A Study on Safety Evaluation in ESS Considering CMV

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Abstract. Recently, the studies for risk level evaluation considering the safety standards are being actively conducted because of fire accidents that be frequently occurred in energy storage systems (ESS). Among these studies, the common mode voltage (CMV) may be negatively influenced ESS safety. Therefore, this paper presents the evaluation considering CMV using the risk priority number (RPN) evaluation method and performs ESS safety evaluation modeling using PSCAD/EMTDC. From the simulation results based on the proposed modeling, the CMV due to IGBT switching is evaluated as "low risk" area. And the CMV due to lightning strike and CB switching during 3-phase short-circuit fault, grounding fault is evaluated as "medium risk" area. additionally, CMV due to MC switching in normal operation is evaluated as "high risk" area. Therefore, it is confirmed that the CMV due to MC switching in normal operation may negatively and seriously influence to ESS safety.

Keywords: Safety Evaluation Method, Common Mode Voltage, RPN Method, Energy Storage System

1. Introduction

This paper presents an evaluation considering CMV using the risk priority number (RPN) evaluation method, which is composed of severity, occurrence and detection degrees and performs ESS safety evaluation modeling. Where, severity degree represents the impact on customers in the case of failure; occurrence degree is defined as possibility of system failure; and detection degree reflects the possibility of detecting potential failure in advance. Namely, severity degree of CMV is classified as "low", "medium", "high", and "very high" based on the magnitude of CMV, and occurrence degree is classified as "low", "medium", and "high" by considering the possibility of system failure. And also, detection degree is classified as "low", "medium", and "high" according to the detection of potential CMV. From the simulation results based on the proposed safety evaluation method for CMV, it is confirmed that the CMV due to MC switching in normal operation may negatively and seriously influence to ESS safety.

2. Safety Evaluation Method for CMV in ESS

As the existing RPN method is too complex to evaluate safety due to various conditions and scenarios, this paper classifies risk degree into “low”, “medium”, “high”, and “very high” as shown in Fig. 1.

<table>
<thead>
<tr>
<th>RPN(SO*D)</th>
<th>RPN rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>severity(S)</td>
<td>low</td>
</tr>
<tr>
<td>occurrence(O)</td>
<td>low</td>
</tr>
<tr>
<td>detection(D)</td>
<td>low</td>
</tr>
</tbody>
</table>

Fig. 1. Proposed RPN chart
Where, the severity degree (S) is calculated as 4 levels according to the magnitude of CMV and the detection degree (D) is evaluated as 3 levels inversely proportional to the magnitude of CMV, as shown in Table 1. In addition, the occurrence degree (O) is classified as 3 levels as shown in Table 2.

### Table 1. Severity and detection evaluation of CMV

<table>
<thead>
<tr>
<th>CMV magnitude</th>
<th>severity degree</th>
<th>detection degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>over several times of insulation breakdown voltage</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td>over insulation breakdown voltage</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>between rated voltage and insulation breakdown voltage</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>less than rated voltage</td>
<td>low</td>
<td>high</td>
</tr>
</tbody>
</table>

### Table 2. Occurrence evaluation of CMV

<table>
<thead>
<tr>
<th>frequency of occurrence</th>
<th>occurrence degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>changing and discharging in ESS is frequently occurred</td>
<td>high</td>
</tr>
<tr>
<td>fault rate in ESS is rarely occurred</td>
<td>medium</td>
</tr>
<tr>
<td>lightning strike is very rarely occurred</td>
<td>low</td>
</tr>
</tbody>
</table>

### 3. CMV modeling of ESS using PSCAD/EMTDC

The entire modeling of characteristics of CMV in ESS using PSCAD/EMTDC can be illustrated as shown in Fig. 2. Where, section A is AC source section composed of main transformer, distribution feeder and grid-connected transformer; section B is PCS section with IGBTs and DC link capacitors; section C is battery section with battery racks and DC line; section D is fault generating device for simulating DC-side fault; and section E is lightning strike device for supplying lightning to the distribution system.

![Fig. 2. Modeling of the entire system](image)

### 4. Case Studies

#### 4.1 Simulation conditions

In order to evaluate the safety of ESS considering CMV, this paper assumes simulation conditions such as stray capacitance of battery, battery rated voltage, switching frequency of PCS and etc. as shown in Table 3.

### Table 3. Simulation conditions

<table>
<thead>
<tr>
<th>items</th>
<th>contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>capacity of ESS</td>
<td>1[MWh]</td>
</tr>
<tr>
<td>stray capacitance of battery section</td>
<td>20[nF]</td>
</tr>
<tr>
<td>battery rated voltage</td>
<td>1[kV]</td>
</tr>
<tr>
<td>voltage ratio of TR</td>
<td>22.9[kV]/440[V]</td>
</tr>
<tr>
<td>magnitude of lighting strike</td>
<td>50[kV]</td>
</tr>
<tr>
<td>switching frequency of PCS</td>
<td>4[kHz]</td>
</tr>
</tbody>
</table>

#### 4.2 Safety evaluation of ESS considering characteristics of CMV

Based on the proposed safety evaluation method, the safety of ESS due to CMV can be obtained as shown in Table 4. Namely, among the five causes of CMV, the CMV due to MC switching in normal operation is evaluated as "high risk" and may negatively and seriously influence to ESS safety.

### Table 4. ESS safety evaluation considering CMV

<table>
<thead>
<tr>
<th>CMV types</th>
<th>magnitude of CMV [kV]</th>
<th>severity degree</th>
<th>occurrence degree</th>
<th>detection degree</th>
<th>risk priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGBT switching</td>
<td>0.5</td>
<td>low</td>
<td>low</td>
<td>high</td>
<td>low risk</td>
</tr>
<tr>
<td>MC switching in normal operation</td>
<td>2.5</td>
<td>medium</td>
<td>high</td>
<td>medium</td>
<td>high risk</td>
</tr>
<tr>
<td>CB switching in short circuit</td>
<td>4</td>
<td>high</td>
<td>medium</td>
<td>low</td>
<td>medium risk</td>
</tr>
<tr>
<td>CB switching in single line grounding</td>
<td>3.1</td>
<td>high</td>
<td>medium</td>
<td>low</td>
<td>medium risk</td>
</tr>
<tr>
<td>lightning strike</td>
<td>18</td>
<td>very high</td>
<td>low</td>
<td>low</td>
<td>medium risk</td>
</tr>
</tbody>
</table>

### References