Measurement 93 (2016) 224–231

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Model of ΔV_{10}-meter signal chain for periodic voltage fluctuation

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ARTICLE INFO

Article history:
Received 31 August 2014
Received in revised form 27 June 2016
Accepted 3 July 2016
Available online 5 July 2016

Keywords:
Power quality
Voltage fluctuation
ΔV_{10} index
Amplitude modulation
Modelling

ABSTRACT

ΔV_{10} index, proposed by the Japanese CRIEPI Institute and used all over the Far East countries, is a measure of voltage fluctuations in power grids. European standards prefer P_{st} and P_{lt} indicators for measuring voltage fluctuations. ΔV_{10} index is an alternative to these indicators to measure flicker severity caused by voltage fluctuations. ΔV_{10} and P_{st}/P_{lt} differ in terms of the characteristics of their measurement signal chains and may, therefore, be characterized by different diagnostic capabilities. The paper describes the definition of ΔV_{10} index and proposes a block diagram for the index meter, based on the structure of a flickermeter. Besides, it presents the equation that models the meter's signal chain for voltage variation, which could be reconstructed through amplitude modulation with periodic signal. The dependency of ΔV_{10} index on the frequency of the modulating signal has been depicted. The values of ΔV_{10} and P_{st} indexes for equal voltage variations have been compared. Laboratory results have also been presented to enable assessment of the ΔV_{10} index model for its dependability. A quantified relation between these indexes for selected shapes of a modulating signal has been defined, which establishes the possibility of converting one measure into the other for voltage fluctuations, reproducible through amplitude modulation with periodic signal.

1. Introduction

ΔV_{10} index is a measure of voltage fluctuations in power grids [1,2], proposed by the Japanese CRIEPI Institute [3] and used all over the Far East countries. Devices used in these countries are adjusted to voltage fluctuations identified with ΔV_{10} index. However, there are only a few publications discussing the capability of this index (e.g. [4,1,5–15,2,3,16]). None of them deals with the analytical model of the ΔV_{10} meter's signal chain. European standards prefer P_{st} and P_{lt} indicators for voltage fluctuation measurements [17,18]. The capabilities of these indicators have been widely discussed (e.q. [19–25]). ΔV_{10} index differs from P_{st}/P_{lt} indicators in terms of their specifications [26,13,12,9,7,3]. Therefore, the measures are to be characterized separately, depending on their diagnostic capabilities. This may lead to the situation wherein one measure may consider the voltage fuctuations of some loads faultless and acceptable, whereas other measures may consider the same faulty and unacceptable. Because of this ambiguity, a load may be classified as obnoxious by using one measure and not-obnoxious by using another. Thus it is difficult to compare the results of any research on obnoxious loads' influence on the basis of ΔV_{10} and P_{st} indexes. The inability to convert the values acquired with one measure into the other comes in the way of certifying the devices manufactured in a country, where a particular measure is used for estimating power quality, in areas where a different measure is used for similar estmation. To overcome this problem, it is necessary to assess the relative merits of different indicators for voltage fluctuation measurements. Such assessment might be very useful in deciding the measure to be applied in a given situation. To conduct such assessment an analytical model of ΔV_{10} meter is indispensable, because no such model has been described earlier in the literature.

The paper presents the definition of ΔV_{10} index. Because there is no standard diagram for the measuring device, a block diagram of a meter, based on the structure of a flickermeter, has been proposed. The signal chain modeling equation has been derived for voltage variation, which is reproducible through amplitude modulation with periodic signal. The dependency of ΔV_{10} index on the modulation signal's frequency has been discussed. The proposed model has made it easier to analyze the diagnostic capabilities of ΔV_{10} index. The values of ΔV_{10} and P_{st} indexes for the same voltage fluctuation have been compared. A quantitative relation between these two indexes for selected shapes of modulation signals has been obtained. To verify the proposed analytical model of ΔV_{10} index meter, a laboratory test has been conducted using the available power quality analyzers. The definition and the structure of the meter of ΔV_{10} index can be found in literature. But, the results of the laboratory tests carried out on the model are the outcome of

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http://dx.doi.org/10.1016/j.measurement.2016.07.010
0263-2241/

this author's own research, these results fill the gap in literature on ΔV_{10} meter.

2. Characteristics of the V_{10} index

ΔV_{10} index is defined by using the following equation [11,8,4,15,3]:

$$\Delta V_{10} = \sqrt{\sum_h \Delta v^2(f_h) \cdot a_n^2(f_h)} \cdot 100\%, \tag{1}$$

where $\Delta v(f)$ – represents relative peak-to-peak value of an f_h frequency sinusoidal component, and $a_n(f)$ – the scaling coefficient of the f_h frequency component.

The value of the scaling coefficient is described by $a_n = \mathrm{f}(f)$ flicker sensitivity curve. The flicker is an impression of unsteadiness of visual sensation, induced by a light stimulus whose luminance fluctuates with time [27]. The perception of flicker and evaluation of its obnoxiousness is a complex process [28–30]. The $a_n = \mathrm{f}(f)$ curve is described by a set of 11 points between 0.01 Hz and 30 Hz frequencies [3] (in [15] the set has been broadened to 34 points). The values between these points are subject to approximation according to the accepted algorithm. Thus, the (1) dependency defines the ΔV_{10} measure for the $f_h < 30$ Hz frequency. Fig. 1 shows a graph of the flicker sensitivity curve $a_n = \mathrm{f}(f)$ with locations of the points. The approximation has been performed using the "spline" algorithm of Matlab software.

The obnoxiousness of voltage fluctuations is derived on the basis of the ΔV_{10} index obtained within one-minute periods. The obnoxiousness level is considered acceptable only if, within one hour, the fourth maximum (4th max) value of the index does not exceed 0.45% [2]. Alternatively, a limit is fixed in Volts, upon the assumption that $U_c = 100$ V. In such a case, $\Delta V_{10} = 0.45\%$ corresponds to $\Delta V_{10} = 0.45$ V.

ΔV_{10} measure "was developed specifically for arc furnaces" [3] and is used in anticipation of the obnoxiousness of EAF influence on a power grid [14]. Nevertheless, it is also used in the assessment of voltage fluctuation obnoxiousness provoked by different loads and distributed power sources (eg. wind power generation system [8]).

To verify the analysis of the ΔV_{10} meter's signal chain, which will be presented later in this paper, laboratory tests have been performed. ΔV_{10} measure has been implemented on some power quality analyzers available in the market. To perform the tests, a PW3198 [31] analyzer has been used. During the period of taking measurements, the ΔV_{10}-measuring-active analyzer's input voltage was equal to (3) for $U_c = 230$ V. For comparison, the P_{st} indicator has been measured using a PQ-Box 100 [32]. The registered results of ΔV_{10} and P_{st} indicators' measurements, described as the results of the laboratory tests, have been depicted as points in selected charts. Measurement results of ΔV_{10} index (obtained with PW3198 analyzer) are given in Figs. 4–6(a), 8(a) and (b), while

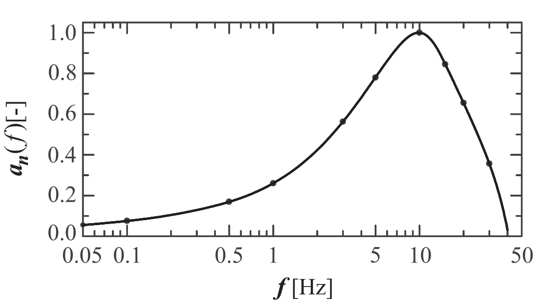

Fig. 1. Flicker sensitivity curve; points determining $a_n = \mathrm{f}(f)$ dependence are marked.

the measurement results of P_{st} indicator (obtained with PQ-Box 100 analyzer) in Figs. 6(a), 8(a) and (b). Values which were calculated directly from ΔV_{10} and P_{st} indicators values (again, obtained with PW3198 and PQ-Box 100 analyzers, respectively) are shown in Figs. 9(a), (b) and 10. "Measurement accuracy" of PW3198 for ΔV_{10} index is "$\pm 2\%\mathrm{rdg} \pm 0.01$ V (with a fundamental wave of 100 Vrms [50/60 Hz], a fluctuation voltage 1 Vrms, and a fluctuation frequency of 10 Hz)" [31]. For others fluctuation frequencies manufacturer does not specify the inaccuracy of ΔV_{10} index measurement. In turn, the "Error limit" of the PQ-Box100 is given as follows: "Flicker, Pst, Plt – ±5% of display over 0.02–20% of ΔU/U" [32]. Because the "Error limit" is referenced to the Class A of the IEC 61000-4-30 standard, it may be presumed that the error value was specified for the $f_m < f_c$.

Assessment of the inaccuracy in ΔV_{10} index measurement is a complex task. On the one hand, it is necessary to build the uncertainty budget, and on the other, from a practical point of view, it is necessary to determine the index measurement errors by laboratory experiments. Building uncertainty budget requires identification of potential causes of inaccuracy. ΔV_{10} measure has no standard specification; what is available in the literature is only a set of points, defined as a flicker sensitivity curve. This complicates the laboratory tests to be carried out for determining the errors in ΔV_{10} index measurement. What is possible under the given circumstances is to compare the measurements results of this index, obtained from power quality analyzers, with the results of the model calculation.

3. V_{10}-meter's block diagram

The specification of ΔV_{10} index does not describe the block diagram of the signal chain. Unlike a flickermeter whose structure is described by the IEC 61000-4-15 standard [17], the structure of ΔV_{10} index meter's signal chain depends on the decision of its designer. The signal chain should process $u_{in}(t)$ input voltage in a way that makes it possible to obtain the values of ΔV_{10} index according to (1). The literature offers some solutions utilizing spectral analysis by using DFT [11] as well as the systems based on the block diagram of a flickermeter [3,9], or the ones closely related to it [3,2]. Besides these, some other methods of ΔV_{10} measurement are also presented (e.g., Adaline adaptive linear neuron system, the particle swarm optimization PSO) [11]. Fig. 2 presents the proposed ΔV_{10} meter's block diagram which relates to the structure of a flickermeter.

The automatic gain control (AGC) circuit (with a built-in divider) scales value of $u_{in}(t)$ voltage in such a way that the average U_c rms value of $u(t)$ equals U_n, the reference value. M1 multiplier functions as a demodulator. F_{1A} and F_{1B} filter cascades eliminate the components stemming from the presence of the carrier. F_{10} filter, having $a_n = \mathrm{f}(f)$ magnitude responses from Fig. 1 and f_{10} medium frequency, is the factor present in Eq. (1) which defines ΔV_{10} index. M2 multiplier scales the $p_{12}(t)$ signal and M3 multiplier; F_{13} filter cascade selects the constant component from the modulating signals. M4 multiplier and the squaring functor make it possible to obtain proper value for ΔV_{10} index. The statistics block obtains the required statistical parameters of ΔV_{10} within the proper periods of time:

- max (ΔV_{10}) – maximum value of ΔV_{10} index,
- inst(ΔV_{10}) – instantaneous value of ΔV_{10} index,
- avg(ΔV_{10}) – average of ΔV_{10} index.

If (18) is fulfilled, then the instantaneous value of ΔV_{10} index equals $P_{\Delta V}$. If not, inst(ΔV_{10}) is calculated in accordance with