Analysis on using a fuzzy logic controller to improve the power and current limiting abilities of wind turbines powered by PMSG in a microgrid

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ABSTRACT

In this study, we suggest a microgrid-fed wind power generating system using fuzzy logic controllers. The main problem for wind power production systems that successfully connects to the grid is imbalanced grid voltage sags. Under an uneven grid voltage, the output power and dc bus voltage will vary. Additionally, voltage sags will cause a rise in peak current, which might pose a threat to the functioning of the wind power system. Based on a thorough investigation of the high peak current, this research suggests a straightforward FLC current limiting control system without the need of any additional hardware. In this system, the grid side converter (GSC) transmits power to the machine side converter (MSC) controller, which modifies the electromagnetic power (GSC). Meanwhile, it converts the unbalanced power on the dc- link into the rotor kinetic energy, avoiding the dc-link overvoltage. The GSC controller can not only ensure that the three-phase inverter currents are in the maximum safe range that the converters can bear, but also provide reactive power support for the grid. Furthermore, the fluctuations on dc bus voltage and output power can be eliminated effectively by using the GSC controller. Thefeasibility of the proposed scheme and thesuperiority over the traditional controlschemes have been verified by simulationsunder different types of unbalanced voltage.

KEYWORDS: MSC, GSC, FLC, DC-LINK VOLTAGE.

INTRODUCTION

Many nations throughout the world have started strategic deployment in the new energy sector in response to the world's worsening environmental issues and energy dilemma. Wind energy has garnered interest on a global scale as a type of clean, renewable energy [1][3]. The wind power generating system is evolving quickly, taking the lead in terms of new energy production, and its share of the power grid is growing. Because of their efficiency, dependability, and larger speed range, permanent magnet synchronous generators (PMSGs) have rapidly gained in popularity among the many types of wind turbine systems [4], [5]. The back-to-back (BTB) converters that link PMSG directly to the power grid in accordance with the design of the wind power system based on PMSG ensure reliable operation of converters is vulnerable to unbalanced grid voltage sags. There are many reasons for unbalanced grid voltage, such as complete grounding, incomplete grounding, intermittent grounding, arc grounding, circuit breakage, etc. [6], [7]. Unbalanced grid voltage will lead to negative sequence components in thesystem. In general, the actual factors such asweak grids may cause output power fluctuations [8]. However, due to the existence of negative sequence components under unbalanced grid voltage, theinteraction between positive and negative sequence voltage and current is the mainreason for the second-order harmonicfluctuations on dc bus voltage and outputpower [9], [10]. In addition, the power owing into the grid will be reduced due to the grid voltage sags. However, MSC is not sensitive to grid voltage sags and generates electric power continuously; resulting in the output power of MSC is not equal to the grid-connected power. This leads to somepractical problems, such as dc-linkovervoltage or over current of three-phase inverter currents [11].

Traditional control methods can not show good control performance under unbalanced grid faults [12], [13]. Vector control in double rotating coordinate frame is proposed in [14][16] during unbalanced conditions. In these control schemes, positive and negative sequence components of current are controlled independently,which is inevitable to separate the positive and negative sequence components. Meanwhile, this control scheme can suppress the fluctuations on output activepower, but the reactive power fluctuations and excessive peak current are not suppressed effectively. A flexible active power control scheme based on a fastcurrent controller and a recognizable reference current selector has been proposedin [17]. The scheme includes five different current control strategies which are instantaneous active-reactive power control, average active and reactive power control, instantaneously controlled positive-sequence, balanced positive sequence control, positive and negative sequence compensation control. These strategies can realize the elimination of power fluctuations or the balance of three-phase inverter currents, providing a theoretical basis for thefollow-up researches. However, theproposed control scheme is not combinedwith PMSG to solve the practical problems such as overvoltage and over current. Aiming at the problem of excessive peakcurrent, a current limiting scheme is proposed in [18] where the peak current is guaranteed within a safe range by controlling the active power. Nevertheless, the positive and negative sequenceseparation of voltage and current are inevitable and the degree of voltage imbalance needs to be fully considered in the realization of the control method. Another control strategy is shown in [19], which determines the current reference value by looking up the table, so as to limit the excessive peak current. But this method needs to calculate the data table offline, which is not easy to realize.

A new method for calculating the reference expressions of active and reactive power is presented in [20], which limits the peak current under unbalanced voltage. However, this method will increase the dc bus voltage. In order to reduce the risk of dc-link overvoltage during the grid voltage sags, some schemes which need to use additional devices have been proposed [21][23]. These additional devices mainly contain the braking chopper (BC), crowbar circuit and energy storage equipments, which increase the control costs. An interesting control strategy is presented in [24][26], which can keep the dc-link voltageconstant without need for any externalequipment. However, MSC and GSCcontrollers need to exchange their controlfunctions. The dc bus voltage is controlled by MSC controller and the maximum power point tracking (MPPT) is implemented by GSC controller. The control performance of this scheme is good under the symmetrical faults, but it is poor under the asymmetrical faults. Furthermore, it is noteworthy that the controller parameters need to be re-tuned,which makes it more difficult to implement the control scheme.

PROPOSED SYSTEM

This paper proposes a modified power and current limiting control scheme for enhanced operation of wind powersystem during unbalanced grid voltage conditions. The proposed control ensures that the three-phase peak currents are in the safe range and the dc bus voltage is stable without any external devices. Meanwhile, reactive power support is provided forpower grid according to the sag degree of grid voltage. In this structure, the MSC controller adjusts the electromagnetic power according to the power transmitted to thegrid by the GSC, and converts the unbalanced power on the dc-link into therotor kinetic energy. The fluctuation suppression of dc bus voltage and output power can be realized by the GSC controller. Furthermore, quasi-proportionalcomplex integral (QPCI) controller is usedto control the inverter current, the positive and negative sequence separation of current and tedious double rotating coordinate transformation can be avoided, which simplifies the control structure.

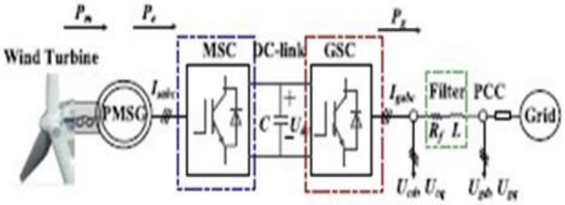


Fig.1. Simplified system structure

The model of wind power system based on PMSG mainly consists of five parts: wind turbine, PMSG, MSC, GSC and grid. It can be shown in FIGURE 1.

A. MODELING OF WIND TURBINE The mechanical power of wind turbine canbe obtained by capturing wind, which can beexpressed as follows [18]:

$$P_m = \frac{1}{2}\pi\rho R^2 C_P(\beta, \lambda)v^3 \quad (1)$$

where and R denote the air density andradius of blades, respectively, denotes the pitch angle and$^{\chi}$ represents tip-speed ratio, v is the wind speed. CP is the wind energy utilization coefficient, which is determined by and , can be expressed as follows

$$\begin{cases} C_P = 0.58(116\lambda_m - 0.4\beta - 5)e^{-21\lambda_m} \\ \lambda_m = \dfrac{1}{\lambda + 0.008\beta} - \dfrac{0.0035}{\beta^3 + 1} \\ \lambda = R\omega_m/v \end{cases} \qquad (2)$$

where ω_m represents the mechanical angular velocity.

The mechanical torque acting on a wind turbine is as follows

$$T_m = P_m/\omega_m = \frac{1}{2}\pi\rho R^3 C_P(\beta, \lambda)v^2/\lambda \qquad (3)$$

B. MODELING OF PMSG

The voltage equation of PMSG in two-phaserotating d-q coordinate system can be expressed as [10]:

$$\begin{cases} L_{sd}\dfrac{dI_{sd}}{dt} = -R_s I_{sd} + \omega_e L_{sq} I_{sq} + U_{sd} \\ L_{sq}\dfrac{dI_{sq}}{dt} = -R_s I_{sq} - \omega_e L_{sd} I_{sd} - \omega_e \psi + U_{sq} \end{cases} \qquad (4)$$

where Usd , Usq, Isd and Isq are the d-q components of the stator voltage and currentin the rotor flux orientated d-q frame respectively. Rs represent the stator resistance. Lsd and Lsq represent the stator dand q-axis inductances that are equal in the surface-mounted PMSG. And represent thepermanent magnet chain and electrical angular speed. The electromagnetic torque of PMSG is written as [10]:

C. MODELING OF GRID Since there is no circulation path of zero sequence component in three-phase three-wire system, zero sequence component is not be considered. The three-phase unbalanced voltages can be decomposed into positivesequence and negative sequence voltage components by the delayed signal cancellation (DSC) method [27]. Theunbalanced voltages can be written as

$$\begin{bmatrix} u_{ga} & u_{gb} & u_{gc} \end{bmatrix}^T = \begin{bmatrix} U^+ \sin(\omega t + \theta^+) + U^- \sin(\omega t + \theta^-) \\ U^+ \sin(\omega t - 120^\circ + \theta^+) + U^- \sin(\omega t + 120^\circ + \theta^-) \\ U^+ \sin(\omega t + 120^\circ + \theta^+) + U^- \sin(\omega t - 120^\circ + \theta^-) \end{bmatrix} \qquad (7)$$

where UC and C represent the voltage amplitude and initial phase of the positive sequence component, respectively. U_c and Urepresent the voltage amplitude and initial phase of the negative sequence component, respectively. ! represents the angle frequency of grid voltage. The three-phase voltages can be converted to stationary coordinate system by Clark transformation,which can be expressed as

$$\begin{bmatrix} u_{g\alpha} \\ u_{g\beta} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} u_{ga} \\ u_{gb} \\ u_{gc} \end{bmatrix} = \begin{bmatrix} u_{g\alpha}^+ + u_{g\alpha}^- \\ u_{g\beta}^+ + u_{g\beta}^- \end{bmatrix} \qquad (8)$$

$$\begin{bmatrix} u_{g\alpha}^+ \\ u_{g\beta}^+ \\ u_{g\alpha}^- \\ u_{g\beta}^- \end{bmatrix} = \begin{bmatrix} U^+ \sin(\omega t + \theta^+) \\ -U^+ \cos(\omega t + \theta^+) \\ U^- \sin(\omega t + \theta^-) \\ U^- \cos(\omega t + \theta^-) \end{bmatrix} \qquad (9)$$

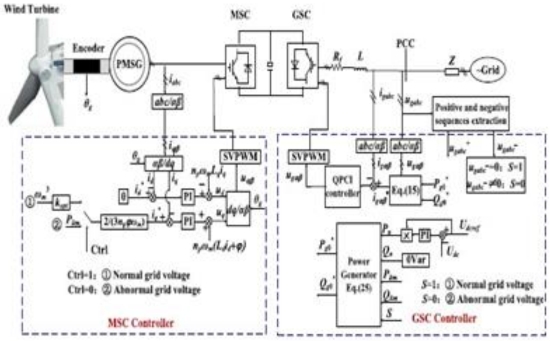
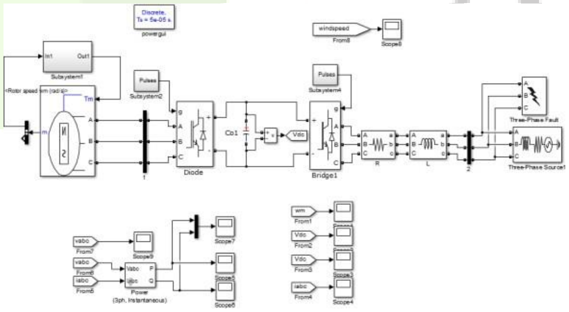


FIGURE 3 illustrates the block diagram of the proposed control strategy. Under normal grid voltage condition, both the MSC and GSC controllers adopt traditional control methods. For the MSCcontroller, the reference current of d-axis is set to zero in order to avoid demagnetizationof permanent magnet and simplify the control structure. The reference current of q-axis can be obtained by optimal torque control (OTC) to achieve MPPT control. Forthe GSC controller, the outer loop realizes dc bus voltage control and the inner loop realizes current control. Meanwhile, the unit power factor control is realized by setting the reactive power Qn D 0. During unbalanced grid voltage conditions, the MSC and GSC controllers need to change their corresponding control modes. For the MSC controller, the power reference of generator side is adjusted according to the power transmitted to the grid, so as to eliminate the unbalanced power on the dc- link, instead of MPPT control. The unbalanced power in the system will be transferred between the mechanical powerand electromagnetic power, and stored in theform of rotor kinetic energy. Meanwhile, GSC controller should adopt the maximum current limiting control to solve the over-current problem which is caused by the unbalanced grid voltage. The reference ofactive power should be switched from Pn to Plim. Moreover, the GSC controller no longer realizes the unit power factor control,the reference of reactive power is converted from Qn to Qlim in order to provide thefriendly support for the power grid based on the drop degree of power grid. In order to avoid the positive and negative sequence separation of current and tedious double rotating coordinate transformation in the control of GSC, the QPCI controller which can effectively control the ac signal is introduced to control the inverter current.The transfer function of QPCI controller canbe expressed as

$$G(s) = K_p + \frac{K_i \omega_c}{s - j\omega_0 + \omega_c} \qquad (32)$$

where Kp and Ki representproportional coefficient and integral coefficient, respectively. is fundamental angular frequency is frequency bandwidth. The controller has been proved to be able to eliminate the steady-state error in the stationary frame and effectively avoid theincense of grid frequency deviation, thereby improving the robustness of the system.

SIMULATION RESULTS



3.1 PROPOSED SIMULINK DIAGRAM

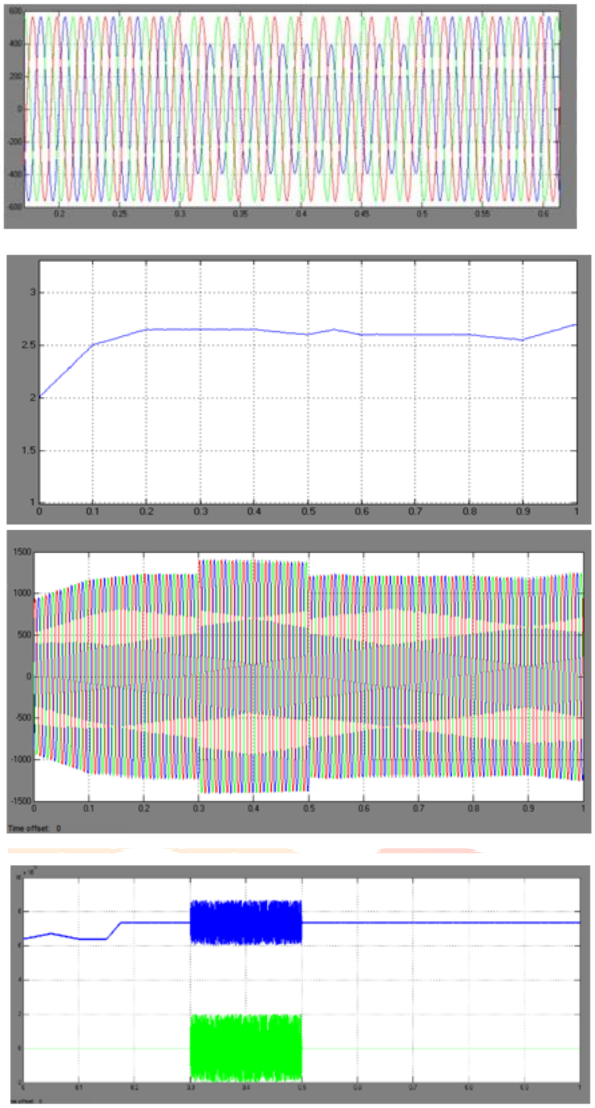


Fig 5 Conventional Control Case 1

FIGURE 5 illustrates the control results using control schemes I, II and proposed scheme undercase 1. The ininfluence of voltage sag is not

fully taken into account in the design of control scheme I. Therefore, the output power and dcbus voltage fluctuate significantly. In addition, the peak current is significantly higher than the normal value.

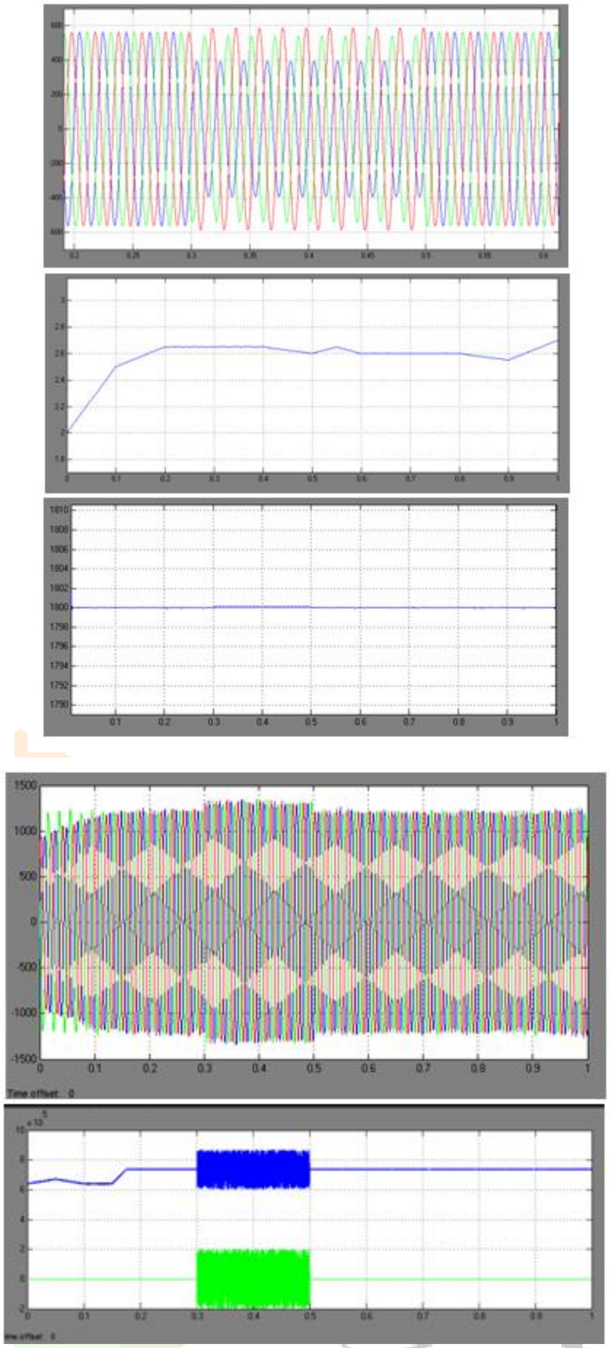
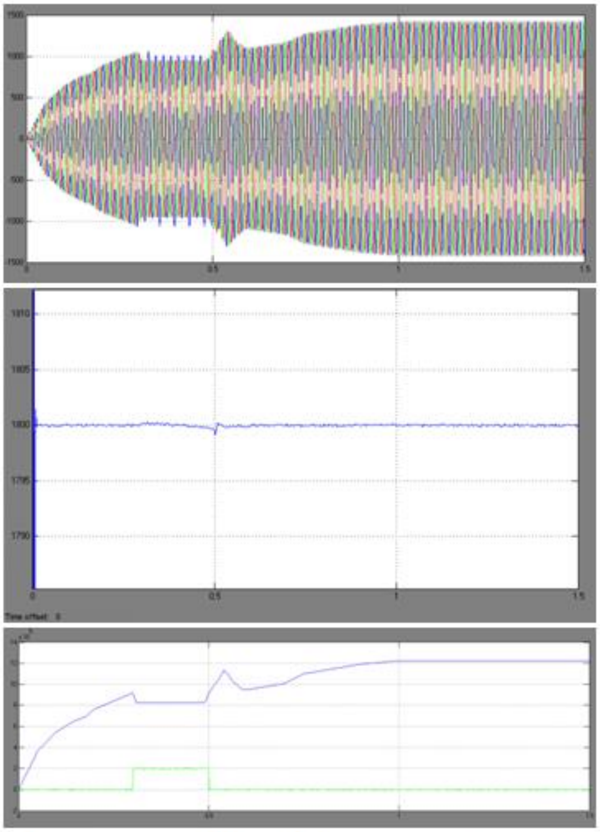


Fig 6 Conventional Control Case 2



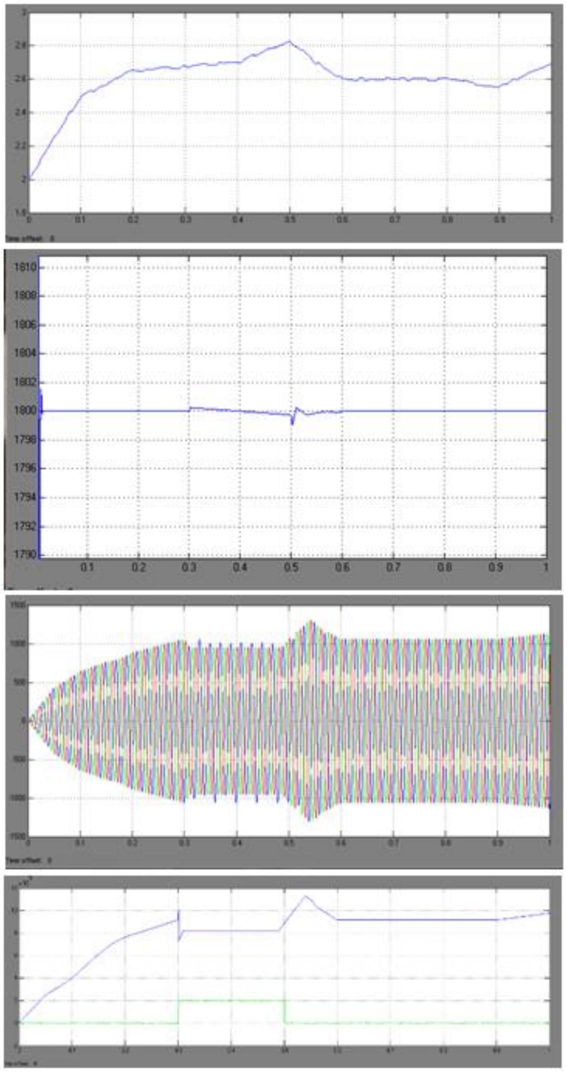


Fig 6 proposed Control C

The control results of different control strategies under case 2 are presented in FIGURE 6. FIGURE 6(a) illustrates the control results usingcontrol scheme I, the fluctuations on output power are quite large and the peak value of output current obviously exceeds the normal value during the grid voltage sag.

Fig 7 Control effect of the proposed controlstrategy with wind speed step change undertwo different grid faults (a) Case 1, (b) case2.

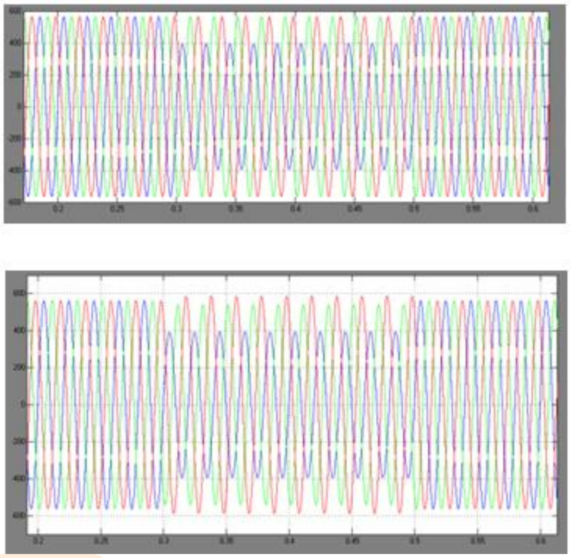


Fig 8 Three-phase grid voltages (a) Case 1, (b)case 2

CONCLUSION

This research provides a novel fuzzy logic controller-based power and current limiting control of a PMSG-based wind turbine for improved operating performance under imbalanced grid voltage. The following are the primary contributions of this work: 1) A peak current limiting scheme is proposed based on a detailed analysis of the output current to ensure the three-phase currents are within the safe range; 2) The unbalanced power in the system is converted into rotor kinetic energy, which solves the problem of dc bus overvoltage; and 3) The fluctuations in dc bus voltage and output power are effectively eliminated. The following are the benefits of the suggested system for this work: There is no need to exchange the control functions of MSC controller and GSC controller, which avoids the problem of resetting the control parameters; 3) The control of three-phase inverter currents is realized in coordinate system, without the separation of positive and negative sequence of current and complex rotating coordinate transformation, the structure is simple1) No additional auxiliary equipment is required, saving money; 2) There is no There is no need to exchange the control functions of MSC controller and GSC controller, which avoids the problem of resetting the control parameters; 3) The control of three-phase inverter currents is realized in coordinate system, without the separation of positive and negative sequence of current and complex rotating coordinate transformation, the structure is simple. The effectiveness and superiority of the proposed control strategy have been verified by comparingthe simulation results with the other two control strategies under the two different grid faults.

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