFIG outputs reactive power

Fig. 4 Relevant Variables Curves Of Wind Farm

Note: Reactive power of wind turbine means the sum of reactive power of all wind turbines in the farm

In process of LVRT, reactive power of wind farm and wind turbine, and bus-bar voltage are as shown in Fig. 4. Different operation situation of wind turbine affect greatly reactive power and voltage. When wind turbine consumes reactive power, relevant bus-bar voltage fluctuates greatly. There is no obvious fluctuation with other two operation situation of wind turbine.

As shown in Tab. 1 and Fig. 4, if wind turbine consumes reactive power in process of LVRT, reactive power inflection point of wind farm will appear, when the capacity of reactive power compensation device reaches a certain value. Then, if increasing capacity of reactive power compensation device, the reactive current of wind farm will reduce, and reactive current of wind farm can't meet requirement of national standard. If power factor of wind turbine is 1.0, in order to meet requirement of national standard, large capacity of reactive power compensation device need be installed in wind farm. If wind turbine can output reactive current, dynamic reactive power support capability of wind farm will be improved greatly, that will help voltage recovery of power system and wind farm. Therefore, reactive power adjustment capability of wind turbine should be made full use of, wind turbine should output reactive current in process of LVRT.

Reactive Power Characteristic of Reactive Power Compensation Device

SVC and STATCOM taken as two types of reactive power compensation devices are researched. SVC represents voltage type of reactive power compensation device, reactive power of SVC is proportional to the square of the voltage. STATCOM represents current type reactive power compensation device, reactive power of STATCOM is proportional to the voltage[8-10]. The tap positions of transformers are set as main transformer 0, box transformer 0. In order to meet dynamic reactive power support requirement of national standard, reactive power compensation capacity demanded of wind farm is as shown in Tab. 2.

Table 2 Treactive power compensation configuration of wind farm

operation situation of wind turbine	Reactive power compensation capacity [Mvar]	
	SVC	STATCOM
output reactive power	60	25
consume reactive power	440*	265*
power factor is 1.0	240	100

Expresses reactive power capacity limit for wind farm, the number is reactive power inflection point of wind farm. That means reactive current of wind farm can't meet requirement of national standard.

If wind turbine consumes reactive power in process of LVRT, reactive power inflection point of wind farm will appear, and reactive current of wind farm can't meet requirement of national standard. If power factor of wind turbine is 1.0, in order to meet requirement of national standard, large capacity of reactive power compensation device need be installed in wind farm. If wind turbine can output reactive current, dynamic reactive power support capability of wind farm will be improved greatly, the capacity of reactive power compensation device demanded of wind farm will reduce greatly.

Tap Position of Transformer

Assume that wind turbine is provided with LVRT capability, and wind turbine can output reactive current same as Eq. 1. In order to meet requirement of reactive current of wind farm, when tap position of transformer is different, STATCOM capacity demanded of wind farm is as shown in Tab. 3.

Table 3 Statcom capacity demanded of wind farm

tap position of transformer	STATCOM [Mvar]
main transformer -8, box transformer +2	15
main transformer 0, box transformer 0	25
main transformer +8, box transformer -2	35

From Tab. 3, in order to meet requirement of reactive current of national standard, when wind turbine output a certain reactive current, tap position of transformer can affect STATCOM capacity. In other words, reasonable tap position of transformer can improve dynamic reactive power support capability of wind farm. But, tap position of transformer can also affect terminal voltage when DFIG operates normally. According to current technical conditions, adjustment speed of tap position of transformer can't match requirement of dynamic reactive power support. Considering voltage level of grid normal operation, voltage level and capacity of reactive power compensation device in wind farm, tap position can be set reasonably to improve dynamic reactive power support capability of wind farm, and reduce cost of STATCOM.

Requirement of Dynamic Reactive Power Support Capability for Wind Turbine

Assume that there is no reactive power compensation device in wind farm, and tap positions of transformers are set as main transformer 0, box transformer 0. In order to meet requirement of reactive current of national standard, reactive current demanded of wind turbine is shown in Fig. 5.

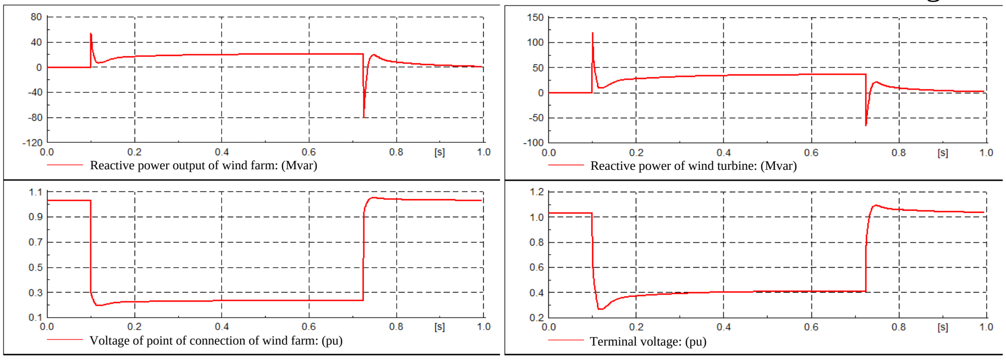


Fig. 5 Reactive Current Demanded of Wind Turbine

From Fig. 5, in order to meet requirement of national standard, reactive current that wind turbine need output is at least

$$I_{Tw} \geq 1.8 \times (0.9-U_{Tw})\, I_{Nw},\ (0.2 \leq U_{Tw} \leq 0.9) \quad (2)$$

where: U_{Tw} ---terminal voltage of wind turbine; I_{Nw} ---Rated current of wind turbine.

It needs to be explained, the result is obtained based on the simulation model. The result of other wind farm maybe different with this paper. Specific wind farm should be analyzed like above based on actual data.

Summary

Dynamic reactive power support capability of wind farm is mainly affected by operation situation of wind turbine. If wind turbine can output reactive current, dynamic reactive power support capability of wind farm will be improved greatly, that will help voltage recovery of power system and wind farm. Therefore, reactive power adjustment capability of wind turbine should be made full use of, wind turbine should output reactive current in process of LVRT.

Dynamic reactive power support capability of wind farm is also affected by type of reactive power compensation device and tap position of transformer. Current source type of reactive power compensation device is more advantageous for dynamic reactive power support capability of wind farm. Tap position can be set reasonably to improve dynamic reactive power support capability of wind farm, and reduce cost of reactive power compensation device.

When there is no reactive power compensation device in wind farm, and tap positions of transformers are set as main transformer 0, box transformer 0. In order to meet requirement of reactive current of national standard, reactive current that wind turbine need output is at least same as Eq. 2. It needs to be explained, the result is obtained based on the simulation model. Specific wind farm should be analyzed like this paper based on actual data.

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