# The Design and Implementation of a 5 kW Programmable Three-Phase Harmonic Generator

**Jeong-Chay Jeon†, Hyun-Jae Jeon*, Myoung-Il Choi*, and Chee-Hyun Park***

**Abstract** – This paper presents the design and implementation of a 5 kW programmable three-phase harmonic generator, which is capable of generating sinusoidal output voltages with adjustable output amplitude and frequency over a wide range as well as arbitrary waveforms. The considered harmonic generator is a linear power amplifier type. This system consists mainly of a power converter to generate and amplify waveform signals, a controller to control the desired output signal and measure the output parameters including voltage and current, and a control program to set the desired output and display the output values. The prototype programmable three-phase harmonic generator has been constructed and tested. Test results show that the developed programmable three-phase harmonic generator performs well.

**Keywords:** Arbitrary Waveform, Programmable Harmonic Generator, Sinusoidal Output Voltage

## 1. Introduction

The voltage and current waveform distortion due to the wide applications of nonlinear loads such as computers, adjustable speed drives, and electric furnaces brings severe trouble to the electric power system [1]. As such, this has created the need for an understanding of the effects of harmonic and waveform distortion on the various devices including protection, control, instrumentation, and measurement equipment.

In order to understand the effects of harmonics on the power system components, it is important to test whether the equipment is influenced by harmonics. The test and evaluation on the effects of harmonics may need sinusoidal waveforms with various voltages and frequencies. A programmable harmonic generator can be very useful for testing the effects of harmonics on the various devices.

A programmable harmonic generator provides sinusoidal output voltages whose amplitude and frequency can be programmed independently from each other. The waveform generation is based on the concept of the complex Fourier series [2]. Any periodic waveform can be reproduced by generating and summing together a set of harmonically related sine-waves with the proper magnitude and phase-shift components.

A harmonic generator is basically used to implement power conversion and frequency control, and generate arbitrary voltages and waveforms. The generated waveforms consist of a sinusoidal function at the fundamental frequency with several harmonic components. Most harmonic generators or power sources available today are linear power amplifier types and pulse width modulated inverter types. The computer based harmonic generator facilities of [2] explained the principal of a harmonic generator and its needs. As well, a single and three-phase AC power source using sliding mode control was proposed by Low and predictive control with pulse width modulated inverters was generalized [3, 4].

The harmonic generator with a pulse width modulated inverter has the problem that switching losses increase with the elevation of the switching frequency [5, 6]. Although its efficiency is poor and a large heat sink and isolation transformer are required which increases the size and the weight of the systems, the harmonic generator with linear power amplifier allows the generation of all waveforms with good input-output characteristics. So, in this paper, the considered harmonic generator is the linear power amplifier type.

This paper describes the design and implementation of a three-phase harmonic generator, which is able to synthesize voltage waveforms and amplitude. In the system, harmonics can be added to the fundamental frequency, so arbitrary waveforms can be generated. Various experiments have been conducted to verify the performance of the system and the results have shown that the developed three-phase harmonic generator performs well.

† Corresponding Author: IT Development Center, KESCO. (cameleon@kesco.or.kr)
* IT Development Center, KESCO (hjeon@kesco.or.kr ) (ken2003@kesco.or.kr) (cheehyunpark@skku.edu)
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## 2. Design and Implementation

The harmonic generator under consideration is depicted in Fig. 1. This consists mainly of power input, a power converter (SCR rectifier and power amplifier) to generate and amplify waveform signals, a controller to control the output signal and measure the output parameters, and a control program to program the desired output values and display the output parameters. A personal computer (PC) and control program are used to provide interface with the harmonic generator. The PC and control program control the waveform's shape with harmonic order and amplitude, and measure the output parameters including voltages and currents.

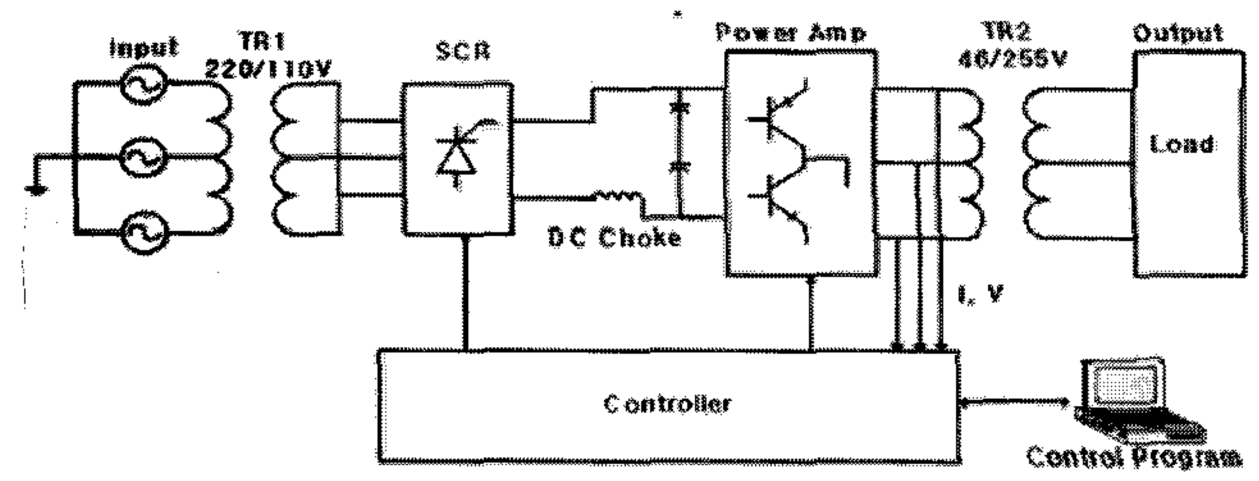



**Fig. 1.** The block diagram of the system

The output reference signal is first generated in the controller illustrated in Fig. 2. In spite of the output voltage and waveform control of the harmonic generator being analogous, the reference signal as well as an on/off signal is generated by the controller in order to allow easy programming of the output voltage and waveform from the PC. An 8 bit microcomputer (PIC18F8720) and digital to analogue (DA) converter (AD 7523) are used to generate the output signal. Furthermore, in order to independently maintain the output function of the DA converter when the microcomputer performs other work, latch-IC 74F573 between the microcomputer and DA converter is used. To execute waveform output command from the PC at high speed, 4Mbit static random access memory (S-RAM) was used. Also, in order to retain the information of the waveform saved in the inside of the controller by modifying and saving the waveform command from the PC, 4Mbit flash read only memory (F-ROM) was used.

In the harmonic generator, in order to provide DC power for digital components and a signal for the power amplifier, a silicon-controlled rectifier (SCR) is used. The signal generated by the controller is then sent by linear power amplifier module. The power amplifier module is consisted of power transistor 2SA1494 (PNP type) and 2SC3858 (NPN type). These linear AC power amplifiers are constructed as shown in Fig. 3. They have the output capacity of 5 kW and are designed so that capacity enlargement in the future is possible. Finally, the amplified voltage is sent to the 46/255 volt transformer to amplify the voltage level.

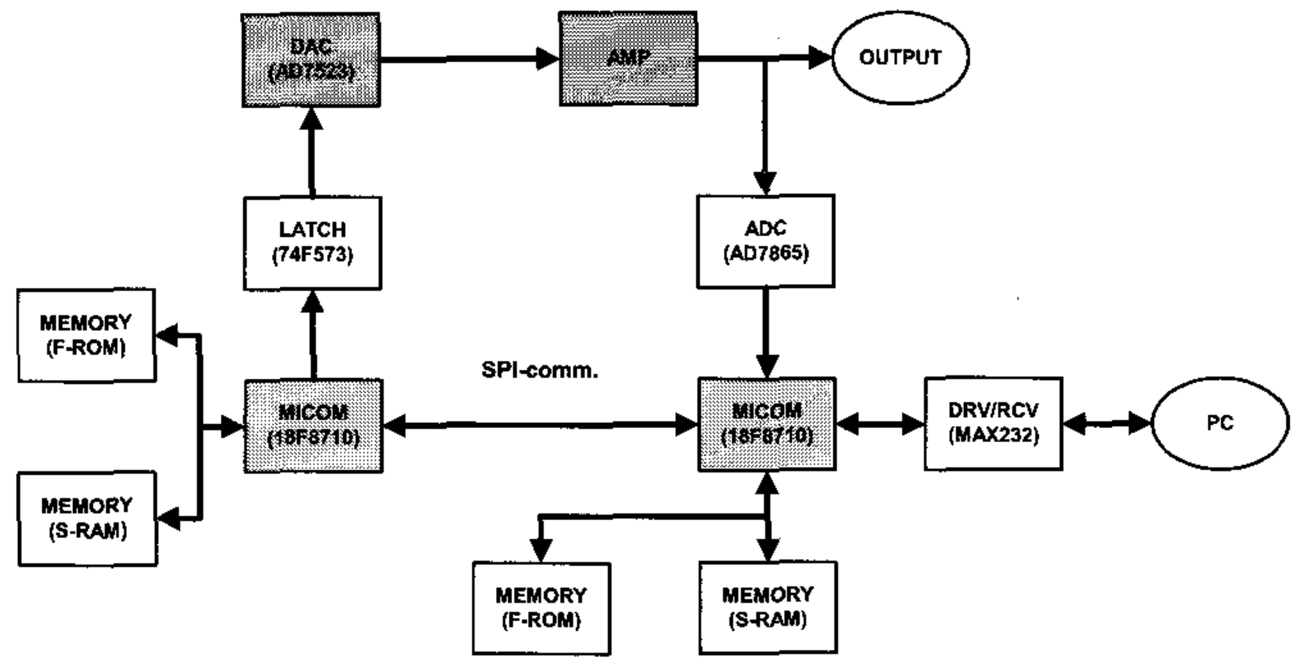



**Fig. 2.** The block diagram of the controller

**Fig. 3.** The developed linear power amplifier PCB (500W*10=5kW)

In the developed three-phase harmonic generator, the output voltage and current are measured by the voltage transducer LV 25-P and current transducer LTS 25-NP, and the measured data are converted to digital signals via a 14bit analogue to digital (AD) converter (AD 7865) as displayed in Fig. 2. In order to protect the system from surge and over-voltage, varistor TNR 20D751K and zener diode 1.5KE15 are used respectively. An 8 bit microcomputer (PIC18F8720) for analogue to digital conversion (ADC) is used to measure and save the output of the harmonic generator in the memory. It is connected to the microcomputer for digital to analogue conversion (DAC) by using serial peripheral interface (SPI) communication in order to transmit the output command from the PC to the microcomputer for DAC. 4Mbit S-RAM for high-speed saving of 14 bit data per channel from the AD converter is used. Also, in order to save transmission command from PC and ADC data, 4Mbit F-ROM is utilized.

## 3. Control Program

In order for the user to determine the desired output voltage amplitude, frequency, and waveforms of the harmonic generator and to confirm output data, the control program using Borland's C++ Builder is developed and RS-232 serial interface is used. The harmonic generator that can be operated remotely has a great advantage. As a serial interface is used, distances between user and the harmonic generator can be handled for safety and convenience.

Figure 4 demonstrates the main window formation of the control program, by which the user can confirm the operational state of the harmonic generator, as well as the output data including voltage (RMS), current (RMS, peak and crest factor), KVA, KW, and power factor (PF). This allows the output voltage to be checked prior to applying power to the load. The serial interface that is used for communication to the microcomputer can be chosen with the setup menu. Work to set and synthesize the waveform including harmonics can be performed in the synthesized menu. Each waveform signal can be any of the first 16 waveforms stored in the memory. The first of these 16 waveforms is a sine wave and cannot be altered and the other 15 waveforms can be altered by the user to produce any arbitrary waveforms as shown in Fig. 5. These waveform libraries can save to files and read from files. Figure 5 indicates the window to set and synthesize the desired output waveform including harmonic order and magnitude.

Finally, the harmonic generator is operated by the menu shown in Fig. 4 and the operating time of the harmonic generator is demonstrated by the elapsed time menu. Communication and output status are confirmed by the com port and the output disable menu, and output information is displayed by the measuring menu.

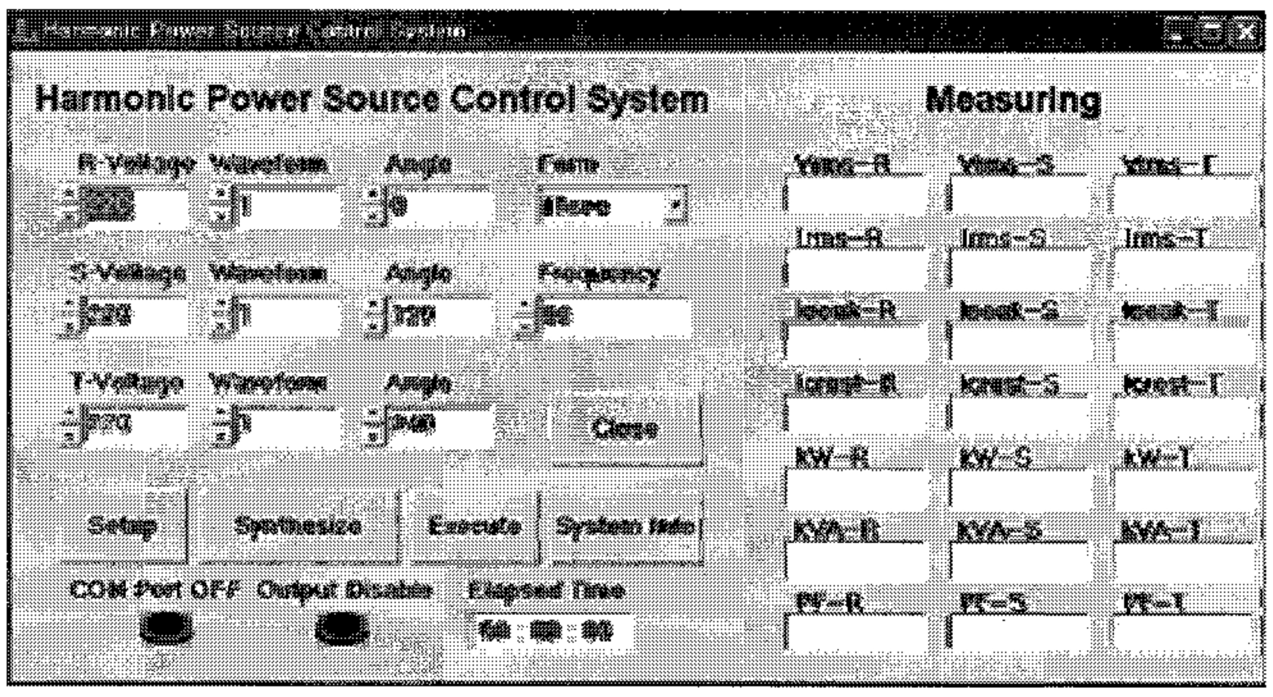



**Fig. 4.** The main window of the developed control program

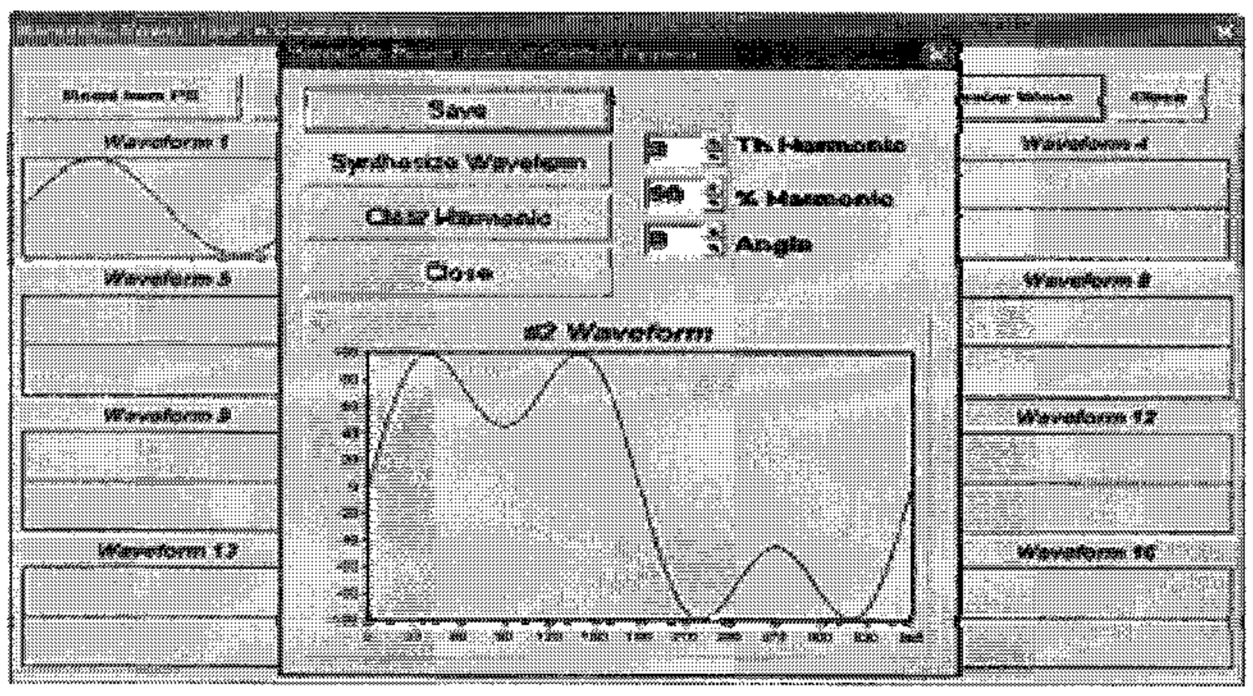


**Fig. 5.** The window to set the desired output waveform including harmonics

## 4. Test and Results

The performance of the programmable harmonic generator is tested by some measurements. In order to measure the output voltage, current amplitude, and waveform of the harmonic generator, the RPM 1650 power quality analyzer is connected to the harmonic generator.

Figure 6 shows the setting of the control program to test the maximum output voltage and current of the harmonic generator and results are measured by the controller. In the experiment, the desired output voltage is set at 260 V (rms) and a fixed frequency of 60 Hz. A constant resistive load is connected to the output such that an output current of 7 A (rms) is drawn. The results measured by RPM 1650 are presented in Fig. 7. As can be seen from the test results, there is no noticeable distortion of the output voltage and current, but the output voltage (a) and current (b) give about 255 V (rms) and 6.8 A (rms) with little error (about 5

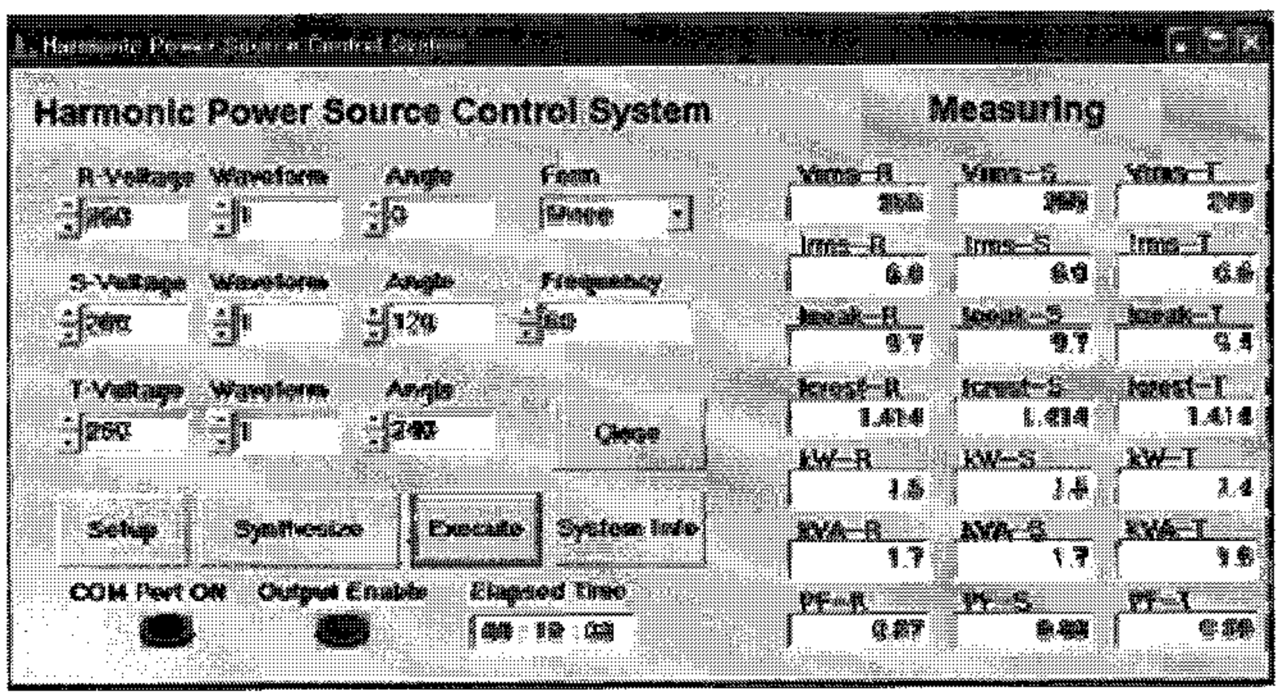
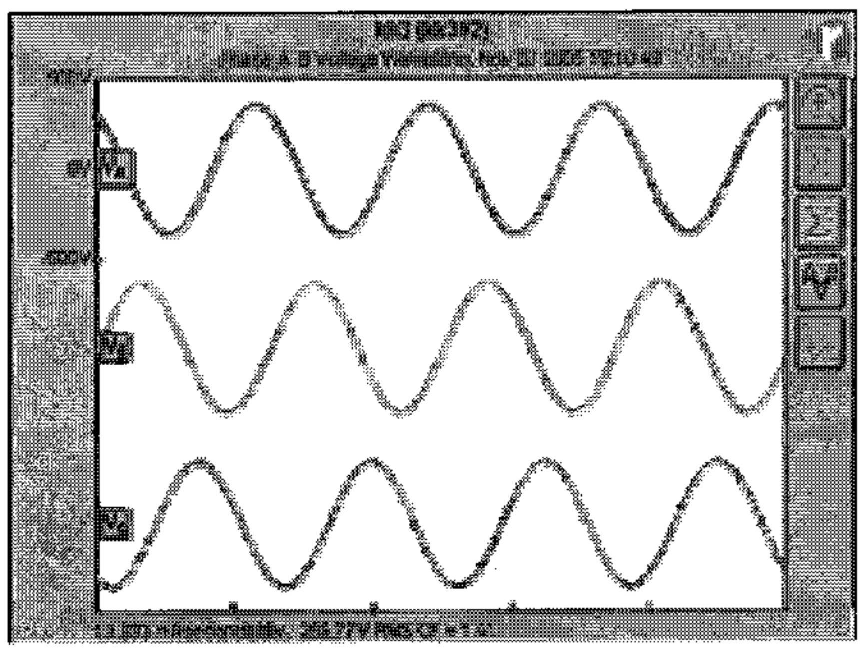
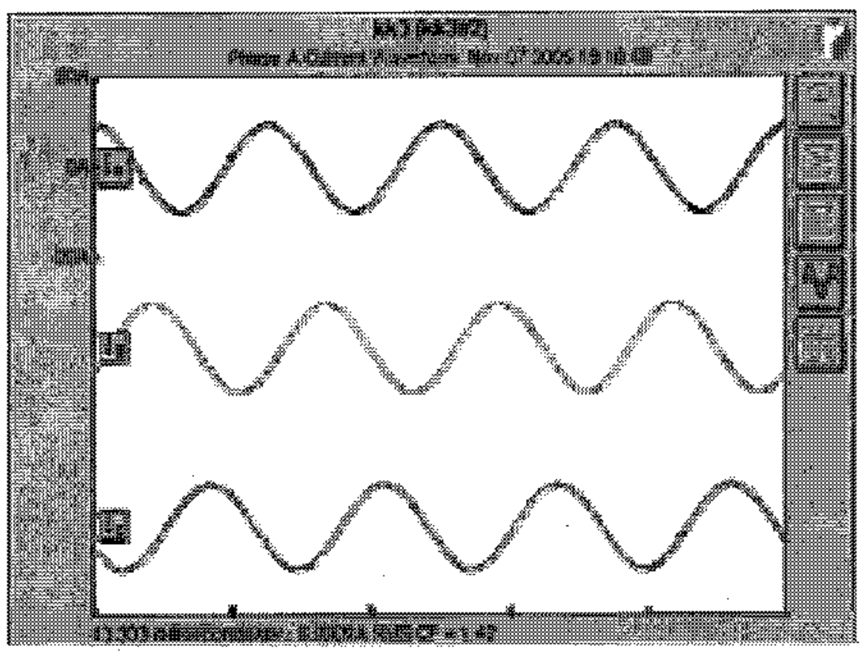



**Fig. 6.** The output setting and measurement



(a) The output voltage



(b) The output current

**Fig. 7.** The maximum output voltage and current

V). It is guessed that the error was generated by the problems of linear AC power amplifiers and the other elements. Therefore, future work to reduce the output error will be needed.

In order to demonstrate the harmonic generator to generate arbitrary waveforms, various experiments are performed. In these experiments, the output of the harmonic generator is connected to a resistive load and RPM 1650 for measuring the output voltage and waveform.

Figure 8 indicates the result that the output voltage has been set as 80V (rms) at 60 Hz, and 10% third harmonics, 15% fifth harmonics, 20% seventh harmonics, 15% ninth harmonics, 10% eleventh harmonics, and 5% thirteenth harmonics are added. Its corresponding harmonic spectrum is given in Fig. 9. It is clear from the test results that there is little error of output voltage due to the linear power amplifiers but the desired waveform is obtained correctly. To remove these errors, the effort to improve the accuracy and reliability of the linear power amplifiers and the other elements should be considered. Figures 10 and 11 depict the other waveforms with a complicated harmonic content, where fundamental frequency is 60Hz.

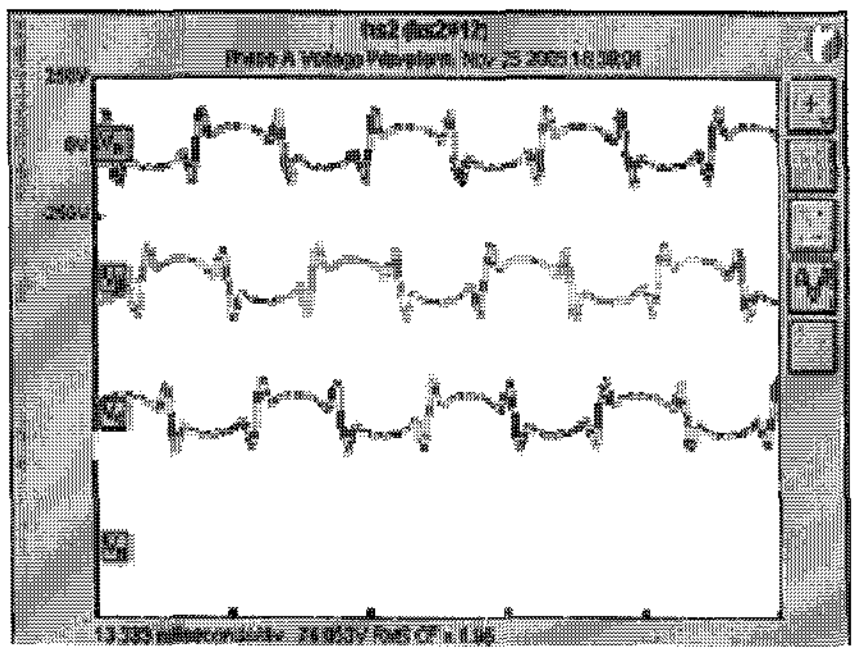


**Fig. 8.** The output voltage waveform of 80 (sinwt + 0.1 sin3wt + 0.15sin5wt+0.2sin7wt+0.15sin9wt+0.1sin11wt + 0.05sin13wt )

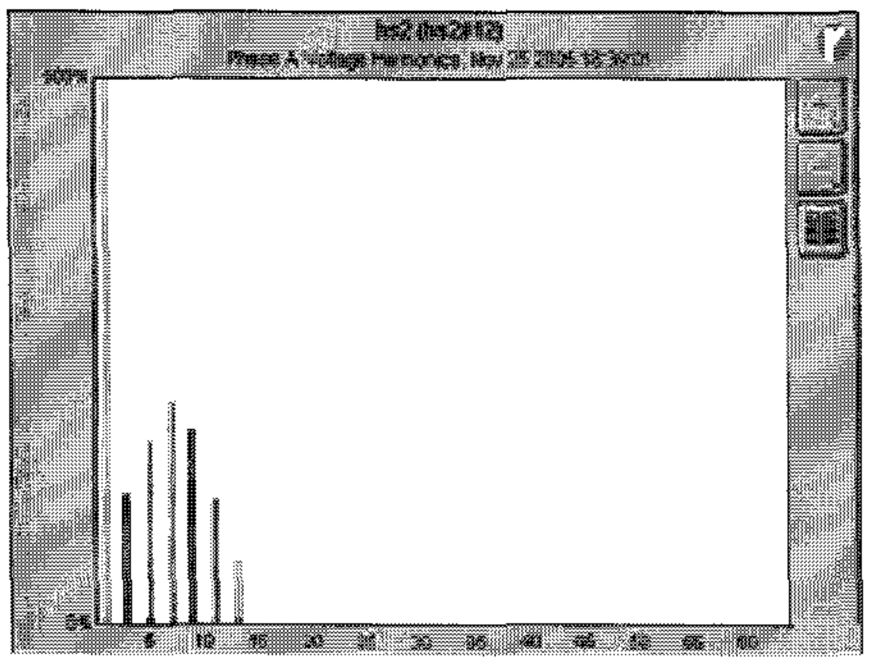


**Fig. 9.** The harmonic spectrum of the voltage waveform in Fig. 8

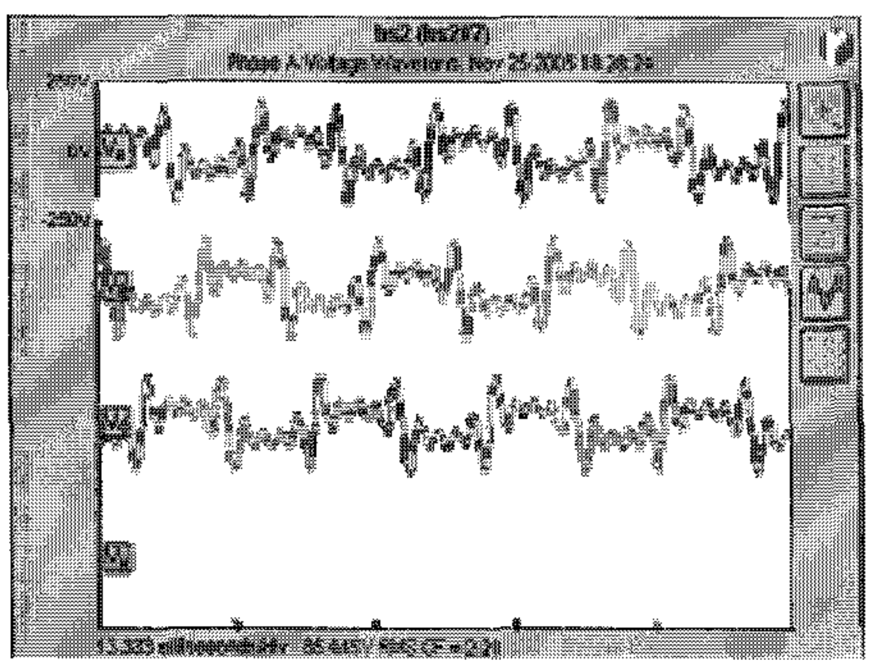


**Fig. 10.** The output voltage waveform of 90 (sinwt + 0.1sin5wt + 0.2sin7wt+ 0.3sin9wt + 0.4sin11wt)

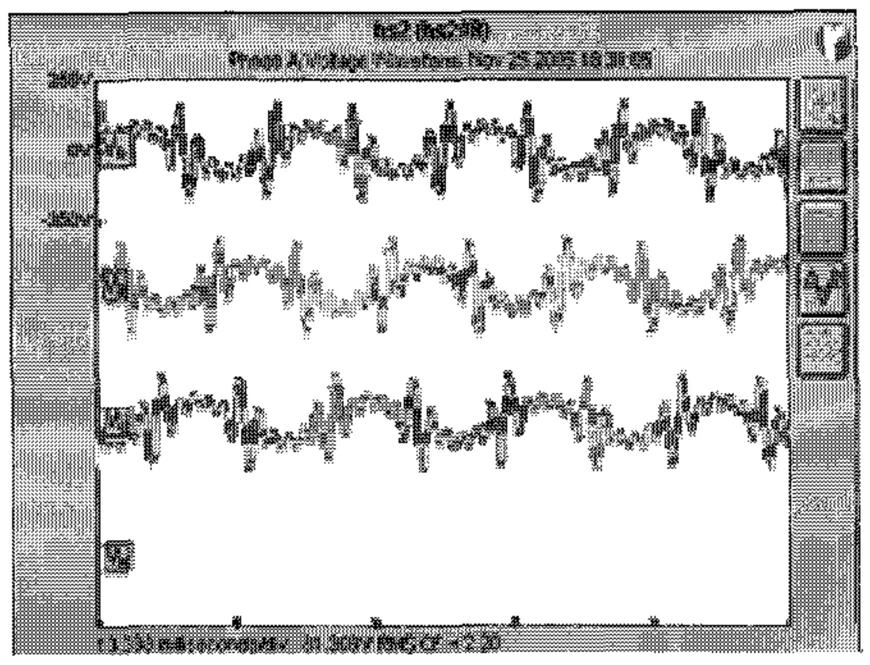


**Fig. 11.** The output voltage waveform of 85 (sinwt + 0.1sin7wt+ 0.2sin9wt + 0.3sin11wt + 0.4sin13wt)

## 5. Conclusion

The 5kW programmable three-phase harmonic generator with adjustable output voltage amplitude and frequency has been successfully developed. In this harmonic generator, in order to control the desired signal and measure the output signal, the controller using two 8 bit microcomputers are developed. And 5 kW linear power amplifiers to amplify the output signal and the control program to set and display the output of the harmonic generator are developed.

In order to verify the developed harmonic generator, various experiments have been conducted using the prototype system constructed in this study. The results have demonstrated that there is little error of output voltage due to the linear power amplifiers but the desired waveform is obtained correctly. And it is clear as the test results indicate that the power level of the developed harmonic generator is about 5 kW. Therefore, future work to reduce the output error and develop a power amplifier with high accuracy and large capacity will be needed.

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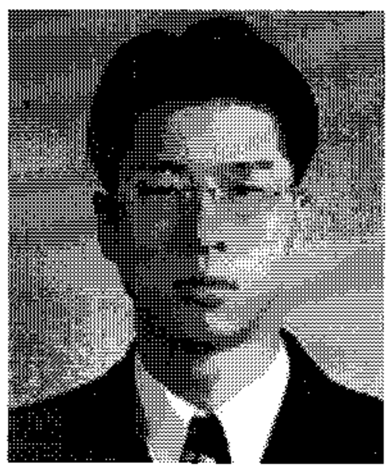

**Jeong-Chay Jeon**
He was born in Yeosu, Korea on June 8, 1971. He received his B.S. and M.S. degrees in Electrical Engineering from Wonkwang University in 1997 and 1999, respectively. He is presently with the Korea Electrical Safety Research Institute, KESCO (Korea Electrical Safety Corporation), as a Senior Researcher in the IT Development Center. His research interests are in the areas of power quality, intelligent control, and embedded systems.

**Hyun-Jae Jeon**
She was born in Dae-Jeon, Korea in 1978. She received her B.S. from Kyungpook National University in 2001 and her M.S. from KAIST in 2003. She is presently with the Korea Electrical Safety Research Institute, KESCO (Korea Electrical Safety Corporation), as a Researcher in the IT Development Center. Her research interest is in the area of circuit design.

**Myoung-Il Choi**
He was born in Dae-Jeon, Korea in 1975. He received his B.E. and M.S. from Changwon National University in 2002 and 2004, respectively. He worked for KERI in Korea to 2001. He is presently with the Korea Electrical Safety Research Institute, KESCO (Korea Electrical Safety Corporation), as a Researcher in the IT Development Center. His research interests are in the areas of Ultrasonic Motors and Finite Element Analysis.

**Chee-Hyun Park**
He was born in Korea in 1973. He received his B.E. and M.S. from Korea University, Korea, in 2000 and 2003, respectively. He worked as a Research Engineer for LG Innotek Company in Korea from 2003 to 2005. Since 2006 he has been with the Korea Electrical Safety Research Institute, KESCO (Korea Electrical Safety Corporation). His research interests are in the areas of signal processing and facility diagnosis. Currently, he is working toward his Ph.D. degree in School of Information and Communication Engineering at the Sungkyunkwan University, Korea.