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Employing instantaneous positive sequence symmetrical components for voltage sag source relative location

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ABSTRACT

Modern industrial facilities are vulnerable to voltage sags and short interruptions as they were in the past to sustainable interruptions. Therefore, modern reliability assessment should include voltage sags and short interruptions. Hence, in order to improve power system reliability it is necessary to mitigate these voltage variations. One of the first steps towards this objective is to locate the source of these disturbances. This paper investigates a number of methods for sag source relative location. Said methods are based on different electrical parameters. Using instantaneous positive sequence components, five novel extended methods for voltage sag source location are proposed for accommodating the transient nature of voltage sag events and for improving unsuitable operation of methods on asymmetrical sags and earth faults. Due to the fact that short circuits are the main reason resulting in voltage sags, this paper focuses on the location of voltage sag sources due to line faults. A comparative analysis between the existing methods and the five novel extended methods is performed by applying extensive numerical simulations in a Brazilian regional transmission and sub-transmission utility. Finally, the effectiveness of all methods is obtained. The results show that the novel extended methods are more effective and among them, the extended methods based on reactive power can locate sag sources with an accuracy of 88%. Also, implementation of the novel extended methods on signal processors is easier with respect to the already implemented methods.

1. Introduction

Voltage sags are an important power quality disturbance that can occur in utilities or in the end user with a frequency of even several thousand times per year [1]. This phenomenon can also cause production loss in a typical industrial plant [2–4]. Therefore, they have a great influence in industrial plant reliability. The magnitude and duration of these voltage sags can be between 10% and 90% of nominal voltage and half cycle to one minute, respectively. Voltage sags can be symmetrical or asymmetrical and may be caused by starting of large motors, transformer energizing, capacitor switching, as well as by overloads and faults. Voltage sags caused by faults are not confined to the fault point, and are propagated through the system affecting connected loads far away from the fault location, causing many disagreements between utilities (transmission–sub transmission, sub transmission–distribution, distribution–distribution and distribution-micro grids) and also between utilities and consumers. Therefore, identification of the event causing the sag is crucial so as to solve such issues. Voltage sag source location is an important topic and is the first stage toward mitigation of power quality problems [5,6].

Many studies and methods have already been reported [7–35] on the subject of voltage sag source location. These methods were divided into five categories. The first category is based on "disturbance power and energy" [7,8–13]. Leborgne et al. [14,15] investigated an alternative approach based on power flow. The second category is based on changes of current. Li et al. [16] introduced a method based on the polarity of slope of system trajectory at the monitoring points. The polarity of active current was proposed to classify the sag source [17]. The third category focuses on impedance changes. Method [16] was generalized by the same authors of the "resistance sign" approach [18]. In this method, the sign of the resistance obtained from incremental impedance was the criterion utilized to locate the sag source. The results of the method depended on the data cycles, so another method [19] was introduced based on negative sequence components. Later, Zhu et al. [20] determined the sag source applying the same theory, according to the neutral point operation mode. Yi et al. [21] pre-

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Nomenclature

PQM	Power quality monitor
DS	Downstream
US	Upstream
DPE	Disturbance power and energy
RP	Reactive power
RCC	Real current component
SST	Slope of system trajectory
DR	Distance relay
(.)	Number of equation relation to the rule of methods
$(.)_{sag}, (.)_{presag}$	During sag and pre-sag
$\Delta(.) = (.)_{sag} - (.)_{presag}$	Change due to the sag
$\angle(.)$	Phase angle
V, I	Voltage and current phasor
θ	Phase angle between voltage and current
Z, R	Impedance and resistance
$(.)^{+}, (.)^{-}, (.)^{0}$	Positive, negative and zero sequence components
v, i, z, r	Instantaneous voltage, current, impedance, resistance
ΔP, ΔQ	Active and reactive disturbance power
ΔE	Disturbance energy on ΔP
$p^{+} = v^{+}i^{+}\cos\left(\theta\right)^{+}$	Active power obtained from instantaneous positive sequence components
$q^{+} = v^{+}i^{+}\sin\left(\theta\right)^{+}$	Reactive power obtained from instantaneous positive sequence components
Δp^{+}	Disturbance active power obtained from instantaneous positive sequence components
Δq^{+}	Disturbance reactive power obtained from instantaneous positive sequence components
$\Delta e^{+}{}_{p}$	Disturbance active energy on Δp^{+}
$\Delta e^{+}{}_{q}$	Disturbance reactive energy on Δq^{+}
$\left(\theta\right)^{+}$	Phase angle between instantaneous positive sequence voltage and current

sented a method using the polarity of the real part of internal impedance in a single-port network. In an alternative method, the sag source was found using the impedance seen by distance relay [22]. This method was tested in a Brazilian network [23,24]. Later, the variation of angle was used instead of the impedance angle [25]. The fourth category is based on voltage measurements only. A method based on the voltage magnitude and phase-angle jump was proposed [26]. Another method [27] based on voltage magnitude at both sides of a power transformer was introduced. The fifth category locates the sag source according to current measurements. The first method in this category [28] is based on the phase change in the positive-sequence current phasor. Its application is, however, limited to systems supplied from two sides. Moradi et al. proposed a further method [29], which used magnitude change in the positive-sequence current phasor as an extra criterion to the method proposed by Pradhan et al. [28].

The testing of some discussed methods for voltage sag source location known from literature shows that in the cases of asymmetrical sags, these methods are rather ineffective [30]. Therefore, Polagzer et al. [8] generalized the methods based on positive sequence phasors. Moreover, since voltage sags are a transient power quality event, the methods based on phasor or positive sequence phasor might have questionable results. Thus, the same authors generalized the methods of Refs. [7,16–18] based on Clarke's components [9,31] in systems with DGs and presence of active loads, and improved the method of Ref. [28] as Refs. [32,33] (this will be discussed from a different viewpoint in Section of 4.2 (results obtained) in this paper). Also, Shao et al. [34] developed method [22] based on Park's components. Voltage sag source location methods along with their features were analyzed in the Catalan network [35]. Mohammadi et al. [36] used a robust machine learning approach, with very high effectiveness, in which they included features of all previous methods.

It is worth pointing out that magnitude, duration, recovery, prediction and detection are highly relevant alternative characteristics of voltage sags and should be taken into account besides the source location of voltage sags [37–39].

In this paper, the rules of six earlier methods for voltage sag source location are briefly explained. Also, five other methods that extended the former are introduced by using instantaneous symmetrical components. All the proposed extended methods are based on instantaneous voltages and currents and not on phasors. After showing the results of existing and extended methods, a comparative analysis is performed between all the methods by applying extensive numerical simulations in a Brazilian regional power network. In this network, six monitors and fourteen fault locations for which all type of faults (symmetrical, asymmetrical and earth faults with low and high faults resistances) at both upstream and downstream locations are simulated. The monitors in the network represent different kinds of system topology (i.e. radial, interconnected, one source, two sources and so on). The obtained effectiveness and accuracy of the discussed methods for all simulated cases is fully presented and a main comparison is performed between them.

2. Methods for voltage-sag source relative location

In methods for voltage-sag source relative location, the relative location of a sag source as observed from a power quality monitor (PQM) is defined as downstream (DS) or upstream (US), using the steady state active power flow direction as reference. DS is the region in the direction of the power flow and US is the region against it, as shown in Fig. 1. The methods for sag source relative location can be divided into several categories based on various criteria such as power, energy, current, voltage and impedance. A description of the conventional methods for DS/US location of voltage sag sources, which are used in this paper for generalization purposes, is given in Table 1.

3. Introducing extended methods for voltage-sag source relative location

In this section, the extended rules for existing original methods are obtained using instantaneous symmetrical components [32,40], and as the main contribution of this paper, novel methods are introduced.

3.1. Instantaneous symmetrical components transformation

Instantaneous voltages ($v_a(t)$, $v_b(t)$, $v_c(t)$) and instantaneous currents ($i_a(t)$, $i_b(t)$, $i_c(t)$) may be transformed into instantaneous positive, negative and zero-sequence voltages (v^{+}, v^{-}, v^{0}) and currents (i^{+}, i^{-}, i^{0}) in a-phase, where F denotes the Fortescue's

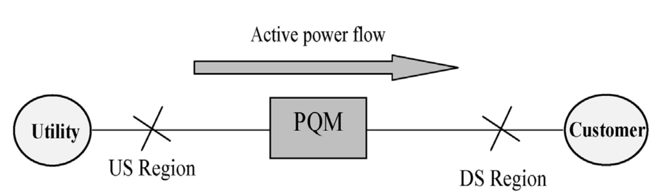

Fig. 1. Relative location of voltage sag source as US and DS.