Harmonic Current International Standards and Measurement Techniques: Measurement Techniques

Harmonic measurement techniques to achieve wide bandwidth up to 9 kHz

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Recently, with the widespread use of devices equipped with high-efficiency switching power supplies, distortion is caused in the current waveform flowing in the power systems, resulting in frequent failures in high-voltage systems. Strict harmonic current regulations are imposed on electrical and electronic equipment to prevent such failures.
Standards are expected to be established in the future for unnecessary signals in the frequency bands from 2 kHz to 9 kHz, which were conventionally unregulated. The latest Precision Power Analyzer, WT5000, provides high-precision harmonic measurements from utility frequencies to high bandwidth.
This paper introduces the details of the measurement techniques.

1. Harmonic currents up to 9 kHz

The switching frequencies of switching power supplies for electrical and electronic equipment, power factor improvement circuits, and inverter sections of power converters are asynchronous to the power supply frequency and range from several kHz to several hundreds of kHz. There is a concern that noise due to this switching frequency propagates to the system power supply as conductive noise.

As a low-frequency emission standard, IEC61000-3-2, which is the standard for harmonic currents, specifies the limits for harmonic currents up to the 40th order (2 kHz when the fundamental wave is 50 Hz), but there is no regulation for the range from 2 kHz to 9 kHz.

Only annex B (Informative) of IEC61000-4-7, which describes harmonic measurement techniques, addresses measurements up to 9 kHz.

The WT5000's harmonic current measurement up to 9 kHz is achieved by expanding the frequency range of the conventional harmonic current measurement with reference to this annex B of IEC61000-4-7.

2. Harmonic measurement in the WT5000

In addition to the conventional harmonic measurement from 50 Hz to 2 kHz, the WT5000 has made it possible to measure harmonics from 50 Hz to 10 kHz in order to support harmonic measurement from 2 kHz to 9 kHz.

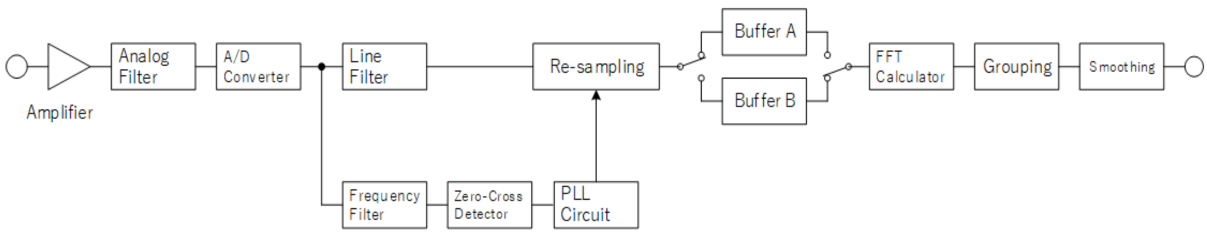

Figure 1. Block diagram of WT5000's IEC harmonic mode

For the following description, the Edition selection of IEC61000-4-7, which is a setting item of WT5000, is set to Edition 2.0 or Edition 2.0 A1, and the fundamental wave is 50 Hz. There would be some difference when the fundamental wave is 60 Hz or the Edition 1.0 is selected.

For that, we decided to increase the maximum measurable order to the 200th order (50 Hz × 200th order = 10 kHz), from the 50th order (50 Hz × 50th order = 2.5 kHz), and increased the sampling frequency for harmonic measurement to 32,768 sample points per window (fundamental wave 10 cycles). Thus, when using an anti-aliasing filter with a cutoff frequency of 30 kHz, the attenuation caused by the filter at 9 kHz is suppressed and the aliasing up to 9 kHz is made to be -50 dB or less.

The WT5000 has a block configuration as shown in Figure 1 in order to realize harmonic measurement compliant with IEC61000-4-7.

The input voltage or current analog signal is regulated by the amplifier, passes through the analog filter (cutoff frequency, 1 MHz), and then is converted to an 18 bit digital value by the A/D converter at a sampling frequency of 10 MS/s.

The zero crossing detector detects a zero crossing after the input signal passes through a frequency filter (digital filter, cutoff frequency 100 Hz) to extract the fundamental frequency from the input signal, and the PLL circuit generates a sampling frequency for harmonic measurement that is 3276.8 times the fundamental frequency.

On the other hand, after passing through the line filter (digital filter, cutoff frequency 30 kHz), the harmonic signal is resampled at the sampling frequency for harmonic measurement and saved in the buffer. The buffer has two 32,768 data surfaces and saves data in the order of surface A, surface B, surface A, and so on.

When one surface is full, FFT is executed using the data of that surface and if the window width is 200 ms (50 Hz fundamental wave 10 cycles), the harmonic signal is converted into frequency components of every 5 Hz.

The FFT result including inter-harmonic components is subjected to the specified grouping process and then smoothed to obtain the harmonic measurement result.

(1) Analog filter

Since the A/D converter operates at 10 MS/s, bandwidth limitation is performed in advance with an analog low pass filter with a cutoff frequency of 1 MHz to suppress the influence of the components that fold back at 5 MHz, which is 1/2 of the sampling frequency.

(2) PLL circuit

A sampling frequency for harmonic measurement is generated from the fundamental frequency of the input waveform. When the fundamental frequency is 50 Hz, the sampling frequency is 3276.8 times the fundamental frequency (50 Hz × 3276.8 = 163.84 kHz).

(3) Line filter

Since the harmonic signal is resampled at the sampling frequency for harmonic measurement, bandwidth limitation is performed in advance with a digital low pass filter with a cutoff frequency of 30 kHz (Figure 2).

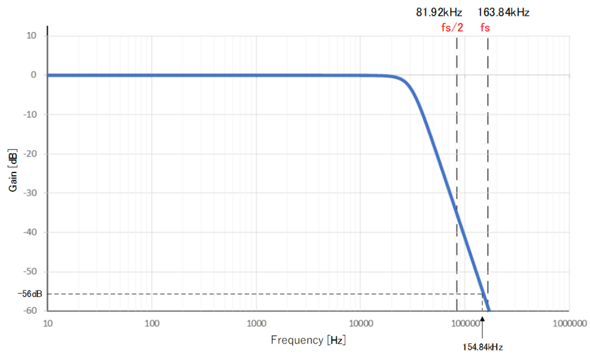

Figure 2. Attenuation characteristics of WT5000's line filter

Aliasing occurs at a frequency more than 1/2 of the sampling frequency of 163.84 kHz, but the aliasing at 9 kHz matches the attenuation of the filter at 154.84 kHz (163.84 kHz-9 kHz), which is -56 dB. This meets -50 dB or less required by the standard.

Also, since the sampling frequency for harmonic measurement is as high as about 164 kHz by the 32768 point FFT, the cutoff frequency of the filter is as high as 30 kHz. As a result, the attenuation at the analysis frequency of 9 kHz is as small as 0.3%.

For comparison, Figure 3 shows the attenuation characteristics of the line filter (cutoff frequency 5.5 kHz) in the IEC harmonic measurement mode of the conventional model WT3000E.

For the conventional model, the number of FFT points is 9000; therefore, the sampling frequency for harmonic measurement is 50 Hz×9000/10 cycles = 45 kHz. Thus, the cutoff frequency of the filter has to be reduced and there is an attenuation of about 20 dB at 9 kHz. Harmonic analysis up to 9 kHz is not possible.

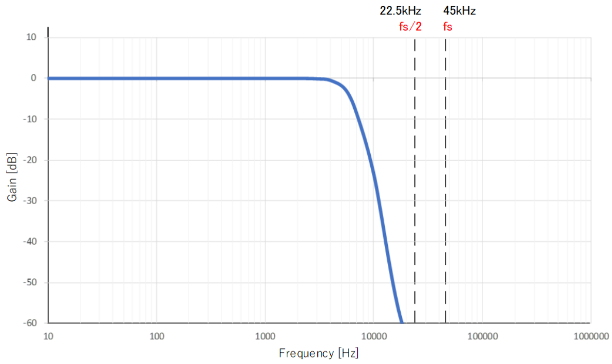

Figure 3. Attenuation characteristics of WT3000E's line filter

(4) Resampling

The harmonic signal is resampled at the sampling frequency for harmonic measurement generated by the PLL circuit. As a result, the number of sample points per window composed of 10 cycles of fundamental wave becomes 32,768 points. (Figure 4)

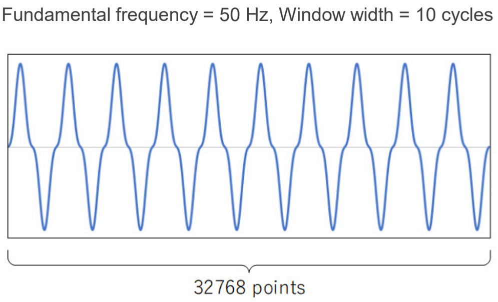

Figure 4. The number of sample points per window

(5) Buffer A/B

The buffer has two surfaces, A surface and B surface, and each can store data of one window, which is 32,768 samples. When the A surface is full, the sample data is stored in the B surface, and then when the B surface is full, it is stored in the A surface. This process continues repeatedly. When one surface is full, FFT is executed using the data of that surface. Since the buffer has two surfaces, the current data can be continuously captured on one surface while the data on the other surface is used for FFT calculation. This prevents data from being missed. This process is required to cause no gaps or overlaps between windows. (Figure 5)

(6) FFT calculator

It performs FFT calculation of 32,768 points. In practice, FFT calculation of up to 6 channels (voltage, current x 3 input elements) is performed in time division, but all the FFT calculations must be completed within the time of the next window.

The WT5000 can provide measurement with no gaps between windows because it uses an optimum calculating device for 32,768 point FFT and the processing has been devised to be completed within the time frame. (Figure 5)

Executing the processing up to the FFT calculation in real-time while minimizing the memory required for the main unit and outputting the harmonic measurement results to the PC application software through communication enable long-term harmonic measurement with no gaps between windows.

(7) Grouping

A grouping calculation including inter-harmonics is performed using equation ①.

$$Y_{g,h}^2 = \frac{1}{2}Y^2_{C,(N\times h)-N/2} + \sum_{k=(-N/2)+1}^{(N/2)-1} Y^2_{C,(N\times h)+k} + \frac{1}{2}Y^2_{C,(N\times h)+N/2}$$

① *1)

Here, $Y_{g,h}$ is the harmonic group of harmonic order h, $Y_{C,(N\times h)+k}$ is the RMS values of each spectrum of the FFT calculation result, $(N\times h)+k$ is the order of the spectrum component, and N is 10 at 50 Hz, and 12 at 60 Hz. In IEC61000-4-7 Edition 2.0 A1, inter-harmonics above the second harmonic are subject to grouping.

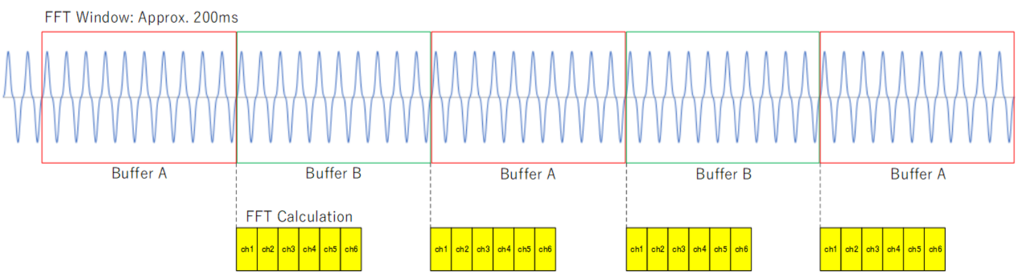

Figure 5. no-gap-no-overlap processing, which is a requirement for measurement instruments specified in IEC61000-4-7

(8) Smoothing

A smoothing process equivalent to a first low pass filter with a time constant of 1.5 seconds is performed. Figure 6 shows the smoothing process details and the time constants when the fundamental frequency is 50 Hz with a window width of 10 cycles, and when the fundamental frequency is 60 Hz with a window width of 12 cycles.

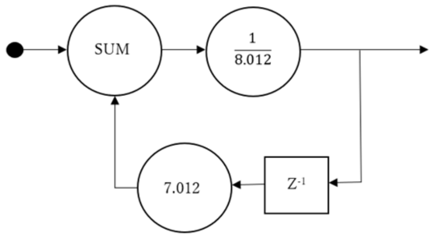

Figure 6. Smoothing *2)

3. Limit judgement by application software

IEC61000-3-2 specifies the permissible limits of harmonic current for each class and has very complicated rules, for example, the limits being replaced according to the relaxation conditions. In response to this, we provide the WT5000 dedicated software.

The main features are as follows.

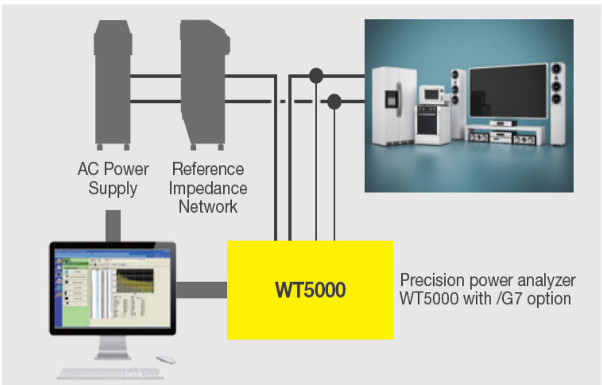

Figure 7. System example and display of harmonic measurement, report example

(1) IEC61000-3-2, IEC61000-3-12, and JIS C61000-3-2 harmonic current standards are supported. The software allows the user to control the WT5000 and perform measurement from a PC. The user can perform limit judgement on a target equipment and create a report without any specialized knowledge.

(2) The software can always keep up with the latest versions of the IEC standards, which are frequently revised.

(3) Since data is managed by a PC, long-term observation and recording are possible with no dependence on the memory capacity in the measurement instrument.

4. Conclusion

In the WT5000's mode to measure harmonic currents according to IEC standards, it is possible to measure harmonic currents up to 9 kHz.

The effect of aliasing on the measurement band is reduced to -50 dB or less, which is required by the standards, by using a line filter with a cutoff frequency of 30 kHz and setting the sampling frequency to 3276.8 times the fundamental frequency. Also, the attenuation by the filter at 9 kHz is small.

For measurement up to 9 kHz, 32,768 point FFT, which is about 4 times that of the conventional model, is required, but using the optimum calculating device and improving the process enables no-gap-no-overlap processing.

We hope that the WT5000's harmonic current measurement up to 9 kHz will be utilized for EMC emission measurement of electrical and electronic equipment.

References

・IEC61000-4-7 Ed 2.0：2002

*1)：5.5.1 Grouping and smoothing Expression (8)

*2)：5.5.1 Grouping and smoothing Figure 5

7 Transitional period Table 2

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