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Locating the source of voltage sags: Full review, introduction of generalized methods and numerical simulations

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ABSTRACT

Locating the source of voltage sags in order to identify the events causing the problem and improving mitigation strategies is a major issue. When two utilities manage interconnected networks or manage a micro grid and an upstream grid, an occurred fault in one area may cause voltage sags that affect sensitive customers/critical loads in another area. From this viewpoint, this paper first reviews and analyses with detail different methods for voltage sag source location. Then eleven generalized method are introduced. A comparative analysis is performed between some of the discussed methods by applying extensive numerical simulations in a Brazilian regional utility by using PSCAD/EMTDC and MATLAB. The location of each monitor represents a difference kind of system topology (radial, interconnected, one source, two sources and interconnected microgrids). In the following, the effectiveness of methods was obtained and comprised for each monitor location and for the whole system.. The results obtained show that the effectiveness of methods based on instantaneous positive sequence components and Clarke's components is equal in many methods except distance relay and resistance sign methods, and that the effectiveness is lower, higher or equal than methods based on positive sequence phasors. The phasor based methods had less effectiveness. The generalized methods based on reactive power using instantaneous positive sequence components and Clarke's components gave the right location in 88% of total simulated cases. The results also provided a comprehensive background to propose future works and to select the best method especially at interconnection point of a micro grid with the presence of renewable distributed energy sources.

1. Introduction

1.1. Problem description

Voltage sags (dips) are a decrease in RMS voltage between 0.1 and 0.9 pu at the power frequency with a duration of 0.5 cycle to 1 min. The characteristics of voltage sags are determined by power quality standards [1,2]. They can occur in transmission, distribution systems, microgrids or even at the customer facility, with a frequency that can reach several thousand times per year [3]. This phenomenon is one of the most important power quality disturbances and due to its impact on sensitive loads and costs incurred by damage and maintenance, has captured the attention of utility engineers and researchers. Voltage sags can also cause substantial loss of product of a typical industrial installation [4–11].

Even though voltage sags can be generated by starting and loading of large induction motors, transformer energizing and saturation, capacitor switching and overloads, are short circuits are the main cause of severe voltage sags.

The durations of these voltage sags can be as short as three to four cycles associated with the fault clearing time. In the cases of line to line or earth faults, which are the most frequent, the resulting voltage sags are asymmetrical. Furthermore, due to high values of magnetizing currents, the voltage sags caused by transformer energizing are asymmetrical and last between 100 ms and 500 ms. Voltage sags caused by a heavy motor starting last longer; from a few seconds to several tens of seconds. These voltage sags are symmetrical. Research on voltage sags can be focused on classification, detection, assessment and representation of voltage profiles. But exact and relative detection

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Abbreviations: 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; RS, Resistance sign; PCSC, Phase change in positive sequence current; CBM, Current based method; VBM, Voltage based method; VSM, Voltage sag magnitude; STDP, S - Transform disturbance power; WMR, Wavelet multi-resolution; PSDP, Phase space disturbance power; SVM, Support vector machine; HHT, Hilbert huang transform; PCC, Point of common coupling; DG, Distributed generation; DER, Distributed energy resources

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Nomenclature

()	Number of equation in 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
VST and IST	S transform voltage and current (vectors $1 \times n$);
ξ	Bandwidth in SVM parameters
$c_j(k)$ and $d_j(k)$	Discrete smooth approximation in the scale space and wavelet transform coefficients in the wavelet space.
θ	Phase angle between voltage and current
Z, R	Impedance and resistance
Z_e^+, Z_e^-, Z_e°	Incremental impedance obtained from positive, negative and zero sequence components
z_e^+	Incremental impedance obtained from instantaneous positive sequence components
$(.)_{\alpha\beta}$	Clarke's components
R_e	Internal resistance for 3 phases
$(.)^+$, $(.)^-$, $(.)^0$	Positive, negative and zero sequence components
v, i, z, r	Instantaneous voltage, current, impedance and resistance
$\Delta s = i_{\alpha presag} \cdot i_{\beta sag} - i_{\beta presag} i_{\alpha sag}$	
ΔP, ΔQ	Active and reactive disturbance power
ΔE	Disturbance energy on ΔP
$\Delta p_{\alpha\beta}$ and $\Delta q_{\alpha\beta}$	Active and reactive disturbance power obtained from Clarke's components
$\Delta e_{\alpha\beta}$	Disturbance energy on $\Delta p_{\alpha\beta}$
$\Delta e_{\alpha\beta}$-q	Disturbance energy on $\Delta q_{\alpha\beta}$
ΔP^+ and ΔQ^+	Positive sequence disturbance active and reactive power
ΔE^+	Positive sequence disturbance energy on ΔP^+
$p^+ = v^+ i^+ cos(\theta)^+, q^+ = v^+ i^+ \sin(\theta)^+$	Active and reactive power obtained from instantaneous positive sequence components
Δp^+ and Δq^+	Disturbance active and reactive power obtained from instantaneous positive sequence components
Δe_p^+	Disturbance active energy on Δp^+
Δe_q^+	Disturbance reactive energy on Δq^+
$V_{i\text{-}sag}$	Lowest during sag RMS voltage between 3 phases
c	Regularized constant in SVM parameters
$E_{v(t)}$ and $E_{i(t)}$	Euclidean norm obtained for voltage and current

of the sag location is another important topic and will be the first step towards mitigation of power quality problems. It also plays a fundamental role in allocation of responsibilities and in determination of financial penalties [12,13].

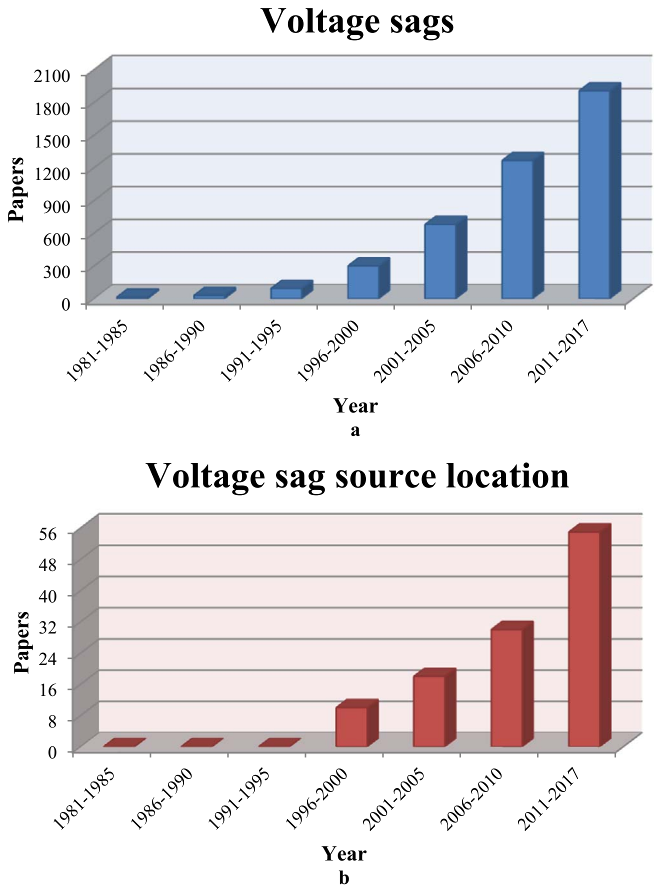

Fig. 1. Voltage sag publications during the period of 1981–2017. (a) Voltage sag (b) Voltage sag source location.

1.2. Literature review

The subject of voltage sag has been presented in the technical literature since the 1960s; however, the number of publications has increased significantly in the last decade, as shown in Fig. 1. The survey at the IET-INSPEC database was made with these entries: a – (voltage sag OR voltage dip) within abstract, b – (voltage sag AND source location/detection/identification) within abstract.

For voltage sag source relative location many studies have been done and various methods have been suggested and reviewed [14–42]. A full review of methods along with introducing new methods for the upstream and downstream detection of voltage sag sources [14–16,18–20,23–26,28,31–35,37–40] will be done in the next section. These methods can be divided into five types. The first type is based on changes of power and energy.

The first comprehensive work was presented in [14] based on “disturbance power and energy”. Later, scholars improved and perfected this method [15–22]. Leborgne et al. [23,24] investigated an alternative approach based on power flow information and on the variation of reactive power.

The second type used changes of current. The method proposed by Li et al. [25] relies on the relationships between the product of voltage magnitude and the power factor against current magnitude at the measured points to determine the sag sources, while the feasibility of this method for non-linear load remains to be discussed. In [26] the polarity of variation of the real current is used to classify the sag source as upstream or downstream.

The third type focused on changes of impedance during voltage sag.

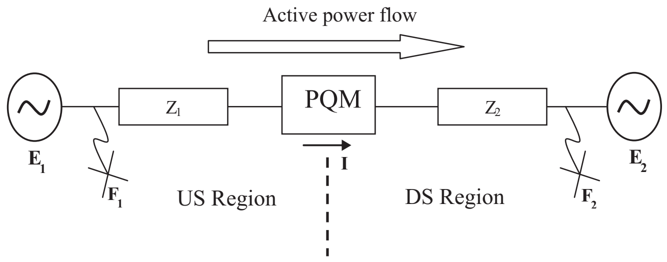

Fig. 2. Basic circuit to describe the US or DS localization of the sag source.