Device for Measuring Total Harmonic Distortion of AC Voltage
เครื่องวัดผลรวมความเพี้ยนฮาร์มอนิกส์ของแรงดันไฟฟ้ากระแสสลับ

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A device used for measuring total harmonic distortion (THD) of AC voltage has been designed and built. The device consists of two microcontroller boards: 1) the 8-bit MCU for signal capturing and 2) the 16-bit MCU for Fast Fourier Transform computing. The AC voltage signal is captured by a 12-bit analog-to-digital converter. The embedded firmware running on 16-bit board computes 128-point FFT. The THD is calculated up to 64-order of harmonic components. The sample measurements of THD for residential and academic building are also reported.

ได้ออกแบบและสร้างเครื่องวัดผลรวมความเพี้ยนฮาร์มอนิกส์ของแรงดันไฟฟ้ากระแสสลับ เครื่องวัดประกอบด้วยบอร์ดไมโครคอนโทรลเลอร์สองส่วน ส่วนแรกเป็นบอร์ดไมโครคอนโทรลเลอร์ขนาด 8 บิต ทำหน้าที่เก็บสัญญาณ และบอร์ดไมโครคอนโทรลเลอร์ขนาด 16 บิต ทำหน้าที่คำนวณฟาส์ทฟูเรียร์ทรานฟอร์ม สัญญาณแรงดันไฟฟ้ากระแสสลับจะถูกแปลงด้วยตัวแปลงอนาลอกเป็นดิจิตอลความละเอียด 12 บิต โปรแกรมที่บรรจุบนบอร์ด 16 บิต จะคำนวณฟาส์ทฟูเรียร์ทรานฟอร์ม 128 จุด ค่าผลรวมความเพี้ยนฮาร์มอนิกส์คำนวณได้ถึง 64 ลำดับ ได้ทดลองเก็บข้อมูลตัวอย่างการวัด THD ที่บ้านพักอาศัยและอาคารเรียนในมหาวิทยาลัย

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Keywords: Total Harmonic Distortion, THD, Power Quality

INTRODUCTION

Quality of the AC electrical supply plays an important role in economic development. One of the quality parameters is the waveshape of the AC line voltage waveform. While the power grid provides nearly perfect sinusoidal voltage source output, the waveshape of the low voltage distribution lines however when connected to customer's loads may be distorted by nonlinear loads. For example, the rectifying circuit built with diode and capacitor, commonly used as an input circuit of a switching power supply, draws current only near the peak of the AC voltage. When a number of them are connected to a given voltage feeder, the peak of the AC voltage waveform is flattened, resulting in the 3rd harmonic voltage. The other loads that tie in parallel to the nonlinear load will thus share

such distorted voltage. To measure the waveshape distortion in the fundamental frequency, Fourier analysis may be used to determine the amplitude of each harmonic component. The total harmonic distortion of AC voltage was defined[1] as the ratio of the sum of the RMS voltages of all harmonic components to the RMS voltage of the fundamental frequency by the equation

$$THD = \sqrt{\frac{\sum_{n} (V_n)^2}{(V_1)^2}} x100\%, \ n = 2,3,4,.. \ . \qquad (1)$$

Where THD is total harmonic distortion in percent,
V is the amplitude of RMS voltage,
n is harmonic component.

The standard limit of THD for low voltage distribution lines (<69kV) recommended by IEEE 512-1992 is 5%. This research developed a low-cost microcontroller-based device that uses Fast Fourier Transformation for computing the amplitude of harmonic components of voltage waveform and computes the THD. The device can record THD with time, printing the result and uploading data to PC.

HARDWARE DESCRIPTION

The hardware block diagram is shown in Fig. 1. The instrument consists of two microcontroller boards. The first board was built with MCS51 as the front-end circuit and the second board is an FFT machine built with Intel 16-bit microprocessor, 80C186EB. The AC voltage input is sampled and converted to digital data by the LTC1298 SPI interface 12-bit ADC. The number of sample is 128 points. The time domain data stream is sent to the 16-bit MCU board through RS485 port. The 16-bit board receives the data and transforms to frequency domain by FFT algorithm and computes the THD. The latter is then sent back to the MCS51 for data logging. The spectrum data can be sent to the terminal for data graphing. The RTC circuit on MCS51 board provides the real-time clock for time stamping when recording THD to RAM. The LCD display is used to show THD.

SOFTWARE DESCRIPTION

The firmware running on MCS51 was developed with C language. The program was compiled by the Keil compiler. The real-time clock interrupts CPU every 5 mins. The CPU reads date and time, then triggers the ADC to convert analog input. The converted data is saved to RAM first, and sent to the 16-bit board. The MCS51 waits for THD calculation by the 16-bit board. When calculation is completed, the value of the THD will be received and saved together with the time stamp. The firmware on the 16-bit board is mainly the FFT program developed with c language and compiled by Pacific compiler. The FFT algorithm is well known and available as the open source, we modify it by adding function that communicates with MCS51 through RS485 port.

EXPERIMENTAL RESULTS AND DISCUSSION

Number of Sample Point Testing

The FFT algorithm running on 16-bit MCU board was tested by HP-VEE V5.01 software. The test is to find the appropriate number of samples for FFT calculation between 256 and 128 points. The superimposed waveform by three-frequency sine waves, i.e. 50Hz, 150Hz

and 250Hz was produced by HP-VEE with 256 and 128 points. Fig. 2 and Fig.5 show the pure sine wave of the three frequencies. The superposition waveforms are shown in Fig.3 and Fig.6. Fig. 4 and Fig. 7 show the corresponding harmonic spectra. The three frequencies are shown clearly separated. Table 1 shows the result of THD calculation. We found that the THD computed using 128 or 256 points shows no significant difference. Thus to reduce calculation time, we chose 128 sample points for FFT calculation. With the clock frequency of 16MHz on 16-bit board, calculation time for 128 points takes approx. 28 seconds.

Test with Square Wave Signal

The square wave signal is used to input to the harmonic meter, HP-VEE and manual calculation. Fig. 8 shows the square wave signal produced by HP-VEE software. The harmonic spectrum plotted by harmonic meter, HP-VEE and manual-calculation are shown in Fig. 9, 10 and 11. Table 2 shows result of THD calculation by the three methods. The value by harmonic meter and HP-VEE are shown nearly the same, 48.3%. A manual calculation result is about 0.8% less. This test confirmed the accuracy of algorithm for FFT calculation.

Test with Nonlinear Load

The nonlinear load shown in Fig.12 was built with diode-capacitor rectifying circuit. The circuit is commonly used in most desktop PC switching power supply. Our harmonic meter was configured to 128 samples FFT. When the load is connected to the AC supply, the consequent flatten-top voltage waveform is shown in Fig. 13. Fig.14 shows harmonic spectrum, we found the amplitude of 3^{rd} harmonic to be 16% of the fundamental frequency. The THD is 16.4%.

Sample of THD Measurement

We have recorded THD with time for two locations, i.e. residential and academic building. The AC supply at the point of common coupling (PCC) is used to measure. Fig. 15 shows result of data logging for 24 hours at residential. Each record was sampled every 5 minutes. We found that THD has changed with time and the value was not larger than 3%. Fig.16 shows the result for academic building. We found THD is changed with time from approx. 1.5% to 3% then fall down to 1.5%. The peak is quite broad during daytime.

CONCLUSION

We have developed a low-cost device for measuring the total harmonic distortion of an AC voltage. The device is tested with HP-VEE and real signal. The device can conveniently be used for measuring the 3^{rd} harmonic appeared in the common electrical power system.

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[1] Roger C. Dugan, Mark F.McGranaghan and H.Wayne, **Electrical Power System Quality**, Newyork: McGraw-Hill 1996.

[2] **IEEE519-1992**, IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems (ANSI). IEEE, New York.

[3] E Oran Brigham, **The Fast Fourier Transform and Its Applications**, Singapore: Prentice Hall 1988.

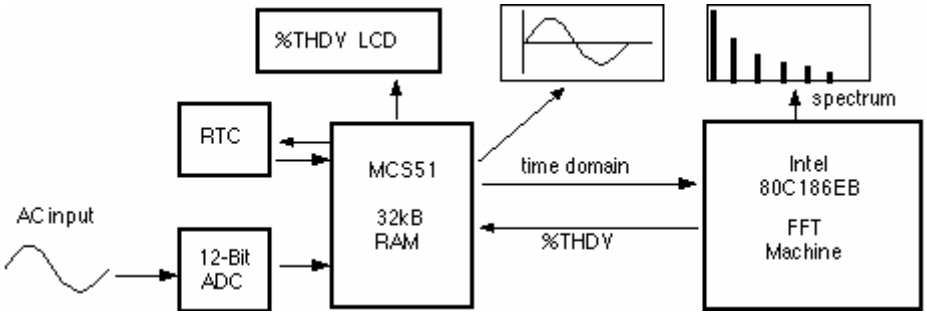

Fig.1 Hardware block diagram.

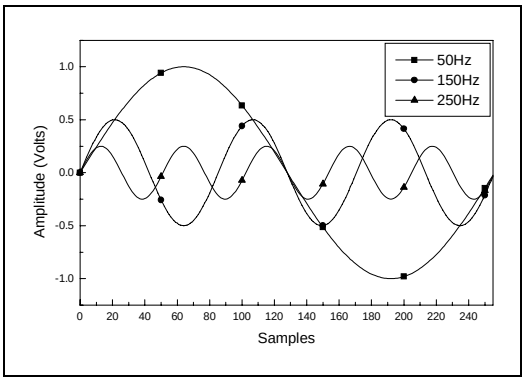

Fig.2 Three-frequency sine waves [256 points].

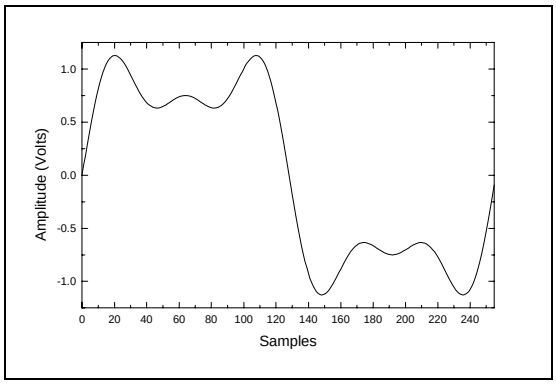

Fig.3 Superposition waveform [256 points].

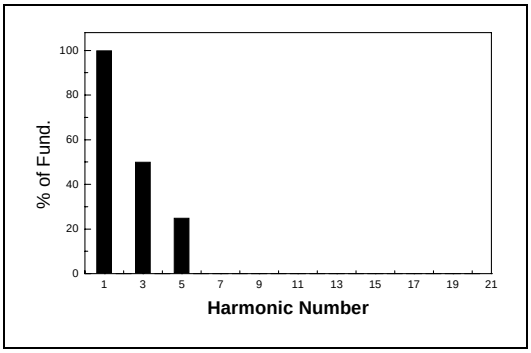

Fig.4 Harmonic spectrum of three-frequency sine waves [256 points].

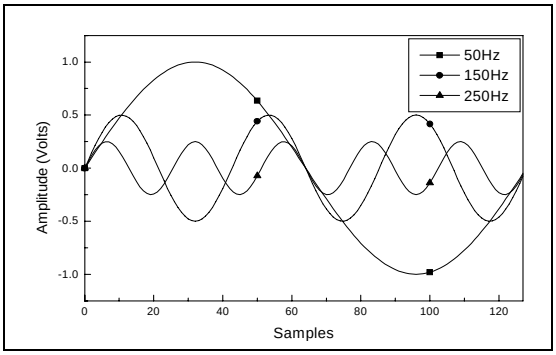

Fig.5 Three-frequency sine waves [128 points].

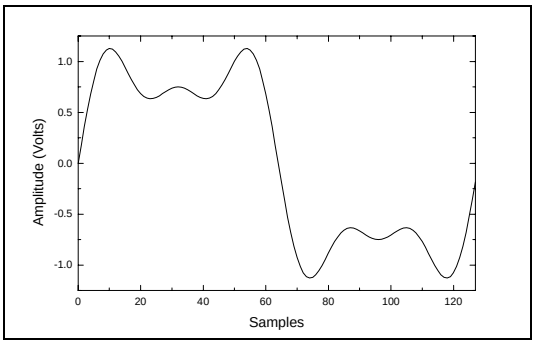

Fig.6 Superposition waveform [128 points].

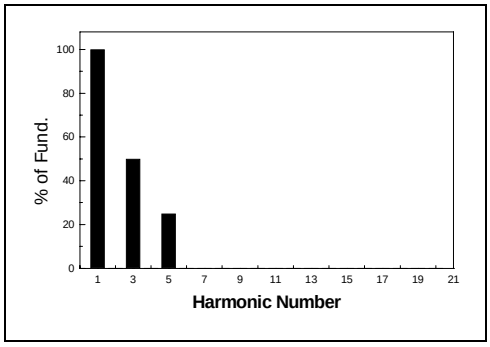

Fig.7 Harmonic spectrum of three-frequency sine wave [128 points].

Table 1 %THD between 256 and 128 points FFT.

Harmonic number	256 points	128 points
1	128.000	64.000
2	0.000	0.000
3	64.000	32.000
4	0.000	0.000
5	31.999	16.000
6	0.000	0.000
7	0.000037	0.000051
8	0.000	0.000
9	0.000001	0.000002
10	0.000	0.000
11	0.000006	0.000005
%THD	**55.901714590**	**55.901734220**

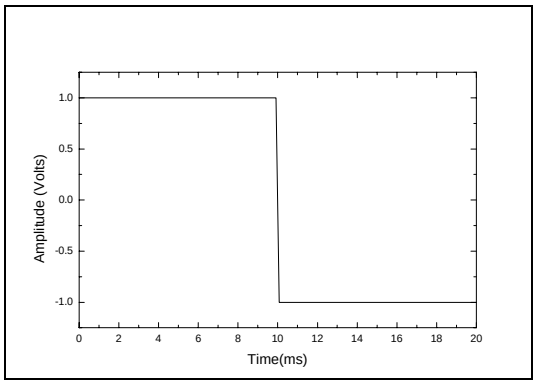

Fig.8 Square wave test signal.

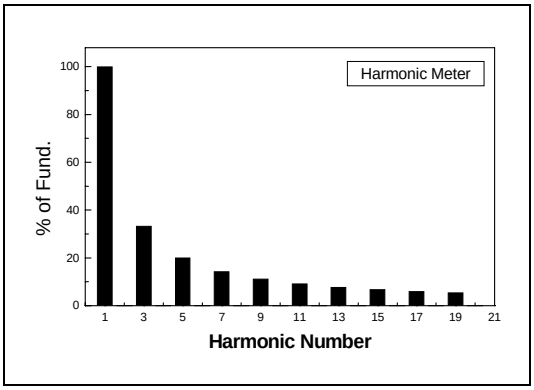

Fig.9 Harmonic spectrum by harmonic Meter, THD = 48.3%.

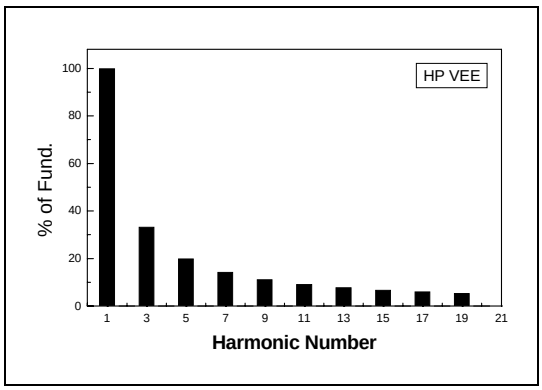

Fig.10 Harmonic spectrum by HP-VEE, THD = 48.3%.

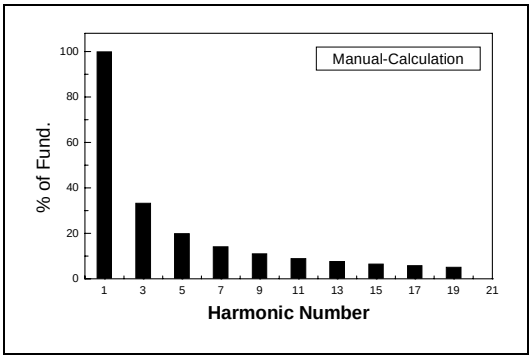

Fig.11 Harmonic spectrum by manual calculation, THD=47.5%.

Table 2 %THD by three methods

Harmonic number	Harmonic Meter	HP-VEE FFT	Manual Calculation
1	81.500	81.502	81.496
2	0.008	0.011	0.000
3	27.190	27.182	27.165
4	0.002	0.008	0.000
5	16.338	16.326	16.299
6	0.006	0.011	0.000
7	11.692	11.693	11.643
8	0.006	0.003	0.000
9	9.129	9.126	9.055
10	0.008	0.006	0.000
11	7.501	7.498	7.409
%THD	**48.318258260**	**48.300150070**	**47.527748280**

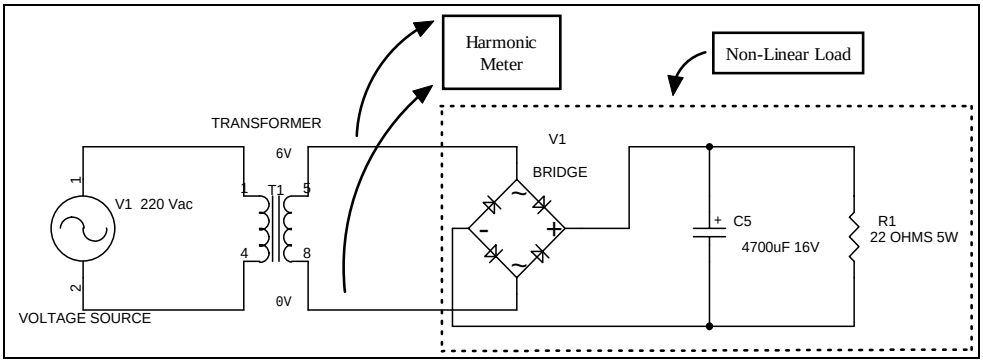

Fig.12 Nonlinear load: rectifying circuit built by diode-capacitor.

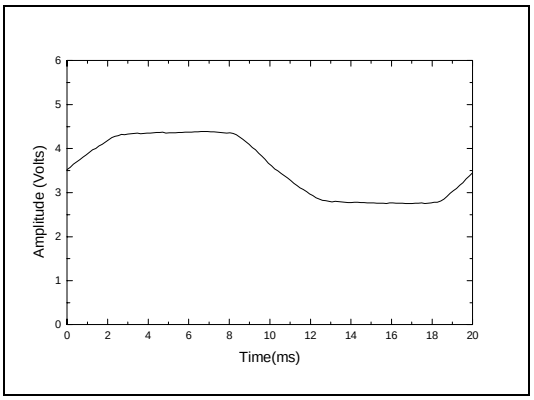

Fig.13 Flatten-top voltage waveform developed across diode-capacitor circuit.

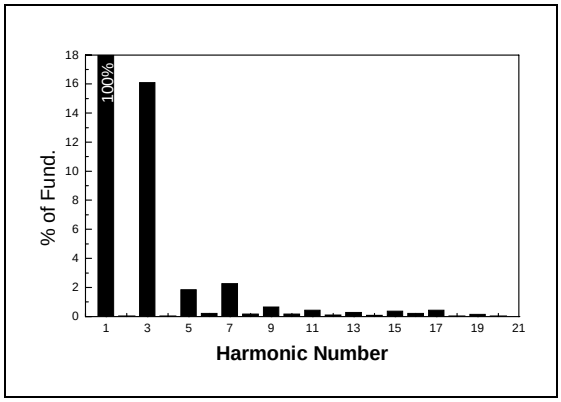

Fig.14 Harmonic spectrum of diode-capacitor load, 3rd harmonic appeared THD=16.4%.

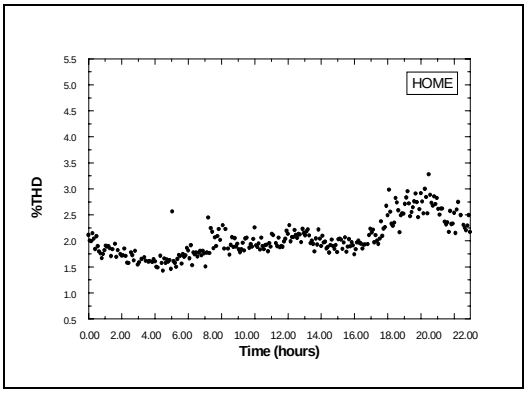

Fig.15 Sample plot of %THD with time for residential.

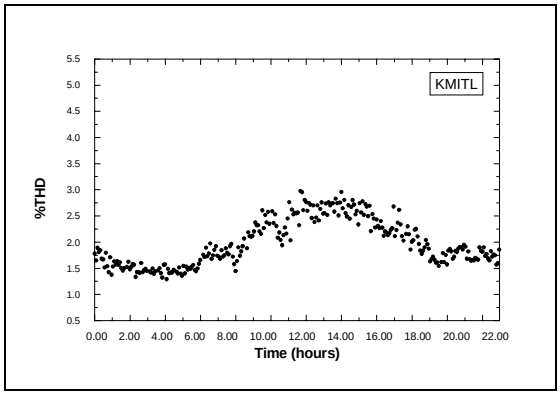

Fig.16 Sample plot of %THD with time for academic building.