Assessment on Voltage Sag in Distribution Network Considering Action Time of Relay Protection

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Abstract

In traditional assessments on voltage sag are simply assumed that the duration obeys some distribution of random or is a constant value. In order to obtain a more accurate assessment of voltage sag, the more accurate duration of voltage sags are needed. The duration of voltage sag caused by fault is depended on the fault clearing time of the protection system. Time characteristic of stepped current protection and protection scope of instantaneous current protection are taken into consideration, the two demarcation points of the protection operation on line are determined, the protection operation time of every segment is analyzed. An example is simulated by PSCAD/EMTDC software, and it is shown that more reasonable assessment is obtained by precise duration of voltage sag.

Keywords: voltage sag, assessment, duration time, stepped current protection.

1. INTRODUCTION

In recent years, with the use of power electronic equipment increasing, electricity loads are more and more sensitive to voltage sag (Naidu, 2012). Voltage sag will cause the program logic controller malfunction, speed regulating device disoperation, and computer data loss (Chan, 2007). Voltage sags which last for only few tenths of a second may cause production stops with considerable associated costs; these costs include production losses, equipment restarting, damaged or lower-quality product and reduced customer satisfaction (Djokic’, 2005; Jong, 2007; Djokic, et al., 2005; Sohel et al., 2012; Petronijevic’ et al., 2011; Gupta, 2006). Voltage sag has become one of the most important power quality problems in power system, Voltage sags caused by the user complaints account for the entire power quality problems complaints 80%. Hence it is necessary to analyze and assess voltage sags (Park, 2007; Juan, 2006) reasonably.

The voltage sag can be caused by short circuit fault, switching operation, the switching of transformer and capacitor, the starting of the large capacity motor in the power system. The influence scope and degree of voltage sag caused by short fault (Milanovic, 2005) is more serious, so the analysis and mitigating of voltage sag (Flavio 2013; Vilathgamuwa 2006; Rubens et al., 2005; Mehdi 2013; Jafari et al., 2011; Wang 2007) caused by short circuit fault has important practical significance.

The value and duration of voltage sag are two important characteristic quantities. Sensitive equipment will show different sensitivity to the voltage sag under different amplitude and duration time. The existing literature has pointed out that the duration time of the voltage sag is determined by the time of the protection of the fault (Le et al., 2010; Aung, 2006), but there is no analysis on general correspondence between the inherent characteristic of the protection action and the duration time of the voltage sag. In traditional assessments on voltage sag (Rodney 2012) are simply assumed that the duration obeys some distribution of random or is a constant value, in traditional
assessments on voltage sag are simply assumed that the duration obeys some distribution of random or is a constant value. For the line without using the full line speed protection, it is not simply assume that the voltage sag duration time of any position on the line is fixed, And the duration time of voltage sag should be determined by line protection time limit characteristics (Chen et al., 2013). Therefore it is necessary that the duration of voltage sag should be depicted precisely to obtain more reasonable and reliable assessment.

Generally the duration of voltage sag is depended on the fault clearing time of the protection system. The damage degree of voltage sag is influenced by the protection characteristic (Chen et al., 2012) and the fault clearing time of the protection operation. Stepped current protection (Wang et al., 2006) is used in distribution network (WANG 2006), instantaneous current protection (Istep) and time-limited instantaneous current protection (IIstep) are line main protection, over current protection (III step) is line backup protection. For this reason, the fault clearing time of line isn’t simply assumed same, the duration of voltage sag should be depicted by time characteristic (Chen et al., 2013) of line protection.

In this paper, in order to depict the duration of voltage sags more precisely, time characteristic of stepped current protection and protection scope of instantaneous current protection are taken into consideration, two demarcation points of protection operation on line are determined, line is divided into three sections: step protection operation section, step protection operation section and the protection operation section to be determined. For step and step protection operation section, without considering the operation mode and fault type, the fault clearing time is determined quickly and accurately. The example simulated by PSCAD/EMTDC software demonstrates that more reasonable assessment is obtained by precise duration of voltage sag.

2. TIME CHARACTERISTIC OF STEPPED CURRENT PROTECTION

The time characteristic of protection is the relation between the time of protection action and the position of short circuit point, the protection time limit characteristic mainly is decided by the protection principle and the protection setting value. Because the whole line can’t be protected by the instantaneous current protection, the end of line 1 is protected by time-limited instantaneous current protection, and the head of line 2 is protected by instantaneous current protection. The fault currents of the end of line 1 and the head of line 2 are almost the same, however, according to the time characteristic of stepped current protection, for the end of line 1, the fault clearing time is more.

3. PROTECTION SCOPE OF INSTANTANEOUS CURRENT PROTECTION
The duration of voltage sag caused by fault is depended on the fault clearing time of the protection system. When fault happen on line, the operation mode, system fault type and fault location should be taken into consideration to determine the fault clearing time.

Short circuit current is influenced by the operation mode, system fault type and fault location. Three phase short circuit current can be expressed as

\[ I_k = \frac{E_\phi}{Z_s + Z_k} \]  

Where \( E_\phi \) is the phase voltage of equivalent source, \( Z_s \) is the impedance between protection element mounting point and equivalent source, \( Z_k \) is the impedance between fault point and protection element mounting point.

For the protection device, the operation mode under which short-circuit current of protection element mounting point is maximum is known as the maximum operation mode. The operation mode under which short-circuit current of protection element mounting point is minimum is known as the minimum operation mode. In order to ensure the selectivity of instantaneous current protection, starting current of the protection device must be larger than the current \( I_{k\text{max}} \) produced by the three-phase short circuit fault occurring on the end of protected line under the maximum operation mode.

\[ I_{\text{k,max}}^{(3)} = \frac{E_\phi}{Z_{s,\text{max}} + zL} \]  

Where \( Z_{s,\text{max}} \) is the impedance between protection element mounting point and equivalent source under the maximum operation mode, \( z \) is the unit impedance of line, \( L \) is the length of line protected.

\[ I_{\text{set}}^1 = K_{rel}^1 I_{\text{k,max}}^{(3)} \]  

Where \( K_{rel}^1 \) is the confidence coefficient, generally its value is 1.2~1.3.

The maximum operation mode, the minimum operation mode and fault type are taken into consideration, protection zone of instantaneous current protection can be written as follows:

Under the maximum operation mode three-phase short circuit occur, the protection zone is:

\[ I_{\text{max}}^{(3)} = \frac{1}{z} \left( \frac{E_\phi}{I_{\text{set}}^1} - Z_{s,\text{max}} \right) \]  

Under the maximum operation mode two-phase short circuit occur, the protection zone is:

\[ I_{\text{max}}^{(2)} = \frac{1}{z} \left( \frac{\sqrt{3}E_\phi}{2I_{\text{set}}^1} - Z_{s,\text{max}} \right) \]
Under the minimum operation mode three-phase short circuit occur, the protection zone is:

\[ I_{\text{min}}^{(3)} = \frac{1}{z} \left( \frac{E_0}{I_{\text{set}}} - Z_{s,\text{min}} \right) \]  

(6)

Where \( Z_{s,\text{min}} \) is the impedance between protection element mounting point and equivalent source under the minimum operation mode.

Under the minimum operation mode two-phase short circuit occur, the protection zone is:

\[ I_{\text{min}}^{(2)} = \frac{1}{z} \left( \frac{\sqrt{3}E_0}{2I_{\text{set}}} - Z_{s,\text{min}} \right) \]  

(7)

4. THE FAULT CLEARING TIME BASED ON STEPPED CURRENT PROTECTION

Under the maximum operation mode, three-phase short circuit fault occurs, if the fault point is within the scope of \( l_{\text{max}}^{(3)} \) protection, the fault clearing time is the first step protection operation time, if the fault point is within the scope of \( l_{\text{min}}^{(3)} \) protection, the fault clearing time is the second step protection operation time. Similarly, for each operation mode, the each fault type has the corresponding scope of protection in line.

Line ij in Figure 2 as an example, under the maximum operation mode, three-phase short circuit fault occurs, the scope of \( l_{\text{max}}^{(3)} \) protection is maximum, its corresponding demarcation point is \( N_{\text{max}} \). Under the minimum operation mode, two-phase short circuit fault occurs, the scope of \( l_{\text{min}}^{(2)} \) protection is minimum, its corresponding demarcation point is \( M_{\text{min}} \). Similarly, the corresponding demarcation point of \( l_{\text{min}}^{(3)} \) is \( M_{\text{max}} \).

![Figure 2. The protection scope and its corresponding demarcation point](image-url)

From the Figure 2, line ij is divided into three sections by \( M_{\text{min}} \) and \( N_{\text{max}} \). When the fault point is within \( iM_{\text{min}} \) section, whether the system is what kind of operation mode, what type of short circuit, short circuit current is greater than the starting current \( I_{\text{set}} \), the fault clearing time is the first step protection operation time, for this reason, \( iM_{\text{min}} \) section is known as the first step protection operation section. When the fault point is
within \( N_{i\text{max}} \) section, whether the system is what kind of operation mode, what type of short circuit, short circuit current is less than the starting current \( I_{\text{set}} \), the fault clearing time is the \( II \) step protection operation time; \( N_{i\text{max}} \) section is the \( II \) step protection operation section. When the fault point is within \( M_{i\text{min}}N_{i\text{max}} \) section, the operation mode, fault type and fault location should be taken into consideration to determine the fault clearing time, for this reason, \( M_{i\text{min}}N_{i\text{max}} \) section is the protection operation section to be determined.

In the same way, line \( jk \) is divided into three sections by \( M_{j\text{min}} \) and \( N_{j\text{max}} \) section respectively, the values of voltage sag caused by the two faults are almost the same, however, \( N_{i\text{max}} \) section is \( II \) step protection operation section, \( M_{i\text{min}} \) section is the \( I \) step protection operation section, the protection operation time of \( N_{i\text{max}} \) section is longer, therefore, the voltage sag caused by the fault occurring on \( N_{i\text{max}} \) section is more serious. It can be seen that the voltage sag caused by the fault occurring on the end of line is more serious than that caused by fault occurring on the head of the adjacent next line.

5. EXAMPLE ANALYSIS

An example in this paper is shown in Figure 3, stepped current protection is used in 35kV line 16 and 67. \( I \) step protection operation time is 150 ms, \( II \) step protection operation time is 550 ms. Bus 5 is connected with a voltage sensitive loads PC, if the voltage is less than 60\% and the duration is more than 240 ms, PC will be affected to be loss of data.

The analysis methods described above is used, the example is simulated by PSCAD/EMTDC software. When faults occur on line 16 and 67, the state of PC on bus 5 is analyzed and assessed. The scope of instantaneous current protection and protection operation section of line 16 and 67 are as shown in Table 1 and 2.

**Table 1** The scope of instantaneous current protection of line 16 and line 67 (km)

<table>
<thead>
<tr>
<th>Line ( ij )</th>
<th>( iM_{\text{min}} )</th>
<th>( iN_{\text{max}} )</th>
<th>( eM_{\text{min}} )</th>
<th>( eN_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 16</td>
<td>14.378</td>
<td>0.608</td>
<td>7.253</td>
<td>3.483</td>
</tr>
<tr>
<td>Line 67</td>
<td>23.548</td>
<td>5.87</td>
<td>16.423</td>
<td>8.745</td>
</tr>
</tbody>
</table>

**Table 2** The protection operation section of line 16 and line 67 (km)

<table>
<thead>
<tr>
<th>Line ( ij )</th>
<th>( iM_{\text{min}} )</th>
<th>( N_{\text{min}} )</th>
<th>( iN_{\text{max}} )</th>
<th>( M_{\text{min}}N_{\text{max}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 16</td>
<td>3.483</td>
<td>5.622</td>
<td>10.895</td>
<td></td>
</tr>
<tr>
<td>Line 67</td>
<td>8.745</td>
<td>1.452</td>
<td>14.803</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.** An example of voltage sag analysis based on stepped current protection
5.1 For a line, if the fault clearing time is simply assumed same, big error assessment results would be obtained.

(1) If the fault clearing time of line 16 is simply assumed 150ms, regardless of voltage sag value of bus 5, the assessment results for the PC is without loss of data. In fact, when the fault point is within $N_{1\text{max}}$ section, (I step protection operation section), that is the fault clearing time is 550ms, and $U_{5\text{sag}} < 0.6$, the PC is loss of data.

(2) If the fault clearing time of line 16 is simply assumed 550ms, when $U_{5\text{sag}} < 0.6$, assessment results for the PC is loss of data, but in fact when the fault point is within $M_{1\text{min}}$ section (I step protection operation section), that is the fault clearing time is 150ms, the PC is without loss of data.

5.2 The voltage sag caused by the fault occurring on the end of line is more serious than that caused by fault occurring on the head of the adjacent next line.

Under the maximum operation mode, two three-phase short circuit faults occur on E and F respectively, the distances of E and F to bus 6 are 2km, as shown in Figure 3. The voltage sags value of bus 5 caused by the two faults have little difference, they are less than 0.6, but the PC state have nothing in common, as shown in TABLE 3. The voltage sag caused by the fault occurring on E is more serious than that caused by fault occurring on F. In this case, the main cause of PC of data loss is the fault clearing time.

<table>
<thead>
<tr>
<th>Fault point</th>
<th>$U_{5\text{sag}}$</th>
<th>Duration Time</th>
<th>PC state</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>0.53</td>
<td>550ms</td>
<td>loss of data</td>
</tr>
<tr>
<td>F</td>
<td>0.57</td>
<td>150ms</td>
<td>Without loss of data</td>
</tr>
</tbody>
</table>

5.3 For the protection operation section to be determined, the operation mode, fault type and fault location should be taken into consideration to determine the fault clearing time. When the fault point is within the corresponding protection scope, I step protection operate, PC is without loss of data, when the fault point is beside the corresponding protection scope, II step protection operate, if $U_{5\text{sag}} < 0.6$, PC is loss of data, if $U_{5\text{sag}} > 0.6$, PC is without loss of data.

6. CONCLUSION

When short circuit faults occur in the actual power network, the characteristics of line protection has great influence on the characteristic of voltage sag. On the basis of the current evaluation method of voltage sag, the evaluation method of voltage sag considering the characteristics of line protection time limit is proposed, which makes the evaluation result more practical. The protection time limit characteristic reflects the actual process of the fault cleared on the line.

According to time characteristic of stepped current protection and protection scope of instantaneous current protection, two demarcation points of protection operation on line are determined, line is divided into three sections: I step protection operation section, II step protection operation section and the protection operation section to be determined. For I step and II step protection operation section, without considering the operation mode and fault type, the fault clearing time is determined quickly and accurately. The example demonstrates that more reasonable assessment is obtained by precise duration of voltage sag.
7. REFERENCES


