A new FRT method of pmsg under grid faults by using improved msc control and smes device

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Abstract. This paper proposes a new Fault Ride Through (FRT) method of Permanent Magnetic Synchronous Generator (PMSG) wind energy system based on the improved machine-side generator (MSC) control and superconducting magnetic energy storage (SMES) under grid symmetric fault condition. The system topology and basic principle of the proposed scheme are investigated in detail. The control strategies of improved MSC control and SMES are also presented. Furthermore, the simulation of PMSG integrated with the proposed scheme is conducted in PSCAD/EMTDC. Simulations show that the proposed FRT method could maintain key parameters of PMSG within the acceptable range and the capital cost of SMES is also reduced during grid fault, which demonstrates its feasibility and practicability.

1. Introduction

In recent years, installed capacity and scale of wind power generation unit with high permeability are continuously enlarging. As one of the mainstreams of wind generator, the Permanent Magnetic Synchronous Generator (PMSG) has been widely investigated and received much attention. Especially, due to the disconnection between PMSG with high permeability and grid may cause grid instability and other serious problem, the FRT scheme of PMSG under grid fault condition has been the universal concern of many scholars [1]. It is usually divided into two categories: modifying PMSG controllers and using external devices [2]. The FRT schemes based on modified pitch controller or back-to-back converters have been proposed and technically validated [3, 4]. These schemes are low cost but have a weak FRT capability enhancement under some severe grid fault conditions. Using external devices is an effective protection scheme for PMSG under severe grid fault condition. The common external devices in the available research include braking-chopper [5, 6], battery system [7], flywheel system [8], electrical double-layer capacitor [9], etc. However, the external devices will cause a high total cost, and introduce related control system of external devices, thereby increasing the complexity of PMSG. Especially, the Braking-Chopper has been widely used in practical engineering owing to its related low cost, simple control and effective FRT capability enhancement.

Recently, the superconducting magnetic energy storage (SMES) has shown superior performance in improving FRT capability of PMSG, due to its better dynamic performance of SMES including the fast charge-discharge rate, high power density and low maintenance cost comparing with other energy storage devices. Some SMES-based schemes have been used to improve FRT capability and smoothen the output power of PMSG [10-12]. However, these schemes only depend on SMES device to improve FRT capability, which cause higher performance requirement and total cost of SMES. Therefore, this
paper tries to propose a new combination scheme of improved machine-side converters (MSC) control and SMES, to enhance the FRT capacity of PMSG, simultaneously reduce SMES costs.

2. Basic topology and principle

2.1. Basic topology of PMSG system with the proposed FRT method

The topology of PMSG system integrated with SMES is illustrated in Fig. 1. The traditional PMSG system topology is formed by wind turbine, PMSG, MSC, dc-link capacitor, grid side converter (GSC) and related control systems. In this proposed method, the SMES is parallel connected with dc-link.

![Figure 1. The basic topology of SMES-integrated PMSG system.](image)

2.2. FRT characteristic during grid symmetric fault

Based on the grid voltage-oriented (d-axis) vector control strategy of GSC, the GSC output power \( P_{\text{gsc}} \) is [4]:

\[
P_{\text{gsc}} = \frac{3}{2} u_{\text{gsc}} i_{\text{gscd}}
\]

where \( P_{\text{gsc}} \) is the active power transferred to grid; \( i_{\text{gscd}} \) is the GSC d-axis current; \( u_{\text{gsc}} \) is the PCC voltage.

The power balance relation of dc-link is [2]:

\[
\frac{1}{2} C \frac{dU_{\text{dc}}^2}{dt} = P_{\text{msc}} - P_{\text{gsc}} = \Delta P
\]

where \( C \) is the dc capacitor capacitance; \( P_{\text{msc}} \) is the MSC output active power; \( U_{\text{dc}} \) is the dc voltage; \( \Delta P \) is the surplus power of dc-link.

Under grid fault condition, the \( u_{\text{g}} \) will be rapidly decreased. According to equation (1), the \( P_{\text{gsc}} \) will start to decrease when the \( i_{\text{gscd}} \) has been increased to its limit, because of the PCC voltage sag. However, the MSC output power \( P_{\text{msc}} \) is not changed because the wind turbine is not affected by grid sag. Based on the equation (2), the dc voltage will excessively be increased, causing fatal damage of converter.

2.3. FRT principle analysis

According to the FRT characteristic during grid fault, the key of FRT capability enhancement is eliminating the surplus power of dc-link (\( \Delta P \)). In the proposed scheme, the SMES is utilized to absorb the \( \Delta P \). From the equation (2), the increase of dc voltage will be avoided during grid fault when \( \Delta P \) is equal to zero, which means that the total surplus power is completely absorbed by SMES. Accordingly, the dc voltage is maintained to the normal level, avoiding the disconnection between PMSG-based wind turbine and grid.

Under some sever grid fault conditions, the surplus power of dc-link is excessive, leading to higher performance requirement of SMES to completely absorb the surplus power. Thus, to reduce the performance requirement of SMES, the improved MSC control is adopted to reduce the \( P_{m} \). From the equation (2), the surplus power \( \Delta P \) will be decreased. In this way, the surplus power absorbed by SMES will also be decreased, thereby reducing the performance requirement and total costs of SMES.
3. FRT Control method

3.1. SMES control method

The SMES is utilized to absorb surplus power by regulating its dc-dc converter. Fig. 2 shows the control diagram of SMES. The duty cycle \( D_1 \) can be obtained by inputting the difference between the actual dc voltage and its reference, to a hysteresis buffer. In addition, the SC current limiter is introduced to obtain another duty cycle signal \( D_2 \), to provide a good operation condition for SMES. Then, the duty cycle \( D \) is obtained by transferring the signal \( D_1 \) and \( D_2 \) to the logic and gate, which is used to control the PWM signals. The duty cycle \( D \) is equal to 1 during grid fault, so the switch gate S1 and S2 are on-switch state. In this way, the superconducting coil (SC) is charged to absorb the surplus power, thereby maintaining constant dc voltage.

\[
U_{dc} + U_{dcref} \equiv V_{min} \equiv V_{max} \quad \text{Isclim} \quad S_1 \quad D_1(0,1) \quad PWM \quad S_1 \quad S_2 \quad D_2 \quad D_1 \quad D_2
\]

Figure 2. Schematic diagram of SMES controller.

3.2. Control method of improved MSC control

The control scheme of improved MSC control is illustrated in Fig. 3. Under grid normal operation condition, a maximum wind power tracking vector control scheme is still implemented. The active power reference \( P_{ref} \) of q-axis outer loop is obtained based on maximum power point tracking (MPPT) function, and it is transferred to current regulator of q-axis inner loop. To realize the operation of unity power factor, the current reference of current regulator of d-axis inner loop is set to 0. However, when grid fault occurs, the \( P_{ref} \) is transferred from maximum power \( P_{nom} \) to lower active power reference \( P_{ref2} \), thereby reducing the output active power of MSC. In this paper, the \( P_{ref2} \) is set to half of normal value of output active power of MSC \( 0.5P_{nom} \).

\[
\omega_L + \frac{i_d}{L} = \frac{u_{dref}}{\omega_L} \quad \theta \quad \text{PLL} \quad \text{MPPT} \quad P_{ref} \quad P_{ref2} \quad P_m \quad i_{ref} = 0 \quad \text{PMSG} \quad \omega_f \quad \text{dq} \quad \text{abc} \quad \text{PWM} \quad \theta \quad \text{PLL} \quad u_{dref} \quad u_{a}, \ u_{b}, \ u_{c} \quad i
\]

Figure 3. Schematic diagram of improved MSC control.

4. Simulation verification

A 2.5 MW PMSG integrated with SMES is constructed in PSCAD/EMTDC. Table 1 shows some key parameters of SMES and PMSG. Note that the actual GSC output power is less than 2.5 MW due to power losses of converters.

Fig. 4(a) indicates that the steady value of GSC output current \( i_{gsc} \) without protection will be increased to 3.5 kA that reaches the maximum value during grid fault. But when the proposed FRT method is adopted, the peak value of \( i_{gsc} \) is limited to 3.23 kA, and its steady value is decreased to 2.71 kA that is closed to normal level. In addition, Fig. 4(e) shows the dc voltage \( U_{dc} \) will be increased to 5.57 pu without protection and the overvoltage of dc-link will cause serious damage to internal components of PMSG. However, with the FRT scheme, the initial \( U_{dc} \) can be suppressed to 1.06 pu, subsequently, dc voltage can attenuate to the normal level. Also, when the grid fault is removed, the maximum \( U_{dc} \) is only increased to 1.2 pu. Therefore, the \( U_{dc} \) is effectively limited admissible range, thereby not destroying the internal components of PMSG.
Fig. 4(c) shows the output active power of MSC ($P_{\text{msc}}$) without protection and with the proposed scheme. Without protection, the $P_{\text{msc}}$ is almost constant during grid fault. Nevertheless, the $P_{\text{msc}}$ is decreased to 1.24 MW due to the improved MSC control. Fig. 4(d) shows the output active power of GSC are respectively decreased to 0.49 MW (without protection) and 0.38 MW (with the proposed scheme) during grid fault. The power difference between two cases is caused by different GSC output current.

Fig. 4(f) shows the SMES current with two different FRT schemes. With the single SMES scheme, the SMES current is increased to 4880 A after grid fault is removed, but the SMES current is more than the critical current (3375 A). Thus, the SMES may be in the abnormal operations, which is not conducive to safe-economic operations of SMES device and cannot effectively improve FRT capability of PMSG. In this way, the SC magnet with larger inductance and critical current is required, thereby increasing the total costs of SMES. However, with the proposed scheme, the SMES current can be decreased to 3300 A that is less than the critical current, because the surplus power is reduced due to the improved MSC control. Thus, the adopted SMES device can normally maintain the dc voltage to admissible range and higher performance requirement and total costs of SMES are avoided.

Figure 4. Simulation results of PMSG without and with the proposed scheme.
Table 1. Key parameters of SMES and PMSG.

| Parameter                   | Value      |
|-----------------------------|------------|
| Rated power                 | 2.5 MW     |
| dc voltage                  | 1200 V     |
| PCC voltage                 | 690 V      |
| Grid frequency              | 50 Hz      |
| Grid line voltage           | 35 kV      |
| Inductance and of SMES      | 0.1 H      |
| Critical current of SMES    | 3375 A     |

5. Conclusion

A new combination scheme based on improved MSC control and SMES for improving FRT capability of PMSG has been proposed and validated. The basic principle, system topology, control strategy, simulation verification and performance evaluation have been conducted. The simulation results under grid fault condition show the SMES device in the proposed scheme can suppress GSC output current and maintain dc voltage to normal level, furthermore, the performance requirement and total costs of SMES are also be reduced comparing with single SMES scheme, because of the improved MSC control in the proposed scheme. Therefore, the feasibility and superiority of the proposed FRT method in enhancing the FRT capacity of PMSG system are verified.

6. References

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