Virtual Instrument for Assessment of Simulated Signal Integrated Harmonics Factors

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Abstract – **The block diagram of the LabVIEW virtual instrument for the assessment of simulated signal integrated harmonics factors is presented. This virtual device version is equipped with the input module for waveform data points import from PSIM output text file. The examples of measurement and use of the integrated harmonics factors values of the investigated voltage for estimating the harmonic distortion of the load circuit current are shown.**

Index Terms – **Weighted THD, n-order integrated voltage (current) harmonics factor (IHF), method of the differential equations algebraization (ADE), LabVIEW virtual instrument, PSIM.**

I. INTRODUCTION

THE SIGNAL harmonic content analysis remains the most needed research operation in radio engineering, electronics and communications systems as well as in electrical engineering and power electronics when it relates to electromagnetic compatibility and efficiency issues [1]-[4].

The conventional factor of voltage harmonics K_{hu} (HF), i.e. the classical voltage THD, is excellent in characterization of the impacting voltage itself only, since it can provide the adequate valuation of the response harmonic contents only for the circuit with the pure active (resistive) load.

The well-known weighted THD (WTHD) factor [5] is used approximately since 2000. It is the most used element of the system of the weighted THD factors for the induction motor load with the frequency-dependent parameters.

The integrated voltage harmonics factors (IHF) were offered by Professor G.S. Zinoviev (NETI, now NSTU, Novosibirsk) much earlier, namely 35 years ago, and they produces weighted (by the harmonic number) summation of harmonics, thereby modeling the effect of the amplitude-frequency characteristic action of the corresponding order idealized electric integrating circuit [6]-[11]. The IHF factors are closely related to the method of the differential equations algebraization (ADE) which allows finding asymptotically with the preset accuracy the closed analytical form expressions for the mathematical relations between the voltages and/or currents RMS values, using the coefficients of the integral-differential equation, that includes these voltages and currents, without solving it [6], [8].

Similar to the THD definitions, the n-order voltage IHF, $\overline{K}_{hu}^{(n)}$, is calculated as follows [6]-[8]:

$$\overline{K}_{hu}^{(n)} = \frac{\overline{U}_{(hh)}^{(n)}}{\overline{U}_{(1)}^{(n)}} = \frac{\overline{U}_{(hh)}^{(n)} \cdot \omega^n}{U_{(1)}}, \qquad (1)$$

$$\overline{K}_{hu}^{(n)} = \frac{\sqrt{\left(\overline{U}^{(n)}\right)^2 - \left(\overline{U}_{(1)}^{(n)}\right)^2}}{U_{(1)}/\omega^n} = \sqrt{\left(\frac{\overline{U}^{(n)} \cdot \omega^n}{U_{(1)}}\right)^2 - 1}, \quad (2)$$

$$\overline{K}_{hu}^{(n)} = \frac{\sqrt{\left(\overline{U}_{(hh)}^{(n)}\right)^2}}{U_{(1)}/\omega^n} = \sqrt{\sum_{k=2}^{\infty}\left(\frac{U_{(k)}}{k^n \cdot U_{(1)}}\right)^2}, \qquad (3)$$

where for estimated voltage u values $U_{(k)}$, $\overline{U}_{(1)}^{(n)}$, $\overline{U}_{(hh)}^{(n)}$ and $\overline{U}^{(n)}$ are the RMS value of the k harmonic component and RMS values of the results of the n-fold indefinite integral taking of the instantaneous values of the fundamental component $\overline{u}_{(1)}^{(n)}$, of the high harmonics component $\overline{u}_{(hh)}^{(n)}$ and of the whole voltage $\overline{u}^{(n)}$, correspondingly; ω is the angular frequency of the fundamental component. Since the process without a DC component is being considered,

$$\overline{u}^{(n)} = \overline{u}_{(1)}^{(n)} + \overline{u}_{(hh)}^{(n)}. \qquad (4)$$

The conventional voltage THD (HF, K_{hu}) corresponds to $n = 0$. The similar way the differentiated voltage harmonics factors (DHF) [6] have been introduced.

In accordance with (3), the n-order integrated voltage harmonics factors IHF can be also referred to as the n-order weighted THD [11]:

$$\overline{K}_{hu}^{(n)} = WTHD^{(n)}. \qquad (5)$$

The IHF factors make it possible to evaluate beforehand the load circuit voltages and currents and their quality indices, such as the load (end user) current THD value. In this, these IHF indices relate not to some particular load circuit parameters and their some particular values, but to the impacting voltage itself (imposed to this load circuit).

II. PROBLEM DEFINITION

One of the main research techniques for electronic circuits now is computer simulation. The friendly user interface and fast speed of simulation of power electronics devices, control systems for electric drive and power conversion systems are provided by the widespread simulation software PSIM developed by Powersim (France) [12]. This software is much faster and much cheaper than Matlab/Simulink system.

Despite the growing number of optional add-on modules available to address specific needs in various applications and giving the flexibility to tailor PSIM for user's own needs, the National Instruments LabVIEW software-hardware environment (Laboratory Virtual Instrument Engineering Workbench) is more attractive as a simulation tool. LabVIEW is used as the standard tool for investigation in industry, scientific researches and education. LabVIEW Programming Structures, such as "For Loop", "While Loop", "Case structure", "Sequence structure", are providing great opportunities. At last, LabVIEW is very promising in terms of both data analysis and moving towards carrying out the real nature measurements [13].

In addition to the regular virtual instrument (VI) "Distortion Measurements Express VI", making it possible to easy estimate the signal THD after specifying the order number N of the highest counted harmonic component, the LabVIEW environment provides the enough wide range of designing means for the harmonic contents monitoring [14]-[16]. However, the need for the consideration of the above mentioned integrated harmonics factors is not satisfied.

Our previous papers proved efficiency of the before offered LabVIEW virtual instrument for IHF assessment of signals constructed within LabVIEW VI itself. In particular, the meander, trapezoidal and triangle waveforms signals have been synthesized and analyzed by means of this VI, the IHF and some DHF estimation results have been compared with analytical ones obtained via harmonic synthesis [17], [18]. The multilevel voltage source inverter (MLVSI) output voltage IHF assessments have been accomplished via controller signals waveforms in [19], [20].

Despite the obvious progress achieved, LabVIEW has natural limitation for our research, namely, it is not intended for any electronics, electrical engineering and power electronics circuits simulation, so we have not here any ready for use models of electric circuit elements, their connections, power switches etc.

The purpose of this paper is to present the LabVIEW virtual instrument for the assessment of simulated signals integrated harmonics factors, which is equipped with the input module for waveform data points import from PSIM output text file. Thus, the capability of the PSIM power elements voltages and currents waveforms processing in advanced LabVIEW environment, avoiding supplementary PSIM modules, is shown.

Also some examples of measurement and use of the integrated harmonics factors values of the investigated voltage for estimating the load circuit THD are demonstrated.

III. LABVIEW VIRTUAL INSTRUMENT

The core part block diagram of the LabVIEW virtual instrument for the voltage harmonics integrated factors evaluation is presented in Fig. 1.

The "IFH-meter" is implementing operations of (1) as definition, which provides the most accurate results [17]. The virtual instruments "Tone Measurements Express VI" and "Simulate Signal Express VI" are used here, respectively, to define the parameters of the fundamental component $u_{(1)}$ and to synthesize it for the further obtaining instantaneous higher harmonics component signal $u_{(hh)}$. The direct current voltage components (the mean values) are eliminated before each integrating and RMS calculating operations.

For multiple data updating, the "IFH-meter" software graphic code can be placed in "For Loop" cyclic structure.

The "Table data converter" operates in the current version as follows (see Fig. 1). The "Open/Create/Replace File" function through the "File path" control opens the output PSIM file, the "Scan From File" function passes the all lines except the first one (the only numeric data). Then the other "Scan From File" function, placed in the "For Loop" structure, reads one line from the file and, according to the specified format template, converts it to output variables. The decimal separator character must be specified for decimal fractions. The above-mentioned function runs as many times as the data lines in the file are. This number is defined here by using the "Read Lines from file" VI and the "Spreadsheet String to Array", "Array Size" and "Index Array" functions. After the data reading at the output of the cycle, two arrays are formed: the time values array and the corresponding signal values array (waveforms elements). At last, the signal time is being scaled up to the original one. The "Scale Delta t" VI is used for this operation, its inputs are supplied with the data signal array, needed to be scaled up, and the scaling parameter. The scaling parameter must be close to the original time step, so the difference between the first two elements of the time array from the two more "Index Array" functions is used. The supplementary "Multiply", "Round to Nearest" and "Divide" functions eliminate insignificant digits which were remaining due to PSIM simulation features.

The "Samples per second" dialog box value of the "Simulate Signal Express VI" in the "IFH-meter" must be set equal to the resulting sampling frequency of the "Table data converter", which in turn is equal to the scaling parameter inverse value and is defined after the first virtual instrument launching.

The "Table data converter" can be also expanded to read from PSIM file more than one signal data columns and rebuild corresponding waveforms in LabVIEW virtual instruments.

The IHF factors measurements results obtained via the offered VI and comparisons between the results for the signal, generated within LabVIEW VI (used as references while the relative error values calculating) and the signal, imported from the PSIM model, are summarized in Table I below. The measured waveform examples correspond to the executed phase-to-neutral voltage of the MLVSI with nearest vector selecting instantaneous space vector control [20].
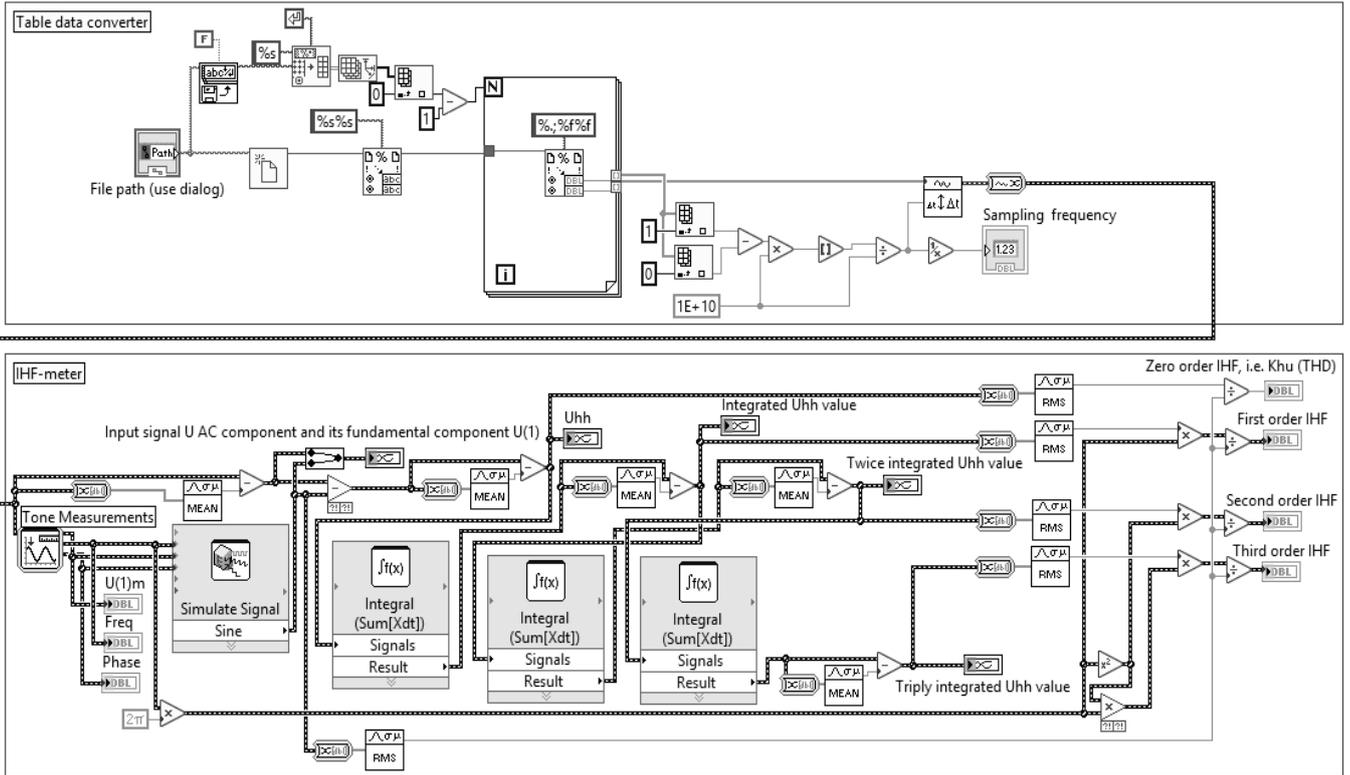
Fig. 1. LabVIEW virtual instrument for voltage harmonics integrated factors evaluation.

Here m_{aY} is the phase voltage amplitude modulation index:

$$m_{aY} = U/U_d = U^*, \qquad (6)$$

where U and U^* are the value and the relative value of the reference voltage space vector magnitude, equal to the reference phase voltage amplitude, U_d is the input DC voltage of the unit (base) level.

The Table I pictures display also sine wave lines of the fundamental components (50 Hz) of the investigated voltage waveforms.

The four amplitude modulation index values have been arbitrarily selected ones. The LabVIEW simulations were carried out under the sampling frequency 1MHz, i.e. with the time step equal to 0.000001 s. The PSIM simulation results and their relative errors are given for the time step 0.000001 s and the time step 0.0000001 s in the first and in the second lines of the table cells, respectively.

The adequate estimation of the zero- to third-order IHF for the PSIM-imported waveforms is demonstrated for cases in which their simulation step has been set to 0.0000001 s. The more accurate estimation of the third-order IHF needs time step value of an order of magnitude below those used here.

In addition to the higher resolution simulating at reduced time step values, the following two simple conditions of the PSIM signal simulations should be followed to obtain the most accurate their measurement results in the LabVIEW virtual instrument:

- A steady-state mode of an investigated electromagnetic process should be considered.

- The X axis (time) settings of the Simview (the waveform display program of the PSIM) should correspond to the only selected fundamental period. The using of the first period is strongly discouraged because of its accessory signal spike and absence of the zero time moment data.

IV. USE OF INTEGRATED VOLTAGE HARMONICS FACTORS

The set of the main needed for the further calculations IHF factors is being determined on the results of the ADE procedure, applied to differential equations that have been derived from some particular load circuits.

The simplified equivalent phase circuits of the MLVSI, as the examples of the circuits with nonsinusoidal voltage source, are shown in Fig. 2, where $u_{EXEan}(t)$ is the phase "a" executed phase-to-neutral ("n") voltage; L_a and R_a are the prospective phase "a" load inductance and resistance, L_f and C_f are the elements of phase "a" MLVSI output LC filter; i_a is the phase "a" load current.
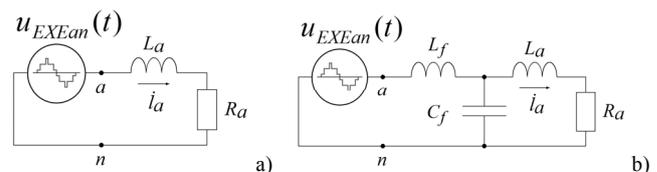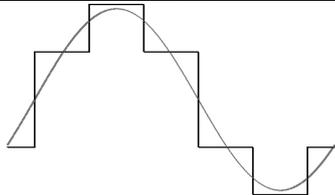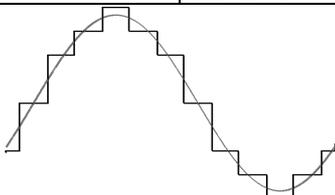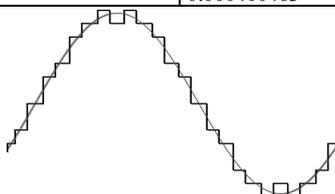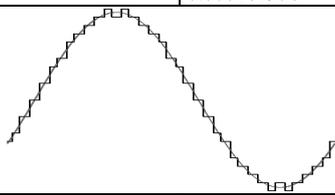

Fig. 2. MLVSI simplified equivalent phase circuits: phase RL load circuit a), phase RL load circuit with MLVSI output filter b).

TABLE I
COMPARISON OF MEASUREMENTS RESULTS

m_{aY}	Result parameters	Origin environment of simulated signal		Relative error,%
		LabVIEW virtual instrument controller model	PSIM power circuit model (high and low simulation time step values)	
0.612	Waveform			-
	$\overline{K}_{hu}^{(0)} = K_{hu}$	0.3108050252	0.3121464292 0.3110606880	0.43 0.08
	$\overline{K}_{hu}^{(1)}$	0.0463705	0.0465907 0.046412	0.47 0.09
	$\overline{K}_{hu}^{(2)}$	0.00856205	0.00881988 0.00857771	3.01 0.18
	$\overline{K}_{hu}^{(3)}$	0.00165464	0.00253593 0.00168449	53.3 1.80
1.26	Waveform			-
	$\overline{K}_{hu}^{(0)} = K_{hu}$	0.1685503522	0.1692846183 0.1686142347	0.44 0.04
	$\overline{K}_{hu}^{(1)}$	0.0156507	0.0157639 0.0156509	0.72 0.0013
	$\overline{K}_{hu}^{(2)}$	0.00229352	0.00254504 0.00229306	10.97 0.02
	$\overline{K}_{hu}^{(3)}$	0.000410563	0.00113811 0.000410463	177.2 0.02
2.16	Waveform			-
	$\overline{K}_{hu}^{(0)} = K_{hu}$	0.1074704251	0.1075494956 0.1075015846	0.07 0.03
	$\overline{K}_{hu}^{(1)}$	0.00918433	0.0091874 0.00918118	0.03 0.03
	$\overline{K}_{hu}^{(2)}$	0.00143054	0.00143456 0.00143031	0.28 0.02
	$\overline{K}_{hu}^{(3)}$	0.00026185	0.000274415 0.000261956	4.80 0.04
3.45	Waveform			-
	$\overline{K}_{hu}^{(0)} = K_{hu}$	0.0636369244	0.0637422427 0.0636811972	0.17 0.07
	$\overline{K}_{hu}^{(1)}$	0.0025928	0.00260175 0.00259187	0.35 0.04
	$\overline{K}_{hu}^{(2)}$	0.000182188	0.000258368 0.000182235	41.81 0.03
	$\overline{K}_{hu}^{(3)}$	0.0000177959	0.000181097 0.000020644	917.6 16.00

The simplest MLVSI load circuit (Fig. 2, a) produces the first order differential equation and reduced integral equation derived from it:

$$L_a \cdot \frac{di_a}{dt} + R_a \cdot i_a = u_{EXEan}, \quad i_a + a_1 \cdot \overline{i}_a^{(1)} = b_1 \cdot \overline{u}_{EXEan}^{(1)}, \quad (7)$$

$$a_1 = R_a/L_a, \quad b_1 = 1/L_a,$$

here and after the rest values designations completely correspond to description of (3). Let's here treat the $\overline{K}_{hu}^{(n)}$ as the n-order IHF of $u_{EXEan}(t)$.

After the ADE technique applying, the phase "a" load current i_a THD value, K_{hia}, can be defined as asymptotic quantity, being approximately calculated as the sum of the finite series with alternating members signs:

$$K_{hia} = I_{a(hh)}/I_{a(1)} \approx$$

$$\approx \sqrt{\left(a_1^2 + \omega^2\right) \cdot \sum_{n=1}^{N_f} \left\{ (-1)^{n-1} \cdot \left(\frac{a_1^{n-1}}{\omega^n} \cdot \overline{K}_{hu}^{(n)} \right)^2 \right\}}, \quad (8)$$

where N_f is the approximation level, related to the "filter hypothesis" [6], [8], namely $\overline{i}_{a(hh)}^{(n \geq N_f)} \equiv 0$. So, the first approximation $N_f = 1$ corresponds to

$$K_{hia} \approx \overline{K}_{hu}^{(1)} \cdot \sqrt{1 + \left(\frac{a_1}{\omega} \right)^2}. \quad (9)$$

The MLVSI phase load circuit with LC filter (Fig. 2, b) leads to the third order reduced integral equation and $N_f = 1$ approximation i_a THD result:

$$i_a + a_1 \cdot \overline{i}_a^{(1)} + a_2 \cdot \overline{i}_a^{(2)} + a_3 \cdot \overline{i}_a^{(3)} = b_3 \cdot \overline{u}_{EXEan}^{(3)}, \quad (10)$$

$$a_1 = \frac{R_a}{L_a}, \quad a_2 = \frac{1}{C_f} \cdot \left(\frac{1}{L_f} + \frac{1}{L_a} \right), \quad a_3 = \frac{R_a}{L_f \cdot C_f \cdot L_a},$$

$$b_3 = \frac{1}{L_f \cdot C_f \cdot L_a},$$

$$K_{hia} \approx \overline{K}_{hu}^{(3)} \cdot \sqrt{1 + \frac{a_1^2 - 2 \cdot a_2}{\omega^2} + \frac{a_2^2 - 2 \cdot a_1 \cdot a_3}{\omega^4} + \frac{a_3^2}{\omega^6}}. \quad (11)$$

Thus, the demanded IHF indices order numbers are strongly dependent on the whole load circuit order and configuration, as well as on the approximation level N_f. In our case, the first three coefficients with $n = 1 \dots 3$ are needed for the simplest circuit current i_a THD evaluation at the approximation level $N_f = 3$ according to (8), and the last of them is the main index for the load circuit with MLVSI output LC filter (and the only index at the level $N_f = 1$).

Let us consider an example of a current THD value calculations via an impacting voltage IHF values and

compare these results with the results of PSIM current waveform measurement in PSIM itself (by the internal means of the Simview) and in the offered LabVIEW virtual instrument. Suppose the Fig. 2,a load circuit has the parameters R_a = 48.13 Ohm, L_a = 0.14 H, and the imposed voltage is again the PSIM-simulated phase-to-neutral voltage of the MLVSI with nearest vector selecting instantaneous space vector control [20], here under m_{aY} = 3.45 (see Table I).

The LabVIEW VI measurement result and the ADE calculations results for the first three approximation levels according to (8) and their corresponding ratio errors, relative to the internal PSIM (Simview) THD estimate, are reflected in Table II. The investigated PSIM waveform, transmitted to the LabVIEW VI, of the MLVSI phase RL load current is shown in Fig. 3.

Despite the almost negligible current waveform distortion value, it has been successfully detected and estimated by the offered LabVIEW virtual instrument for the assessment of simulated signal integrated harmonics factors.

An even higher results precision has been reached through the ADE method calculation under $N_f > 1$, i.e. with using the few impacting voltage IHF values, preliminary measured via the same virtual instrument.

TABLE II
COMPARISON BETWEEN MEASUREMENTS AND CALCULATIONS RESULTS

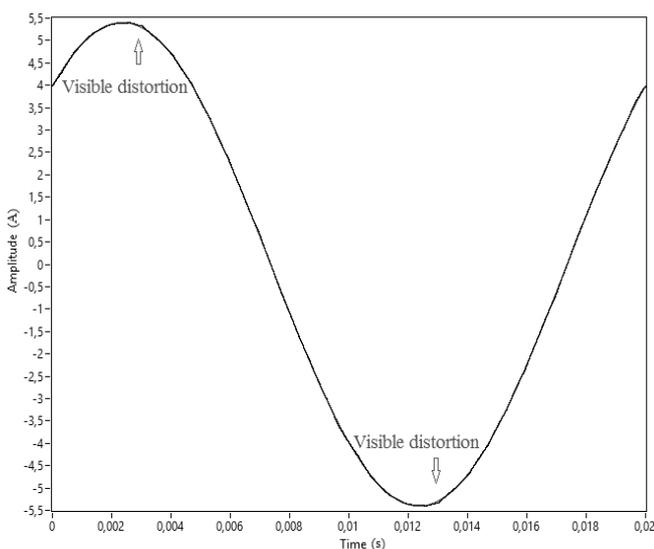| Value origin		Load current waveform THD value (K_{hia})	Relative error,%
Simview measurement		0.0038314100	Reference value
LabVIEW VI measurement		0.003828600977765	0.073
ADE calculations	Approximation level N_f 1	0.00384218048256077	0.281
	2	0.00383079097362870	0.016
	3	0.00383096625679934	0.012

Fig. 3. From PSIM to LabVIEW transmitted power circuit waveform of phase RL load current and its fundamental component (mostly coinciding lines).

V. CONCLUSIONS

The LabVIEW virtual instrument for the assessment of simulated signals integrated harmonics factors, equipped with the input module for waveform data points import from PSIM output text file, is offered and proved to be effective.

The role of the integrated voltage harmonics factors in circuits with nonsinusoidal voltage source for load variables quality evaluation is demonstrated. Some examples of measurement and use of the integrated harmonics factors values of the investigated voltage for estimating the load circuit current THD are presented.

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