

Virtual Harmonic Analyser – Harmonic Analysis and Estimation of THD using LabVIEW

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Abstract- At this modern industrial world 90% of the Electrical supply is flown through Power electronic converters (nonlinear loads) produces harmonics, which are disturbing the other equipments connected in the same supply. Hence it is necessary to measure the harmonic components to estimate their effect. The separation of various frequency components with respect to the fundamental frequency is carried out to calculate the Total Harmonic Distortion (THD) which is useful to design suitable filters to remove the harmonics in the signal. This paper proposes a novel method to analyse the harmonic contents in a non-sinusoidal signal. The proposed method is carried out using ‘Virtual Instrumentation’ concept with the help of Lab VIEW software and low cost DAQ card is designed with the help of PIC microcontroller. A Virtual Harmonic Analyser (VHA) is developed to detect the fundamental frequency of the given non-sinusoidal signal, to separate the different frequency components and to compute the THD. And also, it provides remote accessibility to many users through web. The performance of the proposed VHA is comparable to that of a hardware based analyser.

Keywords – Harmonics, Lab VIEW, Total Harmonic Distortion, Virtual Instrumentation

1. INTRODUCTION

A. Harmonics in a Complex Signal

One of the major problems in power systems is the presence of harmonics [1] in the supply voltage and load current. Current harmonics are generated by non linear loads such as power conversion equipment [1]. Both voltage and current harmonics can be generated by either the source or the load side. Harmonics generated by load are caused by nonlinear operation of devices, including power converters, arc-furnaces, gas discharge lighting devices, etc. [2].

Any periodic waveform can be shown to be the superposition of a fundamental and a set of harmonic components [2]. By applying Fourier transformation, these components can be extracted.

The frequency of each harmonic component is an integral multiple of its fundamental.

The instantaneous current, $i_s(t)$, can be expressed in a Fourier series as

$$i_s(t) = I_{dc} + \sum_{n=1,3..}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \quad (1)$$

If the waveform is symmetrical about X axis, there will be no even harmonics and I_{dc} will be zero and the co-efficients are

$$a_n = 0 \quad (2)$$

$$b_n = \frac{1}{n} \int_0^{2\pi} i_s(t) \sin n\omega t d(\omega t) \quad (3)$$

$$= \frac{2I_a}{n\pi} \sum_{m=1}^P [\cos n\alpha_m - \cos n(\alpha_m + \delta_m)] \quad (4)$$

so,

$$i_s(t) = \sum_{n=1,3..}^{\infty} \sqrt{2} I_n \sin(n\omega t + \Phi_n) \quad (5)$$

Where

$$\left[\begin{array}{l} \Phi_n = \tan^{-1}(a_n / b_n) = 0 \text{ and} \\ I_n = (a_n^2 + b_n^2)^{1/2} / \sqrt{2} = b_n / \sqrt{2} \end{array} \right] \quad (6)$$

Generally, with a certain fundamental of frequency f_0 , we can expect 3rd, 5th, 7th ... multiples of f_0 with progressively reducing amplitudes from the fundamental.

B. Total Harmonic Distortion

There are several methods to indicate of the quantity of harmonic contents. The most widely used measure is the THD. THD [1],[2], is defined in terms of the amplitude of the fundamental A_1 and the amplitudes of the various harmonics A_n (corresponding to frequencies $n\omega_0$, where ω_0 is angular

frequency of the fundamental) where $n = 2,3,4,\dots$. The THD is calculated by,

$$\text{THD} = \frac{\sqrt{A_2^2 + A_3^2 + A_4^2 + \dots}}{A_1} \quad (7)$$

C. IEEE Standard of Voltage and Current

The limits specified by the IEEE/ANSI standard 519, “IEEE recommended Practices and Requirements for Harmonic control in Electrical Power Systems” [3] are the following.

TABLE I.
VOLTAGE DISTORTION LIMITS

Voltage	Individual	Total
<69kV	3.0%	5.0%
<161kV	1.5%	2.5%
>161kV	1.0%	1.5%

TABLE II.
CURRENT DISTORTION LIMITS (<69KV)

kV Isc/I _L	<11	<17	<23	<35
<20	4.0%	2.0%	1.5%	0.6%
<50	7.0%	3.5%	2.5%	1.0%
<100	10.0%	4.5%	4.0%	1.5%
<1000	15.0%	7.0%	6.0%	2.5%

D. Effects of Harmonics

In many circumstances, such as, distortion in mains supply lines due to nonlinear loads, distortion in FM transmission due to high frequency side bands, misinterpretation of absorption in spectroscopy due to electromagnetic radiation (EMR), it is necessary to measure the harmonic components to estimate their effect. The harmonics are the unwanted contents of the signal in these circumstances. Harmonics cause (i) Overheating (ii) Premature failure (iii) Reduction in Power Quality of associated Electrical System. [2]

E. Harmonic Analysis

Normally, the harmonic analysis is carried out by in industrial areas [6],[7] using Spectrum Analysers, digital storage oscilloscopes [4] and there are some computer based measurements [5] also which can show the side banded spectrum in a selectable region of analysis. Now a day’s even artificial neural networks are used for the estimation and analysis [8]. With help of different windowing techniques, a particular region is selected for analysis. These windowing functions and analysis are normally carried out through Digital Signal Processors (DSP). There are some attempts also made to use the Virtual Instrumentation technique for the analysis of the harmonics present in the system [9],

[10], [11], [12]. Those above said methods are using the DAQ system which is costlier and easier. Here the DAQ system is designed with the help of PIC microcontroller and the inputs to the LabVIEW system is given through the serial port. This paper proposes a user friendly Graphical User Interface (GUI) Virtual Instrumentation technique [19], [20], for the real time analysis with the same level of performance parameters.

F. Frequency versus Time Domain

Fourier’s theorem states that any waveform in the time domain can be represented by the weighted sum of sines and cosines. The same waveform can then be represented in the frequency domain as a pair of amplitude and phase values at each component frequency.

We can generate any waveform by adding up sine waves, each with a particular amplitude and phase. Figure 1 shows the original waveform, labeled *sum*, and its component frequencies. The fundamental frequency is shown at the frequency f_0 , the second harmonic at frequency $2f_0$, and the third harmonic at frequency $3f_0$.

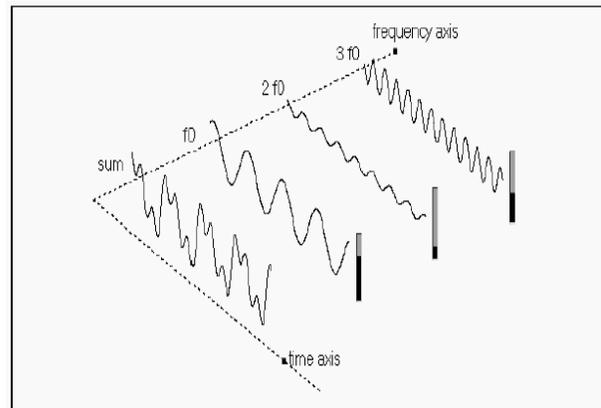


Fig.1 Representation of fundamental and harmonic components.

II. WINDOWING

In practical applications, we obtain only a finite number of samples of the signal. The FFT assumes that this time record repeats. If we have an integral number of cycles in our time record, the repetition is smooth at the boundaries. However, in practical applications, we usually have a non-integral number of cycles. In such cases the repetition results in discontinuities at the boundaries. These artificial discontinuities were not originally present in our signal and result in a smearing or leakage of energy from our actual frequency to all other frequencies. This phenomenon is known as spectral leakage.

The amount of leakage depends on the amplitude of the discontinuity, a larger one causing more leakage. Because the amount of leakage is dependent on the amplitude of the discontinuity at the boundaries, we can use windowing to reduce the size of the discontinuity and hence reduce spectral leakage. Windowing consists of multiplying the time-domain signal by another time-domain waveform, known as a window, whose amplitude tapers gradually and smoothly towards zero at edges. The result is a windowed signal with very small or no discontinuities, and therefore reduced spectral leakage. There are many different types of windows available and we have to choose the window depends on our application.

III. HARMONIC DISTORTION MEASUREMENT

When a single-frequency sine wave is applied to a perfectly linear system, it produces an output that has the same frequency as that of the input sine wave, but with possible changes in the amplitude and / or phase. This also is true when a composite signal consisting of several sine waves is applied at the input. The output signal consists of the same frequencies but with different amplitudes and / or phases. Many real-world systems act as nonlinear systems when their input limits are exceeded, resulting in distorted output signals. If the input limits of a system are exceeded, the output consists of one or more frequencies that did not originally exist at the input.

For example, if the input to a nonlinear system consists of two frequencies f_1 and f_2 , the frequencies at the output are f_1 , f_2 , sums and differences of f_1 and f_2 , and the harmonics of f_1 and f_2 . The number of new frequencies at the output, their corresponding amplitudes, and their relationships with respect to the original frequencies vary depending on the transfer function. We can use distortion measurements to quantify the degree of nonlinearity of a system. Some common distortion measurements include Total Harmonic Distortion (THD), Total Harmonic Distortion + Noise (THD + N), Signal Noise and Distortion (SINAD), and Intermodulation Distortion.

A. Harmonic Distortion

When a signal, $x(t)$, of a particular frequency (for example, f_1) is passed through a nonlinear system, the output of the system consists of not only the input frequency (f_1), but also its harmonics ($f_2 = 2f_1$, $f_3 = 3f_1$, $f_4 = 4f_1$, and so on). The number of harmonics, and

their corresponding amplitudes, that are generated depends on the degree of nonlinearity of the system. In general, the more the nonlinearity, the higher is the harmonics, and vice versa. An example of a nonlinear system is a system where the output $y(t)$ is the cube of the input signal $x(t)$, as shown in the equation

$$\cos(\omega t) \rightarrow y(t) = f(x) = x^3(t) \rightarrow \cos^3(\omega t) \quad (8)$$

So, if the input is

$$x(t) = \cos(\omega t) \quad (9)$$

The output is

$$x^3(t) = 0.5 \cos(\omega t) + 0.25[\cos(\omega t) + \cos(3\omega t)] \quad (10)$$

Therefore, the output contains not only the input fundamental frequency f_0 , but also the third harmonic of f_3 .

B. THD Measurement

The measurement of the THD requires measuring the amplitudes of the fundamental frequency and the amplitudes of the individual harmonics. A common cause of harmonic distortion is clipping that occurs when a system is driven beyond its capabilities. Symmetrical clipping results in odd harmonics, but asymmetrical clipping creates both even and odd harmonics.

IV. DESIGN OF VIRTUAL INSTRUMENTATION SYSTEM FOR HARMONIC ANALYSIS

A Data Acquisition System is designed by using LabVIEW 8.5 [19], [20] as a front end of this analysis. It acquires the signal from the input of the system. It is divided into Front Panel and Block Diagram. Front panel is the appearance of the front view of the Virtual instrument and the block diagram is the internal connections related to the front panel. Front panel shown in Fig.2 consists of 1) Voltage and Current Waveform, 2) Voltage and current Magnitude indicators, 3) Real Power, Reactive Power, Apparent power values 4) power factor of the system, 5) THD indicator and 6) Harmonics frequency Spectrum. While executing this VI program it also stores the waveform data in MS-Excel format for further reference and reconstruction.

This paper describes the utility of virtual instrument to offer a cost effective, but producing the accurate and speed analysis report on the signal harmonic analysis.

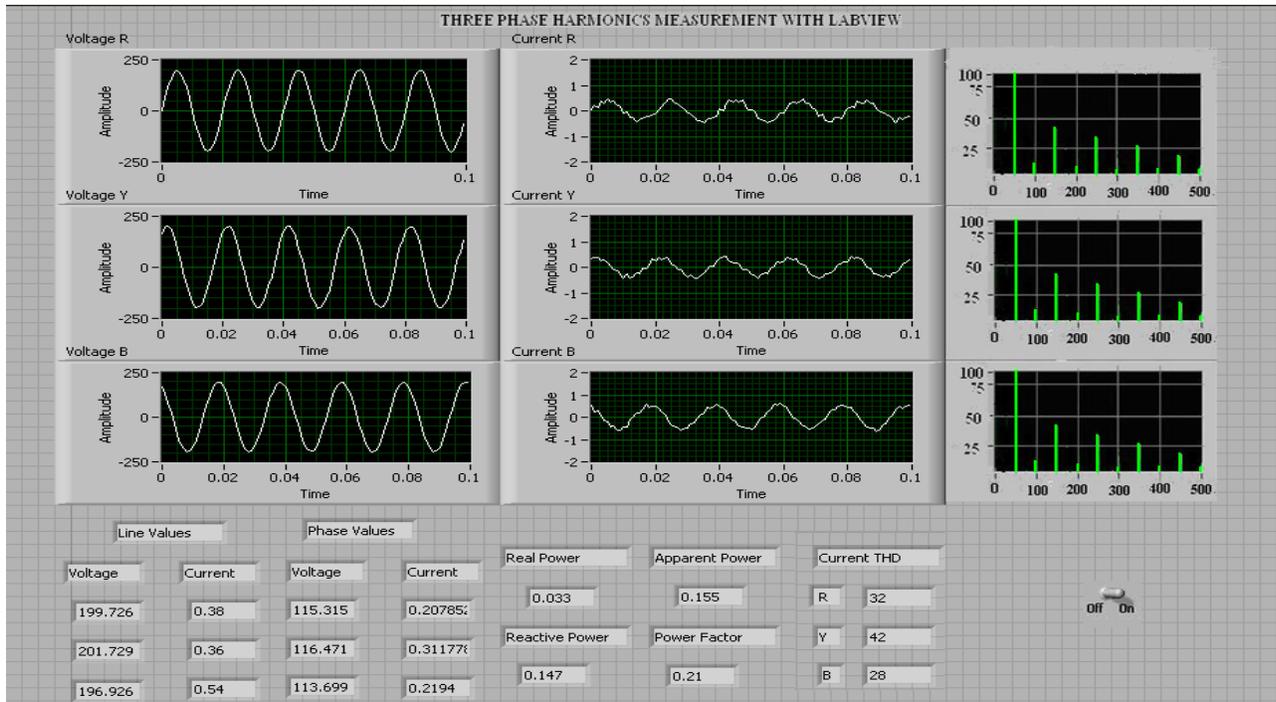


Fig.2 Front Panel – Virtual Harmonic Analyser

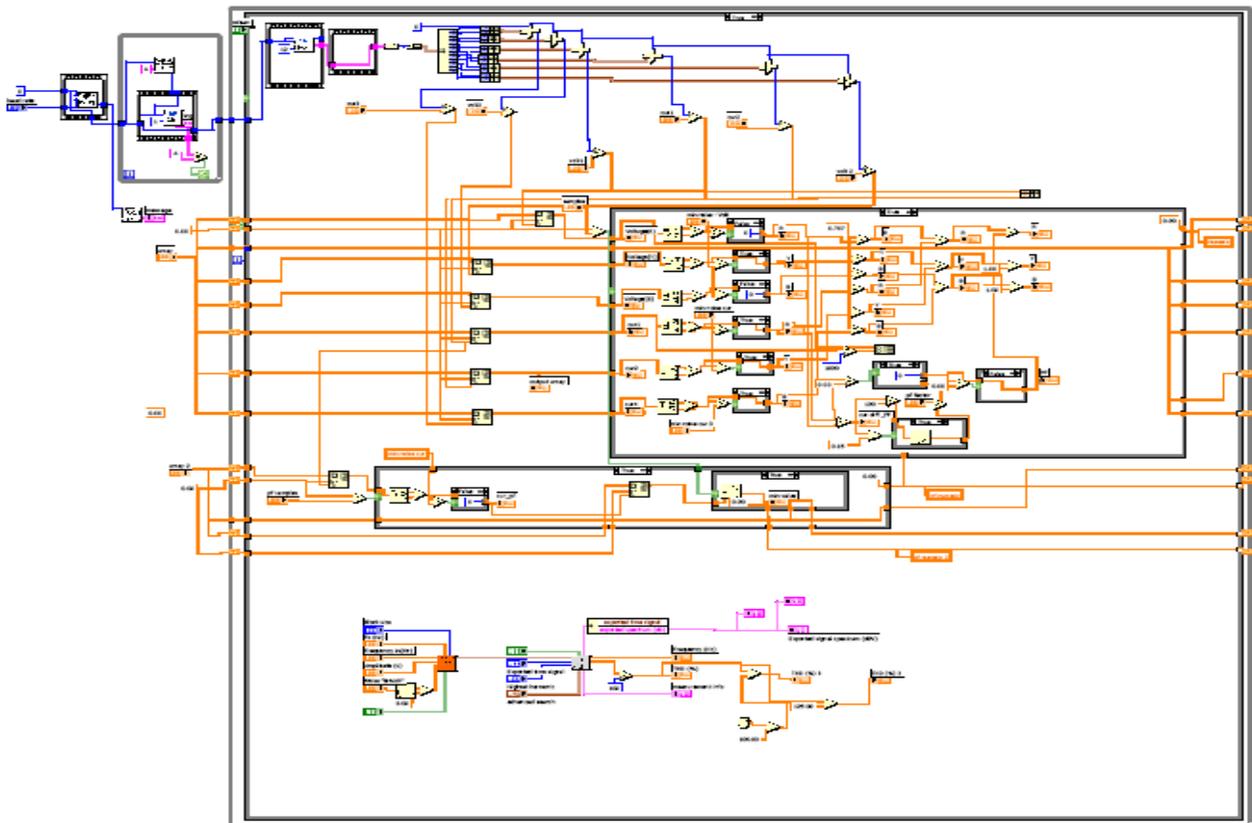


Fig. 3 Block Diagram – Virtual Harmonic Analyse

Fig.3 gives the block diagram of this harmonic analyzer, which has to do the following jobs, (1) Interfacing data with VHA (2) Harmonic Analyser for the signal analysis,

(3) Plot of the frequency vs. amplitude (4) Storing the data in a user specified file.

The VHA has its own internal connections to analyse the input and present the analysed data and to store the readings, file name and path generation for the user access for future retrieval.

In this three phase supply, each phase voltage is given to the potential transformer. The potential transformer steps down the voltage 230V (primary) to (6-0-6)V (secondary). Similarly the current transformer put series with each phase. This current transformer steps down the primary current in the ratio 2:1. This six step downed signals are

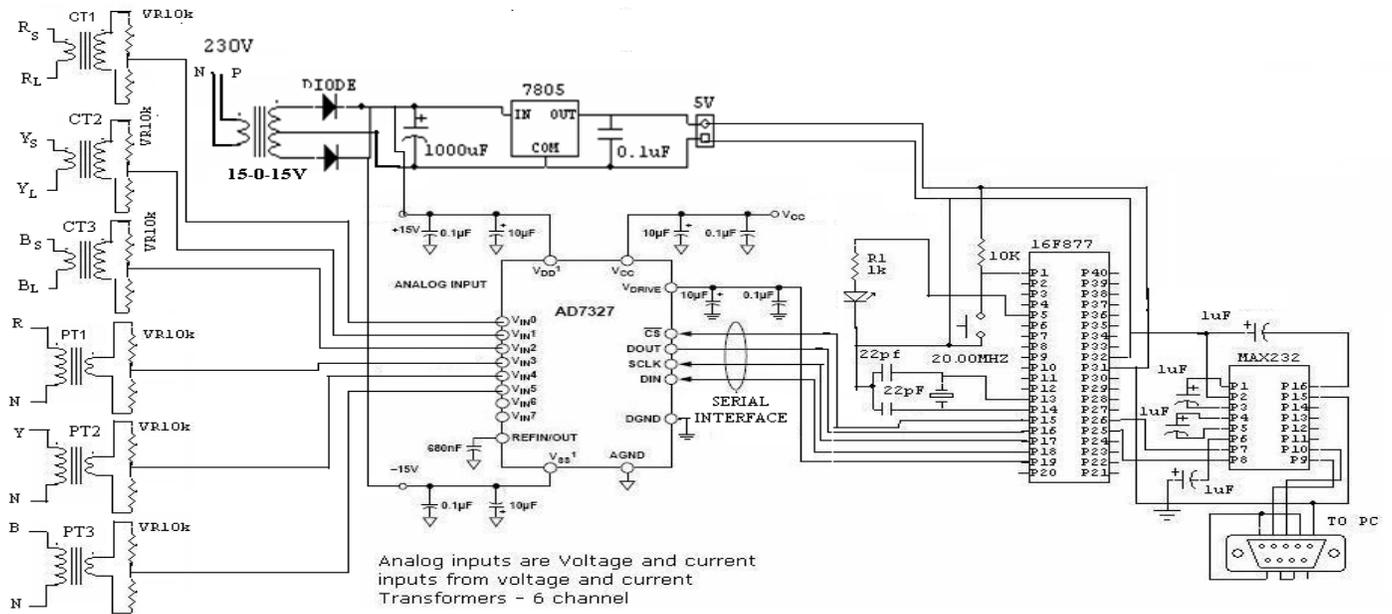


Fig.4 PIC based DAQ

The development of VHA is a cost effective approach with better accuracy. It also provides the data storage on a computing system and sharing through computer network such as LAN.

V. EXPERIMENTAL RESULTS

The experimental results are taken by for the same three phase non linear load. The actual Power Harmonic analyzer that we have used for comparing the results with that of the virtual harmonic analyzer is Chauvin Aronix 8332.

The Capabilities of the C.A.8332 Power Quality Analyzer are

- Measurement of AC rms voltage up to 480 V (phase to neutral) or 830 V (phase to phase) for two-wire or three-wire or four-wire networks.
- Measurement of alternating rms currents up to 300 A.
- Measurement of the frequency of 50 – 60 Hz.
- Calculation of neutral current by vector summing of phase current for star configurations.
- Calculation of peak factors for currents and voltages.

given to the interfacing circuit. In the interfacing circuit, six signals are given to the ADC input port. In the ADC, the analog input signals are converted into digital signal. This digital data is given to the PIC Microcontroller. The PIC Microcontroller sends the signal to the RS232 interfacing IC MAX232. The serial port RS232 sends the digital data to the computer. The digital data received by the LabVIEW block diagram as hexadecimal string. The data type conversion takes place in the LabVIEW block diagram and it displays the following data in the front panel and sent to the data sheet.

- Calculation of the phase unbalance for voltage and current.
- Measurement of harmonic angles and rates for voltage, current or power.
- Calculation of overall harmonic distortion factors.
- Detection of transients and recording of associated waveforms.

The comparison results of the CA 8332 and VHA is shown below.

From TABLE III, results of the VHA are differed to that of the benchmark equipment that we have used. This deviation is caused because of the data input to the LabVIEW is in serial mode. For this purpose we have used the PIC microcontroller. So the accuracy is somewhat less in this case. But the actual cost of the benchmark equipment is much higher than that of the proposed method of calculation. This problem can be solved by designing a DAQ card which can be connected to the parallel port of the PC.

TABLE III.
COMPARISON OF MEASURED VALUES IN CA 8332 AND VHA

Parameter measured	CA 8332	VHA	% of Deviation
Line Voltages			
R	199.6	199	0.3
Y	199	201	-1.0
B	198.7	196	1.35
Phase Voltages			
R	114.7	114	0.6
Y	115.8	116	-0.17
B	114.5	113	1.3
Line Current			
R	0.378	0.38	-0.5
Y	0.388	0.36	7.2
B	0.591	0.54	8.6
Power Factor	0.210	0.24	-14.2
Real power	.032	0.0333	-3.1
Reactive power	0.1496	0.147	1.7
Apparent power	0.1575	0.155	1.58
Current THD			
R	32.9	32	2.7
Y	42.2	42	0.47
B	27.5	28	-1.818

VI. POSSIBLE SOLUTIONS FOR HARMONIC PROBLEMS

Typical symptoms of harmonic problems include spurious fuse blowing, circuit breaker trips, overheating of transformers and motors, misoperation of drives, relays, computers, etc., the following are the possible solutions for the harmonic related problems

- Over sizing of neutral conductors
- Using separate neutral conductors
- Transformer connections
- True rms operating circuit breakers are recommended
- Using capacitor banks

Apart from the above said methods the active filters [13], [14], [15], [16] are also used for nullifying the effects of harmonics in the power system.

VII. CONCLUSION

With the advent of Virtual Instrumentation technology, present costlier bench-top instruments can be made cost effective, accurate and faster DAS. This also rectifies the problems of calibrating the instruments and makes the Virtual Instruments more accurate for much number of uses. The VHA for real-time harmonic analysis and estimation of THD help to design appropriate filters. This also provides a value addition to the usage of LabVIEW 8.5 and proves it as a modern tool with Web enabled feature with remote accessibility of DAQ cards in Advanced Control and Instrumentation field. The analysis and the estimation can be used for providing the solutions for the harmonic problem.

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