LVRT CONTROL FOR WIND GENERATORS IN TERMS OF TWO BESS TOPOLOGICAL STRUCTURES

Wenxia Pan, Rui Quan, Chengcheng Zhang, Jianhong Zhu, Haiping He
Research Center for Renewable Energy Generation Engineering, Ministry of Education, Hohai University
Nanjing, China
E-mail: quanruihaoyang@163.com

ABSTRACT
With the development of battery storage device and technology, many scholars begin to conduct research into the field and gain considerable achievements. Up to now, two main Battery Energy Storage System (BESS) topologies have been applied to enhance the Doubly-Fed Induction Generator (DFIG) Low Voltage Ride Through (LVRT) capacity. In the first one, BESS units are installed at the DFIG back-to-back converter dc-link. While in the second one, single BESS unit is placed at the point of common coupling (PCC). As the different BESS configurations will result in different working principles and battery demands capacity during the whole process of LVRT. Therefore, based on the two topological structures, this paper has made a successful analysis and comparison of output power and battery demands capacity of BESS in the same request of LVRT capacity.

KEY WORDS
Battery Energy Storage Systems (BESS), Doubly-Fed Induction Generator (DFIG), Low Voltage Ride Through (LVRT), Battery demands capacity

1. Introduction
As the energy crisis and the consciousness of the environmental protection cause more and more attention. So the low pollution, low carbon, and reliable wind power generation has got a rapid development recently. The installed capacity of wind driving power is being larger and larger. With the increasing penetration lever, we can not ignore the influence of wind turbines running state on the whole grid system. Just on this background [1], [2]. Many countries grid have stipulated by the strict technical requirements for wind power plants accessing to the whole grid. The common requirements include Low Voltage Ride Through Control, Reactive Power Control, Active Power Control, Frequency Control and etc. The LVRT Control is deemed to the largest challenge between these wind power control technologies. Because the LVRT capacity is largely related to large-scale application of wind power.

The doubly-fed induction generators (DFIG) have been extensively adopted for the current commercial mega-watt wind turbines. Because the rotor speed of DFIG is only 40%-60% of the synchronous speed, so there will be a slip power transferred bidirectionally by DFIG converter. The volume of DFIG is relatively small. The cost of DFIG is also much lower. But compared to other kinds of wind power turbines, DFIG units are more difficult to realize LVRT capacity. Recently, with the development of large-capacity energy storage device and technology, people have began to improve the LVRT ability based on the energy storage device. The uses of battery energy storage system (BESS) are widespread nowadays. As far as BESS configuration concerned, there will be completely different in their topology structure. Up to now, it has been presented the major two kinds of topology structure. In [3], [4], it proposed that BESS units were installed at the DFIG back-to-back converter dc-link for improving the LVRT capacity. In this scheme, the BESS interface circuit belongs to be DC/DC. In [5], it suggested that DFIG can also achieve the same LVRT ability, by placing BESS at PPC. And in this scheme, the topological structure turned out to be DC/AC. Although two schemes have been presented, but so far there have been no research on discussing which kind of schemes can possess...
2. LVRT Control Strategy

In order to analyze the difference of battery demand capacity, it is necessary to first introduce the control strategy of BESS. Although the two BESS topological structures can achieve the same LVRT capability, but the control strategy of the two BESS configurations are totally different.

2.1 Influence By Voltage Dip

When local system has a voltage drop, it will cause the power network voltage falling down instantly. As the DFIG Stator connects to the power grid directly, it will lead to the DFIG terminal voltage decreasing. And then the output active power of DFIG will be reducing, accompany with the stator current rising. At this moment, the strong coupling effect is being produced between the stator and rotor. So the rotor current will also increase immediately. According to the magnetic flux linkage conservation principles, generator stator flux can not change at once. At the beginning, the stator flux contains a dc component. As the dc component decays rapidly, so the stator flux will achieve stability at once, then it declines at the same proportion as the generator terminal voltage. While the electromagnetic torque is directly proportional to stator flux, so it will decrease correspondingly. Meanwhile, if the wind speed remains unchanged, it is equal to keeping a constant torque input to generators. Eventually, it will cause rotor speed increasing. As DFIG units may run at super synchronous, synchronous or sub-synchronous speed, so the active power through the rotor-side converters (RSC) and grid-side converter (GRC) respectively will be inconsistent. It can lead to dc bus voltage fluctuating finally[6], [7]. Further, the rising or falling of dc bus voltage is decided by the generators running states at super synchronous or sub-synchronous speed when voltage dip happens in the grid [5].

2.2 BESS Configuration at DC-Link

In [3], [4], they both referred that the BESS should be installed at back-to-back converter dc-link for improving the DFIG LVRT capability. But there are different in the BESS operation modes. In [3], it suggested to place the BESS at the DFIG back-to-back converter dc-link, by absorbing or releasing the active power to suppress the wave. As the active powers through the RSC and GRC respectively are unbalanced, so it will cause the voltage of dc-bus fluctuating. The control strategy based on this kind of control structure is shown in Fig.1.

2.3 BESS Configuration at PCC

As the performance characteristics of wind power are intermittent and randomness, it will cause the output...
power of the wind generators waved largely. It will can not be unacceptable for the system to access a large installed capacity of wind driving power. In order to solve the problem, we can set the BESS at the PCC of Wind Farm. Then the BESS will absorb or release the power to stabilize the fluctuation during the whole process. In this case, the whole BESS topological structure is shown in Fig. 2.

![Fig.2 Topological structure based on BESS configuration at PCC](image)

In Fig.2, DC/DC Bidirectional Chopping Circuit can work on the following two modes:

A. During the process of aluminum battery in charging, Chopping Circuit should operate on Buck Circuit status.

B. During the process of aluminum battery in discharging, Chopping Circuit can work on Boost Circuit status.

In this paper, it has adopted a four-quadrant Voltage Source Inverter in AC/DC Bidirectional Converter. The aim of the AC/DC Converter is designed to realize the Nonlinear PI Coupled Control of the Active Power and Reactive Power. Just by regulating the phase and amplitude of the grid-side bus current, BESS can absorb or release the reactive power according to the specific requirement. In [9], it put forward that BESS can control the reactive power output competently just by tracking the dynamic change of the PCC voltage. And the BESS will provide a fit reactive current to stabilize the system. Foremost, it will play a supporting role on the recovery of power grid voltage, so as to achieve a better LVRT capability level. Fig. 3 shows the control strategy of LVRT based on BESS configuration at PCC.

![Fig.3 The control strategy of LVRT based on BESS Configuration](image)

### 3. Comparison of Different BESS Configurations

As previously mentioned, there have been no research on the comparison of the different BESS configurations at least so far. Firstly, the different roles played in the different configurations should be clearly distinguished. And this section mainly studies on the specific difference in the battery demand capacity during the whole process of LVRT. In order to express the details more conveniently, the following gives the own introduction of the two schemes:

i. Scheme One: 20 BESS units were installed at each DFIG back-to-back converter dc-link.

ii. Scheme Two: Single BESS unit was installed at the PCC shown in Fig. 4.

### 3.1 Comparison of Different Roles

Based on the above analysis, we can conclude that the
main role of BESS is to suppress the dc-link voltage fluctuation in Scheme One. While in Scheme Two, the main function is designed to control the reactive output by tracking the PCC voltage dynamically. And then it will provide the reactive current to satisfy the stability of the grid system, thereby enhancing the LVRT capacity.

3.2 Comparison of Battery Capacity Demands

Supposed at the same LVRT ability level based on the two schemes, the key point is to study the different battery capacity demands. In Fig.4, the system model has been built on the PSCAD/EMTDC simulation software.

![Fig.4 System simulation model](image)

In Fig.4, the whole system simulation mode shows that twenty doubly-fed induction generators are passing through a 0.86/10kV step-up transformer independently and then connecting to the PPC all together. And PCC bus connects to the 110kV system through a 10/115kV step-up transformer. Some main system parameters are shown in Table 1 and Table 2. Wind turbines speed was set at a constant value 16m/s.

<table>
<thead>
<tr>
<th>$V_{in}$</th>
<th>$V_R$</th>
<th>$V_{out}$</th>
<th>$\rho$</th>
<th>$R$</th>
<th>$P_N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4m/s</td>
<td>16m/s</td>
<td>25m/s</td>
<td>1.225kg/m³</td>
<td>40m</td>
<td>2MW</td>
</tr>
</tbody>
</table>

Table 1

Wind Turbine Parameters

As many kinds of faults can cause the system voltage dip, and different system faults level can cause the different degree of voltage drop. Considered as many factors as possible, this simulation work sets the voltage drop rate at 30%, 50%, 70%, the recovery time at 0.5s, 0.3s, 0.2s respectively. The total simulation time was set at 4s. The starting time of fault was set at 2s.

3.3 The Simulation Results and Analysis

Making a simulation with PSCAD/EMTDC software, we can print the following parameter waveform diagrams by adopting Scheme One and Scheme Two separately.

<table>
<thead>
<tr>
<th>$U_N$</th>
<th>$f_N$</th>
<th>$P_N$</th>
<th>$R_s$</th>
<th>$R_r$</th>
<th>$L_{ls}$</th>
<th>$L_{lr}$</th>
<th>$L_m$</th>
<th>$T_J$</th>
</tr>
</thead>
<tbody>
<tr>
<td>690V</td>
<td>60Hz</td>
<td>2MW</td>
<td>0.00164pu</td>
<td>0.002pu</td>
<td>0.03pu</td>
<td>0.03pu</td>
<td>2pu</td>
<td>1s</td>
</tr>
</tbody>
</table>

Table 2

Doubly-Fed Induction Generator Characteristics
3.3.1 Waveform diagrams when voltage drop rate at 30%

In Fig.5, four simulation graphics have been obtained by supposing that the voltage dip happened at 2s. From the first picture, we can see that there is a good efficacy to protect the voltage drop rate reducing to 20%. If there are no protection to act on the system fault, the voltage drop rate will stay at 30%. Further to see, the oscillograms of PCC Voltage are almost coincident between Scheme One and Scheme Two. It is equal to represent that the two schemes can result almost the same LVRT capacity. Although the BESS topologic structures and the working principles are completely different, but the two schemes can reach the same LVRT ability lever just by some specific controls.

The second picture in Fig.6 shows that the waveforms of Output Reactive Power in the two schemes are very close to each other.

And the last two pictures show the oscillograms of Output Active Power of BESS respectively. Seen from them, the Output Active Power of single BESS unit is 0.8MW. As the whole wind farm has installed 20 BESS units at each DFIG back-to-back converter dc-link. So the total requirement for Output Active Power ($P_1$) is 16MW. Meanwhile, based on Scheme Two, BESS should output 48MW Active Power ($P_2$) during the process of voltage dip.

According to the above data, we can calculate the battery demand capacity respectively as the following (1), (2).

$$C_1 = P_1 \times t = 16MW \times 0.5s = 2.22kWh \quad (1)$$

$$C_2 = P_2 \times t = 48MW \times 0.5s = 6.66kWh \quad (2)$$

The parameter $t$ in the above formulas (1), (2) is defined as the fault recovery time. The parameters $P_1, P_2$ are regarded as the average output active power of BESS during the recovery time. So the ratio of the battery demand capacity between the two schemes can be figured out as 0.33:1 approximately.
3.3.2 Oscillograms of parameters when voltage drop rate at 50% and 70%

a) Voltage of PCC

b) Output Reactive Power of BESS

c) Output Active Power of BESS (Scheme One)

b) Output Reactive Power of BESS

d) Output Active Power of BESS (Scheme Two)

Fig. 6 Waveform diagrams when voltage drop rate at 50%
c) Output Active Power of BESS (Scheme One)

Fig. 7 Waveform diagrams when voltage drop rate at 70%

Fig. 6 and Fig. 7 show the different oscillograms of parameters during the voltage dip rate at 50% and 70% respectively. We can make a similar analysis as the previous section.

Seen from Fig. 6, the Output Active Power of single BESS unit is 1.1MW, so the total active power is 22MW based on Scheme One. While in Scheme Two, BESS should output 54MW Active Power to demand for the LVRT.

In Fig. 7, the Output Active Power of single BESS is 1.3MW in Scheme One, so the total is 26MW. And compared to the Scheme Two, BESS should output 53MW Active Power during the voltage dip. By adopting the similar analysis, the ratios of the battery demand capacity can be calculated out. And the total results are shown in Table 3.

<table>
<thead>
<tr>
<th>Voltage dip rate</th>
<th>Scheme One BESS Demand Capacity (kWh)</th>
<th>Scheme Two BESS Demand Capacity (kWh)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>2.22</td>
<td>6.66</td>
<td>0.33:1</td>
</tr>
<tr>
<td>50%</td>
<td>3.06</td>
<td>7.64</td>
<td>0.40:1</td>
</tr>
<tr>
<td>70%</td>
<td>1.44</td>
<td>2.94</td>
<td>0.49:1</td>
</tr>
</tbody>
</table>

Seen from Table 3, the battery demand capacity of the two schemes are different during the whole process of LVRT. Furthermore, the battery demand capacity of Scheme One is relatively less. And the ratio between the Scheme One and Scheme Two work out to be 0.33, 0.40 and 0.49 when the voltage dip rate set at 30%, 50% and 70% respectively. Taken as many fault factors as possible, the ratio will be 0.3~0.5 approximately. Because the value of the proportion will increase with the growth of voltage drop rate correspondingly.

3.3.3 Comparison of other aspects

In Scheme One, BESS units are installed at the DFIG back-to-back converter dc-link. And the BESS topological structure proves to be a DC/DC circuit. However, in Scheme Two, the single BESS unit is placed at the PCC, connecting to a AC circuit directly. So the BESS topological structure is a DC/AC circuit. And there are different requirements for nominal capacity of BESS interface converters. In general case, the nominal capacity in Scheme Two should be 1.24~1.43 times of that in Scheme One[10]. In addition, there are two operation modes to achieve the LVRT capability in Scheme One. While in Scheme Two, BESS can only work on a single mode by controlling the Output Reactive Power of BESS during the process of LVRT. Just from this perspective, it is considered that Scheme One is more flexible than Scheme Two. More over, as far as the LVRT capacity limit concerned, Scheme One have an advantage over Scheme Two. Because the rotor speed of DFIG is only 40%~60% of the synchronous speed, so the the power transferred by converter is 40%~60% of DFIG nominal
capacity in Scheme One. It means that there will be a slip power flowing bidirectionally through the back-to-back converter. However in Scheme Two, the percentage of the BESS capacity in the total installed capacity of wind driving power is only 25% [11]. It results the difference of the LVRT capacity limit. And the Scheme One is superior to the Scheme Two explicitly . So when there happens a large voltage dip in system, there is more efficient LVRT capability by installing the BESS at DFIG back-to-back converter dc-link than at PCC.

4. Conclusion

This paper has analyzed and compared the control strategies and operating modes of BESS based on the two topological structures. Above all, this paper has mainly studied on the BESS demand capacity in terms of the two schemes. According to the results of the simulation and analyzation, we can get the following conclusions:

1) Based on the same LVRT capacity level, the proportion range of BESS demands capacity between the configuration at dc-link and at PCC will be 0.3 ~0.5 approximately. Because the value of the proportion is related to the voltage drop rate. More precisely, the ratio will increase with the growth of voltage dip rate.

2) If BESS units are installed at DFIG back-to-back converter dc-link, there will be some advantages over that at PCC on the aspects of operation modes and LVRT capacity limits during the process of voltage dip.

References


[9] He.P.P, Research on low voltage ride through technology of wind power Based on battery energy system (College of electrical engineering, , HHU, Nanjing, 2012).
