EFFECT OF SMES UNIT ON THE PERFORMANCE OF TYPE-4 WIND TURBINE GENERATOR DURING VOLTAGE SAG

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Abstract

Direct-drive variable speed wind turbine with full scale converter or so-called type-4 wind turbine generator has been installed increased to about 20.3% worldwide in 2002. Voltage sag in the grid side may cause the wind turbine to be disconnected from the grid. In this paper, Superconducting Magnetic Energy Storage (SMES) unit is applied to improve the fault ride through capability of type-4 wind turbine during voltage sag in the grid side. Simulation is carried out using MATLAB/Simulink software and the results show that SMES unit can significantly improve the performance of type-4 wind turbine and prevent it from being disconnected during a certain degree of voltage sag depth in the grid side.

1 Introduction

Wind turbine is one of the most attractive renewable energy sources. Its capacity has reached to 94000 MW worldwide by the end of 2007 and it is expected to provide more than 10% of the global electricity in 2020 [1]. Type-4 wind turbine generator (WTG) is direct-driven wind turbine generator with full-scale converter which has the capability of working optimally and tracking the maximum power during variable wind speed conditions. In 2003, this type of wind turbine has reached 20.3% of the total wind turbine installed globally [2]. The ability of wind turbine to withstand various disturbances in the system (fault-ride-through capability) depends on several parameters such as voltage at DC link, stator voltage and stator current [3] which vary according to the manufacturer. In this paper, Superconducting Magnetic Energy Storage (SMES) is applied to improve the fault-ride-through (FRT) capability of the type-4 WTG and prevent it from being disconnected from the system.

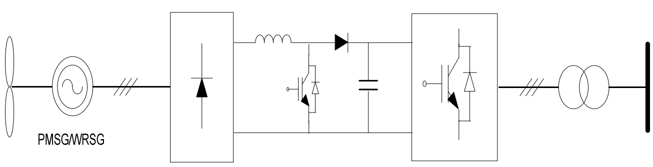


Figure 1: Typical configuration of type-4 WTG

2 System under study

Fig. 2 shows the model under study which consists of five-2 MW type-4 WTG connected through a 30 km transmission line and two transformers by the grid. The type-4 WTG consists of synchronous generator connected to a diode rectifier, DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter as shown in Fig. 1. This configuration will enable the turbine to take part in the power control [4]. The reactive power produced by the wind turbine is regulated at 0 Mvar in normal condition. For a wind speed of 15 m/s which is used in this paper, the turbine output power is 1 pu, the pitch angle is 8.9° and the generator speed is 1 pu which is maintained by the control system of the DC-DC converter [5].

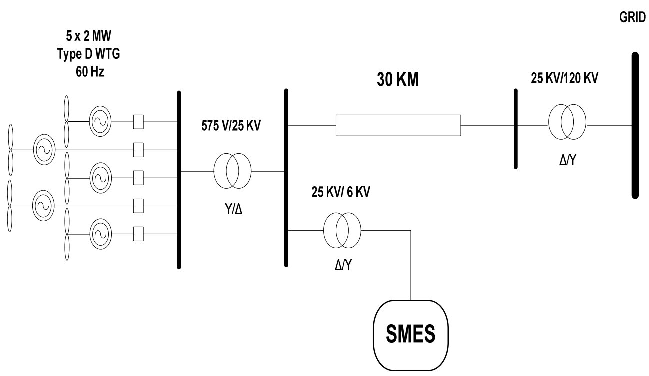


Figure 2: Model System

3 SMES Configuration and Control Scheme

Superconducting Magnetic Energy Storage (SMES) is one of the promising storage systems that stores magnetic energy in its superconducting coil and deliver it to the system when required. The coil should operate at very low temperature (cryogenic temperature) typically between 32° K to 127° K to maintain the resistance value of the coil close to zero. This condition makes the ability of the coil to store energy without any electrical losses and since the SMES system has no moving part such in pumped hydro or flywheel energy storage, the efficiency of SMES unit can reach 90 to 99% [6-9].

The stored energy in SMES can be calculated as:

$$E_{SM} = \frac{1}{2} \times I^2_{SM} \times L_{SM} \qquad (1)$$

Where E_{SM} is the stored energy; I_{SM} is the SMES current and L_{SM} is the SMES inductance coil.

The SMES unit configuration used in this paper consists of voltage source converter (VSC) and DC-DC chopper which are connected through a DC shunt capacitor. The VSC is controlled by a hysteresis current controller (HCC) while the DC-DC chopper is controlled by fuzzy logic controller (FLC) as shown in Fig. 3.

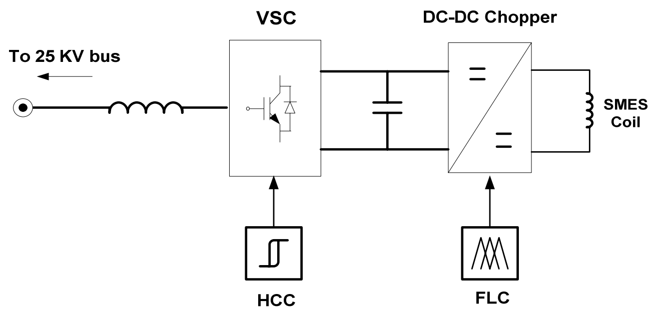


Figure 3: SMES configuration

DC-DC Chopper along with FLC is used to control charging and discharging process of the SMES coil energy. The generator active power and the current in the superconductor coil are used as inputs to the fuzzy logic controller to determine the value of the DC chopper duty cycle, active power of type-4 WTG and SMES coil current are used as inputs of the fuzzy logic controller. The duty cycle (D) is compared with 1000 Hz saw-tooth signal to produce signal for the DC-DC chopper as can be seen in Fig. 4.

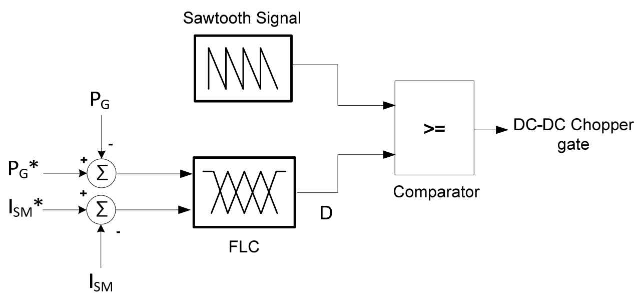


Figure 4: Control algorithm of DC-DC chopper

Compared with pulse width modulation (PWM) technique, the hysteresis band current control has the advantages of ease implementation, fast response, and it is not dependent on load parameters [10]. Hysteresis current control (HCC) is used to control the power flow exchange between the grid and the SMES unit. HCC is comparing the 3-phase line currents with the reference currents (I_d* and I_q*). The value of I_d* and I_q* are generated through the conventional PIs controller both from the deviation of the capacitor voltage V_{dc} and system voltage V_s. To minimize the effect of phases interference while maintaining the advantages of the hysteresis methods, phase-locked loop (PLL) technique is applied to limit the converter switching at a fixed predetermined frequency [11]. The proposed control algorithm in this paper is much simpler and closer to realistic application compared with the controller used in [12], where four PIs controller were used which complicate the process of finding the optimal parameters of the PIs, moreover, only P_g was used as the control parameter of the DC-DC chopper and it ignored the energy capacity of the SMES coil. The detailed VSC control scheme used in this paper is shown in Fig. 5. The rules of duty cycles D and the corresponding SMES action are shown in Table I. When D is equal to 0.5, SMES unit is in idle condition and there is no power exchange between the SMES unit and the grid. When there is any voltage drop because of fault, the controller generates a duty cycle in the range of 0 to 0.5 according to the value of the inputs and power will be transferred from SMES coil to the system. The charging action (corresponding to the duty cycle higher than 0.5) will take place when SMES coil capacity is dropped and power will be transferred from the grid to the SMES unit.

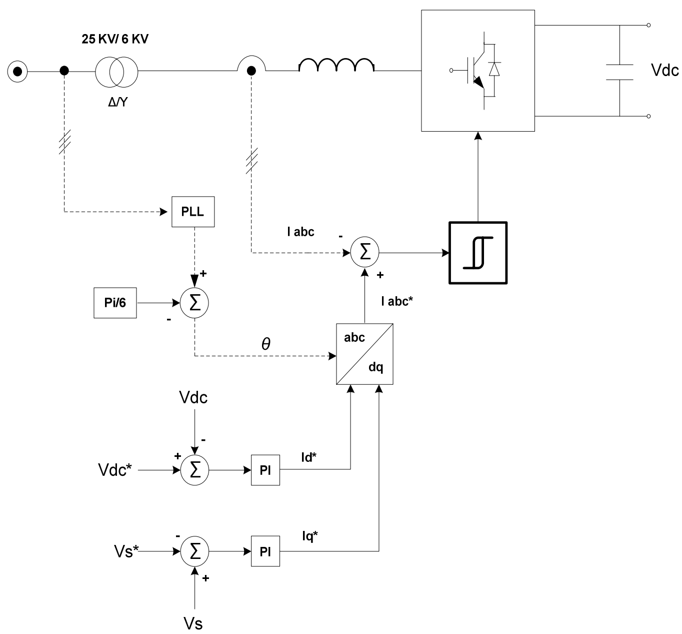


Figure 5: Control algorithm of VSC

Duty Cycle (D)	SMES Coil Action
D = 0.5	standby condition
0 ≤ D < 0.5	discharging condition
0.5 < D ≤ 1	charging condition

Table 1: Rules of Duty Cycle.

The variation range in SMES current and WTG output power and the corresponding duty cycle are used to develop a set of fuzzy logic rules in the form of (IF-AND-THEN) statements to relate the input variables to the output. The duty cycle for any set of input date (P_g and I_{SMES}) can be evaluated from the surface graph shown in Fig. 6.

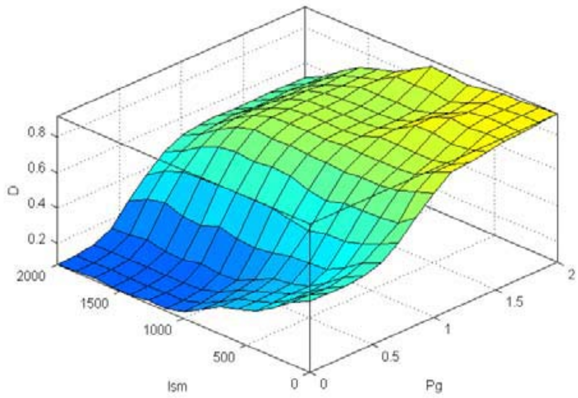


Figure 6: Surface graph- Duty cycle

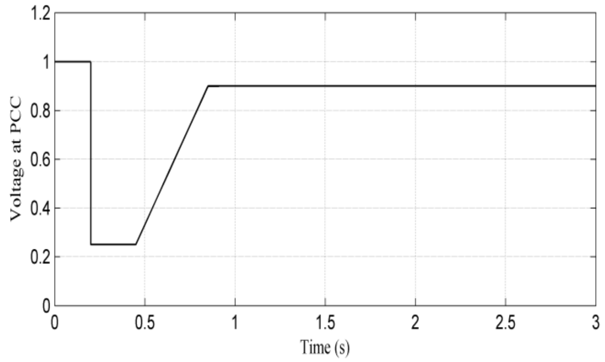


Figure 7: FRT capability of Svenska Krafnat-Sweden

4 Simulation Results

In this paper voltage sag is applied in the grid side at 0.5 s to 0.63s. The depth of voltage sag is following the characteristic of Svenska-Krafnat Sweden FRT graph shown in Fig. 7 where the permissible voltage drop at the point of common coupling (PCC) is limited to 0.75 pu. Voltage drop below the line will cause the WTG to be disconnected from the grid. The WTG parameters V_{DC}, I_{stator} and V_{gsc} are defined as:

$$V_{dc,peak} = \frac{\max |V_{dc}(t)|}{V_{dc,base}} \qquad (2)$$

$$I_{s,peak} = \frac{\max|I_{sa}(t)|,|I_{sb}(t)|,|I_{sc}(t)|}{I_{s,base}} \qquad (3)$$

$$V_{m\_gsc,drop} = \frac{\min |V_{m\_gsc}|}{V_{gsc,base}} \qquad (4)$$

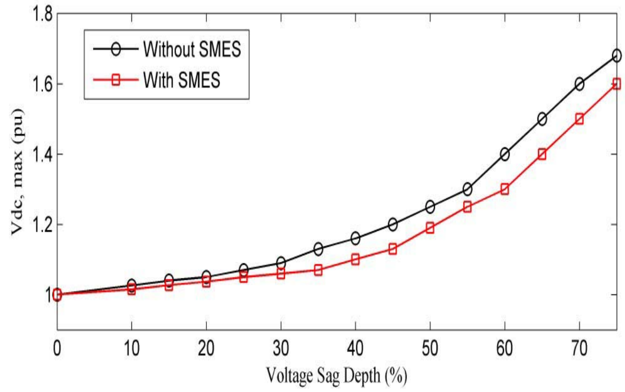
Where:

$V_{dc,\,peak}$ is peak voltage of DC link

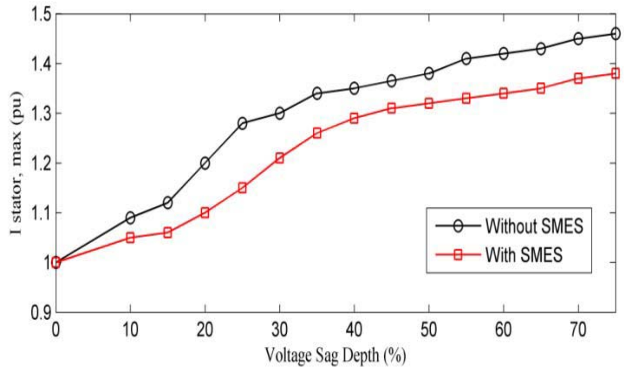
$I_{s,\,peak}$ is peak of current stator

$V_{m\_gsc,\,drop}$ is magnitude voltage drop at the grid side converter.

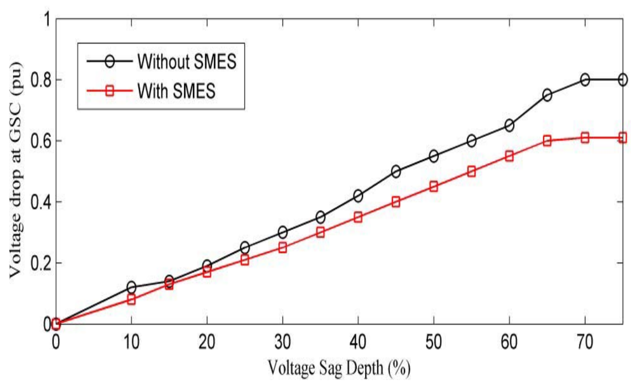
These parameters are obtained from the time domain simulation at the moment when the fault occurs similar to the previous work in [13]. In the system under study, voltage sag of variable levels is simulated at the grid side and the impact of each level on the above parameters is plotted as shown in Fig. 8



(a)



(b)



(c)

Figure 8: Parameters of interest for type-4 WTG during voltage sag

The safety margin of these parameters depends on the manufacturer. As can be seen in Fig. 8 (a), if 1.2 pu is designed as the safety margin level for V_{DC} parameter, without SMES, 45% of the voltage sag depth at the PCC can cause the converter protection to block and isolate the converter. However, with SMES, the voltage sag safety margin is extended to 52%. If the maximum V_{DC} parameter is upgraded to 1.4 pu, without SMES, the converter will be blocked at 60% of voltage sag depth which will be extended to 65% with the SMES unit. Another important parameters for the WTG performance is the stator current shown in Fig. 8 (b). High overshooting in stator current may cause damage to the generator winding. When the maximum allowable limit of the stator current is chosen to be 1.2 pu, without SMES unit, the safety margin for voltage sag depth is 20%, however with the SMES unit, the voltage sag depth is extended to 30% for the same stator current level. Voltage drop at the point of common coupling is another parameter that important to be taken into account. If the design strictly requires to block the converter during voltage drop of 0.2 pu, as described in Fig. 8 (c), without SMES unit, the converter should be blocked at 20% pu of voltage sag depth while with SMES, the converter still be able to operate under this voltage drop. If the converter is designed to hold up until 0.4 pu of voltage drop at the grid side converter, without SMES, the converter should be blocked at 0.4 pu of the voltage sag depth. However, in this condition the converter maximum voltage drop is maintained at 0.38 pu if connected with SMES.

5 Conclusion

The simulation results show that with SMES connected with the type-4 WTG, the probability of the WTG being disconnected from the grid during voltage sag at the grid side can be reduced. This is quite significantly improve the WTG capability to withstand and continue to supply power to the grid even in the situation where voltage sag occurs in the grid side, however, keep in mind that might be some manufacturers set the standard of maximum current and voltage value in both stator and the DC link respectively which required the converters to stop switching according to the parameters value in this study.

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