

Enhancing the LVRT Capability of PMSG-Based Wind Turbines Based on R-SFCL

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Abstract. A novel low voltage ride-through (LVRT) scheme for PMSG-based wind turbines based on the Resistor Superconducting Fault Current Limiter (R-SFCL) is proposed in this paper. The LVRT scheme is mainly formed by R-SFCL in series between the transformer and the Grid Side Converter (GSC), and basic modelling has been discussed in detail. The proposed LVRT scheme is implemented to interact with PMSG model in PSCAD/EMTDC under three phase short circuit fault condition, which proves that the proposed scheme based on R-SFCL can improve the transient performance and LVRT capability to consolidate grid connection with wind turbines.

1. Introduction

For the past few years, Permanent Magnetic Synchronous Generator (PMSG) has become an important research topic in the field of wind power technology, due to its high reliability and low failure rate. However, grid-connected operation capability of PMSG with high penetration will be deteriorated when the grid is in faults. Thus, some grid codes that require wind turbine to be connected to grid during grid faults are proposed [1, 2].

In terms of improving LVRT capability of PMSG, there are usually divided into two solutions: external devices and modified controllers [3, 4]. In terms of methods based on external devices, the popular devices in the available research can be divided into Braking-Chopper or Active Crowbar [5, 6], Energy Storage Systems (ESS) [7, 8], etc. This scheme can improve the LVRT capability, but the cost is increased due to the additional hardware devices. In addition, the modified controllers of pitch angle and back-to-back converters are proposed, which is less cost but has limited ability to LVRT enhancement [9, 10].

In this paper, a novel LVRT capability enhancement scheme based on the R-SFCL is proposed, which effectively suppress DC voltage rise by upraising GSC output voltage during grid faults.



Moreover, the principle of proposed scheme with R-SFCL in series between transformer and GSC is presented in details. Finally, the performance evaluation based on simulation also is conducted, which demonstrate the feasibility of the proposed LVRT scheme.

2. Modelling and transient response of PMSG during grid faults

2.1. Modelling of PMSG-based wind turbine

PMSG-based wind turbine system is usually composed of wind turbine, permanent magnet synchronous generator, machine side converter (MSC), DC capacitor, grid side converter (GSC) and related control system. The typical topology is shown in Fig. 1.

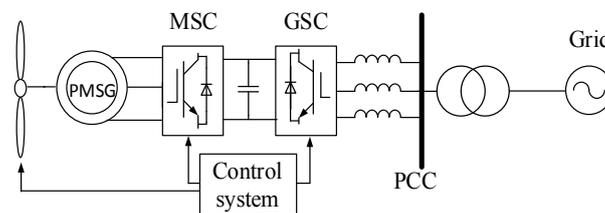


Figure 1. The topology of PMSG-based wind turbine system.

2.2. Transient Response of PMSG under grid faults conditions

According to the Fig.1, the power balance relationship in DC-link can be expressed as:

$$\frac{1}{2}C \frac{dU_{dc}^2}{dt} = P_s - P_g \quad (1)$$

Where P_s and P_g are the generator active power and active power injected into grid, respectively.

The injected active power from GSC under rotating coordinate system can be expressed as:

$$P_g = \frac{3}{2} u_g i_{gd} \quad (2)$$

Where u_g is the PCC voltage, and i_{gd} is the GSC q-axis current .

When some severe faults occurs in the grid, the PCC voltage u_g will be decrease rapidly. According to equation (2), in order to maintain constant power the GSC current i_{gd} will increase and when it has increase to its limit, the active power injected to grid will start to decrease. Nevertheless, the generator active power injected to DC-link will keep constant as MSC cannot directly sense grid voltage sag. According to equation (1), the DC voltage will excessively raise, resulting in damage to converter and thereby leading to disconnection between PMSG and grid.

3. The modelling and principle of LVRT enhancement scheme

3.1. Principle of LVRT capability enhancement

Based on aforementioned analysis, a LVRT scheme with R-SFCL in series between the GSC and the transformer as shown in Fig.2 is proposed, which effectively represses DC voltage rise.

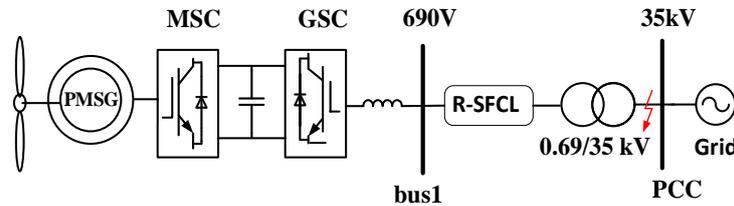


Figure 2. The topology of PMSG-based wind turbines with R-SFCL.

When a short-circuit fault occurs in the point of common coupling (PCC), R-SFCL will be transformed from superconducting state to high resistance state so as to effectively decrease the fault current and upraise the voltage at bus 1, thus ensuring the normal operation of PMSG.

3.2. Modelling of R-SFCL

According to the available research, the equivalent resistance curve of R-SFCL under different operation condition is shown in Fig.4, which is divided into five segments [11, 12].

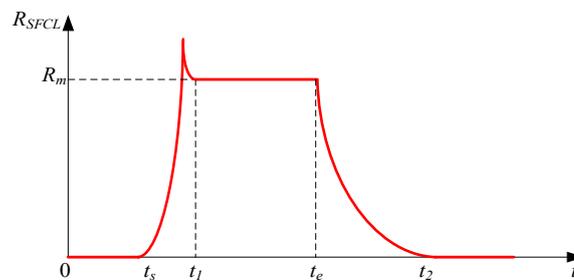


Figure 3. The equivalent resistance of R-SFCL under different operation condition

From the Fig.3, the equivalent R-SFCL resistance can be represented as [12]:

$$R_{SFCL} = \begin{cases} 0 & t < t_s \\ E_c I_r^{n-1} / I_c^n & t_s < t < t_1 \\ R_m & t_1 < t < t_e \\ R_m e^{-(t-t_e)/\tau_2} & t_e < t < t_2 \\ 0 & t > t_2 \end{cases} \quad (3)$$

where E_c is the critical electrical field; n is the exponential value of tape; τ_2 is the recovery time constant; t_s and t_e are the start and removal time of fault, respectively; t_1 is the response time of R-SFCL transition from superconducting state to high impedance state; t_2 is the time to recover superconducting state; R_m is the pre-set resistance of R-SFCL in high resistance state.

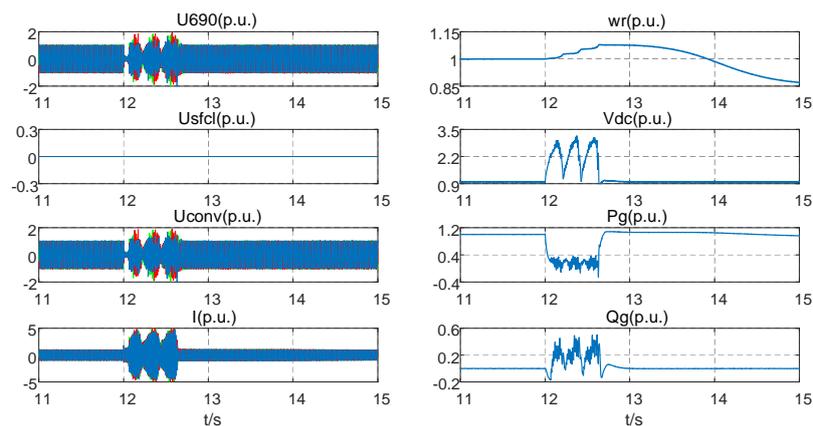
4. Simulation results and analysis

To verify the effectiveness of the proposed scheme, a 5 MW PMSG-based wind turbines with R-SFCL model as shown in Fig.2 is constructed in PSCAD/EMTDC under three phase fault condition. The basic parameters of PMSG is listed in Table 1. The pre-set resistance is set to 0.092 Ω to ensure that the GSC output voltage is within the safety margin during grid fault.

Table 1. The basic parameters Parameter of the PMSG.

Parameter description	Value
Rated power	5 MW
Rated voltage of GSC	690 V
DC-link voltage	1450 V
filter inductance	0.135 mH
Transformer ratio	690V/35kV
Grid line voltage	35 kV
Grid frequency	50 Hz

Fig.4 shows the transient response of PMSG without SFCL during the fault. The GSC output voltage is rapidly decreased to 0.1 p.u., causing a rapid arise of GSC output current and the decline of active power due to current limiting of GSC and thereby causing a substantial increase in DC-link voltage. Worst of all, PMSG will get out of control leading to a sharp oscillation on all parameters. For example, the DC-voltage is almost 3.3 p.u., which will cause a disconnection between PMSG and grid.

**Figure 4.** The transient response of PMSG without SFCL under three fault condition

The transient response of PMSG with SFCL is illustrated in Fig.5, which shows that the oscillation of all parameters is eliminated. The GSC output current is almost suppressed to 1 p.u. because of the R-SFCL and the GSC output voltage U_{conv} is unchanged with the compensation of the R-SFCL voltage U_{sfcl} . In addition, the DC-link voltage is also decreased from 3.3 p.u. to 1 p.u. and the power injected into grid is keep the normal value. Thus, PMSG almost immune to grid faults, which verifies that effectiveness of the proposed scheme on improving LVRT capability and transient performance of PMSG-based wind turbines.

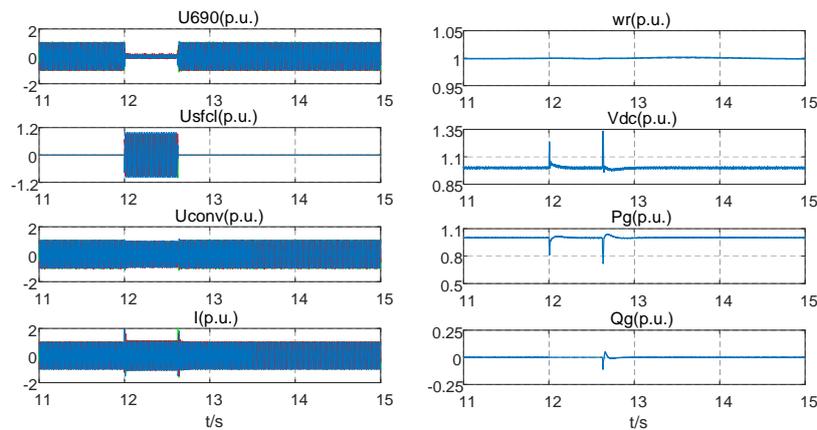


Figure 5. The transient response of PMSG with SFCL under three phase fault condition.

5. Conclusion

A LVRT enhancement scheme based on R-SFCL in series between GSC and transformer is proposed. The principle of LVRT capability enhancement is described in detail. Especially, the equivalent resistance model of R-SFCL is presented, which is divided into five segments. Finally, the performance evaluation of the two cases with or without R-SFCL is conducted based on the simulation results under three phase faults condition, which shows the R-SFCL can effectively suppress the GSC output voltage decrease and fault current increase and make PMSG almost impervious to grid faults. Therefore, the proposed LVRT enhancement scheme can improve the transient performance and LVRT capability of PMSG-based wind turbines.

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