Active Control Method for Torsional Vibration of DFIG Drive Chain Under Asymmetric Power Grid Fault

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ABSTRACT When the asymmetric fault occurs in power grid, it will cause the oscillation of the electromagnetic torque of the doubly-fed induction generator(DFIG). The oscillation of the electromagnetic torque will cause the torsional vibration of the drive chain, and the long-term torsional vibration will shorten the service life of DFIG. The analysis shows that the positive and negative sequence current components generated by DFIG terminals are the main factors that cause electromagnetic torque oscillation when the asymmetric faults occur. Therefore, the suppression of positive and negative sequence current components is the key to achieve active control of torsional vibration of drive chain, the traditional PID control can only adjust the direct-current(DC) component without static error, and cannot suppress the negative sequence alternating-current(AC) component. In this paper, based on the traditional PID regulator, the resonance(R) current regulator with the specific frequency is incorporated into the grid-side converter(GSC) to form the PID-R current controller. The PID-R current controller can realize accurate and effective control of the positive and negative sequence components in the forward rotation synchronous speed rotating coordinate system without decomposing the positive and negative sequence components, and can actively suppress the electromagnetic torque oscillation, thereby realize the active control of the drive chain torsional vibration. MATLAB/Simulink verifies the effectiveness of PID-R current controller.

INDEX TERMS Asymmetrical power grid fault, drive chain torsional vibration, DFIG, electromagnetic torque, negative sequence current.

I. INTRODUCTION

Doubly-fed induction generator (DFIG) has become the mainstream of wind power generation. Due to the stator of the DFIG is directly connected to the grid, the grid-side converter(GSC) is more vulnerable to the influence of grid asymmetric fault [1]. When the power grid has asymmetric fault, it is easy to cause direct-current(DC) bus voltage oscillation, current harmonic, electromagnetic torque continuous oscillation and other effects, which seriously affect the operation safety and output power quality of generating unit [2]. The severe oscillation of the electromagnetic torque will cause great harm to the drive chain shaft system, which is the main electrical factor that causes the torsional vibration

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of DFIG [3]. Therefore, when the asymmetric fault occurs in the power grid, effective active control must be given in the operation control.

There are extensive researches on the control of DFIG in under normal and abnormal conditions of the power grid [4]. The direct power control method can reduce the current unbalance and torque ripple of stator and rotor [5], [6]; The accurate control of the positive and negative sequence current of the rotor can be realized by the current predictive controller[7]; Proposes the control strategy based on reference current generator, which is used to control three-phase inverters under balanced and unbalanced grid conditions, and the oscillation of reactive power has a good suppression effect [8]; A two-channel active damping control method is proposed to improve the electromagnetic torque of the drive chain and suppress the torsional vibration of the drive

chain [9]; It will cause serious torque ripple that under the interaction of positive sequence, negative sequence and harmonic voltage and current [10], [11]; The GSC can not only realize the voltage stability at the DC side, but also provide reactive power compensation and suppress harmonics to the grid [12]; The Chopper device is used to limit the overvoltage on the DC side, at the instant of the fault, the generator side converter blocks the pulse signal, and the rotor overcurrent charges the DC bus capacitor through the antiparallel diode of the machine side converter [13], [14]; The control effect of the control strategy based on active demagnetization is limited by the capacity of the doubly-fed converter [15]–[20]; Introduce the rotor current transient feed forward term to minimize rotor transient current[21]; Control method of drive chain torsional vibration under power grid fault [22]–[26]; Control the mechanical torque to restrain the torsional vibration of drive chain [27], [28]. Although the existing control methods have certain control effect on the unbalance of stator and rotor current in the power grid fault state, they rarely involve the active control of DFIG drive chain torsional vibration in the case of power grid asymmetric fault.

The DC bus voltage of DFIG can decouple the two converters, which makes it possible to control the two converters independently without mutual interference. When the asymmetric fault occurs in the power grid, the GSC can be independently controlled. This paper starts with the control of the GSC of the DFIG when the power grid has asymmetric fault, and comprehensively evaluates the harm of electromagnetic torque oscillation caused by the positive and negative sequence current components on the operation safety of the drive chain shafting in case of power grid asymmetry fault, and then the active control strategy of electromagnetic torque oscillation is proposed. Because the GSC is directly connected to the power grid, the advantage of using the PID-R current controller for the GSC is that can be directly controlled from the source to prevent the DFIG from being affected by the asymmetric fault of the grid. The PID-R current controller can realize the precise control of the positive and negative sequence components in the GSC without decomposing the positive and negative sequence components. The simulation results verify the effectiveness of the control scheme.

II. MODELING OF DFIG
The basic structure diagram of the DFIG wind turbine system is shown in Figure 1. The stator of the DFIG is directly connected to the power grid, when the asymmetric fault occurs in the power grid, the GSC will be impacted by the asymmetric voltage.

A. MODEL OF DFIG UNDER ASYMMETRICAL FAULT OF POWER GRIDF
For the asymmetrical three-phase electromagnetic quantities F_a, F_b, and F_c according to the principle of asymmetric component, they can be decomposed into the sum of three-phase symmetrical positive sequence components F_{a+}, F_{b+},
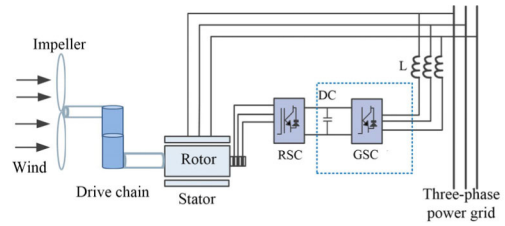

FIGURE 1. The basic structure diagram of DFIG wind turbine system.

and F_{c+} and negative sequence components F_{a-}, F_{b-}, and F_{c-} which is:

$$\begin{cases} F_a = F_{a+} + F_{a-} \\ F_b = F_{b+} + F_{b-} \\ F_c = F_{c+} + F_{c-} \end{cases} \qquad (1)$$

where, F broadly represents voltage, current and flux, and the subscripts +, - represent positive and negative sequence components respectively.

The vector diagram of the forward and reverse synchronous speed ω_s rotation dq^+, dq^- coordinate system and the static coordinate system is shown in Figure 2.
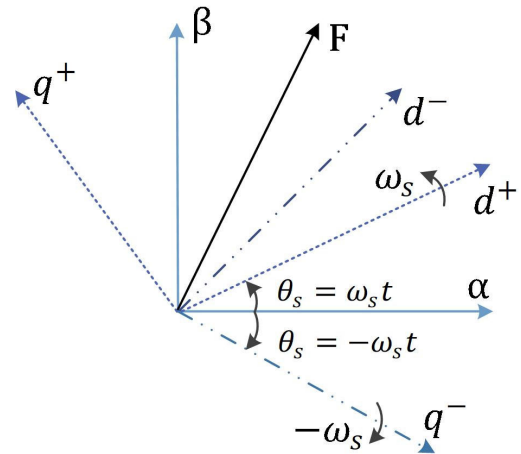

FIGURE 2. Relationships between the $\alpha\beta$, the $dq+$ and dq^- reference frames.

The equivalent model of DFIG in the dq^+ coordinate system of forward rotation synchronous speed rotation in the case of power grid asymmetric fault is shown in Figure 3 [29].

According to Figure 3, the voltage equation and magnetism equation of stator and rotor are as shown follows[30]:

$$\begin{cases} U_{sdq}^+ = R_s I_{sdq}^+ + \dfrac{d\Psi_{sdq}^+}{dt} + j\omega\Psi_{sdq}^+ \\ U_{rdq}^+ = R_r I_{rdq}^+ + \dfrac{d\Psi_{rdq}^+}{dt} + j\omega_{slip}\Psi_{rdq}^+ \end{cases} \qquad (2)$$

$$\begin{cases} \Psi_{sdq}^+ = L_s I_{sdq}^+ + L_m I_{rdq}^+ \\ \Psi_{rdq}^+ = L_m I_{rdq}^+ + L_r I_{rdq}^+ \end{cases} \qquad (3)$$
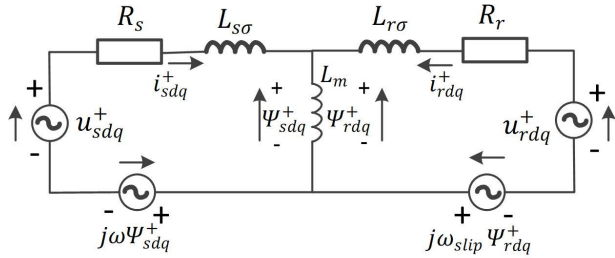
FIGURE 3. DFIG equivalent circuit in *dq+* coordinate system.

where, U_{sdq}^+, U_{rdq}^+ are stator and rotor voltage vectors respectively, I_{sdq}^+, I_{rdq}^+ are stator and rotor current vectors respectively, Ψ_{sdq}^+, Ψ_{rdq}^+ are stator and rotor magnetism respectively chain vector; R_s, R_r are stator and rotor resistance, $L_s = L_m + L_{s\sigma}$ is the total self-inductance of the stator winding, $L_r = L_m + L_{r\sigma}$ is the total self-inductance of the rotor winding, L_m is the mutual inductance between the stator and the rotor, $L_{s\sigma}$ is the stator leakage inductance, $L_{r\sigma}$ is the rotor leakage inductance, ω_{slip} slip angular velocity.

B. MODELING AND ANALYSIS OF THE GSC UNDER ASYMMETRIC FAULT

Starting from the mathematical model of the three-phase static coordinate system of GSC by the coordinate transformation, the mathematical model of the GSC two-phase synchronous rotating coordinate system is established. The topology of the main circuit of the GSC is shown in Figure 4.
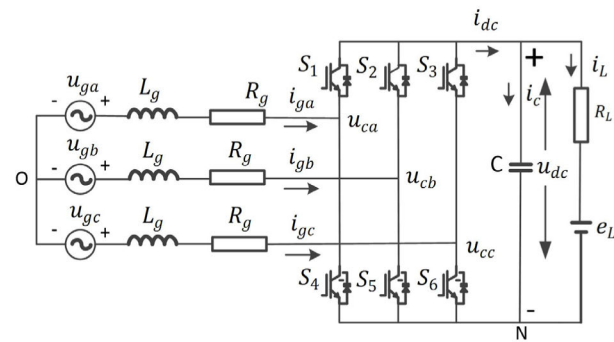

FIGURE 4. The topology of the main circuit of the GSC.

In the figure, u_{ga}, u_{gb}, u_{gc} are the three-phase voltage on the alternating-current(AC) side, i_{ga}, i_{gb}, i_{gc} are the three-phase current on the AC side, u_{ca}, u_{cb}, u_{cc} are the three-phase voltage on the input side of the rectifier bridge, i_{dc} is the DC side voltage, or load current, O is the midpoint of the power grid. L_g, R_g are respectively the line inductance and its equivalent resistance, C is the DC bus capacitance, R_L is the DC side load, and e_L is the DC electromotive force.

The GSC model is converted to the two-phase stationary coordinate system by equal-amplitude Clarke transformation.

The transformation relationship can be expressed as:

$$\begin{bmatrix} x_\alpha \\ x_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (4)$$

After Clarke transformation, the mathematical model of the GSC can be expressed as:

$$\begin{bmatrix} u_{g\alpha} \\ u_{g\beta} \end{bmatrix} = L_g \begin{bmatrix} \frac{di_{g\alpha}}{dt} \\ \frac{di_{g\beta}}{dt} \end{bmatrix} + \begin{bmatrix} R_g & 0 \\ 0 & R_g \end{bmatrix} \begin{bmatrix} i_{g\alpha} \\ i_{g\beta} \end{bmatrix} + \begin{bmatrix} u_{c\alpha} \\ u_{c\beta} \end{bmatrix} \quad (5)$$

$$C\frac{du_{dc}}{dt} = \frac{3}{2}\left(i_{g\alpha}S_\alpha + i_{g\beta}S_\beta\right) - i_L \quad (6)$$

The conversion relationship between the two-phase stationary coordinate system and the two-phase synchronous rotating coordinate system is:

$$\begin{bmatrix} x_d \\ x_q \end{bmatrix} = \begin{bmatrix} cos\omega_g t & sin\omega_g t \\ -sin\omega_g t & cos\omega_g t \end{bmatrix} \begin{bmatrix} x_\alpha \\ x_\beta \end{bmatrix} \quad (7)$$

For Equation(5), the synchronous rotating coordinate transformation(7) can be used to obtain the mathematical model of the GSC in the synchronous rotating coordinate system, which is:

$$\begin{bmatrix} u_{gd} \\ u_{gq} \end{bmatrix} = L_g \begin{bmatrix} \frac{di_{gd}}{dt} \\ \frac{di_{gq}}{dt} \end{bmatrix} + \begin{bmatrix} R_g & -\omega_g L_g \\ \omega_g L_g & R_g \end{bmatrix} \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + \begin{bmatrix} u_{cd} \\ u_{cq} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} u_{cd} \\ u_{cq} \end{bmatrix} = u_{dc} \begin{bmatrix} S_d \\ S_q \end{bmatrix} \quad (9)$$

$$C\frac{du_{dc}}{dt} = \frac{3}{2}\left(i_{gd}S_d + i_{gq}S_q\right) - i_L \quad (10)$$

$$\begin{cases} P_g = \frac{3}{2}u_{dq}^T i_{dq} = \frac{3}{2}\left(u_{gd}i_{gd} + u_{gq}i_{gq}\right) \\ Q_g = \frac{3}{2}u_{dq}^T \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} i_{dq} = \frac{3}{2}\left(u_{gd}i_{gd} + u_{gq}i_{gq}\right) \end{cases} \quad (11)$$

where, u_{cd}, u_{cq}, i_{gd}, i_{gq} are the GSC voltage and current d, q-axis components; u_{gd}, u_{gq} are grid voltage d, q-axis components; ω_g is grid voltage angular velocity.

C. DRIVE CHAIN MODEL UNDER ASYMMETRIC POWER GRID FAULT

In this paper, the two-mass models are used as the research object, because it can better reflect the torsional vibration of the drive chain and the accuracy can achieve the requirements. The model structure is shown in Figure 5 [31].

In the Figure, T_t, H_t, and ω_t are aerodynamic torque, inertia time constant and speed of wind turbine, respectively; T_e, g, and ω_g are electromagnetic torque, inertia time constant and speed of the DFIG, respectively; φ, ε, and T_s are respectively the torsional angle, torsional angular speed and torque of the drive shaft; b, k is the damping coefficient and stiffness coefficient of the drive shaft, D_t and D_g are the self-damping of the wind wheel and the generator.
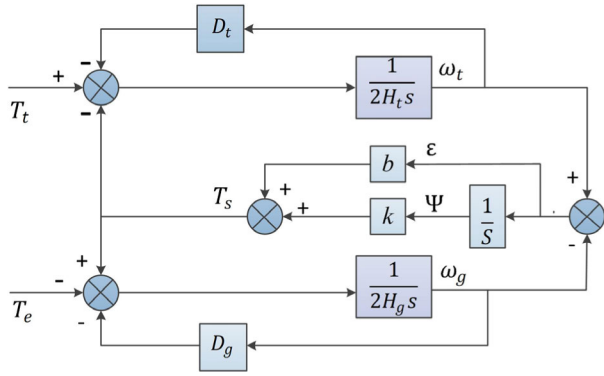
FIGURE 5. Two-mass models of drive chain.

III. DESIGN OF ACTIVE CONTROL METHOD

A. ANALYSIS OF TORSIONAL VIBRATION CHARACTERISTICS OF DFIG DRIVE CHAIN WHEN POWER GRID IS ASYMMETRIC

The equation of state of the drive chain shaft system is as follows [32]:

$$
\begin{cases}
2H_t\Psi_t'' = T_t - T_s - D_t\Psi_t' \\
2H_g\Psi_g'' = T_s - T_e - D_g\Psi_g' \\
T_s = k\Psi + b\Psi'
\end{cases}
\tag{12}
$$

where, $\Psi = \Psi_t - \Psi_g$ is the torsional angle, and Ψ_t, Ψ_g are the angular displacement of wind turbine and the DFIG, respectively.

In general, D_t and D_g are very small, and the influence of D_t and D_g can usually be ignored. Therefore, the Euler equation of the drive chain shaft system under natural oscillation can be obtained from Equation(12):

$$
(\Psi_t'' - \Psi_g'') + b\left(\frac{1}{2H_t} + \frac{1}{2H_g}\right)\Psi'
$$
$$
+k\left(\frac{1}{2H_t} + \frac{1}{2H_g}\right)\Psi = 0
\tag{13}
$$

The Euler equation is a second order linear homogeneous differential equation with constant coefficients, the natural oscillation frequency of the shaft system is:

$$
\omega_n = \sqrt{k\left(\frac{1}{2H_t} + \frac{1}{2H_g}\right)}
\tag{14}
$$

The damping loss factor of the shafting is:

$$
\gamma_0 = b\left(\frac{1}{2H_t} + \frac{1}{2H_g}\right)/2
\tag{15}
$$

The damping ratio of the shafting is:

$$
\gamma_0 = \frac{\gamma_0}{\omega_n}
\tag{16}
$$

The torsional vibration is accompanied by the dynamic change of the energy stored on the shaft. Therefore, the characteristic quantity that can reflect the torsional vibration of the shaft system is the torsional angular speed, which is defined as the rotational speed difference of the mass blocks connected at both ends of the flexible shaft, the transfer function from the torsional angular speed to electromagnetic torque can be written:

$$
\frac{\varepsilon(s)}{T_e(s)} = \frac{s}{2H_gs^2 + \frac{H_t+H_g}{H_t}bs + \frac{H_t+H_g}{H_t}k}
\tag{17}
$$

The drive chain parameters are shown in Table 1. According to Equation(16), the damping ratio can be determined to be far less than 1, so the system is a typical underdamped system, and shaft vibration is easily excited. According to the model of the drive chain, the aerodynamic torque and electromagnetic torque are the main factors affecting the torque angle.

TABLE 1. The drive chain parameters.

H_t	H_g	b	k	ω_n	γ_0
2.5	0.5	0.1	157.07	13.7	0.06

In this paper, the torsional vibration of drive chain is studied when the asymmetric fault occurs in power grid. Because the duration of asymmetric fault is usually short and the inertia time constant of wind turbine is large, it can be considered that the speed and aerodynamic torque of wind turbine are basically unchanged. It can be seen from Equation(17) that the main factor that causes the torsional vibration of the drive chain under the asymmetric fault of the power grid is the electromagnetic torque of the DFIG.

B. ACTIVE CONTROL DESIGN OF TORSIONAL VIBRATION OF DRIVE CHAIN WHEN POWER GRID IS ASYMMETRICAL

When the asymmetric fault occurs in the power grid, the GSC will contain the positive-sequence DC component and the AC component that doubles the grid frequency. The traditional PID current controller can only adjust the DC component without static error, and cannot provide enough amplitude and phase gain for doubles the grid frequency. In this paper, the R regulator with doubles grid frequency is added to the traditional PID current controller to form PID-R current controller. When the asymmetrical fault occurs in the power grid, the PID-R current controller can provide effective amplitude and phase gain for the control of the AC quantity at doubles the frequency of the power grid, effective control of the positive and negative sequence currents in the GSC is realized in the synchronous rotating coordinate system.

The voltage equation of vector converter with positive and negative sequence components in the rotating coordinate system:

$$
U_{gdq}^+ = R_gI_{gdq}^+ + j\omega L_gI_{gdq}^+ + V_{gdq}^+ + L_g\frac{dI_{gdq}^+}{dt}
\tag{18}
$$

where

$$
U_{gdq}^+ = U_{gdq+}^+ U_{gdq-}^- e^{-j2\omega t}
$$

$$V_{gdq}^{+} = V_{gdq+}^{+} + V_{gdq-}^{-} e^{-j2\omega t}$$
$$I_{gdq}^{+} = I_{gdq+}^{+} + I_{gdq+}^{-} e^{-j2\omega t}$$

According to Equation(12), the differential form current expression of the GSC including positive and negative sequence components in the forward rotation synchronous speed rotating coordinate system when the power grid is asymmetrical fault is:

$$\frac{dI_{gdq}^{+}}{dt} = \frac{1}{L_g}\left[U_{gdq}^{+} - (R_g + j\omega L_g) I_{gdq}^{+} - V_{gdq}^{+*} \right] \quad (19)$$

where, V_{gdq}^{+*} is the control reference voltage output by the PID-R current controller on the grid side in the forward rotation synchronous speed rotating coordinate system.

Without the introduction of positive and negative sequence current decomposition V_{gdq}^{+*} can be designed by PID-R controller:

$$V_{gdq}^{+*} = -L_g V_{gdq}^{+\prime} - (R_g + j\omega L_g) I_{gdq}^{+} + U_{gdq}^{+} \quad (20)$$

where

$$V_{gdq}^{+\prime} = \left[k_{igp} + \frac{k_{igi}}{s} + N\frac{k_{igd}}{s+N} \right.$$
$$\left. + \frac{\omega_{igc}k_{igr}s}{s^2 + 2\omega_{igc}s + 4\omega^2} \right](I_{gdq}^{+*} - I_{gdq}^{+}) \quad (21)$$

where, k_{igp}, k_{igi}, k_{igd}, and k_{igr} are the proportional, integral, differential and resonance coefficients of the GSC PID-R current controller, respectively, ω_{igc} represents the attenuation coefficient of the GSC R current regulator, N is the time constant.

When the asymmetric fault occurs in the power grid, the voltage frequency will fluctuate. In order to reduce the sensitivity of R current regulator to grid voltage frequency fluctuation, the $2\omega_{igc}$ attenuation term is added to the R current regulator. The R current regulator can provide enough amplitude gain for the frequency fluctuation of grid voltage when the power grid has asymmetric fault.

The control scheme of the GSC based on PID-R current controller in dq^+ coordinate system is shown in Figure 6. E_{sdq}^{+} is the equivalent stator anti-electromagnetic force that interferes with the PID–R controller.

From the Equation(20), the component forms of d^+, q^+ in the forward rotation synchronous speed rotating coordinate system can be obtained:

$$\begin{cases} v_{gd}^{+*} = -L_g V_{gd}^{+\prime} - R_g i_{gd}^{+} + \omega L_g i_{gq}^{+} + u_{gd}^{+} \\ v_{gq}^{+*} = -L_g V_{gq}^{+\prime} - R_g i_{gq}^{+} + \omega L_g i_{gd}^{+} + u_{gq}^{+} \end{cases} \quad (22)$$

From the Equation(21), the component forms of d^+, q^+ in the forward rotation synchronous speed rotating coordinate
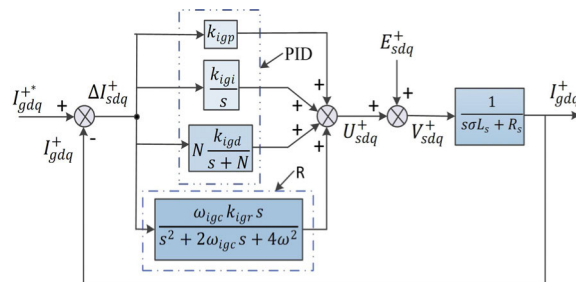

FIGURE 6. Control scheme of the GSC based on PID-R current controller in dq^+ coordinate system.

system can be obtained:

$$\begin{cases} v_{gd}^{+\prime} = \left[k_{igp} + \frac{k_{igi}}{s} + N\frac{k_{igd}}{s+N} + \frac{\omega_{igc}k_{igr}s}{s^2 + 2\omega_{igc}s + 4\omega^2} \right] \\ (i_{gd}^{+*} - i_{gd}^{+}) \\ v_{gq}^{+\prime} = \left[k_{igp} + \frac{k_{igi}}{s} + N\frac{k_{igd}}{s+N} + \frac{\omega_{igc}k_{igr}s}{s^2 + 2\omega_{igc}s + 4\omega^2} \right] \\ (i_{gq}^{+*} - i_{gq}^{+}) \end{cases} \quad (23)$$

Without introducing any positive and negative current decomposition links, the PID-R current controller realizes unified control and regulation of the positive and negative sequence currents on the GSC. The proportional-integral-differential parameters can be designed with reference to the proportional-integral differential regulator in the synchronous rotating coordinate system under traditional balance conditions, while ensuring that the dynamic performance and output power of the entire GSC remain unchanged, accurate control of the negative sequence current is achieved. The diagram of the control principle of the GSC when the asymmetric fault occurs in the power grid is shown in Figure 7.

The transfer function of traditional PID controller and PID-R current transfer function designed in this paper can be expressed as:

$$\begin{cases} G_{PID}(s) = k_{igp} + \frac{k_{igi}}{s} + N\frac{k_{igd}}{s+N} \\ G_{PID-R}(s) = k_{igp} + \frac{k_{igi}}{s} + N\frac{k_{igd}}{s+N} + \frac{\omega_{igc}k_{igr}s}{s^2 + 2\omega_{igc}s + 4\omega^2} \end{cases}$$
$$(24)$$

According to the transfer function, the Bode diagram of the closed-loop transfer function of traditional PID control and PID-R control can be obtained, as shown in Figure 8. The Bode diagram shows that when the asymmetric fault occurs in the power grid, the PID controller cannot provide sufficient amplitude and phase margin, the PID-R current controller can provide more sufficient gain and phase margin to the control system than the PID control, indicating that the PID-R control system responds faster. Meanwhile, it also can be seen that the effect of the R regulator on the control system is very small, and the final control result is as stable as the PID control is used.
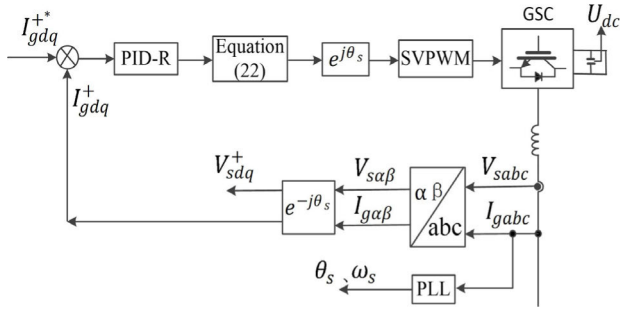
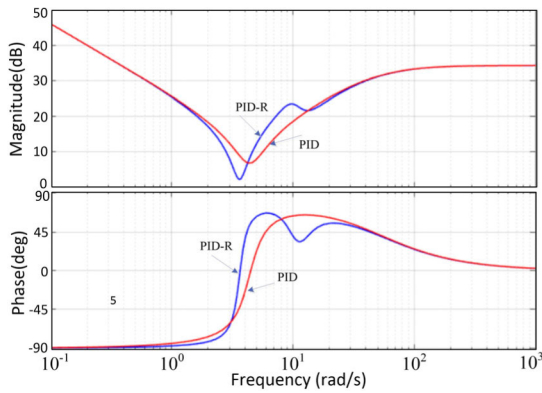**FIGURE 7.** Schematic diagram of the current controllers for GSC.

FIGURE 8. Bode diagram of PID and PID-R current controllers.

IV. SIMULATION RESULTS

MATLAB/Simulink is used to verify the control strategy proposed in this paper. The simulation time is 5s, in which 2s-3s grid has asymmetric fault. The rated power of DFIG is 1.5MW, and the switching frequency for both the GSC and rotor-side converter RSC is 5kHz, the parameters are shown in Table 2. The current, torque, torsion angle, and power in the simulation results are all in per-unit(pu), and their rated value is defined as 1.0pu.

TABLE 2. DFIG simulation parameters.

Rated power	1.5MW
Stator voltage	690V
Stator/rotor turns ratio	0.38
R_s	0.00706pu
R_r	0.005pu (referred to the stator)
L_m	2.9pu
$L_{\sigma s}$	0.171pu
$L_{\sigma r}$	0.156pu (referred to the stator)

The simulation results are shown in Figure 9.

In order to better illustrate the control effect of PID-R current control, the comparison results of PID controller and PID-R current controller are given. $I_s(\%)$, $I_r(\%)$, and $V_{dc}(\%)$ in the table are the current unbalance degree and bus voltage unbalance degree caused by asymmetric fault of power grid, T_e and P are the oscillation of electromagnetic torque
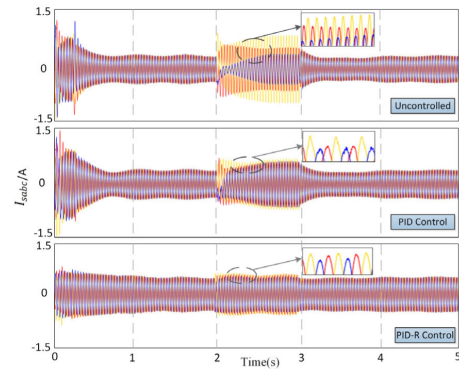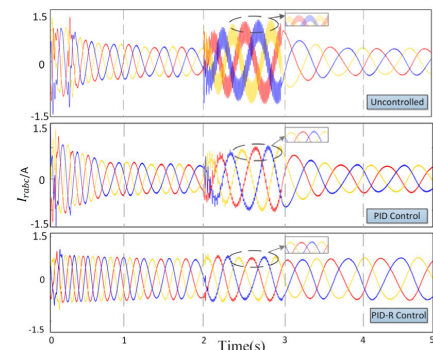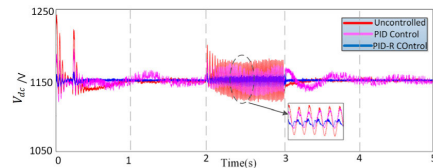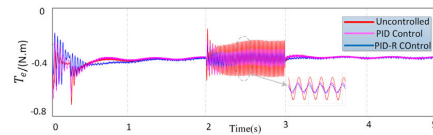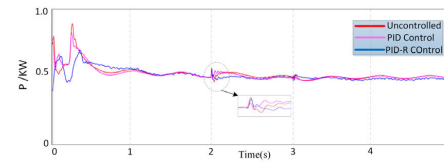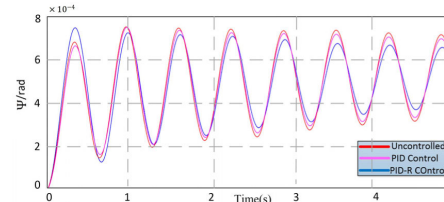

FIGURE 9. (a) Stator three-phase current; (b) Rotor three-phase current; (c) DC bus voltage; (d) Electromagnetic torque; (e) Active power; (f) Torsion vibration angle.

and active power when the grid asymmetric fault occurs. As shown in Table 3.

Control Strategy	Is(%)	Ir(%)	V_{dc}(%)	T_e	P
uncontrolled	2.08	1.63	0.026	0.44	0.15
PID control	1.05	1.09	0.017	0.27	0.06
PID-R control	0.06	0.83	0.004	0.20	0.04

It can be seen from the simulation results in Figure 9(a), (b), and table 3 that when the asymmetric fault occurs in the power grid during 2s-3s, the stator and rotor currents will oscillate due to the existence of positive sequence DC and negative sequence AC components, the stator and rotor current oscillate violently without any control, when the PID control is adopted, the oscillate of stator and rotor current can be suppressed, but the effect is not obvious. Compared with the PID control, the PID-R current controller designed in this paper has better control effect, which can ensure the normal operation of the DFIG during the power grid asymmetric fault.

Since the DFIG is directly connected to the power grid, when the asymmetric fault occurs in the grid, the DC bus voltage will be directly impacted. Figure 9(c) and Table 3 shows that when the asymmetric fault occurs in the power grid, the DC bus voltage will oscillate violently under uncontrolled conditions, and the PID control alone cannot well suppress the oscillation. Compared with PID control, the PID-R current controller can control the oscillation of the DC bus voltage during the asymmetrical fault of the power grid more obviously.

The oscillation of electromagnetic torque will cause torsional vibration of the drive chain. It can be seen from Figure 9(d) and table 3 that during the period of time when the power grid has asymmetric faults, the electromagnetic torque will oscillate violently without any control. Only the PID control is adopted, and the electromagnetic torque oscillation is not significantly suppressed, the PID-R current controller can suppress the oscillation more obviously.

It can be seen from Figure 9(e) and Table 3 that when no control is adopted, the power will have a transient impact when the asymmetric fault occurs in the power grid, which will cause power oscillation during the fault. Compared with PID for transient impulse control, the PID-R current controller designed in this paper can well suppress the transient impact of active power and active power oscillation when the asymmetric fault occurs in the power grid, and will not affect the power output.

Figure 9(f) shows that when the asymmetric fault occurs in the power grid, the PID-R current controller designed in this paper is compared with the PID control of the drive chain torsional vibration, thereby reducing the unit's shafting hazards and improving the unit's safe operation capability.

V. CONCUSION

This paper analyzes the causes of the drive chain oscillation when the asymmetric fault occurs in the power grid, and establishes the model of the GSC and the model of the DFIG drive chain. Through analysis, it is concluded that the positive sequence DC component and the negative sequence AC component generated when the grid fault occurs will cause the oscillation of stator and rotor current, DC bus voltage, active power and electromagnetic torque, and the electromagnetic torque oscillation is the main factor causing the torsional vibration of drive chain.

When the asymmetrical fault occurs in the power grid, this paper proposes the PID-R current control strategy for the GSC of the DFIG to eliminate electromagnetic torque oscillations. PID-R current controller can accurately control the positive and negative sequence components of the GSC in the forward rotation synchronous speed rotating coordinate system without decomposing the positive and negative sequence components. Simulation shows that the control strategy can effectively control the positive and negative sequence components caused by asymmetric faults in the power grid, thereby effectively suppressing stator and rotor current, DC bus voltage, active power, electromagnetic torque. So, PID-R current controller can realize active control of torsional vibration of drive chain under asymmetric fault of power grid.

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