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Research Article

Analysis of Voltage Sag Measurement Algorithm

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Abstract

This paper analyzes accuracy of algorithms commonly adopted in instrument devoted to the detection and the characterization of voltage dips (also called sags). This analysis is particularly interesting because the results of dip measurements are utilized for calculation of severity levels and the site index assessment that are parameters adopted in determination of quality level of power supply, but also in developing planning and design criteria of new electrical power grid or for selecting equipment with proper intrinsic immunity. Anyway there is a certain degree of freedom left to instrument manufacturers and it can be found that different instruments significantly disagree in some actual measurements. The paper analyses voltage sag measurement algorithm.

Keywords: *Voltage sag, Power Quality Measurement, Accuracy analysis*

1. Introduction

The Power Quality (PQ) phenomena that involve rms voltage variation such as long and short interruption, overvoltage and voltage dip (in UK English) or sag (in American English - the two terms are equivalent) are currently PQ issues with the greater economic impact. In fact, especially industrial customers highly suffer from regular production stoppages due to these phenomena (UIE, 2001). Remarkable voltage reductions are caused by a short circuit or earth fault close to a substation that will force the voltage to a very low value in one or more phases. Smaller reductions are caused by the timely varying loads. Usually the reduction ends within a short time due to automatic switching actions, fault reparation or load stabilization. These phenomena can be classified as voltage dips or interruption with respect to the event duration and the minimum voltage magnitude during the event. For the purpose of this paper we will refer to dip events as their durations is typically less than 0.1 s, so presenting greater measurement problems. Anyway obtained conclusions and described procedure can be extended to interruptions with minor changes. Many IEEE groups and task forces are working to develop a recommended practice for converting a suitably sampled voltage and current data set into specific power quality categories and describe specific attributes within each category. In particular, IEEE 1159.2 Working Group focuses on events such as dips and other non-harmonic events between that delivered by power suppliers and that needed by equipment manufactures without technical digital definitions. The translation from sets of digital data to statistically comparable events would be used for purposes of comparing power suppliers, comparing susceptibility qualities of equipment, and evaluating performance versus specification or contract. Therefore a recognized set of digital definitions will benefit all the stakeholders of electrical energy market.

Anyway, instruments for dip measurement still present unresolved technical and theoretical issues related to performance assessment. So that, different implementations that fully meet definitions reported in standard (D. L. Brooks *et al*, 1998) can still disagree significantly in some actual measurements. Mainly it happens, because standards do not include a well-defined procedure for their performance characterization. The paper analyses voltage sag measurement algorithm.

2. Voltage Sag Measurement

2.1. RMS Measurement

The measurement of dip parameters essentially lays on voltage rms measurement. According with (IEC EN 61000-4-30, 2003), the basic rms measurement adopted for purpose is the value of the rms. voltage measured over 1 cycle, commencing at a fundamental zero crossing, and refreshed each half-cycle (in the following simply called $U_{rms(1/2)}$). The $U_{rms(1/2)}$ values are measured on each channel. In this way, for polyphase systems, this technique will produce rms values at different time instants on different channels. These values are used not only for voltage dip measurements but also for voltage swell and interruption detection. The synchronization to the fundamental zero crossing straightforwardly implies a

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systematic deviation in measurement of dip duration due to rounding that applies in detection of beginning and of the ending of the event. The authors of the standard are aware of this aspect and, in facts, accuracy specifications, reported in (IEC EN 61000-4-30, 2003) about voltage dip, requires that the measurement results of best class instrument shall be within 1 cycle that is really poor accuracy for a time measurement. Moreover, it is possible to prove that, in a lot of practical dip events, systematic deviation much greater than 0.2% applies also for residual voltage measurements (G. Bucci *et al*, 2003). A minor impact is related with accuracy in residual amplitude measurement nevertheless the problem also applies. Moreover, obviously, this permissible error reflects also in calculation of severity index with very remarkable effects especially for short events: it can make double the index of severity. It is important to underline that this tolerance is systematic because it comes from detection algorithm that is imposed, in such a way that an instrument cannot perform better measurement in agreement with. This makes the instrument IEC 61000-4-30 compliant useless for severity index and site index assessment. Another important aspect to point out is related to the way to keep on performing rms measurements after the beginning of a voltage dip. During this event zero crossing are no more reliable reference because fundamental components even could miss at all or a phase shift may occur. This aspect is not clearly addressed by (IEC EN 61000-4-30, 2003).

Another important aspect to point out is related to the way to keep on performing rms measurements after the beginning of a voltage dip. During this event zero crossing are no more reliable reference because fundamental components even could miss at all or a phase shift may occur. This aspect is not clearly addressed by. Also different approaches for dip event characterization exist (M. Bollen *et al*,) and they adopt as the basic block of measurement, the rms voltage calculated over a full-cycle sliding window. In this way rms value is recomputed every sampling point. With this approach an increased resolution in residual voltage and duration parameters is expected (G. Bucci *et al*, 2003). On the other hand higher computational burden or specific synchronization hardware is required to keep the window length fitting actual fundamental period (G.Betta *et al*, 1999).

2.2. Duration Measurement

A not trivial question about dip characterization is measurement of the event duration. In fact, event beginning and ending are ideally time instants but for their measurement reference is made to rms value that is an integral value thus defined over a time interval. It is worthwhile analytically calculating, even under simplified hypothesis, delay phase angle, α, between the beginning and the detection of the event. Let consider a sinusoidal signal, with, U_i the relative rms amplitude before that the event applies, U_r is the relative amplitude after beginning of the event (the residual amplitude) that is considered constant until detection applies, ΔU_n the relative detection threshold, φ the phase angle at which the event starts, and *α* the delay phase angle after which the event is detected performing a continuous rms calculation with a sliding window of one period. With some mathematical manipulation (D. Gallo *et al*, 2009) the relation among parameters can be written as:

$$2\pi \frac{U_i^2-\Delta U_n^2}{U_i^2-U_r^2} = \alpha - \sin\alpha \cos \alpha + 2\varphi \qquad (1)$$

This is an implicit function that can be only numerically inverted. It is worthwhile underlining that relation (1) can be used also for sudden amplitude increasing but in this case the delay in detection of event is equal to *2π-α*. For sake of clarity, in following detection delay is expressed in relative term that is a percentage of the fundamental period:

$$d = \alpha \frac{100}{2\pi} \qquad (2)$$

This result can be easily associated to time interval multiplying for fundamental time period. Starting from the detection delays obtained with (1) for a rms calculation with sliding window, the delays for a synchronized rms calculation, α_s, can be calculated by

$$\alpha_s = ceil \ \frac{\alpha+\varphi}{\pi} \ .\pi - \varphi \qquad (3)$$

Where, *ceil*, the function that rounds to the nearest integer towards infinity, was introduced. The phase angle affects the detection delay for a maximum value that is 50% of period. This additional delay can be reached whatever residual amplitude is accounted. The worst case reaches the values of nearly 150 %. It applies when residual voltage is equal to detection threshold (*Ar* =0.9) and event begins immediately after the zero crossing. Also in this situation α_s values can be used for calculating delays for detection of a sudden amplitude increasing. In this case, the (3) become:

$$\alpha_s = ceil \ \frac{2\pi-\alpha-\varphi}{\pi} \ .\pi + \varphi \qquad (4)$$

Minimum delay is about 20%. It applies when the detection of the dip is immediately before the zero crossing. Nevertheless, also for synchronized rms calculation, the minimum delay could be even lower reaching nearly zero value if the initial amplitude, *Ai*, was only slightly higher than detection threshold so that the amplitude reduction is immediately detected.

3. Numerical Case Study

In order to apply the obtained results, two numerical case studies are presented.

Let consider a voltage dip characterized by a 70% of residual voltage for exactly 2 cycles and with initial phase angle equal to zero (see fig. 1a). The depicted signal is what a power quality calibrator presents as output when 2 cycle 70% dip with 0 initial phase angle is required. Nevertheless, even with an ideal measurement of voltage rms (see fig. 5b)), this event has a different duration.

Performing rms calculation with a sliding window (solid line in 5b) event duration is estimated as 241 %, considering rms values each half cycle synchronized with fundamental zero crossing (dots in 1b) the time duration is 250 %. No method detects 2 cycle event. This means that in accuracy assessment of dip detection instrument, adopting calibrator settings as reference values produces unfair deviations that should be corrected before accuracy calculation in order to find out real performances. Of course this deviation depends on dip depth and starting phase angle. Tab. I report the results of application of formulas from (1) to (4). The parameters of first two rows correspond to the situation of first case study and the results are in agreement with delays found with the numerical simulation: the difference between delay in detection of ending and beginning of the event correspond to found deviation. This means that formulas (1)-(4) can be utilized to correct systematic deviation from calibrator settings before calculation of instrument accuracy.

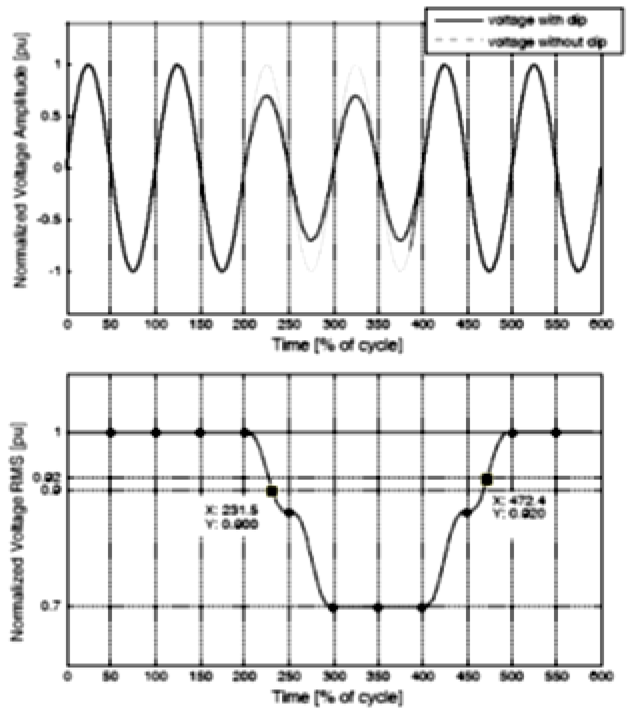

Fig. 1 Case study 1: voltage dip a) instantaneous voltages; b) rms values

Table I. Time Delay Calculation

φ [deg]	Ui [%]	Ur [%]	∆Un [%]	d [%]	ds [%]
0	100	70	90	31.47	50
0	70	100	92	72.42	100
90	100	80	90	51.39	75
90	0	95	92	96.85	125

A little more complex situation is considered in next case study. Let consider a voltage dip characterized by a initial phase of 90 degree the amplitude at first decreases to 80% for one cycle, then becomes 0% for another cycle. Finally, the value of restored voltage is 95% (see fig. 2). Once again actual event duration is 2 cycle but sliding method detects a duration of 246% and synchronized method a duration of 250%. The parameters of last two rows correspond to the situation of second case study and also in this more complex case the results are in agreement with delays found with the numerical simulation. It worthwhile underlining that proposed approach for the calculation of systematic delays cannot be directly applied in field measurement because some of parameters of (1) are unknown at measurement time and they could be only estimated which leads to a not reliable application. Anyway, these results can be very useful in performance assessment of instruments for dip monitoring. In fact, during these tests, rms voltage before and during test is known with negligible uncertainty, and formula (1)-(4) can be used in calculating what is the expected value of dip duration from an ideal meter including the systematic deviations due to rms calculation and threshold utilization.

4. Conclusion

This paper analyzed accuracy of algorithms commonly adopted in instrument devoted to the detection and the characterization of voltage dips (also called sags). In this paper analytical formulas are derived: some related to maximum relative rms deviation versus frequency de-synchronization; some other related the delay phase angle after which the event is detected. The results were applied for accounting systematic deviations in testing accuracy of commercial instrument is presented.

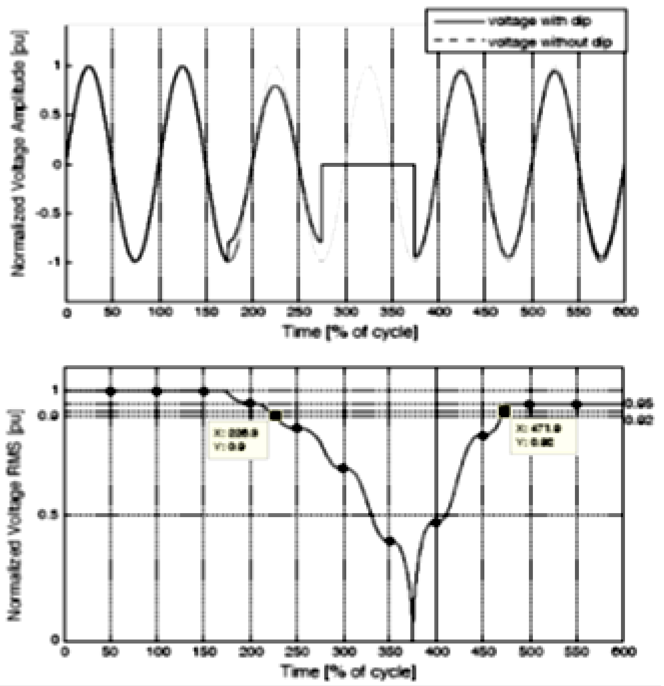

Fig. 2 Case study 2: voltage dip a) instantaneous voltages; b) rms values

Table 2 Experimental results

Residual voltage [%]	Phase [deg]	Duration [ms]	Duration (corr.) [ms]	Measured [ms]	Deviation [%]
0.5	0	30	40	38	-5
0.5	45	30	40	32.2	-20
0.5	90	30	40	40	0
0.5	135	30	40	30	-25
0.25	0	20	30	21	-30
0.25	45	20	30	26.6	-11
0.25	90	20	20	20	0
0.25	135	20	20	20	0
0.12	0	20	10	20	100
0.12	45	20	20	20	0
0.12	90	20	10	10	0
0.12	135	20	10	16.4	64
0.5	0	250	260	254.6	-2
0.5	45	250	260	260	0
0.5	90	250	260	257.8	-1
0.5	135	250	260	250	-4

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