Monitoring Reach Area Based Optimal Location of Voltage Sag Monitors

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Abstract

This paper presents a new technique to address the problems of identifying the optimal location of voltage sag meters to monitor the voltage sags in the power transmission lines. The proposed method in this paper is based on estimating the number of different voltage sags occurring in the power transmission lines at nonmonitored buses from the number of voltage sags recorded at limited number of monitored buses in the power system network. An integer programming-based algorithm has been used for choosing the location of voltage sag meters. That is, the location of voltage sag monitors obtained by the means of the proposed algorithm ensures that any event leading to a voltage sag in the power transmission line is monitored by, at least, one voltage sag meter. The proposed method is based on the 9 bus power system network to maximize the monitoring reach area based optimal location of voltage sag meters.

Keywords: Power quality; voltage sags ; power transmission line ; voltage sag calculation.

1. Introduction

Voltage sag is a short duration reduction of the rms voltage due to the short circuits, overloads or starting of large motors. In recent years, different stochastic approaches, such as the well-known method of fault positions, have been proposed for estimating the voltage sag performance at a certain bus of an electrical system [1]–[2]. Stochastic methods make use of historical fault statistic data which are usually known for an
existing system. However, the system fault rates can vary widely from one year to another depending on different factors, such as weather conditions, maintenance, etc. [3], [4]. Therefore, the probabilistic nature of stochastic methods makes them suitable for long term estimations, but in a specific year, the predicted number of voltage sags can differ substantially from the number measured. In addition, in some cases, historic data are not available when analyzing a part of the system recently introduced or modified.

An alternative approach to overcome the aforementioned shortcomings of the stochastic procedures is the monitoring of the power supply. This method can provide a direct assessment of the voltage sags performance of the monitored site. Based on recent studies on power quality, voltage sags are considered to be the most frequent type of disturbances in the field and their impact on sensitive loads is severe [5]. In order to understand these disturbances and to mitigate the voltage sag problem, it is necessary to develop a power quality monitoring program especially to assess voltage sags in distribution systems. The reason is that most of the sensitive loads are in distribution systems.

In this research paper an integer programming-based method is proposed for choosing the minimum number of meters and their location in the power system. The location of monitors selected by means of this method can provide a good estimation of the average number of sags experienced in the system. To be effective, the monitoring program must be representative in time and space. At least four questions need to be answered:

- How many monitors need to be installed?
- Where should the monitors be installed?
- What voltage threshold should be set?
- How long should the monitoring program be?

This paper addresses to the three first questions. An integer programming model is introduced that allows minimizing the number of meters needed to characterize a large transmission network in terms of voltage sags [6]. The optimal monitoring program determines optimal locations for meters so that the complete network could be monitored. The optimization method is implemented on a 9-bus network.

2. Parameters to be Determined

2.1 Power Quality

“Power Quality is the combination of current quality and voltage quality, involving the interaction between the system and the load. Voltage quality concerns the deviation of the voltage waveform from the ideal sinusoidal voltage of constant magnitude and constant frequency. Voltage quality involves the performance of the power system towards the load, while current quality involves the behavior of the load towards the power system”.

Several reasons have been given to explain the current interest in power quality.
• Equipment has become less tolerant to voltage disturbances. Industrial customers are much more aware of the economical losses that power quality problems may cause in their processes.
• Equipment causes voltage disturbances. Often the same equipment that is sensitive to voltage disturbances will itself cause other voltage disturbances.
• Power quality can be measured. The availability of power quality monitors means that voltage and current quality can actually be monitored on a large scale.

2.2 Voltage Sag
Among all power disturbances, voltage sags are considered as the most frequent type of disturbances and their impact on sensitive loads is severe. According to the Standard IEEE 1346 a voltage sag is “a decrease in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 minute”. To give a numerical value to sag, the recommended usage is sag to X%, which means that the line voltage is reduced down to X% of the normal value.

![Voltage sag characteristics](image)

Fig. 1.1: Voltage sag characteristics.

Voltage sag and voltage dip refer to the same disturbance. Figure 1.1 illustrates a single-phase dip and its basic characteristics. It should be noted that the starting and ending threshold might not be equal. This project focuses on fault-caused dips.

3. MRA Based Location of Voltage Sag Monitors
3.1 Definition of Monitor Reach Area
The monitor reach area (MRA) is defined as the area of the network that can be observed from a given meter position. According to this definition, faults occurring inside the MRA will trigger the sag meter while faults outside will not. There is a close relation between the concept of MRA and the concept of observability of a network. Observability of the entire network refers to the ability of the monitoring program to capture all events that lead to voltage sags of a given magnitude at load buses in the
network. A full monitoring program, i.e., one that includes all load buses of the network, ensures observability for voltage sags of any magnitude since all buses are equipped with sag-monitors. On the contrary, a limited monitoring program might not ensure that all potential events leading to voltage sags of a given magnitude are captured by the meters. To analyze the performance of a limited monitoring program, it is essential to study the MRA of the possible monitor locations.

3.2 Definition of Monitor Reach Matrix
The monitor reach area (MRA) is defined as the area of the network that can be observed from a given meter position [7]. According to this definition, faults occurring inside the MRA will trigger the sag meter while faults outside will not. A full monitoring program, i.e., one that includes all load buses of the network, ensures observability for voltage sags of any magnitude since all buses are equipped with sag-monitors. On the contrary, a limited monitoring program might not ensure that all potential events leading to voltage sags of a given magnitude are captured by the meters. To analyze the performance of a limited monitoring program, it is essential to study the MRA of the possible monitor locations.

3.3 Monitor Reach Matrix Considering Faults at Fault Positions along Lines
Consider Fig3.1 where a generic power system is illustrated. The figure shows a transmission line located between buses k and j. The location at which a fault occurs along the line is identified by means of parameter $\psi$. This parameter varies from 0 to 1, as the fault position moves from bus $k$ to bus $j$, therefore is defined as

$$\psi = \frac{L_{kp}}{L_{kj}} \quad (1)$$

Where, as shown in Fig.1.2

$L_{kp}$ distance between bus $k$ and $p$ the generic location where the fault occurs;
$L_{kj}$ total length of transmission line placed between buses $k$ and $j$.

The voltage at a generic bus $m$ of the system when a fault takes place at position $p$ of line $l$ can be calculated by

$$V_{m}^{l} = V_{m}^{pf} - Z_{mp}I_{p} \quad (2)$$

Where

$V_{m}$ remaining voltage at bus $m$ when a fault occurs along line $l$
$V_{m}^{pf}$ prefault voltage at bus $m$;
$Z_{mp}$ transfer bus impedance between busbar of the system and the position of the fault $p$ in line $l$;
$I_{p}$ fault current phasor at $p$.

It is important to realize that the voltage in (2) is expressed in terms of the transfer impedance $Z_{mp}$ associated with a fictitious node $p$ whose position is determined by the continuous variable $\psi$. Since $p$ is a non-existing node, its value cannot be found in the $Z$-bus matrix.
Fig. 1.2: Electric power system.

For the example shown in Fig.1.3, the reach matrix for buses $m$, $m'$, $m''$ and segments $s_1,s_2,s_3,s_4$ and of line $l$ is

$$M_l = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 \end{pmatrix} \quad (3)$$

This process should be carried out in a similar way for the $L$ lines of the power system. In this way, a reach matrix $M$ could be formed for the whole system by making use of the sub matrices calculated individually for each line.

Fig. 1.3: Remaining voltage at buses $m,m',m''$.

4. Results

The implementation of the construction of the monitor reach matrices based on analytical expressions has been programmed using MATLAB. In the case studies presented in this section, the performance of different methods for optimal location of monitors is compared.

The IEEE 9-bus test system consists of 3 generating stations, 9 buses interconnected by 9 lines and three transformers. The buses for optimal location of monitors obtained by means of the aforementioned methods when a voltage threshold 0.9 & 0.8 p.u. is selected and three-phase balanced faults are assumed. In the case of the faults at one or two fault positions along the lines have been considered. It can be observed that the solution obtained by the proposed analytical method demands two monitors (placed at buses 6, 8).
5. Conclusion
This research paper has described a method for finding the optimal placement and number of monitors in order to detect sags originated by faults in large systems. The proposed formulation is based on the use of a monitor reach binary matrix that is obtained by applying an analytical method to calculate the remaining voltage caused by faults occurring along lines. The proposed optimal placement method has been implemented and applied to the 9-bus test system it also ensures complete observability of the network for the different voltage threshold.

References