THE FPGA BASED POWER MONITORING SYSTEM FOR TPS FACILITY

Chih-Sheng Chen#, Zong-Da Tsai
NSRRC, 101Hsin-Ann Road, Hsinchu Science Park, Hsinchu 30076, Taiwan.

Abstract

There are more and more non-linear electronic equipments such as inverters using in facility nowadays. These non-linear electronic equipments let us achieve energy saving, but induce other electrical pollution to the whole power grid in contrast. Among these electrical pollutions, electric harmonic is the most common and harmful to power facility. Therefore, how to monitor the electrical noises from these non-linear equipments becomes an important issue. In this article, a set of power quality monitoring system based on FPGA (Field-Programmable Gate Arrays) modules and PAC (Programmable Automatic Controller) has been built because of their programmability and fast processing speed. By using this monitoring system, any abnormality in power system and its spectrum will be recorded thoroughly. On the other hand, the maintainer could follow the trace of noise and then propose a suitable solution to eliminate the electrical interference too.

INTRODUCTION

For the trend of automation and energy-saving in modern electronics lab and business office building, many types of non-linear electric equipments are applied to precision control. However, these equipments, such as inverters or UPS, will become non-linear loadings and cause various electrical problems. The most common is electric harmonics. Once the harmonics happens in power system, the whole power grid will suffer a quality reduction due to the THD (Total Harmonics Distortion). The worse case may lead to over voltage or over current and then damages electronic equipments. Furthermore, the power cables will induce magnetic field by the harmonic current, and then interrupt or affect these precision facilities. The above influences not only shorten the life of power equipments but also affect power quality even cause huge economic cost.

In facility field, power electronics are applied generally in the air condition systems and process cooling water systems. Among these devices, VFD (Variable-Frequency Drive) is the most popular type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed and torque by varying motor input voltage and frequency. As the trend of automation in facility, more and more VFDs are used as system control strategy. The ratios of polluted power quality and the reduction of power factor increase gradually. Thus, the performance of VFD plays a very critical role in driving systems. To decide a good VFD can be achieved by three factors. First, is the affect to loadings by total output harmonic voltage. Secondly, the harmonic pollution output to power grid. Third is the efficiency of VFD. As a result, besides the cost down of production and increasing the control precision, the manufacturers of VFD must put lots of efforts in minimizing the pollution in power quality and rising up power factor during operation.

The DC/AC chokes, Multi-Pulse, Delta-Start and filers are the methods to improve harmonics. The most common strategy is adding harmonics filters, including active filters, passive filters and hybrid filters. The efficiency of passive filter will change with impedance of loadings. While loadings change, the passive filters could not operate in proper frequency band. The passive filters may resonant with harmonics and become another source of harmonics. Although the active filters perform well, their high prices confine the universality. Therefore, how to detect the power pollution precisely and effectively is a very important step to make power system better.

EXPERIMENTAL METHODS AND THEORY

Ideal power wave consists with one basic frequency only. The basic frequency is 60 Hz in Taiwan. If the power system contains with non-linear loadings, these non-linear loadings will generate the currents with other frequencies. These components are so called Harmonics. The harmonic can be represented by the following equation.

$$X(t)=\sqrt{2}\left[\sum_{h-1}^{\infty} A_h \sin(2\pi f_h t+\theta_h)\right] \quad (1)$$

In the above equation, $X(t)$ stands for the voltage or current value in time domain. A_h is the effective voltage of h-order harmonic. f_h is the voltage or current frequency of the h-order harmonic. θ_h is the phase angle of h-order harmonic voltage or current. And the harmonic distortion (HD) is defined as:

$$HD=\frac{A_h}{A_1} \quad (2)$$

And the total harmonic distortion (THD) can be written as:

$$THD=\frac{\sqrt{\sum_h^{\infty} A_h^2}}{A_1} \quad (3)$$

Power harmonic is a kind of steady state phenomenon. If the harmonic happens in a power system, the effect to power facility is not always revealed instantly. It does damages to the equipments when the harmonic is lasting for a while. It also cuts down the life time of power equipments and let them fail randomly. Besides, some harmonics induce other resonances in power system. These resonances may cause power facilities overload and influence the power quality. The harmonic current will induce magnetic field to interrupt other facilities (see table 1.).

Table 1: Effects to Equipments from Harmonics

Power Equipment	Effects
Transformer	Increase iron loss and copper loss. Induce resonances and noises in coils.
Motor	Increase iron loss and copper loss. Rise up moter tempertures. Lower efficiency and shorten life time of motor.
Capacitor	Induce resonances causing overload and over temperture. Shorten life time of capacitor.
Cable	Insulation aging. Rise up cable temperature and shorten life time.
Counter	Counting errors.
Relay	Relay malfunctions.
Electronic Equipment	Equipment malfuctions. Causing capacitors, transistors and diodes failed.
Lighting Equipment	Shorten life time of bulbs.
Communication	Interfering cables and affecting communication quality.

Due to the various damages from harmonics, most countries define standards to restrict harmonics from commercial household electrical appliances. IEC 61000-3-2 and IEC 61000-3-4 define the harmonics of electric equipments from the Europe. The European standards classify the electric appliances by four classes. The Class C equipment includes lighting facility with total current less than 16A. It confines the maximum permissible of second order harmonic expressed as a percentage of the input current at fundamental frequency to 2%, and the third order to 27%.

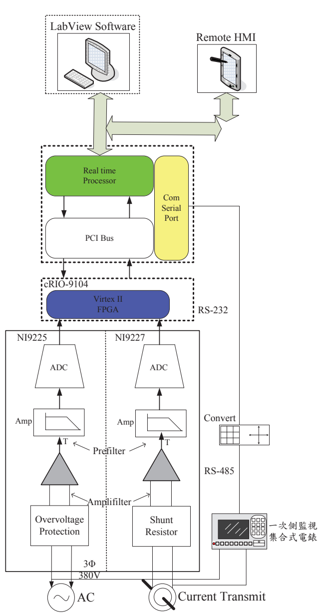

Figure 1: Scheme of the FPGA based power monitoring system.

As for the experimental setup, this measurement is divided to hardware and software two portions. The FPGA is the most critical part to process the wave forms and calculate the mass data. After getting the waveforms, several calculations including digital filtering and window correcting were completed instantly. The real-time processor preceded the correction of FFT (Fast Fourier transform) and STFT (Short-time Fourier transform). The analytical factors of phase angles, amplitudes and harmonics were obtained and shown on a graphic control program. The results were saved and simulated by a remote computer through Ethernet. The overall structure is shown as figure 1.

An inverter of AHU (Air Handling Unit) had been measured this time. By measuring the power quality factors of the inverter, the processes of how harmonics happen and the effects of harmonics suppression devices are discovered. The specification of DUT (Device Under Test) is listed as Table 2.

Table 2: Specifications of Experimental Devices

AHU			
Air flow (CMH)	45000	Shaft power (kW)	10.8
Static pressure (Pa)	500	Fan speed (RPM)	683
Outlet air speed (m/s)	11.82	Motor power & pole (kW/#)	15/6
Operation current (A)	25.4	Motor efficiency	0.85
Inverter			
Power (kW)	15	Control mode	V/F, Vector
Rated voltage (V)	400	Frequency (Hz)	0~60
Protocal	Ethernet TCP/IP	Rated current (A)	30
AFE			
Power (kW)	15	Control mode	SPWM
Rated voltage (V)	380~460	Efficiency	0.95~0.99
Protocal	Modbus RTU	Rated current (A)	35
Reactance current (A)	35	Inductance (mH)	5.28

About the software, a power quality monitoring system is built up by the Labview, a kind of graphical language. It not only reduces the development time, there are many accessory applications make it easier for data processing. And the customized program is the most suitable for lab scale since there are lots of try and error.

EXPERIMENTAL RESULTS

A set of capacitors is used as filter to reduce the effect of harmonics in this article. According to the results, the amplitudes of harmonic current are significant at 5th, 7th and 11th orders (see lower left in figure 2.). Although the voltage waveforms seem to be fine (upper right in figure 4), however, there are serious defects exist in current waveforms. It is observed that many "bunny's ears" multiply on the original sine waves. The amplitude of each phase current reduces to only 3.7A.

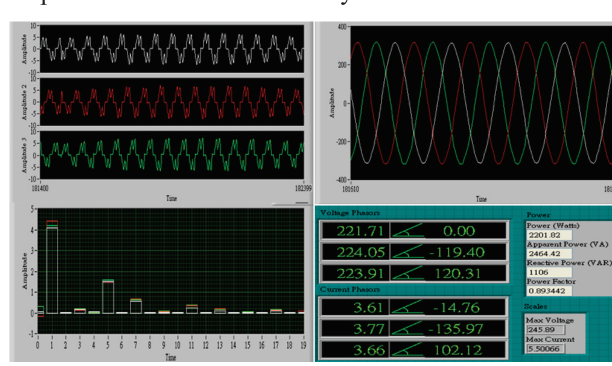

Figure 2: The results without capacitors.

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Comparing these results to the spectrums acquired by a commercial FLUKE power meter, the defects on current waveform still retain, and the total current reads slightly bigger (see figure 3).

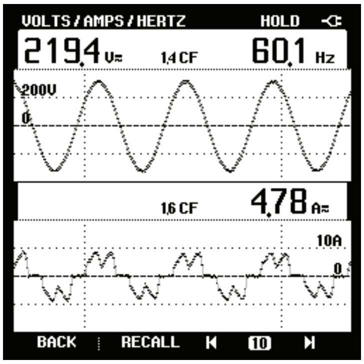

Figure 3: Result from FLUKE meter.

As the amount of capacitor increases, the defects on current waveforms diminish gradually. The current returns to its original value from 3.7A to 6.1A step by step as the capacitor added. The amplitude of 5th order harmonic is a little bigger, but the amplitudes of the other higher order harmonics become smaller than before. It can be observed clearly in figure 4 and figure 5.

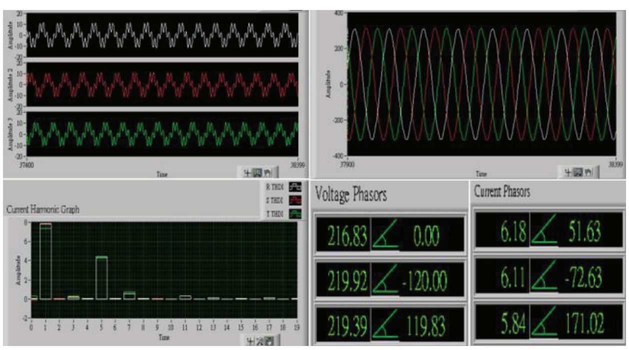

Figure 4: The results with one set of capacitors added.

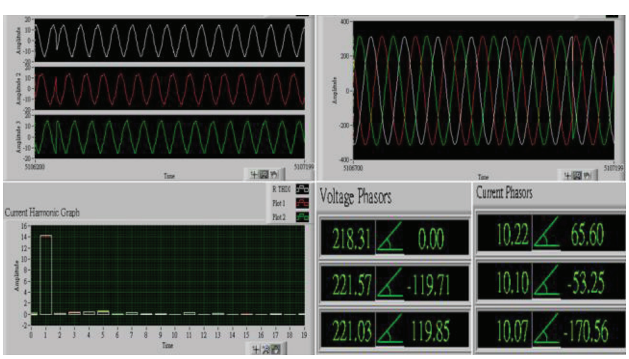

Figure 5: The results with two set of capacitors added.

Figure 5 shows the results after two set of capacitors added. The rugged waveform becomes smooth and the all waveform dots are recorded in details. The magnitude of 5th order harmonic diminishes to be ignored. The readings of each phase current increase to 10A or so. That is triple bigger than the case without any capacitor. From this result, it is confirmed that adding capacitors could reduce the effect of harmonics conditionally. As the harmonic current decreasing, total operation current will increase obviously.

As for the software, because the FPGA modules deal with huge amount of data in FIFO (First-in First-out) mode, data lost will occur occasionally. While the modules access memory directly (DMA), the sampling rate of FIFO buffer must be adjusted in accordance with the hardware ability. Otherwise, the discontinuity of waveform will appear and influence the accuracy of measurement.

CONCLUSIONS

The goal of this paper is to build up a more convenient way to detect the problems resulting from non-linear loadings. This power monitoring system can show many important information including harmonics, phase angles, power factors and power quality. The system is based on FPGA modules to realize the high speed access and complete complex calculations. An AHU is under test in the first step. By adding capacitors, the harmonics reduce obviously and the power lost resulted from harmonics diminish as well. It is a lasting task to improve this system in the future.

REFERENCES

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