2 kWatt Harmonic Analyzer Prototype Using Discrete Fourier Transform Method

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Abstract

We knew that there are so many power harmonic analyzer in the market. Much of them are from well known company and commercialize that bring the engineer found it easily. In this paper we just want to proclaim that Indonesian engineer has capability to develop such that system. That is why we want to introduce a 2kWatt harmonic analyzer prototype using Discrete Fourier Transform (DFT). The prototype is built up using ATMega 32 Microcontroller. Fourier transform mechanism is made and then plant in the microcontroller that is functioned as a processor. This controller is chosen, because it has some advantages, one of it is an internal ADC that give the user easily to convert from analog unit into digital one.

After prototype was completely finished, it was tested with 13 different types of load and compared with the well know product of Fluke 41B Power Harmonics Analyzer. From that test, we can deliver some conclusion are the error average of voltage THD is 1.8% and error average of current THD is 1.96%.

Keywords: DFT, voltage THD, current THD, harmonic.

1. Introduction

We knew that there are so many power harmonic analyzer in the market. Much of them are from well known company and commercialize that bring the engineer found it easily.

Harmonic is a voltage or current that presence in power system with the frequency is an integer number multiplication with fundamental frequency. It become important thing in power system, because harmonic inherently destructive in electrical system. As we've ever undergone electrical crisis around 2005, and government electrical company (PT. PLN) insist to the consumer to change their incandescent lamp with compact fluorescent lamp in order to reducing power demand. But it release another result in electrical system, that is harmonic. High level harmonics in power system will bring destructive behavior. For example, industrial motor is getting hotter, shorter motor live time, relay wrong detection, change impedance system, etc. To know how much the level of harmonic, it is needed harmonic analyzer. This device is very important, complex and costly.

In this paper we just want to proclaim that Indonesian engineer has capability to develop such that system. The test result as a conclusion is stated in this paper as well.

2. Configuration System

The proposed system is like the figure shown below.

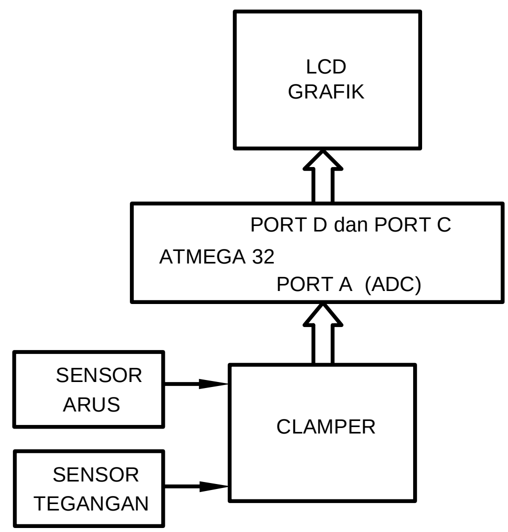

Figure 1. Harmonics Analyzer Prototype

The system comprises Processor, LCD graph, clamper circuitry, current sensor and potential sensor.

Current and voltage are detected by sensor simultaneously. Clamper circuitry is used to shift up current and voltage magnitude produced by sensor, which is stand as an input for Analog/Digital Converter.

ATMega32 microcontroller is stand for processor that process the data from input and the outcome is displayed in LCD graph.

3. Theory

3.1. What Is Harmonic

In the ideal Alternating Current (AC) system, wave form of current and voltage must be sine. That is meant that the wave form of it must pure sine without any disturbance in certain frequency. That is an ideal sources that electrical customer must receive it.

When in a certain period, the wave form is no more pure sine wave, then we call it disturbance was taken place. There are many kind of disturbance, one of then is harmonics. Harmonics are a voltage or current that presence in power system with the frequency is an integer number multiplication with fundamental frequency. This interference wave form will distort the fundamental wave, that cause the wave form of system is no more pure sine wave and occurs periodically. Figure below depict what happen when fundamental is distorted by third harmonic wave from.

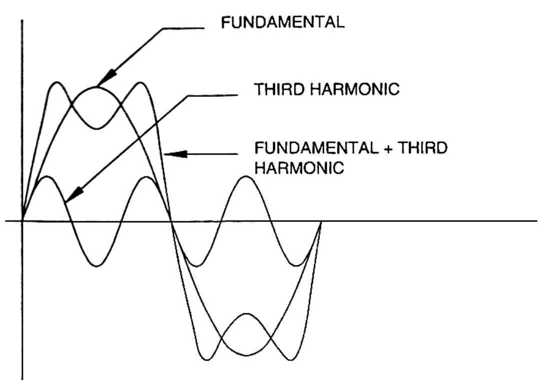

Figure 2. Distorted wave form

Current and voltage measurement are very important to calculate how much total harmonic distortion occurs in the system.

$$V_{THD} = \frac{\sqrt{\sum_{\tau=2}^{N-1} V_n^2}}{V_1} x100\% \quad \ldots\ldots\ldots\ldots (1)$$

$$I_{THD} = \frac{\sqrt{\sum_{\tau=2}^{N-1} I_n}}{I_1} x100\% \quad \ldots\ldots\ldots\ldots (2)$$

3.2. What Are Contribute To Generate Harmonics

There are several ways why harmonic presence in the system. And the most significant is the impact of non linear loads. Non linear load is the load that encompasses semiconductor material inside it. For instance of non linear loads are compact fluorescent lamp, TV, computer, electric drive, phase control rectifier, etc.

3.3. Discrete Fourier Transform (DFT)

Fourier transform is a traditional mathematical method that decomposes a certain signal into its constituent frequencies. The original signal depends on time, and therefore is called the time domain representation of the signal, whereas the Fourier transform depends on frequency and is called the frequency domain representation of the signal. It is bring the signal from time domain and convert into frequency domain. And on the other side, Fourier transform can be viewed as a device to change a certain distorted signal into summation of sine wave signal with different frequency. Fourier transform uses sine and cosine bases which have different frequencies. The results of Fourier transform is a spectral density that characterizes the distribution of amplitude and phase of the various frequencies that make up the signal.

To perform a certain digital signal into frequency domain, it could be used Discrete Fourier Transform (DFT). DFT is the equivalent of the continuous Fourier Transform for signals known only at N instant separated by sample times T. For instance a source of continuous signal given by *f(t)*. If we take sample on it for N sample then we obtain *f[0], f[1], f[2], …., f[k], …, f[N-1]*.
The FT of the original signal f(t) would be

$$F(j\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t} dt \quad \ldots\ldots\ldots\ldots (3)$$

We could regard each sample f[k] as an impulse having area f[k]. Then, since the integral exist only at the sample point:

$$F(j\omega) = \int_{0}^{(N-1)T} f(t) e^{-j\omega t} dt$$

$$= f[0]e^{-j0} + f[1]e^{-j\omega T} + ... + f[k]e^{-j\omega kT} .$$

$$+ ..... + f[N-1]e^{-j\omega(N-1)T}$$

. . . . (4)

So the DFT could be written as:

$$F(v) = N^{-1} \sum_{\tau=0}^{N-1} f(\tau) e^{-i2\pi(v/N)\tau} \quad \ldots\ldots\ldots (5)$$

3.4. Transformer

The transformer is an electrical device that converts alternating current voltage from one level to another through a magnet coupling and based on the principles of electromagnetic induction-. The transformer consists of a core, made of iron plated or other material and two coils, the primary coil and secondary coil.

Transformer working principle is based on Ampere's law and Faraday's law, that is an electric currents can cause magnetic fields and a magnetic fields can cause the opposite electric currents. If one coil on the transformer rated with alternating current, then the number of lines of magnetic force becomes fickle. As a result on the primary side occurs induction and on the secondary side receive varying lines of magnetic force from the primary side. Then on the secondary side also arise induction, that give the result between the two ends have a different voltages.

$$\frac{Np}{Ns} = \frac{Vp}{Vs} = \frac{Is}{Ip} \quad \text{. . . . . (6)}$$

Where,
Np = number of primary coil
Ns = number of secondary coil
Vp = primary voltage
Vs = secondary voltage
Ip = primary current
Is = secondary current

4. System Design

For making this prototype, it is needed to realize all of block diagram as shown in Figure 1. There are 5 block diagrams, but in this paper we only made current sensor and clamper circuitry. For voltage sensor, microcontroller and LCD graph we bought it in the market.

4.1. Current sensor

This prototype used ferrite core for current sensor. Since we found ferrite in market and never knew the type of ferrite, we try to make this current sensor by trial and error method.

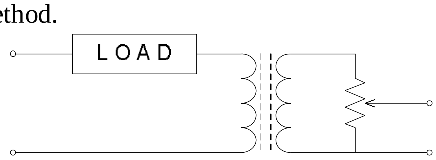

Figure 3. Current sensor

To design current transformer from this unknown ferrite property, we should to determine how much current flowing, without to bring this core into saturate. In other side we have to consider as well, that flux must be transferred to the secondary coil. From the experiment using maximum load we obtained data as:

Np = 3 turns
Ns = 1400 turns

$$Ip = 2000/220 = 9.09 \quad A$$

$$I_{out} = \frac{N_p}{N_s} \times I_p \text{ . . . . . (7)}$$

By checking 9.09 A current at primary coil and check the current at secondary coil we obtained secondary current is 19.48 mA. This secondary current must be read by ADC as a voltage of 5V, at the two end of current transformer.

$$V = I \times R$$

$$R = 5/19.48m = 0.257k\Omega$$

We need 257Ω to convert secondary current into maximum 5 V.

4.2. Voltage sensor

As we know that this sensor is to convert 220VAC level into 5VAC level peak to peak. We use the circuitry as shown bellow.

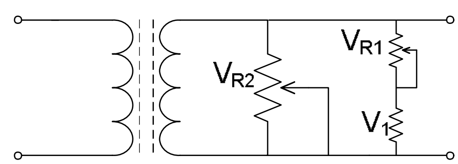

Figure 4. Voltage sensor

Vs = 4,5 Vrms = 4,5x2 $\sqrt{2}$ Vpp = 12,73 Vpp
Is = 350 mA

If R1 = 1 kΩ, then value of VR1 is

$$\text{Vout} = \frac{R1}{R1 + VR1} x12{,}73Vpp \text{ . . . . . (8)}$$

$$5 \text{ Vpp} = \frac{1K\Omega}{1K\Omega + VR1} x12{,}73Vpp$$

$$\text{VR1} = \frac{1K\Omega x12{,}73}{5} - 1K\Omega$$

$$= 1{,}546 \ K\Omega$$

4.3. Clamper circuitry

Clamper circuitry is a circuit to shift up a level of signal. In this paper, clamper circuitry is designed to shift up output signal from current and voltage sensor till there is no negative level, before bring it into ADC.

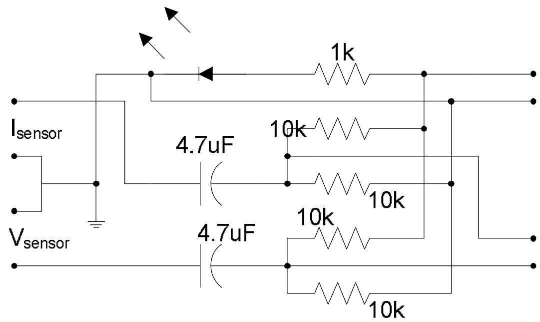

Figure 5. Clamper circuitry

$$Vx = Vin + \left(\frac{10K\Omega}{10K\Omega + 10K\Omega}\right) x5V \quad \ldots\ldots\ldots\ldots \text{(9)}$$

= Vin + ½ x 5 V
= Vin + 2,5 V

From calculation above, it can be seen that the input level must not more 2.5Vac peak to peak to obtain maximum 5 Vdc in the input side of ADC.

4.4. Processor circuitry

Analog data from output side of both either current sensor or voltage sensor must be converted into digital ones using ADC. This preprocessed signal then lead in to processor to be processed. In this paper, processor that is to be used is IC ATMega 32 which is has 10 bit ADC.

Analog data then converted into digital one which the value is laid from 0 – 255 decimal number.

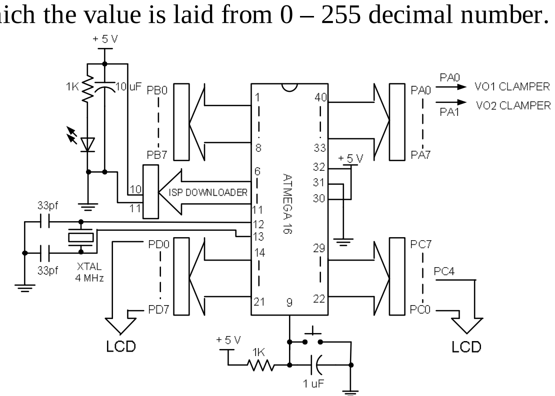

Figure 6. Processor circuitry

In this processor it is planted a calculation algorithm to decomposes input signal using DFT.

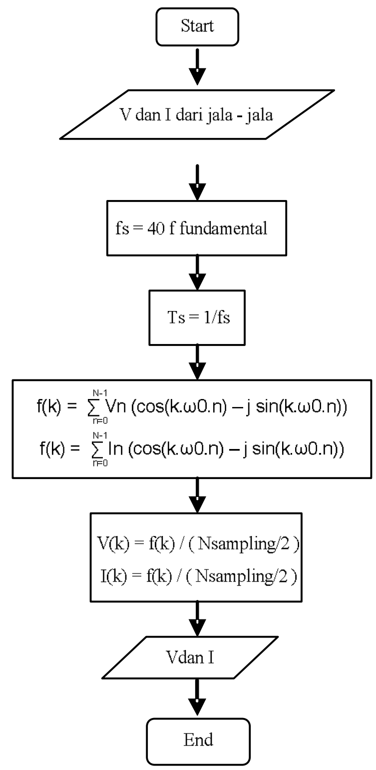

Figure 7. Algorithm

5. Evaluation

5.1. Current and voltage sensor

To evaluate current and voltage sensor whether its correct, it is compared input and output signal for each sensor. And when the system is loaded with resistive load, the output current and voltage must be in phase. The result shows that input and output signal is in phase and the shape is very similar, it shows that they work correctly.

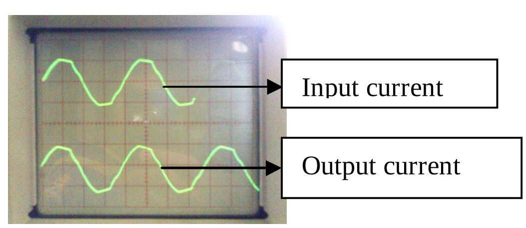

Figure 8 current sensor signal

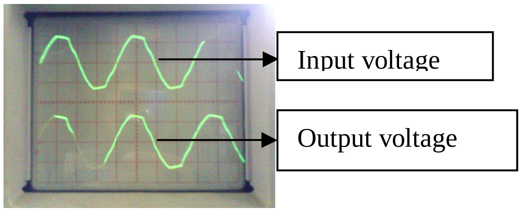

Figure 9 voltage sensor signal

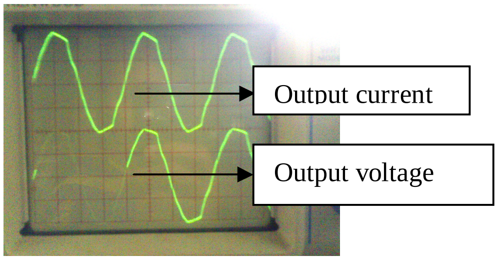

Figure 10. Output current and voltage

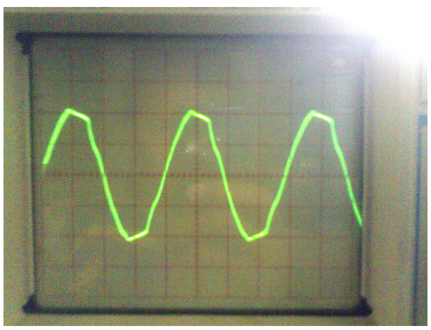

Figure 11. Output current and voltage are in phase

5.2. System

To evaluate overall system, this prototype will be loaded with some kind of loads and the result will be compared with FLUKE 41B Power Harmonics Analyzer

Tabel 1. Load measurement with Prototype

	DATA PENGUJIAN					
	BEBAN	Propotype Harmonics Analyzer				
		V (V)	I (A)	P (VA)	THDV (%)	THDI (%)
	BEBAN LINIER :					
1	BOLAM 60W	220,23	0,29	64,18	4,07	11,05
2	SOLDER 40W	217,09	0,14	30,14	4,92	22,44
3	HEATER 300W	217,47	1,64	357,59	4,85	4,51
4	SETRIKA	219,16	1,76	385,39	4,19	4,33
	BEBAN NON LINIER :					
5	OSCILOSCOPE	220,84	0,2	43,27	4,2	58,4
6	FUNCTION	219,34	0,06	13,48	4,04	89,83
7	GENERATOR	220,74	0,24	52,32	4,10	56,16
8	OSCILOSCOPE + FG	217,78	1,27	276,29	5,83	13,83
9	BOR LISTRIK	219,04	0,93	202,92	4,6	103,35
10	PC + MONITOR	219,94	2,03	446,67	4,49	86,35
11	2 PC + 2 MONITOR	221,13	0,13	28,84	4,44	28,56
12	KIPAS AC DESPENSER	218,57	1,71	374,32	5,14	5,18
13	BEBAN CAMPURAN : BOLAM 60W + BALLAST LAMP 8 W	218,14	0,34	73,08	4,8	14,05

Tabel 2. Load measurement with Fluke 41B

	BEBAN	FLUKE 41 B (ALAT PEMBANDING)				
		V (V)	I (A)	P (VA)	THDV (%)	THDI (%)
	BEBAN LINIER :					
1	BOLAM 60W	220	0,26	57	3,7	16,5
2	SOLDER 40W	219	0,18	38	3,2	25,5
3	HEATER 300W	218	1,38	300	3,2	4,4
4	SETRIKA	218	1,47	320	3,3	4,3
	BEBAN NON LINIER :					
5	OSCILOSCOPE	220	0,2	43	3,2	59
6	FUNCTION	220	0,11	23	3,2	92,6
7	GENERATOR	219	0,23	51	3	55
8	OSCILOSCOPE + FG	219	1,02	220	3,3	11
9	BOR LISTRIK	219	0,8	170	3,5	97,3
10	PC + MONITOR	218	1,7	370	3,4	90,3
11	2 PC + 2 MONITOR	221	0,17	37	2,9	28,4
12	KIPAS AC DESPENSER	219	1,35	300	3,7	4,7
13	BEBAN CAMPURAN : BOLAM 60W + BALLAST LAMP 8 W	219	0,31	68	3,2	14,2

Tabel 3. Decomposes of signal from 60 W of incandescent lamp

No.	DFT ADC		DFT Real	
	V	I	V	I
0	129,35	133,72	306,20	15,07
1	132,43	3,79	313,49	0,43
2	2,10	0,21	4,98	0,02
3	3,85	0,24	9,11	0,03
4	0,55	0,05	1,31	0,01
5	0,30	0,05	5,44	0,01
6	0,30	0,13	0,71	0,01
7	2,41	0,07	5,71	0,01
8	0,49	0,05	1,16	0,01
9	1,61	0,03	3,81	0
10	0,45	0,11	1,06	0,01
11	1,23	0,11	2,91	0,01
12	0,98	0,05	2,33	0,01
13	1,95	0,14	4,61	0,02
14	0,36	0,15	0,85	0,02
15	0,38	0,05	0,89	0,01
16	0,25	0,05	0,59	0,01
17	0,23	0,08	0,54	0,01
18	0,17	0,12	0,39	0,01
19	0,36	0,05	0,85	0,01

6. Conclusion

From overall system evaluation, it shows that the prototype is working correctly. When it was compared with FLUKE 41B Power Harmonic Analyzer, as stated on the table above, from 13 different loads it can be drawn a conclusion are the error average of voltage THD is 1.8% and error average of current THD is 1.96%. For the next research it will be better if voltage transformer is replaced with other sensor which have better quality.

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