FAULT RIDE THROUGH TECHNIQUE FOR PMSG

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Abstract: This paper deals with a ride-through technique for permanent-magnet synchronous generator (PMSG) wind turbine systems using energy storage systems (ESS). If the grid side fault occurs then an active surplus energy is stored by energy storage system. A control strategy which consists of current and power control loops for the energy storage systems is proposed. In addition, the power fluctuations due to wind speed variations can be smoothened by controlling the ESS appropriately. The effectiveness of the proposed method is verified by the simulation results for a 30 KW PMSG wind turbine system.

Key Words: Energy storage system, PMSG, Power smoothening, Ride-through.

I. INTRODUCTION

If the Grid side fault occurs then the Grid side power is zero or very low. But in this case turbine moves with synchronous speed and PMSG generate constant power. So DC link voltage is unbalanced due to active surplus energy. There are two types of strategies in smoothening the wind turbine output power fluctuation. In one type, the turbine output power is controlled and smoothened without any extra apparatus, where the blade pitch angle and generator output power are controlled with the high system inertia considered [1]-[6]. One disadvantage of blade pitch angle control for smoothening the output power fluctuation is that the mechanical stress on the wind turbine systems becomes large[6]. In addition, the energy captured by the turbines is not optimal due to the effect of the pitch systems. In the other type, additional devices such as ESS or flywheel systems are required to mitigate the output power fluctuation [6]-[11]. Using the external devices increases the cost of the whole system. With the ESS added to wind generation systems, not only the power smoothening but also fault ride-through can be achieved effectively [7], [11] problem practically. The ESS consisting of electric double-layer capacitors (EDLC) is connected to the DC-link side of the back-to-back converters in a PMSG wind turbine system, as shown in Fig.1. This scheme cannot only offer ride-through capability but also suppress the output power fluctuation of the wind turbine systems with relatively low cost. In this method, the ESS is used to control the power which is absorbed from the system or released to the grid for both normal and fault conditions. Meanwhile, the LSC is used to control the DC-link voltage under both normal conditions and grid sags. However, with deep unbalanced voltage sags, excessively high grid current references, that depend on the grid voltages, are required to control the DC-link voltage [15]-[16]. So, the amount of the reactive power provided to the grid by the LSC does not satisfy the grid code requirement due to a limited current capability of the LSC. Another control scheme for LVRT compliance of the wind power systems in grid voltage disturbances was presented in [17]-[18], in which the DC-link voltage was controlled by the generator-side converter and the power mismatched between the turbine and grid sides are stored in the system inertia by increasing the generator speed. In this paper, an FRT technique of the PMSG wind turbine system is proposed during the grid fault. By switching the control mode, the ESS is operated to control the DC-link voltage of the back-to-back converters during the grid voltage sags. Meanwhile, the LSC is utilized to supply the reactive current to the grid for satisfying the reactive current requirements of the grid code. By this, the grid voltage can be recovered rapidly without an
external STATCOM after fault clearance. Also, the generator active power can be absorbed fully by the ESS during the voltage sags.

II. SYSTEM CONFIGURATION

The configuration of a direct-driven PMSG wind turbine system is shown in Fig. 1. The energy storage system consists of an EDLC and a bidirectional DC-DC converter, which is connected at the DC-link of the back-to-back converters. The parameters of the system components are listed in Tables 1 and 2 in the Appendix. In normal conditions, the LSC controls the DC-link voltage of the back-to-back converters and the ESS is able to smoothen the power ripples. In grid fault conditions, on the other hand, the LSC functions as STATCOM and the ESS controls the DC-link voltage.

III. ENERGY STORAGE SYSTEM

1. Control of the ESS

Under voltage sags, the generator output power may exceed the maximum level which the grid can absorb through the LSC due to decreases in the grid voltage. Therefore, to keep the DC-link voltage constant, the ESS is activated to absorb the differential energy between the generator and grid, which is expressed as:

\[ P_{\text{diff}} = P_{\text{gen}} - P_{\text{grid max possibility}} \]

Where, \( P_{\text{diff}} \) is the differential power between the generator and the grid, \( P_{\text{gen}} \) is the generator power, and \( P_{\text{grid}} \) is the grid power. During a voltage sag, the LSC is operated at its rated current. As a result, the generator can deliver as much power to the grid as is possible.
2. Rating of the ESS
During the operation of the ESS, the voltage of the EDLC varies, so that its capacitance, \( C \), can be determined from the following relationship as:

\[
c = \frac{2 \times E_{LVRT}}{\Delta V_{cap} \times V_{cap}^{rated}}
\]

Where, \( V_{cap}^{rated} \) and \( \Delta V_{cap} \) are the rated voltage and the voltage variation of the EDLC, respectively.

3. Batteries for energy storage system
Batteries are the most common conventional energy storage used for wind grid integration system. Batteries are used to store and support DC power unless if it is accompanied with an electrical converter to convert the DC power to AC power and vies versa. There are different types of batteries according to different application. Wind turbine grid integration application needs deep cycle, heavy duty batteries that designed for high reliability and long life so it can be fully charged and discharged. Battery developments are ongoing to develop a fast charging rate and lighter batteries.

**Battery**
There are three important types of batteries that have been developed and they operate as the conventional batteries but in large scale and they have a long life and low temperature performance and they are:
1. Lead-Acid (LA)
2. Nickel-Cadmium (NiCd)
3. Sodium-Sulphur (NaS)

These types of batteries have two electrodes that are immersed in an electrolyte, to produce a current as a result of a chemical reaction. There is another type of battery energy storage called flow batteries energy storage (FBES) that are electrochemical energy storage based. These types of batteries have a charge to discharge ratio, depth of charge (DOC) and memory effect terminologies and they are three primary types.
1. Vanadium-Redox (VR)
2. Polysulphide-Bromide (PSB)
3. Zinc-Bromine (ZnBr)

**Supercapacitor Energy Storage (SCES)**
Lithium-ion supercapacitors or ultracapacitors are consisting of to parallel metal plates, one coated with activated carbon and another one is coated with Lithium doped carbon and they are separated by an insulator. The plate coated with activated carbon has a positive charge and the other which is coated with Lithium doped carbon has a negative charge and both electrodes are immersed in Lithium salt solution as an electrolyte. During charging, negative ions move toward the positive electrode and positive ions move to the negative electrode and this induce an electric field so that energy can be stored. Supercapacitors have many advantages over the regular batteries and it can be connected either in series or in parallel. They have energy density about of 20 MJ/m³ to 70 MJ/m³ and efficiency of 95%, fast charge and discharge rates and long cycle life about 1 x 10⁶ cycles. In addition, supercapacitors show minimal degradation due to the deep discharge, no deed for heat dissipation because it does not heat up and does not produce hazardous substances. Although supercapacitors have a relatively low energy density, it is very good for short time compensation for stabilization and fluctuation and it can be rated even up to 5000F.

**IV. SIMULATION RESULTS**
To verify the feasibility of the proposed scheme, MATLAB simulations have been performed for a 30[KW] PMSG wind turbine system. The system parameters for the simulation are listed in Table 1.
The grid voltage is 0.6[kV]/60[Hz]. The parameters of the ESS are listed in Table2. The grid voltage is 600[V]/60[Hz]. The DC-link voltage is controlled at 500[V] for the IGBT back-to-back PWM converters, for which the switching frequency is 5[kHz]. In case of grid site 3 phase fault occurrence, the grid power becomes 0. Also it is observed that when the grid power becomes 0, the DC volt is constant, approximately 500volts and the fault period is 0.1 seconds to 0.3 seconds.

![Graph](image_url)

**Fig.3**

V. CONCLUSIONS

This paper has proposed ride-through and power smoothening techniques for PMSG wind turbine systems using an ESS. It has been shown that the power capacity of the ESS can be reduced by up to half of the power rating of the system, when compared with the conventional method, while the performance of the system is kept unchanged under power fluctuations and abnormal grid voltage conditions.

**TABLE 1: Parameters of 30KW PMSG**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>30 KW</td>
</tr>
<tr>
<td>Stator voltage</td>
<td>600V</td>
</tr>
<tr>
<td>Stator resistance</td>
<td>0.000856 ohm</td>
</tr>
</tbody>
</table>

**TABLE 2: Parameter of ESS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated energy of ESS</td>
<td>1 MJ</td>
</tr>
<tr>
<td>ESS power</td>
<td>50KW</td>
</tr>
<tr>
<td>Operating Voltage of Vcap</td>
<td>500V</td>
</tr>
<tr>
<td>Capacitance of battery</td>
<td>200F</td>
</tr>
<tr>
<td>Capacitance of Supercapacitor</td>
<td>500F</td>
</tr>
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</table>
REFERENCES


