VOLTAGE SAG SOURCE LOCATION IDENTIFICATION

Ahmed LATHEEF
University of Tasmania – Australia
alatheef@utas.edu.au

Michael NEGNEVITSKY
University of Tasmania – Australia
Michael.Negnevitsky@utas.edu.au

Vitaly FAYBISOVICH
Southern California Edison - CA, USA
Vitaly.Faybisovich@sce.com

ABSTRACT

In recent years several methods have been proposed to identifying the voltage sag source location. The basis of most of these methods is to determine if the source originated upstream or downstream from the monitoring location. This study proposes a method that is capable of identifying the voltage sag originated bus. A technique of observing the network based coefficients is applied network wide, where any unmonitored bus voltages are estimated prior to making a decision on voltage sag source location. The study concludes with the outcome and limitation of this method and proposes further improvement.

INTRODUCTION

Voltage sag is regarded by many as one of the most problematic types of power quality (PQ) disturbances within electric power systems. In the past, several methods were proposed in identifying the location of these voltage sags [1-9]. Most of these methods rely on the decision made from one monitoring bus, whether the voltage sag originated from upstream or downstream from that bus. Therefore these methods may not be directly applicable for identifying the network wide voltage sag location. One application of the existing methods for voltage sag source location techniques is used by industrial customers in determining if the voltage sag initiated within their plant or from the network. Hence, may be useful for determining the responsible party. As for network operators, the existing concepts may lead to inaccurate results in identifying voltage sag location and may require a significant number of monitors, especially in fully meshed networks. In order to address the two cases (industrial customer and network operator), a method is required to accurately identify the exact source of voltage sag and provide voltage estimations of unmonitored buses in the network. This method can be referred as network wide voltage sag source location identification.

The main objective of this study is to propose a new method to identify voltage sag source location in power systems. The proposed method includes establishment of a bus voltage relation coefficient matrix for power system observation. The coefficient matrix is then used to determine the behavior of a given bus change in voltage to that of other buses. Based on the available bus voltage measurements and relationship established from the coefficient matrix, a mean square error is estimated.

VOLTAGE SAG DEFINITION

Two of the most common definitions for voltage sag are given in the Institute of Electrical and Electronics Engineers, Inc (IEEE) and International Electrotechnical Commission (IEC) documents. Discussion on how these standards are applied in commercial power systems is given in [10]. Though the definitions for voltage sag are similar in IEEE and IEC, the definition adopted for this study is based on IEEE [11]. ‘A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min. Typical values are 0.1 to 0.9 pu’ (per unit pu). However, for the purpose of this study the duration of the sag is not incorporated, the minimum value of the voltage during sag is utilised.

POWER SYSTEM MODEL

The test system used in this study is the IEEE 9 bus system. The 9 bus system has 3 voltage controlled buses behind a transformer, 6 load buses and three loads. The existing loads in the system are presented as typical loads consuming MW and MVAr at approximately 0.9 pf. A similar test load was used to create a voltage sag by switching into the system, without a transformer. As for the purpose of this study, connecting a transformer with the load was considered as having insignificant impact creating an extra bus. The IEEE 9 bus test system is shown in Figure 1. It is assumed for steady state condition of power system, the voltage controlled buses are capable of supplying enough reactive power to the system.

Figure 1 IEEE 9 bus test system
Hence controlled buses reach a steady state voltage condition after the load is switched on. The system wide steady state voltages are given in Table 1.

<table>
<thead>
<tr>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>B7</th>
<th>B8</th>
<th>B9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.040</td>
<td>1.025</td>
<td>1.025</td>
<td>1.026</td>
<td>0.996</td>
<td>1.013</td>
<td>1.026</td>
<td>1.016</td>
<td>1.032</td>
</tr>
</tbody>
</table>

Table 1 Steady state voltage of system

**METHOD**

To proceed with the method of analysis of identifying the location of the voltage sag source bus, it is necessary to first observe the network wide voltage changes. Hence, a decision regarding the location of the voltage sag can only be made once all the voltages are observable or estimated in the system. The overall estimation of the systems’ unmeasured voltages is given by (1)

$$V_{est} = [C_{sys}] [V_{measured}] + [\varepsilon]$$

where $V_{est}$ is the estimated voltage matrix of the system, $C_{sys}$ is the systems coefficient matrix, $V_{measured}$ is the available voltage measurements matrix and $\varepsilon$ is the incorporated error in estimating the unmonitored bus voltage.

It is typical in power system studies to represent the voltage sag as a percent of steady state voltage pu. Hence, this gives the ability not only to understand the voltage sag depth, but also to relate the change with other buses in the system. The percentage of voltage sag to that of steady state voltage is given by equation (2).

$$V_{\%} = \frac{V_{ss} - V_{sag}}{V_{ss}} \times 100$$

Where $V_{\%}$ is the percentage change of voltage sag, $V_{ss}$ is the steady state bus voltage and $V_{sag}$ is the minimum value of the voltage sag. The voltage sag source bus can be referred to as the maximum of $V_{\%}$ of all buses, given by equation (3)

$$V_{sag,k} = \max \{V_{\%,1}, V_{\%,2}, V_{\%,3}, \ldots, V_{\%,n}\}$$

Where ‘n’ is number of buses in the system and ‘k’ is the voltage sag source bus. However a decision is only made by $V_{sag,k}$ once all bus voltages are available.

In typical systems, all buses are not monitored due to constraints in cost and analysis of data. Therefore a method is required to estimate system wide bus voltages based on available voltage measurements. Considering the steady state voltage of the system for a given bus voltage change from $V_{ss}$, the other buses voltage will deviate in proportion. In this study, system wide voltage changes can be regarded as approximately linear and directly applied to estimate unmonitored buses.

In order to establish the voltage relationship coefficients, a matrix system can be adopted. Since all buses in the system have their own coefficients, this matrix can be referred to as a ‘system coefficient matrix’ and can be expressed in the form shown by equation (4).

$$C_{sys} = \begin{bmatrix} \psi_1^1 & \psi_2^1 & \psi_3^1 & \ldots & \psi_n^1 \\ \psi_1^2 & \psi_2^2 & \psi_3^2 & \ldots & \psi_n^2 \\ \psi_1^3 & \psi_2^3 & \psi_3^3 & \ldots & \psi_n^3 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \psi_1^n & \psi_2^n & \psi_3^n & \ldots & \psi_n^n \end{bmatrix}$$

where ‘m’ is the number of voltage sag tested buses i.e. if all buss were tested then ‘m’ is equal to ‘n.’ Each element in system coefficient matrix is a proportional factor contributing to estimate a given unknown bus voltage based on a measured bus voltage. The coefficient matrix is a diagonal ‘1’ matrix, with off-diagonal elements representing the reciprocal of the cross element. The system coefficients are derived based on the average of all test cases used to estimate the coefficients, i.e. in this case four test loads were conducted on each bus.

For example, if bus 3 voltage was known and used to estimate bus 2 voltage, then the contribution from bus 3 to estimate bus 2 voltage is given by equation (5) for a given switching condition.

$$\psi_2^3 = \frac{V_{\%,2}}{V_{\%,3}}$$

**Error**

When voltages are estimated based on limited monitored buses, an error is established with the voltage. The method of error estimation used in this study is based on mean square error, with the coefficient error determined by equation (6).

$$\varepsilon_j = \frac{1}{n} \sum_{i=1}^{n} |C_{sys,j} - C_{measured,j}|^2$$
RESULTS

The presented method was tested based on commercially available software [12, 13]. The term referred to as measured value in the previous section is generated based on software in order to test the method. When a load is switched-on on a bus, it is evident from Figure 2 that the voltage deviates from its steady state magnitude on all load buses while all voltage controlled buses remain unchanged. Based on the relative change of the voltage, the voltage sag source bus is identified as having the largest deviation from its steady state voltage, as shown in Figure 3. As mentioned previously, if unmonitored buses exist, the voltage on these buses needs to be estimated. A detailed result for all buses in the system to be estimated is beyond the scope of this study (the complexity of this issue is discussed in the next section); however one instance of load switch condition and error related to estimating one bus voltage is presented here.

As test case load is switched on bus 5. In Figure 4, the graph represents the relation of bus 5 voltage to all other buses. Figure 4 also agrees with the assumption made in the previous section, bus voltages change is approximately linear as per this study.

In order to present the error in estimating the unmonitored bus voltage, the coefficients of equation (4) are observed. As seen in Figure 5, the coefficients are approximately linear; the error using equation (6) is provided in Table 2. Table 2 also provides the error associated with estimating B5 voltage B4, B6, B7, B8 and B9. Though the errors are significantly small as per this study, the complexity arises due to many reasons. This will be discussed in the following section.
FUTURE WORK

Identification of network wide voltage sag source location still requires further development. Three possible areas of extending this study are:

1) Voltage sags occur due to many reasons and in most of these cases the power systems bus voltage relation may not behave in a linear manner. Using this study as a base case further development is needed to represent complex bus voltage relation in order to establish the system coefficient matrix.

2) An issue that can contribute to the complexity of voltage sag source location identification is when significantly few system bus voltages are available. In this case the complexity arises due to available bus voltages closely matching other estimated buses. In such case it can be difficult to make an accurate estimate on the voltage sag source bus. This requires accurate observability analysis of power system.

3) Development of a system wide optimum monitoring location scheme

CONCLUSION

This study presents a simple method that can be used to identify voltage sags source location in power systems due to load switching. It is anticipated that this methodology can be used by both industrial customers and network operators for the purpose of identifying exact bus of voltage sag source and provides a more comprehensive analysis compared to some existing methods for revealing upstream downstream concept.

An insight to this topic reveals that voltage sag source location identification can lead to additional complexity when a power system is monitored with very limited bus voltages.

REFERENCES


