Analysis of the influence of different control modes on the transient power characteristics of DFIG

Zhiping Li* and Na Cao
College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao, Shandong, 266590, China
*Corresponding author’s e-mail: caona@sdust.edu.cn

Abstract. In the event of failure, the doubly-fed Induction Generator (DFIG) with low voltage ride through (LVRT) ability will have different effects on the parallel network characteristics due to the different control mode. In order to analyze the influence of different control modes on the transient power characteristics of DFIG, three kinds of transient response states of wind power system under grid fault are modeled by using power superposition principle based on RSC / GSC controller sampling link and PWM small inertia link, and the accurate transient power response models of different control modes are obtained. The accuracy of the model is verified by simulation with PSCAD/EMTDC, and the influence of control mode on system frequency stability is analyzed.

1. Introduction
With the large-scale development and utilization of clean and renewable energy, the installed capacity of wind power and photovoltaic system is increasing. As the main type of DFIG, its proportion in the power generation structure is rising rapidly [1]. The control modes of DFIG are constant power factor control and constant voltage control, among which constant power factor control is the most widely used. The transient short-circuit current of DFIG is affected by the control of motor and converter, so it is difficult to calculate the system current and reactive power characteristic of the generator. Reference [2-3] deduces the rotor current of wind turbine after fault by analytical method; Reference [4] based on the superposition theorem of power supply, the transient response of the wind power system under the commutation failure fault is established. Reference [5] the impacts of output power variation of DFIGs on voltage stability of power grid under different grid-connection modes are researched by and time-domain simulation. And Simulation results show that constant voltage control mode possesses superiority than constant power factor operation control mode in the improvement of power grid voltage stability. Reference [6] simulates and analyzes the transient stability of the grid-connected system of wind turbines in different working modes under fault conditions. The research of different control methods is based on simulation analysis, and however there is no theoretical explanation. Therefore, this paper will theoretically analyze the grid-connected characteristics of doubly-fed wind turbines with low voltage ride-through capability due to different control modes when they are connected to the grid.

In view of the above, this paper will take into account sampling link and PWM small inertia link of the RSC/GSC controller, using the power superposition principle, the wind power system transient response of the three states is modeled respectively, and the accurate transient power response model of DFIG with LVRT capability under different control modes is obtained. The PSCAD/EMTDC simulation platform is used to verify the correctness of the model, and then the effect of DFIG control...
In steady state, the motor speed of DFIG is constant, the grid frequency is stable, and the flux linkage modes on the system frequency stability is analyzed after the simulation analysis.

2. Transient response of DFIG under constant voltage control
According to the DFIG model, it is assumed that DFIG uses grid voltage vector control: the stator voltage d-axis is oriented to the grid voltage get DFIG output to the grid active and reactive power as:

\[
\begin{align*}
P(t) &= P_s(t) + P_q(t) = \frac{3}{2} \omega_s \psi_r \psi_m + \frac{3}{2} \alpha_m \psi_r i_r \\
Q(t) &= Q_s(t) + Q_q(t) = \left( \frac{3}{2} \alpha_m \psi_r i_r \right) + \frac{3}{2} \psi_r i_r
\end{align*}
\]

(1)

2.1.1. Mathematical modeling in steady state (state 0)
In order to reduce the risk of serious voltage drop due to faults, LVRT control is set up by DFIG. Therefore, the basic structure of rotor side converter of DFIG under constant voltage control considering LVRT control is obtained as shown in Figure 1,and the control target is the grid-connected point voltage \( U \).

![Figure 1. Rotor side converter control model of DFIG with constant voltage control](image)

2.1.2. Transient response characteristics of rotor-side converter
In order to reduce the risk of serious voltage drop due to faults, LVRT control is set up by DFIG. Therefore, the basic structure of rotor side converter of DFIG under constant voltage control considering LVRT control is obtained as shown in Figure 1, and the control target is the grid-connected point voltage \( U \).

![Figure 2. T-type equivalent circuit diagram of rotor side converter of DFIG](image)

2.1.1. Mathematical modeling in steady state (state 0)
In steady state, the motor speed of DFIG is constant, the grid frequency is stable, and the flux linkage...
of stator and rotor is linear with the current of stator and rotor. Therefore, the T-type equivalent circuit diagram of DFIG in dq coordinate system of two-phase synchronous rotation shown in Fig. 2 (a) is established. From Fig. 1 and Fig. 2 (a), the expressions of stator and rotor voltage of DFIG in steady state are as follows:

\[
\begin{align*}
U_{d0} &= -\alpha_0 L_{d} \frac{dL_{d0}}{dt} + \alpha_0 L_{s} \frac{dL_{s0}}{dt} + \alpha_0 L_{m} \frac{dL_{m0}}{dt} - a_0 L_{d} I_{d0} + L_{s} I_{d0} + L_{m} I_{m0} + (\Delta u_d) \\
U_{q0} &= -\alpha_0 L_{d} \frac{dL_{d0}}{dt} + \alpha_0 L_{s} \frac{dL_{s0}}{dt} + \alpha_0 L_{m} \frac{dL_{m0}}{dt} - a_0 L_{q} I_{q0} + L_{s} I_{q0} + L_{m} I_{m0} + (\Delta u_q)
\end{align*}
\]

(3)

Among them: \( \Delta u_d = -\omega_0 \sigma L_{d} I_{d0} + \frac{\alpha_0 L_{d} U_{d0}}{\alpha_0 L_{s}} \) and \( \Delta u_q = \omega_0 \sigma L_{q} I_{q0} \).

By solving formula (3), the expressions of stator and rotor voltage in steady state are obtained:

\[
\begin{align*}
U_{d0} &= -\alpha_0 L_{d} \frac{dL_{d0}}{dt} + \alpha_0 L_{s} \frac{dL_{s0}}{dt} + \alpha_0 L_{m} \frac{dL_{m0}}{dt} - a_0 L_{d} I_{d0} + L_{s} I_{d0} + L_{m} I_{m0} + (\Delta u_d) \\
U_{q0} &= -\alpha_0 L_{d} \frac{dL_{d0}}{dt} + \alpha_0 L_{s} \frac{dL_{s0}}{dt} + \alpha_0 L_{m} \frac{dL_{m0}}{dt} - a_0 L_{q} I_{q0} + L_{s} I_{q0} + L_{m} I_{m0} + (\Delta u_q)
\end{align*}
\]

(4)

2.1.2. Mathematical modeling of stator voltage change after fault (state 1)

The value of \( U_{s1} \) is dropped due to the voltage drop of DFIG due to fault, the stator transient voltage of DFIG after three-phase short circuit fault is \( U_s = U_{s0} + U_{s1} \). According to Figure 2(b), the stator and rotor voltage expressions of stator voltage drop are obtained:

\[
\begin{align*}
U_{d1} &= R_{d} L_{d} \frac{dL_{d1}}{dt} + \frac{3}{2} U_{s0} G_{d0} G_{s0} - a_0 L_{d} I_{d1} + L_{s} I_{d1} + L_{m} I_{m1} + (\Delta u_d) \\
U_{q1} &= R_{q} L_{q} \frac{dL_{q1}}{dt} + \frac{3}{2} U_{s0} G_{d0} G_{s0} - a_0 L_{q} I_{q1} + L_{s} I_{q1} + L_{m} I_{m1} + (\Delta u_q)
\end{align*}
\]

(5)

Based on Laplace variation, the expressions of stator and rotor current components caused by stator voltage change are obtained:

\[
\begin{align*}
&\begin{pmatrix}
0 & -a_0 L_{d} & R_{d} & -a_0 L_{d} \\
0 & a_0 L_{q} & R_{q} & -a_0 L_{q} \\
-R_{d} & + G_{d0} & \frac{3}{2} U_{s0} G_{s0} G_{d0} & a_0 L_{d} \\
-R_{q} & + G_{s0} & \frac{3}{2} U_{s0} G_{d0} G_{s0} & a_0 L_{q}
\end{pmatrix} & \frac{d}{dt} \begin{pmatrix}
\frac{dL_{d1}}{dt} \\
\frac{dL_{q1}}{dt} \\
\frac{dL_{d1}}{dt} \\
\frac{dL_{q1}}{dt}
\end{pmatrix} = \begin{pmatrix}
U_{d1} \\
0 \\
0 \\
0
\end{pmatrix}
\end{align*}
\]

(6)

2.1.3. Mathematical modeling of rotor voltage change after fault (state 2)

When the fault occurs, the sudden change of the reference value of rotor current will cause the change of excitation voltage on the rotor side of the wind turbine. The initial value \( U_{ro} \) is dropped due to the voltage drop of DFIG due to fault, the stator transient voltage of DFIG after three-phase short circuit fault is \( U_{ro} = U_{ro0} + U_{ro1} \). According to Figure 2(c), the expression of rotor voltage change caused by sudden rotor voltage reference change is as follows:

\[
\begin{align*}
U_{d2} &= -\alpha_0 L_{d} \frac{dL_{d2}}{dt} + \alpha_0 L_{s} \frac{dL_{s2}}{dt} + \alpha_0 L_{m} \frac{dL_{m2}}{dt} - a_0 L_{d} I_{d2} + L_{s} I_{d2} + L_{m} I_{m2} + (\Delta u_d) \\
U_{q2} &= -\alpha_0 L_{d} \frac{dL_{d2}}{dt} + \alpha_0 L_{s} \frac{dL_{s2}}{dt} + \alpha_0 L_{m} \frac{dL_{m2}}{dt} - a_0 L_{q} I_{q2} + L_{s} I_{q2} + L_{m} I_{m2} + (\Delta u_q)
\end{align*}
\]

(7)

Therefore, the expressions of stator and rotor current:
Based on the principle of power supply superposition, the time domain model of stator side voltage and current of DFIG after fault can be obtained by Laplace Inverse Transformation of formula (4), (6) and (8): isd (t)、isq (t)、ird (t)、irq (t)、Usd (t)、Usq (t).

\[
\begin{align*}
\begin{bmatrix}
    i_{sd} \\
i_{sq} \\
i_{rd} \\
i_{rq}
\end{bmatrix} =
\begin{bmatrix}
    sL_m & -\alpha_1L_m & R_s + sL_m & -\alpha_2L_m \\
    \alpha_1L_m & sL_m & \alpha_1L_m & R_s + sL_m \\
    R_s + sL_s + G_{pf} & -\frac{\alpha_1L_s}{L_s} & L_s & -\alpha_2L_s \\
    \frac{\alpha_1L_s}{L_s} & R_s + G_{pf} + sL_s & \alpha_1L_s & sL_s
\end{bmatrix} \begin{bmatrix}
    i_{sd} \\
i_{sq} \\
i_{rd} \\
i_{rq}
\end{bmatrix}
\end{align*}
\]

Equation (8)

2.2. Transient response characteristics of grid side converter

The model of grid side converter of DFIG under constant voltage control mode is shown in Figure 3. The grid side converter adopts a double closed-loop cascade structure controller with DC side voltage outer loop control and AC side current inner loop control. In this way, the voltage outer loop controls the output of DC voltage, the output of voltage controller is used as the setting of current inner loop, and the current controller controls the AC side current, which could track the current command quickly.

![Grid side converter control model](image)

(a) Grid side converter control model d axis  (b) Grid side converter control model q axis

In order to get accurate calculation results, based on the sampling link of GSC controller and the small inertia part of PWM, according to the voltage closed-loop transfer function shown in Figure 3, the expression of DC voltage Udc of DFIG can be obtained as follows:

\[
U_{dc} = \frac{1}{c} \left( s + \frac{1 + \alpha_{dc}}{2s \tau_{dc} + 1 + \alpha_{dc}} \right) [0.75m(i_{sd} \cos \delta_s - i_{sq} \sin \delta_s)] + \frac{s}{s + \frac{1 + \alpha_{dc}}{2s \tau_{dc} + 1 + \alpha_{dc}}} \left( \frac{U_s}{2} - \frac{U_{ref}}{2} \right)
\]

Equation (10)

When a three-phase short-circuit fault occurs in DFIG, according to the principle of power superposition, the transient response (voltage or current) of any branch of a linear circuit with multiple independent sources can be regarded as the algebraic sum of the responses when each independent source acts independently. Therefore, the transient response of grid side converter of DFIG is divided into three state components: steady state before failure(state 0), considering the state of grid voltage change(state 1) and state of output voltage change of GSC converter(state 2), whose equivalent circuit diagram is shown in Figure 4. The transient response of grid side converter of wind turbine under different states will be derived as follows.

![Equivalent circuit diagram of grid-side converter](image)

(a) state 0  (b) state 1  (c) state 2

2.2.1. Mathematical modeling in steady state (state 0)

Since the grid side converter of DFIG is directly connected to the grid, when the grid voltage oriented
vector control is adopted, \( u_{gd0} = u_g \) is obtained. According to Figure 4(a) and Figure 3, through the voltage and current on the filter inductance \( L_f \), it is concluded that:

\[
\begin{align*}
\Delta u_{gd} &= (U_{dref} - U_d)G_{grd} - i_{gref} + i_{gd} + \Delta u_{gd} = (U_{dref} - U_d)G_{grd} + \Delta u_{gd} \\
\Delta u_{gq} &= (U_{qref} - U_q)G_{gq} + \Delta u_{gq} = (U_{qref} - U_q)G_{gq} + \Delta u_{gq}
\end{align*}
\]

Among them, the fed-forward voltage compensation of DFIG:

\[
\begin{align*}
\Delta u_{gd} &= \alpha_0 L_1 i_{gref} \\
\Delta u_{gq} &= \alpha_0 L_1 i_{gref}
\end{align*}
\]

According to formula (11), the GSC current can be obtained by using Laplace variation:

\[
\begin{align*}
\left(i_{gref}\right) &= \left(sL_f + G_{gq} \alpha_0 L_1 \alpha_0 L_1 \right)^{-1} \left((U_{dref} - U_d)G_{grd}G_{qref} + \Delta u_{gd}\right) \\
&= \left(sL_f + G_{gq} \alpha_0 L_1 \alpha_0 L_1 \right)^{-1} \left((U_{qref} - U_q)G_{gq}G_{qref} + \Delta u_{gq}\right)
\end{align*}
\]

(12)

2.2.2. Mathematical modeling of grid voltage change (state 1)
The grid connected voltage of DFIG will drop in case of fault, and the voltage sag amplitude is \( U_g1 \). According to the equivalent circuit diagram shown in Figure 4(b), the output current of GSC controller can be obtained:

\[
\begin{align*}
-u_{gref} &= L_1 \frac{di_{gref}}{dt} - \alpha_0 L_1 i_{gref} \\
u_{gref} &= L_1 \frac{di_{gref}}{dt} + \alpha_0 L_1 i_{gref}
\end{align*}
\]

(13)

Where \( \omega_{g} \) is the rotational angular velocity corresponding to the grid voltage frequency.

2.2.3. Mathematical modeling of GSC converter with variable output voltage (state 2)

After the fault occurs, the output voltage of the grid side converter will change with the amplitude of the voltage drop. Through Figure 4(c) and Figure 3, the output voltage of GSC can be obtained:

\[
\begin{align*}
u_{gd2} &= (U_{dref} - U_d)G_{grd} - (i_{gref} + i_{gd2})G_{gq} + \Delta u_{gd2} = L_1 \frac{di_{gd2}}{dt} - \alpha_0 L_1 i_{gd2} \\
u_{gq2} &= (U_{qref} - U_q)G_{gq}G_{qref} + \Delta u_{gq2} = L_1 \frac{di_{gq2}}{dt} + \alpha_0 L_1 i_{gq2}
\end{align*}
\]

(14)

The output voltage of the GSC converter can be obtained by using the Laplace change:

\[
\begin{align*}
\left(i_{gref}\right) &= \left(sL_f + G_{gq} \alpha_0 L_1 \alpha_0 L_1 \right)^{-1} \left((U_{dref} - U_d)G_{grd}G_{qref} - (i_{gref} + i_{gd2})G_{gq} + \alpha_0 L_1 i_{gd2}\right) \\
&= \left(sL_f + G_{gq} \alpha_0 L_1 \alpha_0 L_1 \right)^{-1} \left((U_{qref} - U_q)G_{gq}G_{qref} + \alpha_0 L_1 i_{gq2}\right)
\end{align*}
\]

(15)

According to the principle of power superposition, the time domain model of grid side converter voltage and current of DFIG under constant voltage control is obtained by inverse Laplace transform of formula (13), (14) and (16): \( i_{gd2}(t) \), \( i_{gq2}(t) \), \( U_{gd2}(t) \), \( U_{gq2}(t) \).

\[
\begin{align*}
\left[u_{gd} = \Delta u_{gd} + u_{gd1} \right] \\
\left[i_{gd} = i_{gd1} + i_{gd2} \right] \\
\left[u_{gq} = \Delta u_{gq} \right] \\
\left[i_{gq} = i_{gq1} + i_{gq2} \right]
\end{align*}
\]

(16)

3. Transient response of DFIG under constant power factor control

Constant power operation control is to control the reference value of reactive power \( Q_{sref} = P_{sref} \tan \phi \) as the control objective. Therefore, the basic structure of DFIG under constant power factor control is obtained, as shown in Figure 5.

3.1. Transient response characteristics of rotor-side converter
Because the constant power factor control and constant voltage control mode will adopt LVRT control when the DFIG fails, the derivation process of GSC and RSC is consistent with the constant voltage control mode. Therefore, DFIG under constant power factor control, the expressions of stator and rotor current under steady state, when stator voltage changes and rotor voltage changes are shown in equations (17), (6) and (18):

\[
\begin{align*}
\begin{cases}
(\omega_s) \\
(\omega_l) \\
(\omega_m)
\end{cases}
\begin{bmatrix}
0 & -\alpha L_s & 0 \\
\alpha L_s & R + G_m & -\alpha L_r \\
G_m - \frac{\alpha L_s^2}{L} & -R - G_m & 0
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
&= 
\begin{bmatrix}
0 \\
R + \omega_s G_m & 0 \\
0 & R + \omega_m
\end{bmatrix}
\begin{bmatrix}
U_{is} \\
U_{il} \\
U_{im}
\end{bmatrix}
\end{align*}
\]  

(17)

\[
\begin{align*}
\begin{cases}
(\omega_s) \\
(\omega_l) \\
(\omega_m)
\end{cases}
\begin{bmatrix}
\alpha L_s & -\alpha L_s & 0 \\
\alpha L_s & R + \alpha L_s & -\alpha L_r \\
\alpha L_r & R + \alpha L_s & 0
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
&= 
\begin{bmatrix}
0 \\
R + \omega_s G_m & 0 \\
0 & R + \omega_m
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
\end{align*}
\]  

(18)

3.2. Transient response characteristics of grid side converter

According to the derivation process of DFIG under constant voltage control, combined with the expression of reactive power reference value, the grid side current expression under constant power factor control, grid voltage change and GSC converter output voltage change can be obtained, as shown in formula (19), formula (13) and equation (20):

\[
\begin{align*}
\begin{cases}
(\omega_s) \\
(\omega_l) \\
(\omega_m)
\end{cases}
\begin{bmatrix}
\alpha L_s & -\alpha L_s & 0 \\
\alpha L_s & R + \alpha L_s & -\alpha L_r \\
\alpha L_r & R + \alpha L_s & 0
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
&= 
\begin{bmatrix}
0 \\
R + \omega_s G_m & 0 \\
0 & R + \omega_m
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
\end{align*}
\]  

(19)

\[
\begin{align*}
\begin{cases}
(\omega_s) \\
(\omega_l) \\
(\omega_m)
\end{cases}
\begin{bmatrix}
\alpha L_s & -\alpha L_s & 0 \\
\alpha L_s & R + \alpha L_s & -\alpha L_r \\
\alpha L_r & R + \alpha L_s & 0
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
&= 
\begin{bmatrix}
0 \\
R + \omega_s G_m & 0 \\
0 & R + \omega_m
\end{bmatrix}
\begin{bmatrix}
\omega_s \\
\omega_l \\
\omega_m
\end{bmatrix}
\end{align*}
\]  

(20)

Then, using the superposition principle of power supply and inverse Laplace transform get the time-domain model of voltage and current at the grid side under constant voltage control igd (t)、igq (t)。Ugd (t)、Ugq (t) is obtained by :

\[
\begin{align*}
\begin{cases}
\omega_s = U_{is} + U_{igd} \\
\omega_m = 0 \\
\omega_m = I_{igq} + I_{igd}
\end{cases}
\end{align*}
\]  

(21)

4. Simulation Verification

In order to verify the correctness of the transient power model of doubly fed wind turbine, a 1.5MW doubly fed wind power system simulation model is established, and the specific parameters are shown in the literature [8]. In order to reduce the system active power loss, the doubly fed wind farm is usually operated at unity power factor based on power factor of 1. At the same time, Usref=0 of constant voltage control is set, so under the condition of the same voltage sag amplitude, the mathematical model of active and reactive power output by DFIG under constant power factor control mode and constant voltage control mode is compared with the simulation results according to the results, as shown in Figure 6. As the output power of the fan is different under different control modes, the frequency stability of the system in the fault stage is affected indirectly. The system frequency response curves under different control modes are obtained, as shown in Figure 7.
According to the system output response curve in Figure 6, the power response curve of the system obtained by the mathematical model and the simulation model is basically the same. The errors of active power and reactive power are both on the order of 10^{-2}Hz, which is not much different. In other words, the mathematical model can reproduce the simulation experiment results well. And when the DFIG adopts constant voltage control mode after the fault occurs, it can provide continuous reactive power support more quickly to give full play to the reactive power regulation ability of DFIG. In the fault stage, the output reactive power under constant voltage control mode is lower than that under constant power factor control mode, and the output active power under constant power factor control is slightly lower than that under constant voltage control, that is to say, adopting constant voltage control mode is beneficial to improve the voltage stability of the system, but under this control mode, the improvement of power factor is not fully considered. However, with constant power factor control, the power factor will not change with the change of wind farm output. When DFIG is connected to the grid, without considering the impact of wind turbine output power fluctuation on the grid and assuming that there is no reactive power exchange between the whole wind farm and the power network, the default active power output is the rated value, and the reactive power output is close to 0. Therefore, when DFIG is connected to the single machine infinite bus system, the system frequency deviation is obviously less than that under the constant voltage control under different control modes, which is conducive to the frequency stability of the system.

5. Conclusion
In this paper, the accurate transient active and reactive power mathematical models of DFIG under constant power control mode and constant voltage control mode are established by using the principle of power superposition. The model takes into account the influence of RSC/GSC controller sampling link and PWM small inertia link, and the accuracy of the mathematical model is verified by the simulation results of three-phase short circuit fault in power grid. The results show that the constant power factor control mode is more conducive to the stability of the system.

References
[1] Qiangnian L, Qiaoni Z, Yan N, et al. (2019) Research on the Factors Affecting the Development of Wind Power Industry Based on Analytic Hierarchy Process (AHP)——Taking Jiuquan Wind Power Generation Base in Gansu Province as an Example. Power System and Clean Energy, 35, 10: 75-81.
[2] Zengping W, Jing L, Ping Z, et al. (2018) Calculation and Analysis of Transient Short Circuit Current of Doubly-Fed Induction Generator Considering Convertor Current Limitation and GSC Current. TRANSACTIONS OF CHINA ELECTROTECHNICAL SOCIETY, 33,17: 4123-4135.
[3] Shuying Y, Dengyue C, Xing Z, et al. (2013) Study on Electromagnetic Transition of DFIG-based Wind Turbines Under Grid Fault Based on Analytical Method. Proceedings of the CSEE, 33: 13-20.
[4] NIAN H, JIN X, Guanghui L, et al. (2013) Influence of UHV DC Commutation Failure on the Transient Reactive Power Characteristics of Wind Turbines in Sending Terminal Grid. Proceedings of the CSEE, 40, 13: 4111-4121.
[5] Ming D, Binbin L, Pingping H, et al. (2010) Impacts of Operation Modes of Doubly-Fed Wind Turbine Generator on System Voltage. Power System Technology, 34,10: 26-31.
[6] Qiming C, Lu C, Yinman C, et al. (2020) Research on coordinated control method of AC micro-grid based on improved constant voltage control and DC voltage control. ACTA ENERGIAE SOLARIS SINICA, 41,3: 65-73.
[7] Jun A, Shi Z, Gang M, et al. (2017) Study of DFIG wind farm real power dispatching mode influence on transient stability of wind thermal bundled power system. ACTA ENERGIAE SOLARIS SINICA, 38,5: 65-73.
[8] WU Yuzhang. (2017) Transient stability analysis of DFIG system based on transient energy function method [D]. Tianjing: TIANJIN UNIVERSITY,