Harmonics Assesment at Demand Site Through a 220V Wall Outlet

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Abstract
In recent year, non-linear loads, such as televisions, micro-computers and robotic equipments are increasingly connected to the system. These non-linear load inject a large amount of harmonics, especially third, fifth and seventh.Formerly, people just paid attention to the harmonics problem in the high voltage area. However, nowadays the effects of harmonics in the distribution system become more significant. Sometimes, the harmonics ratio and the total harmonics distortion exceed the national harmonics standard for the public supply network. For this reason, we need to measure and asses the level of harmonics in the Distribution System. This paper will discuss about harmonics and how to deal with it. It also considers how we assess the harmonics in a distribution feeder. This project used both hardware and software to build the system. The RMS900 from Hathaway is used to record the snapshot data from the line. A computer program, called HAP that is written in MATLAB is used to analyze the data and Modbus protocol make possible the communication the RMS900 and the PC.

Keywords: Harmonics, RMS900, Modbus Protocol

I. BACKGROUND TO HARMONICS

Ideally, the power electric system must supply the load with a perfect sinusoidal voltage of constant amplitude and frequency. However, in real condition this requirement cannot be fulfilled. Like the air that is always contaminated with a pollutant, the voltage on the system is also polluted by a pollutant, in this case voltage distortion. The distortion in voltage will also cause distortion in current, and vice versa.

Voltage distortion is any deviation from the nominal sine waveform of the AC line voltage. A similar definition applies for current distortion; however, voltage distortion and current distortion are not the same. Each effect loads and power system differently, and each requires a different solution. In discussing harmonic distortion we must also address several other parameters involved with distortion namely, what is a harmonics and how do we quantify with it.

Fourier analysis allow us to breakdown a distorted waveform into a set of sine waves with certain characteristics. One characteristic is frequency, a second is magnitude and third is phase angle.

The first characteristic is frequency. The distorted waveform repeats itself with some basic frequency. The sine waves associated with this frequency, which is normally 50 Hz, is the fundamental. Each successive sine waves, or harmonics, of this particular set has a frequency that is an integer multiple of the fundamental. So, the second harmonic has frequency of 100 Hz, the third is 150 Hz, the 4^{th} at 200 Hz, and so on.

The second characteristic is magnitude, also called the harmonic distortion factor. Each of the sine waves may have a different magnitude from others depending on the actual distorted signal. Typically, the magnitude of each harmonic is represented as a percentage of the RMS value of the fundamental, not the total RMS of the distorted waveform.

The third characteristic is the phase angle. The fast Fourier transform produced a set of complex number with a real and imaginary component. This set of number can be represented by a magnitude and a phase angle

The aggregate effect of all harmonics is called the Total Harmonic Distortion, or THD. THD equals the RMS value of all harmonics divided by the RMS value of the fundamental, and is usually converted to a percentage.

HARMONICS SOURCES

There so many sources of harmonics on the distribution system. They may come from the supply side and/or from the load connected to the distribution network. Mainly, the harmonics sources on the distribution system comes form: Generating Unit, Transformer Saturation, Rotating Machine, Arc Furnace And Arc Welding, UPS, Battery Charger And Electric Appliances, Fluorescent Lamp, Switched Mode Power Supply, Microcomputer, Television Set, and many others.

EFFECTS OF HARMONICS

The level to which harmonics can be tolerated is determined by susceptibility of the load

(or power source) connected to them. The most susceptible type is the equipment that needs a (nearly) perfect sinusoidal fundamental input. The examples of this type of equipment are communication and data processing unit. The least susceptible type of equipment is that which the main function is for heating, such as an oven or a furnace.
There are thousands of harmonics sources in the distribution system. They produce voltage waveform and current waveform distortion. The main effects of the contaminated waveform are:

1. Amplification of harmonic level resulting from series and parallel resonance
2. Reducing the efficiency of power generation, transmission and utilization
3. Ageing the insulation of electrical equipment and then shortening of their useful life
4. Mal operation of compensating condenser
5. Mechanical vibration, noise and additional loss in the rotating machine
6. Increasing the errors in measurement instruments
7. Mal operation of the protection relays
8. Interference on communication signals

HOW TO DEAL WITH HARMONICS

Various techniques are taken to improve the input current waveform. The intent of all technique is to make the input current more continuous to reduce the overall current harmonic distortion. The different techniques can be classified into five broad categories:

1. Line reactors;
2. Passive Filters (series, shunt and Low Pass broad band filters);
3. Phase multiplication (12 pulse, 18 pulse rectifier system) ; and
4. Active harmonic compensation.

HARMONICS ANALYSIS

In the early of 19^{th} century, Jean Babstite Fourier proved that any mathematical function could be decomposed into a sum of sine waves, called harmonics. A very complicated mathematical relationship could be considered as the sum of a large number of simple expressions. Graphically, this relationship is illustrated on the figure 1.

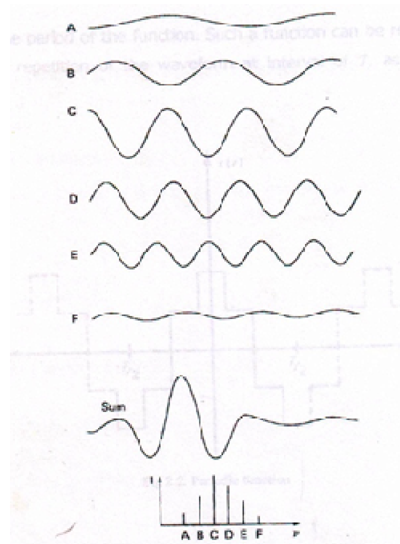


Figure 1. Decomposition of a Mathematical Function into It's Harmonics Component

The Fourier transform and its inverse are used to map any function in the interval -∞ to +∞, either in the time or frequency domain into a continuous function in the inverse domain. The Fourier series therefore represents the special case of the Fourier transform applied to a periodic signal.

Harmonic analysis is the process of converting domain waveforms into their frequency component. The data is available in the form of sampled time function. They are represented by a time series of amplitude and separated by fixed time intervals of a limited duration.

ASSESSMENT SYSTEM

The RMS900 is a Distributed Automation Controller that is used as a remote terminal unit (RTU) to interface field equipment to a SCADA system. In addition, it can be used as an intelligent Electronic Device (IED) for real time data acquisition and supervisory control. The unit can be used to perform monitoring in the system through the status input (DC digital input) and DC analog inputs. The RMS900 (figure 2) also permits the user to initiate the control of field equipment, such as CB, transformer tap changer, capacitor switches and reclose through digital input.

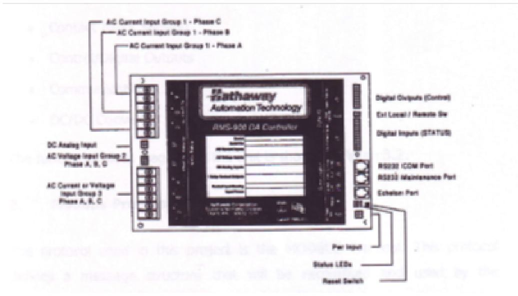


Figure 2. RMS900 I/O Layout

The interfacing between RMS900 and the field equipment is done via analog and digital I/O circuitry. AC power is monitored through transducers such as CT, VT, Low Power Sensors and other similar devices. Status monitoring, DC analog monitoring and device control is performed by connecting the field equipment to the respective RMS900 digital and analog I/O. to enable the communication in between RMS900 and SCADA or PC based automation system, a Modbus protocol was used.

The RMS900, together with the EPRComm and the Modbus protocol captured and stored the data into the PC from the laboratory electrical outlet. The Fast Fourier Transform method was applied to convert the data from the time domain into the frequency domain. This process was taking part in the EPRComm program. The time consumed to snap the data and convert it to frequency domain was about 425 second.

Raw data from RMS900 was retrieved into The Harmonics Assessment Program (HAP), written in MATLAB and VB. Spectral data is the calculated data that show the magnitude of voltage or current of each harmonic order produced by the HAP. The phase angle of the corresponding waveform can be seen from the spectral graph results.

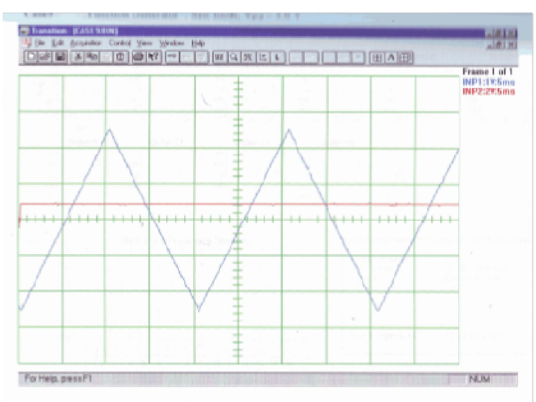


Figure 5. Input Signal for Experiment

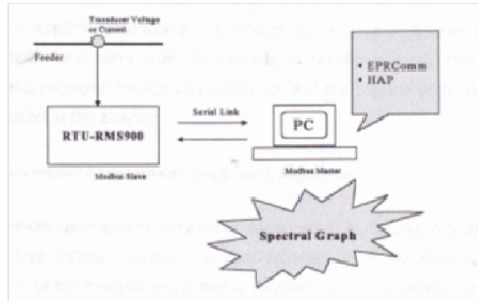


Figure 3. Assessment System Layout

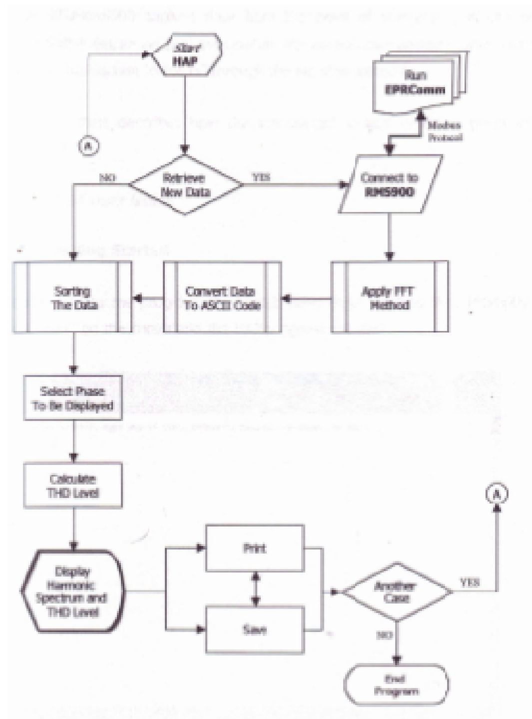


Figure 1. HAP's Flowchart

ANALYSIS AND DISCUSSION

The experiments described in the previous chapter provide a description about the effect of non-linear load, bulb with a dimmer switch, on the quality of the power supply. When the dimmer was at maximum position, the total harmonic distortions significantly smaller than when it was set to half of it maximum or minimum position. This is because at the maximum position the voltage's waveform closes to sinusoidal.

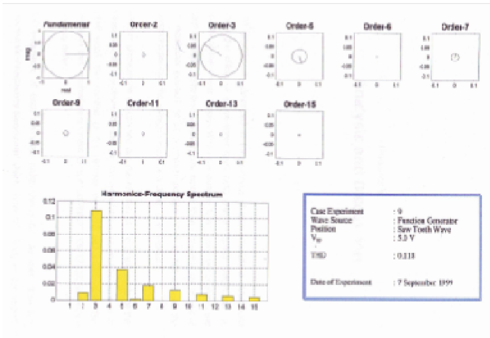


Figure 6. HAP Output Display

Another phenomena, we can see are the rotation of the phase angle of the harmonics. At the experiment 1a and 1b, the waveform input is the same or in other word, the position of the dimmer switch was not changed. The spectrum resulted were similar except that the phase angle of the harmonics at every order.

The magnitude of each harmonics order clearly can be seen from the Harmonic-Frequency Spectrum Chart. From this chart, we can observe the percentage of each harmonic magnitude to the fundamental. The THD can be seen from the right hand side of the graph.

At case 7[th], a function generator was used to simulate an almost perfect sinusoidal waveform. As it can be seen from the input waveform, the wave has small ripple on it. The spectral output given at the figure below tells us that there are some small harmonics magnitude at order 2, 3, 4, 5, 6 and 7. The highest one is at order three. However, the total of their harmonics level (THD) is only 0.005 where in the real system this level is still acceptable, based on the IEEE Engineering Recommendation G5/3 1976. Mathematically, it can be proved that a square waveform only consist of ODD order of harmonics, where the magnitude of order 3, 5, 7, …15 are 1/3,

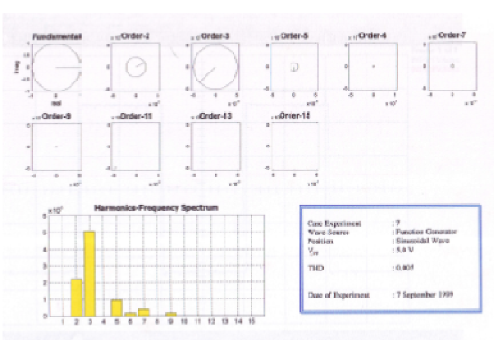


Figure 7. Harmonics Spectrum Chart for near-sinusoidal waveform

1/5, 1/7, …1/15 of the fundamental harmonics respectively. Let's consider a square wave with $f_{max}=k$ at base frequency 50 Hz.
The function $f(t)$ has halfwave symmetry since:

$$x(t) = -x\left(t + \frac{T}{2}\right)$$

i.e. the shape of the waveform over a periode of $t+T/2$ to $t+T$ is the negative of the waveform over periode t to $t+T/2$.

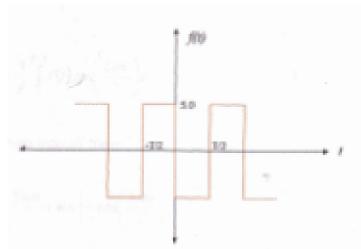


Figure 8. Square Wave Function (fx)

The fourier coefficient then;

$$a_n = \frac{2}{T \int_0^{\frac{T}{2}} f(t)\left[\cos\left(\frac{2\pi nt}{T}\right) - \cos\left(\frac{2\pi nt}{T} + n\pi\right)\right] dt}$$

If n is an *odd* integer then:

$$\cos\left(\frac{2\pi nt}{T}\right) = -\cos\left(\frac{2\pi nt}{T} + n\pi\right)$$

and

$$a_n = \frac{4}{T}\int_0^{\frac{T}{2}} f(t)\left[\cos\left(\frac{2\pi nt}{T}\right)\right] dt$$

If n is an *even* integer then:

$$\cos\left(\frac{2\pi nt}{T}\right) = \cos\left(\frac{2\pi nt}{T} + n\pi\right)$$

So that:

$$a_n = 0$$

Similarly to coefficient b_n;

$$b_n = \frac{4}{T}\int_0^{\frac{T}{2}} f(t)\left[\cos\left(\frac{2\pi nt}{T}\right)\right] dt$$ for n = odd

$$b_n = 0$$ for n = even

Therefore, waveforms, which have halfwave symmetry, contain only odd order harmonics.

In the frequency domain, the waveform in figure 8 can be drawn as in the figure 9 below, where harmonics magnitude of order 3, 5, 7, 9, … are 1/3, 1/5, 1/7, 1/9,… respectively.

Case 8 of the experiment gave the result that fulfills the explanation above.

CONCLUSION

In reality, the power electric system can not supply the load with a perfect sinusoidal voltage of constant amplitude and frequency. Some of the problems that can pollute the waveform of the supply are non-linear load, saturation characteristic in transformer and electric machinery as well as AC/DC converter.

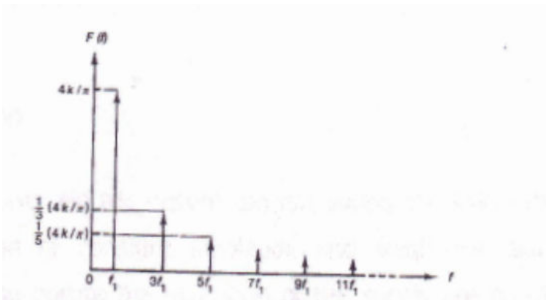
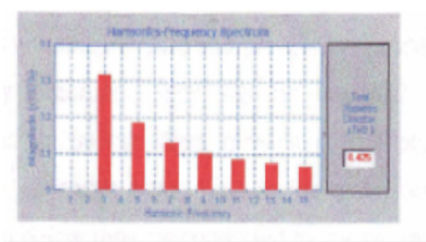


Figure 9. Line Spectrum representation of a square wave



igure 10. Harmonic Spectrum given by experiment using HAP

Various techniques are taken to cure and prevent the supply waveform from being affected by the distortion. They can be classified into five broad categories: line reactors, passive filters, phase multiplication, active harmonic compensation and preventive action such as the examination of THD of a new non-linear load before they are connected to the system.

Before we can take any prevention or curative action due to the level of harmonics distortion on the system, we need to asses how far is the total harmonic distortion (THD) from the limit of harmonic allowed. For this reason, the computer application called Harmonic Assessment Program (HAP) is needed.

The use of an RTU RMS900 from Hathaway was introduced. The RMS900 is capable of recording the voltage and/or current at a certain sampling time. This set of data then transferred to a data-handling program for further process. The result is a spectral out representation, which is ready for further power system analysis.

REFERENCES

[1]. ***Electrical Power System Quality***, Roger C Dugan, et.all, Book, Mc. Graw-Hill, 1996.

[2]. ***A Load and Harmonics Data Assesment Program***, Tony Cheung, Third Year Project Report, Department of Electrical Engineering & Electronics, UMIST, 1998.

[3]. ***Harmonics Assesment in the Distribution Feeder***, Khairudin,MSc. Dissertation, Department of Electrical Engineering & Electronics, UMIST, 1999.

[4]. ***Harmonic Pollution in Electrical Energy System***, L.L.Lai, third International Conference on Advanced in Power System Control, Operation & Management, page 729-734, proceedings volume 2 of 2, Hongkong Convention and Exhibition Center, Wanchai, Hongkong, 9 – 11 Nov. 1995.

[5]. ***Harmonics Sources in The City Distribution System***, Zhou Young, fourth International Conference on Advanced in Power System Control, Operation & Management, page 729-734, proceedings volume 2 of 2, Hongkong Convention and Exhibition Center, Wanchai, Hongkong, 11 – 14 Nov. 1997.

[6]. Harmonics Filters for Industrial Power System, D.Sutanto,et..Al, IEEE International Conference on Advanced System Control, Operation & Management, page 594-598, Hongkong, Nov. 1997.