AN EFFECTIVE TIME FREQUENCY METHOD FOR VOLTAGE SAG-SOURCE DETECTION

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ABSTRACT

Voltage sag is considered as the most common power quality problem in the world and it could disrupt the operation of sensitive equipment. Therefore it is vital to detect and locate the source of voltage sag. This paper presents a novel method for voltage sag source detection using the S-Transform (ST) time-frequency representation technique. The method uses ST to generate an index called ST Disturbance Power (STDP) which indicates the origin of the voltage sags. The performance of this new technique is validated by tests performed on various real voltage sag event data recorded in an industrial power system in Malaysia. Furthermore, the effectiveness and superiority of the new method is demonstrated by comparing its results with the existing sag-source detection techniques.

INTRODUCTION

Voltage sag is considered as the major power quality disturbance in the power supply industry as it can disrupt the operation of sensitive equipment and cause hours of downtime. The information about the actual sources and causes of voltage sags is very important to the plant engineers who had experienced sudden production stoppage due to these disturbances. Moreover, this information is important for making decision to resume back the operation after being interrupted by the voltage sag. If the source of the sag is internal, then the plant engineer needs to troubleshoot his internal electrical systems in order to identify the source of the problem. On the other hand if the source is external, the plant can resume back operation. Therefore, in order to enhance service to customers, it is imperative that the power utilities are able to detect voltage sags in their networks and then share the relevant information with their customers.

One of the most important steps in managing voltage sags is to install a permanent on-line power quality monitoring system (PQMS) at selected sites either at the main substations or at the point of common coupling (PCC) between customers and the power utility as shown in Figure 1. The PQMS of Figure 1 comprises of a power quality recorder (PQR) and is connected via a communication network to transmit the power quality measurement data to the power utility engineers. The summaries of the power quality events would be sent to the engineers' mobile phones using the short message system (SMS). An example of information received through the SMS is shown in Figure 2. The information shows that the voltage sag has been recorded at a substation named TKBU. The voltage magnitudes were 105% (red), 82% (yellow) and 116% (blue). The duration of the sag was 380 ms. Details of the data are also accessible through a desktop computer in the engineer's office. This information would enable them to respond promptly to undesirable system performances.

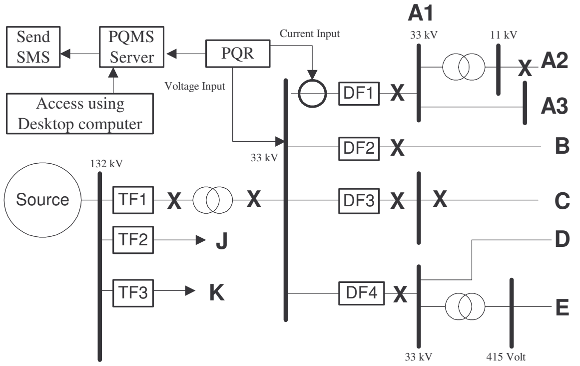
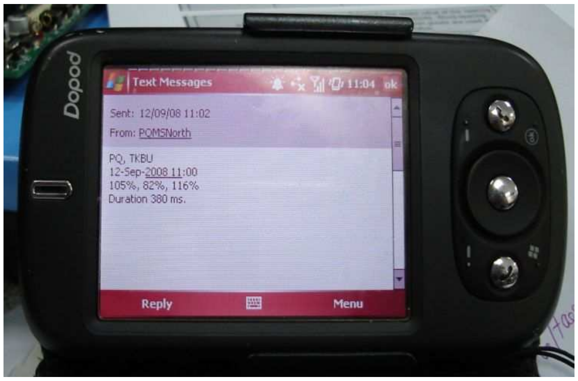


Fig.1: Configuration for power quality monitoring system



Sent: 12/09/08 11:02
From: PQMSNorth

PQ, TKBU
12-Sep-2008 11:00
105%, 82%, 116%
Duration 380 ms.

Fig.2: Example of information sent to mobile hand phone

However, the sources and causes of voltage sags are only known after the site inspections have been conducted. Frequent site inspection is a time consuming activity. Therefore, customers may have to wait longer for the correct information before their production can recommenced. According to the Figure 1, the sources of the sags can originate either from distribution feeders (DF1 to DF 4) due to faults at points A1 to E, or from the transmission feeders (TF2 and TF3) due to faults at point J, K or other points in the transmission networks. To expedite the diagnosis of voltage sags, an automated process is required. Automation will convey fast and accurate information to customers to assist them in making decision to resume back the process after the occurrences of voltage sags. This information is also very important to resolve disputes for voltage sag originated from a customer's installation and had affected other customers' sensitive equipment.

In this paper, the concept of automatic sag source detection is illustrated comprehensively as shown in Figure 3. In Figure 3, a PQR is installed at point M in a power supply network. If voltage sag occurs in the network, the PQR will detect and record the disturbance depending upon its voltage threshold settings which are basically based on the definition of voltage sags [1]. The source of sag can originate either from upstream (U/S) or downstream (D/S) with respect to point M. Upstream side can be defined as the side that supplies the fundamental power into the monitoring point at steady state conditions whereas the downstream side is defined as the side that leaves the fundamental power from the monitoring point.

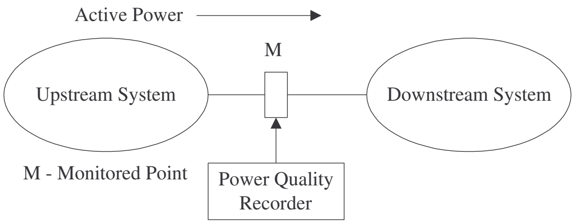


Fig.3 Concept of upstream and downstream voltage sags

The following section presents an overview of existing sag source detection methods. Next, the novel method named the S-Transform Disturbance Power (STDP) method is introduced for performing sag source detection. Lastly, the performances of the existing sag source detection methods are compared with the novel method in identifying the origins of symmetrical and asymmetrical voltage sags recorded in Malaysia.

OVERVIEW ON EXISTING METHODS FOR SAG SOURCE DETECTION

Voltage-Current (V-I) Amplitude Method

This method is based on the assumption that currents measured at the monitoring point will increase during downstream events and decrease during upstream event [2]. Consider the phasors of the fundamental components of line voltages, $V_k = |V_k|\, e^{j\varphi u,k}$ and currents, $I_k = |I_k|\, e^{j\varphi i,k}$ which are calculated from the measured waveforms. $|V_k|$ and $|I_k|$ are phasor lengths, while $\varphi_{u,k}$ and $\varphi_{i,k}$ are phasor angles for voltage and current, respectively. The subscript, k represents red, yellow or blue phase. Generally, a phase angle is defined as $\varphi_k = \varphi_{u,k} - \varphi_{i,k}$. During a voltage sag, the points of $(|I_k|, |V_k \cos\varphi_k|)$ are calculated using the linear function for each phase individually in order to investigate its slope. If the slope is > 0, then the source is said to be at upstream, and if the slope is < 0 then the source is in downstream. This method is termed as method M1.

Disturbance Power Flow (DP) Method

A method to identify the source of voltage sag based on the flow of power and energy during the disturbances was developed in [3]. This method relies on the fact that energy tends to flow towards a disturbance source during a disturbance. In this method, if the value of the disturbance power during voltage sag is negative, then the source of the sag is upstream to the monitoring point. And if the value of the disturbance power is positive, it indicates that the source of the sag originates from downstream. This method is termed as method M2.

Incremental Impedance (I-I) Method

Another method to pinpoint the origin of voltage sag based on the incremental impedance of a non-disturbance side was developed in [4]. The sign of the fundamental frequency positive sequence resistance estimated at a monitoring point is used as an indicator to determine the origin of voltage sag. If the fundamental frequency positive-sequence resistance or the real part of the impedance, Z_e, Real $(Z_e) > 0$, the source of voltage sag is upstream with respect to the monitoring point and if Real $(Z_e) < 0$, the source of voltage sag is downstream from the monitoring point. This method is termed as method M3.

Distance Relay (DR) Method

The approach using distance relay algorithm developed in [5] is slightly different from the above mentioned sag source detection methods. The basic idea is to analyze the impedances seen before (Z_{presag}) and during (Z_{sag}) a voltage sag event. The impedances are estimated using the voltage and current phasors at the monitored location.

If $|Z_{SAG}| < |Z_{PRE-SAG}|$ and $angle(Z_{SAG}) > 0$, the sag source is said to be upstream. If $|Z_{SAG}| > |Z_{PRE-SAG}|$ and $angle(Z_{SAG}) < 0$, then the sag source is downstream. This method is termed as method M4.

Real Current (RC) Component Method

Another sag source detection method developed in [6] uses the polarity of the real current component to determine the sag location relative to the monitoring point. The product of the RMS current and the power factor angle at the monitoring point is used to determine the sag source location. This method is termed as method M5.

The performances of the existing sag source detection methods, namely V-I, DP, I-I and RC component methods were studied by Polajžer et al. 2007 [7] and Leborgne et al. 2006 [8]. Polajžer et al. found that the V-I and DP methods gave low accuracies (50 – 70 %) in the detection of upstream sag sources due to asymmetrical faults in the networks. Leborgne et al. evaluated the performances of the

V-I, DP, I-I and real current component methods for the detection of sag sources due to symmetrical and unsymmetrical faults in the transmission networks. The evaluation results gave accuracies of 87% and 65% for the detection of sag sources due to symmetrical faults and asymmetrical faults, respectively. From these results, it is noted that there is a need for a more accurate method for identifying the origin of voltage sags.

A NOVEL SAG SOURCE DETECTION METHOD USING THE S-TRANSFORM

A new voltage sag source detection method is proposed by using the S-transform in which an index named as the S-transform disturbance power (STDP) is developed. The derivation of the STDP is given in the sub-section below.

ST Disturbance Power

The S-transform (ST) for a function *h(t)* is shown below;

$$S(\tau, f) = \frac{|f|}{\sqrt{2\pi}} \int_{-\infty}^{\infty} h(t) e^{-\frac{(t-\tau)^2}{2}} e^{-i2\pi ft} dt \qquad (1)$$

where t and τ are both time, f is the frequency and the $e^{-i2\pi ft}$ is the oscillatory exponential kernel which selects the frequency being localized. Basically the ST is the time localizing Gaussian that is translated while the oscillatory exponential kernel remains stationary.

Using equation (1), the time frequency representation for a red phase voltage signal, v_R , can be represented as:

$$STV_R = \frac{|f|}{\sqrt{2\pi}} \int_{-\infty}^{\infty} v_R(t) e^{-\frac{(t-\tau)^2}{2}} e^{-i2\pi ft} dt \qquad (2)$$

where STV_R is the S-matrix of size m x n for voltage signal, v_R .

By obtaining the maximum values from each column of STV_R matrix, it is possible to construct a column vector, V_{STR}, of size n which represents the time component of v_R . The V_{STR} is called the ST voltage for the red phase. Using a similar procedure, the ST voltage for the yellow phase, V_{STY} and the blue phase, V_{STB} can be obtained. Next consider the the time frequency response for a red phase current, i_R, which is represented as:

$$STI_R = \frac{|f|}{\sqrt{2\pi}} \int_{-\infty}^{\infty} i_R(t) e^{-\frac{(t-\tau)^2}{2}} e^{-i2\pi ft} dt \qquad (3)$$

where STI_R is the S-matrix of size m x n for current signal, i_R .

By obtaining the maximum values from each column of STI_R matrix again, it is possible to construct a column vector, I_{STR} of size n which represents the time component of i_R. The I_{STR} is called the ST current for the red phase. Similarly, the yellow and the blue phase currents, I_{STY} and I_{STB} can be obtained independently.

The S-transform disturbance power (STDP) is then expressed as,

$$STDP = [(V_{STR} * I_{STR}) + (V_{STY} * I_{STY}) + (V_{STB} * I_{STB})] \qquad (4)$$

where the operator * represents element by element multiplication.

The same criteria used by the DP method for determining the origin of voltage sags is adopted by the STDP method that means, if the value of STDP > 0, then the sag source is a downstream source. On the other hand, if the STDP < 0, then the sag source is an upstream source. This method is termed as method M6.

VOLTAGE SAG SOURCE DETECTION RESULTS

In this section, the performance of the STDP method is compared with the existing sag source detection methods, namely, the V-I, DP, I-I, DR and RC methods. The effectiveness of the STDP method is evaluated by using two hundred and thirty seven (237) voltage sag data recorded for a period of 36 months beginning September 2007 and ended in September 2010. One hundred eighty three (183) voltage sag data was known to be from upstream of the PQR monitoring point while fifty four (54) voltage sag data was identified as downstream events. These data is used to evaluate the accuracy of the sag source detection methods.

Examples of the voltage and current waveforms are shown in Figures 4 and 6. The source of the disturbance waveforms in Figure 4 were due to U/S faults in the transmission network (TN) originating from point J or K in Figure 1. The graphical results of the sag source detection are shown in Figure 5. The results showed that all methods successfully detected the origins of the sags except method M1. The examples in Figure 6 were due to downstream (D/S) asymmetrical fault in the distribution network (DN) either from points B, C, D and E in Figure 1. The graphical results of the sag source detection are shown in Figure 7. The results showed that all methods successfully detected the origins of the sags to be downstream from the PQR.

The overall results for detecting the 183 numbers of upstream sag sources from the monitored point showed that only the proposed STDP method achieved 100% accurate in the detection of upstream sag sources for both symmetrical and asymmetrical voltage sags while the other methods gave accuracies in the range of 25.1% to 74.3%. The results of this analysis proved that the STDP method which is based on the ST is superior in the detection of upstream sag sources compared to the other existing sag source detection methods.

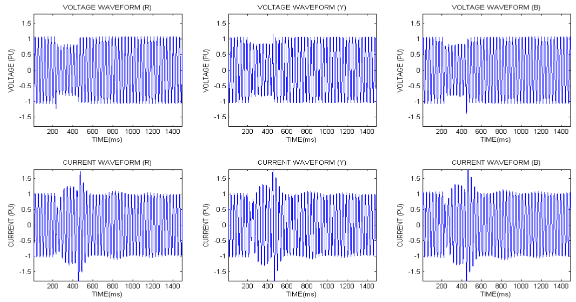


Fig. 4 Waveforms due to U/S symmetrical faults in TN

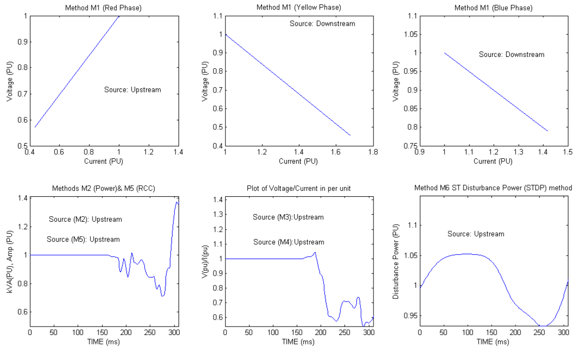


Fig. 5 Results of Sag Source Detections for U/S faults

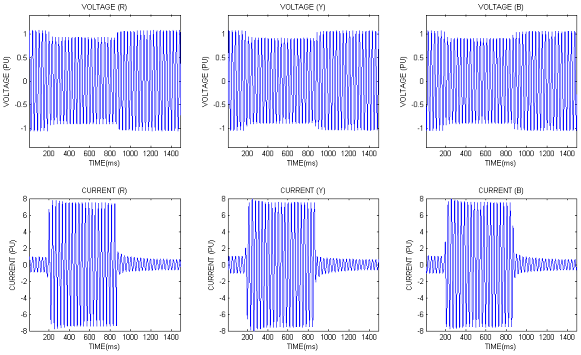


Fig. 6 Waveforms due to D/S asymmetrical fault in DN

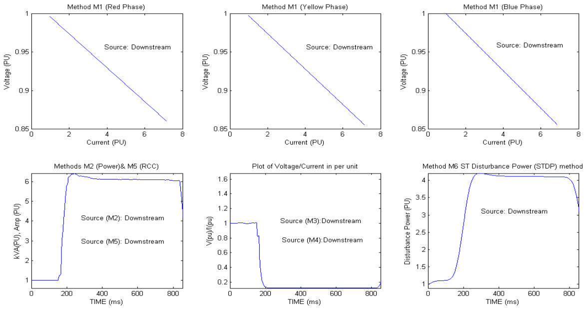


Fig. 7 Results of Sag Source Detections for D/S faults

The overall results for downstream sag source detection for 54 samples of voltage sags showed that all the existing methods successfully detected the origins for symmetrical voltage sags. Perfect results were also seen for all methods except for method V-I (M1) in detecting the sag sources for asymmetrical voltage sags. The novel method STDP (M5) based on ST registered perfect accuracy in identifying downstream sag sources due to both symmetrical and asymmetrical faults in the distribution networks.

CONCLUSION

In this paper, the performance of a novel sag source detection method developed from the S-transform (ST) was compared with the existing methods in detecting the origins of voltage sags. From the analyses done on 237 samples of voltage sag data, the proposed STDP method scored 100% in identifying the sources of voltage sags which are either upstream or downstream from the monitoring point. The percentage upstream sag source detection accuracies of the other methods are 25.14% (V-I), 50.82% (DP), 74.32% (I-I and DR) and 50.82% (RC). For downstream sag source detection, all the methods except for the V-I method (50%) correctly identify all the sag sources. This study proved that the novel STDP method is superior to the other methods in the detection of upstream and downstream voltage sag sources.

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