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Comments and suggestions on ERGEG document "Towards Voltage Quality Regulation in Europe" (ref. E06-EQS-09-03) expressed by:

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For years our activity deals, both from the research and professional point of views, with topics correlated with the power quality.

In this area the following comments are expressed.

A. point 5 on page 5/47: The minimum value of the network's short circuit power is not a sufficient measure for characterizing the mains voltage distortion level due to the harmonic currents adsorbed by the load. The characterization of the network's frequency response at different harmonics is necessary. This measure highlights the possible critical situations linked with the network resonance. The resonance can occur in the presence of capacitors, not only used for power factor improvement, but also the ones of the lines;

B. point 4 on page 5/47: The norm should define better the unpredictable, large random event concept. Thus, the responsibility of the various parts involved is possible to be individuated in a less arbitrary way;

C. page 27/47 (distinction between voltage dip and interruptions): Conceptually, this distinction should not be correlated with the residual voltage value. The distinction should be linked with the fact that the upstream active power system is becoming passive, or in other words the power system impedance seen by the customer is increasing dramatically. Thus is not capable to sustain, even at values inferior to the reference voltage, any kind of voltage. What purpose can have in practice a classification of the voltage dips with depth between 90% and 99% of the reference voltage, and interruptions with depths between 99% and 100% of the reference voltage? If it is not useful, why should be made this distinction (while the distinction in duration is important)? Also, the measurement of a voltage dip (retained voltage and duration) should account for the hysteresis effect, which has typically values of 2% of the reference voltage (in conformity with IEC-61000-4-30). Thus, the dip begins when the voltage falls below the dip threshold and ends when the voltage is equal to or above the dip threshold plus the hysteresis voltage.

D. Three-Phase Systems

Definitions of voltage levels referred to in the document are systematically on single phase base, except some occurrences as unbalance index and similar.

But, as long as the systems we are discussing about are generally 3-phase, with three line-to-ground voltages and three line-to-line voltages, many ambiguity and complexities arise. Each phase must be considered separately, or a suitable average between phases must be assumed? Moreover the reference point for line-to-ground voltages may depend on local measurement set up and is often meaningless in three-wire systems.

On the other hand, considering the actual trend in power device evolution and in measurement method improvements, standards have to describe events and prescriptions in the most detailed and rigorous form.

The fact is that three-phase systems are more that a simple superposition of three single phase ones and must not be view in this rough manner. Therefore it is convenient to separate the single phase applications and norms from specific 3-phase applications and norms.

Important feature of 3-phase systems is that sinusoidal positive sequence is the reference condition instead of simple sinusoidal.

Of particular importance are definitions and measurements rules concerning rapid voltage dips and swells. Single-phase measurements have to calculate rms over at least half a period, whereas on 3-phase systems faster and simpler measurement results are possible, therefore corresponding definitions are to be desired.

Proposes for 3-phase systems standard

Main characteristic of 3-phase system is that ideal 3-phase conditions are sinusoidal balance. In fact generation, transmission, grid regulation and most of utilizations (rotating motors) are based on fundamental frequency positive sequence component. Negative and zero sequence components, as well as harmonics, are generally unwanted as growing losses and malfunctioning.

A compact and effective way to represent 3-phase instantaneous quantities is by means of the space vector (see Appendix). In case of sinusoidal balance, voltage space vector (5) becomes (11) with constant amplitude and constant angular speed.

We propose to assume those reference values as reference to be compared with the actual 3-phase values.

Consequently we propose the amplitude of space vector (5) to be referred to in standard as the actual 3-phase voltage (measured according (7)). Such way the voltage amplitude is an instantaneous quantity and no rms calculation is needed. Therefore 10ms (half period) or 20ms (period) intervals are not yet necessary to define voltage levels. Standards for 3-phase systems may refer to a instantaneous quantities instead of a rms ones. A voltage dip shorter than 10 ms may be considered.

Such way the comparison with sinusoidal balance condition or moving away from this condition are evidenced, instead of referring to a simple sinusoidal waveform.

In standards all occurrences "rms voltage" and similar when referred to 3-phase may be changed in "voltage amplitude" (or "instantaneous space voltage amplitude").

More clear and formally correct statements are obtained specially in fast transient phenomena.

Moreover a continuous output from measuring devices may easily result.

When averaged valued are indicated, the interval on which average is evaluated need not be an integer multiple of half a period.

In details, measurement of average value or rms of 3-phase voltage may use directly the instantaneous signal (7) or its square as input of a Low Pass filter. One calculation of average is requested instead of three.

Time derivative measurements and definitions, as in rapid voltage variations, are easier on a continuous signal, instead on a discontinuous one.

In this approach 3-phase prescriptions are independent from reference point of line-to-ground voltages. In other words, zero sequence voltage is completely disregarded. Whether necessary, different measurements and prescriptions may be applied to zero sequence.

This fact is similar to single phase practice of taking mainly into account the wire-to-wire voltage, while the common-mode voltage toward ground is subject to different treatments.

Important advantage of this approach is that all 3-phase prescriptions refer only to positive sequence component, as the only useful component in power transmission and distribution.

Similarly we propose to assume the instantaneous angular speed of space voltage (5) on complex plane as the frequency of 3-phase system. This angular speed becomes constant in ideal conditions and overcomes the problem of detecting the zero crossing of voltage waveforms. The average value may be performed directly on space vector angular speed instead of elaboration of discontinuous data as the instants of zero-crossing.

Actual methods of frequency detection based on 3-phase PLL or similar give as result an average of angular speed of space voltage.

In conclusion, the aforementioned approach for 3-phase systems is more rigorous and clear in respect to the conventional one, besides needed measurements are more simple. The condition is to separate the 3-phase standards from single phase ones, and, if needed, from zero sequence part of 3-phase system.

Notes about voltage unbalance evaluation (pag. 44 Annex 3).

The ratio of negative and the positive sequence component under the hypothesis of sinusoidal steady-state can be obtained measuring the axes of the ellipse (12).

Maximum V_{max} and minimum V_{min} value of signal (7) are easily obtained. Voltage unbalance is

$$u_2 = \frac{negativesequence}{positivesequence} 100\% = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} 100\%$$

valid for $negativesequence \le positivesequence$

Much more convenient than formula of pag. 44/47 from the document.

In conclusion, the comments and suggestions afore reported rise problems that require further investigations.

Appendix. Mathematical background on 3-phase system

For 3-phase systems a well consolidated approach has been developed in the last decades, as follows.

Symmetrical components

In sinusoidal steady-state the symmetrical component transformation applies on phasors.

Phasor is a complex constant whose amplitude is the rms of a sinusoidal waveform and angle is the phase displacement. The symmetrical components are

$$\underline{V}_+ = \frac{\underline{V}_a + \alpha \underline{V}_b + \alpha^2 \underline{V}_c}{\sqrt{3}} \quad (1.a)$$

$$\underline{V}_- = \frac{\underline{V}_a + \alpha^2 \underline{V}_b + \alpha \underline{V}_c}{\sqrt{3}} \quad (1.b)$$

$$\underline{V}_o = \frac{\underline{V}_a + \underline{V}_b + \underline{V}_c}{\sqrt{3}} \quad (1.c)$$

Where $\underline{V}_a \; \underline{V}_b \; \underline{V}_c$ are phasors of line-to-ground voltages

$$\alpha = e^{j\frac{2}{3}\pi} = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$

$\underline{V}_+$ is the phasor of positive sequence

$\underline{V}_-$ is the phasor of negative sequence

$\underline{V}_o$ is the phasor of zero sequence

Space vector

In general conditions and in transients the Clarke transformation (or Park-Gorev transformation on stationary reference frame) applies on instantaneous values

$$v_\alpha(t) = \sqrt{\frac{2}{3}}\left[v_a(t) - \frac{v_b(t) + v_c(t)}{2}\right] \quad (2.a)$$

$$v_\beta(t) = \frac{v_b(t) - v_c(t)}{\sqrt{2}} \quad (2.b)$$

$$v_0(t) = \frac{v_a(t) + v_b(t) + v_c(t)}{\sqrt{3}} \quad (3)$$

Where

$v_\alpha(t)\ v_\beta(t)$ are named $\alpha\ \beta$ components

$v_o(t)$ is the instantaneous zero sequence component

Organizing $\alpha\ \beta$ components in one complex quantity, the space vector (or Park vector) is defined

$$\underline{v}(t) = v_\alpha + jv_\beta \quad (4)$$

Or, from (2)

$$\underline{v}(t) = \sqrt{\frac{2}{3}}\left[v_a(t) + \alpha v_b(t) + \alpha^2 v_c(t)\right] \quad (5)$$

Space vector (5) and the zero sequence (2) fully represent 3-phase voltages in whatever conditions.

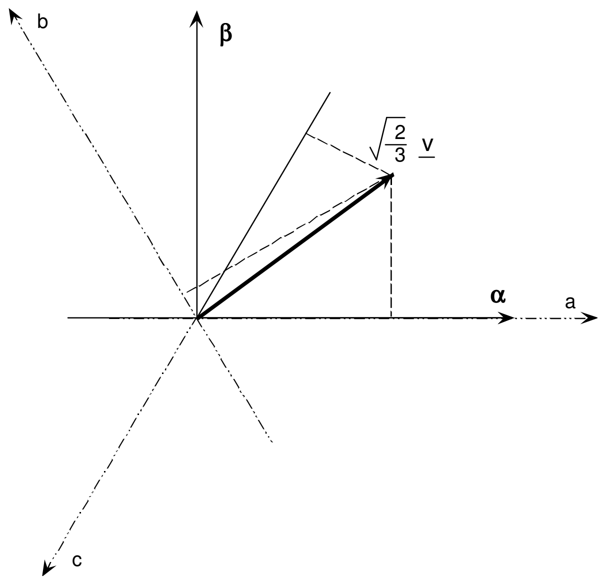
Only (3) depends on the reference point for line-to-ground voltages. Space vector (5) is independent from it, therefore the space vector may be evaluated from instantaneous line-to-line voltages, by means of the equivalent expressions (only two are needed, as $v_{ab} + v_{bc} + v_{ca} = 0$)

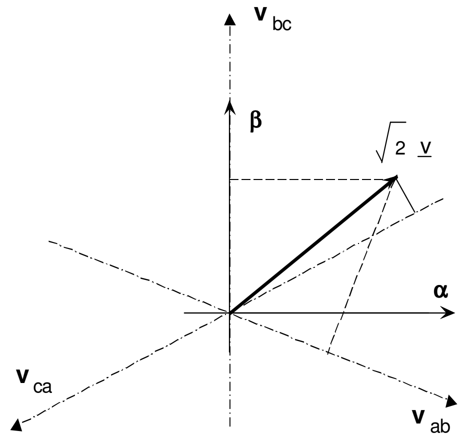
$$\underline{v}(t) = \frac{v_{ab}(t) - v_{ca}(t) - j\sqrt{3}\left(v_{ab}(t) + v_{ca}(t)\right)}{\sqrt{6}} = \frac{2v_{ab}(t) + v_{bc}(t) + j\sqrt{3}v_{bc}(t)}{\sqrt{6}} = \frac{-2v_{ca}(t) - v_{bc}(t) + j\sqrt{3}v_{bc}(t)}{\sqrt{6}} \quad (6)$$

From (6) the amplitude of (5) may be evaluated by two line-to-line voltages as

$$v(t) = |\underline{v}(t)| = \sqrt{\frac{2}{3}\left(v_{ab}(t)^2 + v_{bc}(t)^2 + v_{ab}(t)v_{bc}(t)\right)} \quad (7)$$

In order to evidence the practical significance of the space vector, the line-to ground voltage waveforms (apart the zero sequence) as well as the line-to-line voltage waveforms may be obtained by a projection of voltage space vector over three equally spaced directions, as shown





Line-to-ground voltages without zero sequence Line-to-line voltages

Under periodic steady-state of period T the following relation between rms values holds

$$V_a^2 + V_b^2 + V_c^2 = V^2 + V_0^2 \tag{8}$$

where $V_a\ V_b\ V_c$ are rms of line-to-ground voltages

V is rms of voltage space vector (5) as $V = \sqrt{\frac{1}{T}\int_T \left|\underline{v}(t)\right|^2 dt}$

(9)

V_o is rms of zero sequence voltage (3).

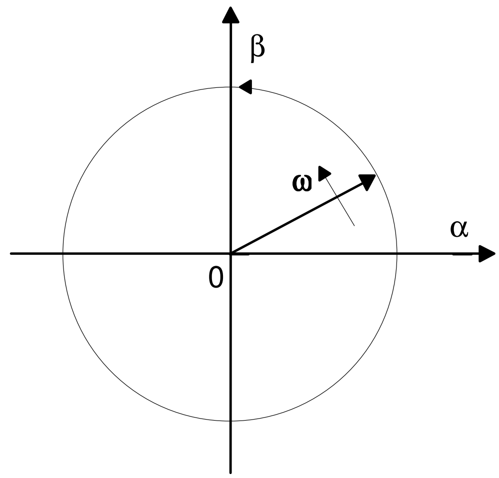
Rms of voltage space vector (5) may be evaluated also from rms of line-to-line voltages as

$$V = \sqrt{\frac{V_{ab}^2 + V_{bc}^2 + V_{ca}^2}{3}} \tag{10}$$

In *sinusoidal balance* (positive sequence) steady-state of angular frequency ω, (5) and (3) become

$$\underline{v}(t) = \underline{V}_+ e^{j\omega t} \qquad v_0(t) = 0 \qquad (11)$$

In sinusoidal balance the space vector has constant amplitude and rotates at constant speed ω anticlockwise in the complex plane.

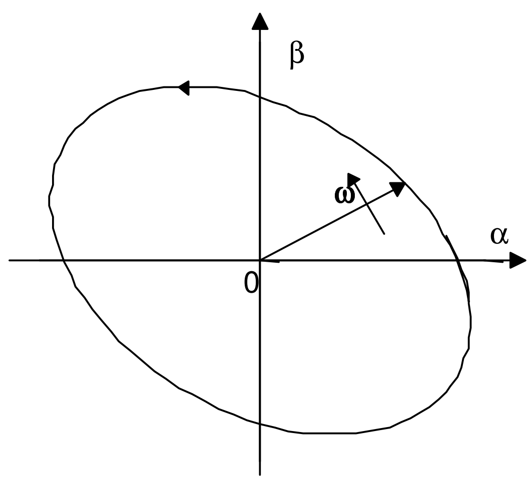


In generic *sinusoidal steady-state* of angular frequency ω, (5) and (3) become

$$\underline{v}(t) = \underline{V}_+ e^{j\omega t} + \underline{V}_-^{\ *} e^{-j\omega t} \qquad\qquad v_o(t) = \sqrt{2}\left|\underline{V}_o\right| \cos\left[\omega t + \arg(\underline{V}_o)\right] \tag{12}$$

where $\underline{V}_-^{\ *}$ is the conjugate of $\underline{V}_-$

In sinusoidal steady-state the space vector trajectory is an ellipse in the complex plane.



Under *distorted steady-state* of fundamental angular frequency ω, the space vector may be expanded in complex Fourier series

$$\underline{v}(t) = \sum_{k=-\infty}^{+\infty} \underline{V}_k e^{jk\omega t} \qquad \text{with} \qquad \underline{V}_k = \frac{1}{T}\int_T \underline{v}(t) e^{-jk\omega t} dt \tag{13}$$

Index k>0 corresponds to a positive sequence terms. k=1 is the fundamental positive sequence.

Index k<0 corresponds to a negative sequence terms. k=-1 is the fundamental negative sequence

Index k=0 corresponds to constant (average) terms.

The conventional Fourier expansion is applied to zero sequence component.

Note. The coefficients $\frac{1}{\sqrt{3}}$ in (1) and (3), $\sqrt{\frac{2}{3}}$ in (5) give rise to the so-called rational form of transformations. Such forms have the property of invariance of power. In this case under sinusoidal balance conditions the positive sequence phasor and the amplitude of the space vector (11) are equal to each other and to line-to-line rms voltage.