A DIDACTIC MICROCONTROLLED THREE-PHASE SIGNAL GENERATOR

Wilson Komatsu Antonio Ricardo Giaretta Lourenço Matakas Jr.
Escola Politécnica da Universidade de São Paulo CEP 05508-900 São Paulo SP BRAZIL
Av. Prof. Luciano Gualberto, trav. 3, no. 158
E-mail: matakas@pea.usp.br

***Abstract* – This paper presents the development of a didactic microcontrolled three-phase signal generator. This generator allows independent frequency and phase amplitude variation, inclusion of harmonics and introduction of pre-programmed voltage sags and swells. The generator, coupled to a switched power amplifier, constitutes a three-phase power supply for small loads (e.g. 127Vac @ 5A). The generator software and hardware, as well as the power amplifier and power voltage filter are described.**

***Keywords* - Education in Power Electronics, Electrical Energy Quality, Microcontroller Applications, three-phase signal generator.**

I. INTRODUCTION

Power electronics and power quality experiments frequently demand three-phase power generators with programmable output waveforms. Such equipment can cost as much as US$15,000.00 [1]. However, for applications such as didactic laboratories (e.g., for undergraduate courses) one does not need such sophisticated equipment in order to provide basic three-phase voltage waveforms, inclusion of (some) harmonics, sags and swells.

This paper presents the development of a didactic microcontrolled three-phase signal generator. This generator allows frequency and phase variation, independent phase amplitude control, inclusion of harmonics and introduction of programmed voltage sags and swells. The generator, coupled to a switched power amplifier, constitutes a three-phase power supply for small loads (e.g. 127Vac @ 5A). The generator software and hardware, as well as the power amplifier and power voltage filter are described. Some results are presented in order to testify expected performance.

Presentation is organized as follows: Chapter II describes implemented three-phase signal generator with hardware and software diagrams. Chapter III details a three-phase power source constituted by the proposed generator associated with a switched power supply and power filter. Chapter IV shows some measurement results of the generator. Chapter V brings some final remarks.

II. THREE-PHASE SIGNAL GENERATOR

The proposed didactic generator has main characteristics given by Table 1. It can provide both analog (through D/A converter) and PWM outputs. The PWM output can be connected to a three-phase power inverter (Chapter III), where an optional power filter at the output of this inverter allows elimination of PWM carrier signal.

The generator was developed using PIC16F873 and PIC18F6620 microcontrollers [2], which control the man-machine interface (LCD display and keyboard) and the generation of signals, respectively. They are interconnected by their Serial Peripheral Interfaces (SPI). Figure 1 shows the block diagram of the implemented generator.

Table 1
Didactic signal generator main characteristics

Output voltage range	0 to 20Vpp – (Analog output) 0 to 5V – (PWM output)
Output fundamental freq.	40 to 70Hz
Phase angle range	0 to 240º (for fundamental frequency)
Harmonics	Up to 13th order (max. 3 simultaneous) Harm. phase angle always equal to zero
Sag	Programmable duration (1 up to 255 cycles) and depth (from 1% up to 100%)
Swells	Programmable duration (1 up to 255 cycles) and intensity (from 1% to 100%)

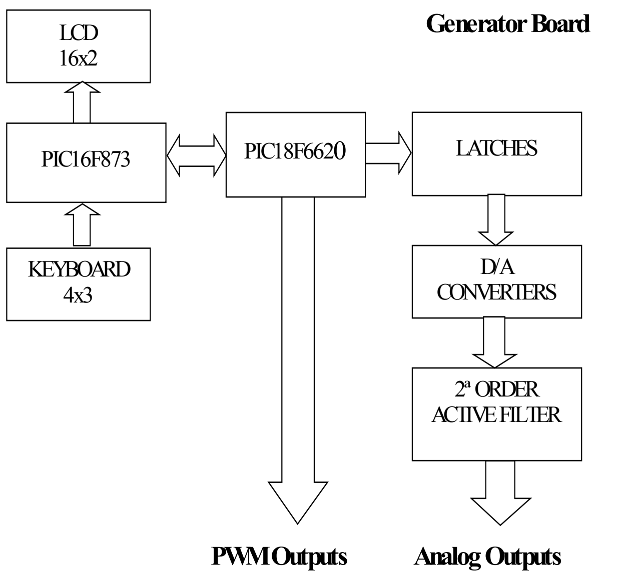

Fig. 1: Three-phase Signal Generator Hardware Diagram

Each phase voltage amplitude, angle and frequency can be independently configured. Harmonics (up to 3 harmonics simultaneously) can be introduced defining their order and amplitude as well as sags and swells defining the depth or rise and the number of cycles of their duration. Out of range programming input is signaled by an error message on the LCD display. D/A converters outputs are filtered by a 2nd order Butterworth filter, to allow analog outputs signals softening (minimization of the steps at the analog outputs caused by the zero order sample & hold of the D/A converters).

Software was developed using C and assembly [3][4]. Its flowchart is presented in figure 2. Sine tables from the 1st to the 13th harmonic are accessed by a pointer, which represents the actual output angle. For instance, generic phase i output (i=R, S, T) for a time vector t is given by (1).

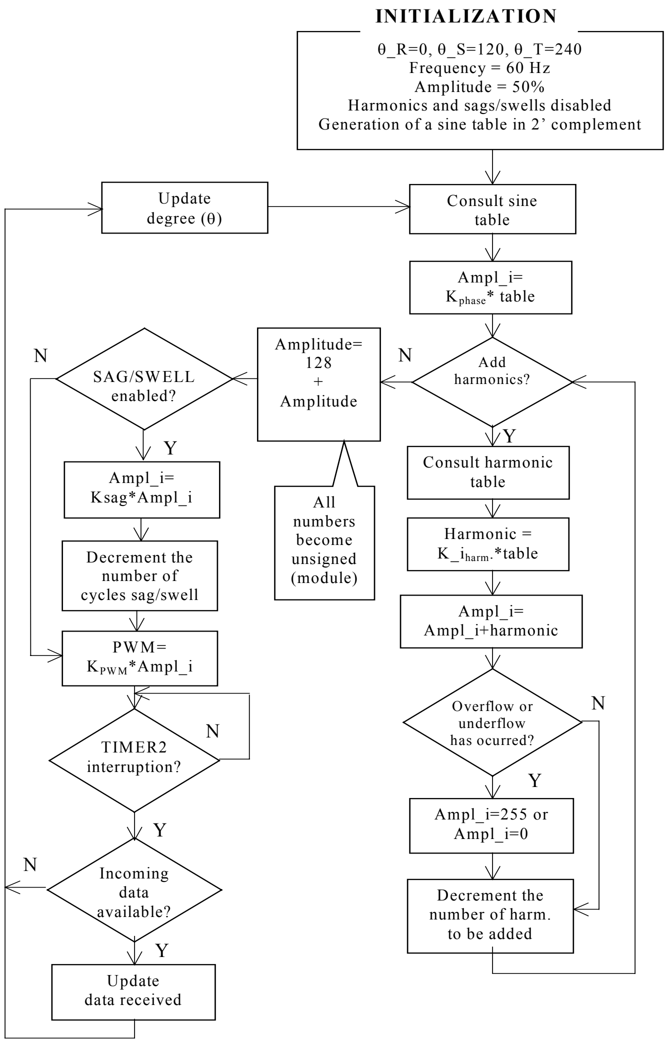

Fig. 2: Flow chart of the signal generation (inside PIC18F6620).

$$Ampl\_i = Ks \cdot sin(2\pi f \cdot t + \theta i) + + \sum_{n=2}^{13} kn \cdot sin(n \cdot 2\pi f \cdot t) \quad (1)$$

Where:

Ki – Phase i amplitude of the 1st harmonic;

θi – Phase i angle;

f – Frequency (Hz) of the 1st harmonic;

Kn – N-th harmonic amplitude (value for phases R,S,T). Notice that phase for all harmonics are equal to zero in this prototype.

The signal given by (1) is available at one of the digital PWM outputs, and also at one of the analog outputs after the D/A conversion and filtering. Values of Kn, K_R, K_S, K_T, θs, θt and ω are modified according to incoming data from the SPI module of the PIC18F6620. Phase R angle θ_R is fixed and equal to zero.

System programming is made through the keyboard and LCD display. Figure 3 shows navigation inside programming menus. For each option, symbol * on keyboard is the ENTER key (acceptance of the option), and symbol # on keyboard represents ESC (escape) function, returning to the Main Menu. All other options and values are to be input numerically in the keyboard. Modification of its programming is immediately accepted and put into the outputs when * (ENTER) key is pressed. For the Sag/Swell option, all values below 100 generate sags and above 100 (up to 200) generate swells. The generator delivers at its outputs the default values seen in the Initialization block of fig. 2, when it is energized.

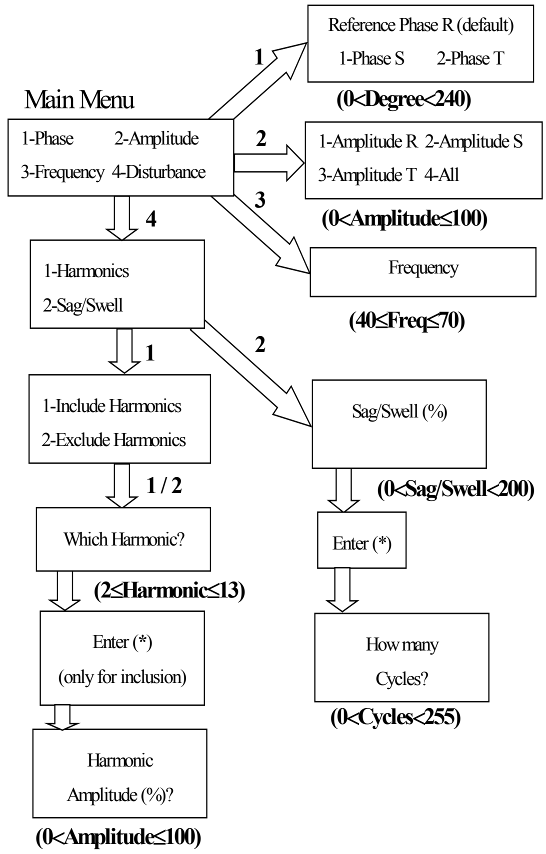

Fig. 3: Generator configuration menu schematics. Bold numbers (and number ranges) beside arrows are to be punched in the keyboard in order get the desired set (identified with numbers inside the option boxes). In the prototype, option names were shortened due to the 16x2 LCD display limitation.

III. THREE-PHASE POWER SOURCE

A three-phase power generator can be achieved by connecting the proposed generator to a power inverter. Such implementation block diagram is shown in fig. 4.

The power inverter (fig. 4) was implemented using IRF840 (8A, 500V) transistors and IRF2110 drivers [5][6][7] and its electrical circuit is given in fig. 5. Optocouplers interface the generator board to the inverter board, providing insulation between both parts. A logical circuit allows hardware dead time setting by modifying a RC value. DC link voltage can be set up to levels in the order of 300-350 V DC (depending on the available AC mains), which allows feeding of three-phase loads with phase voltages up to 127 V rms and currents up to 5A rms (to ensure a operation safety margin). Maximum swell is limited to the maximum output value of the signal generator, which corresponds to the DC link voltage of the PWM inverter. For instance, with a nominal output of 75% (considering 100% the maximum output of the signal generator and the DC link voltage value), the maximum available swell is 33%, which gives the maximum 100% output value of the signal generator and the DC link.

PWM signals switching frequency is 120 times the frequency of the fundamental (which varies from 40 to 70Hz). In order to filter these PWM high frequencies from the power inverter output, an optional second order LC filter was adopted (fig. 6).

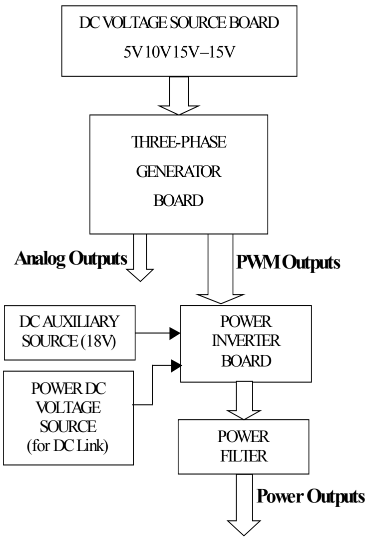

Fig. 4: System Hardware Diagram (Generator + Sources + Power Inverter)

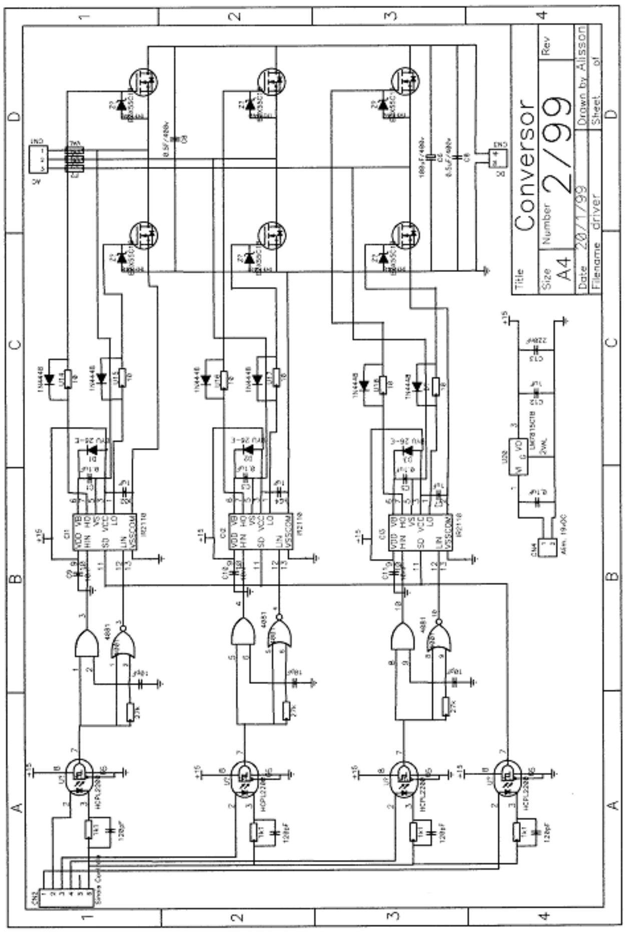

Fig. 5: Power inverter board electrical circuit.

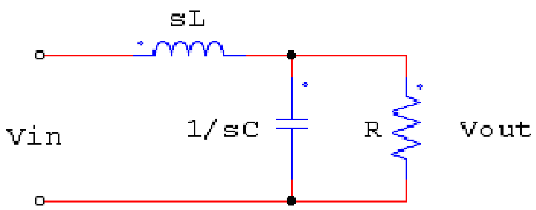

Fig. 6: Low-pass voltage filter for the power inverter output.

Figure 6 circuit relationships are given by (2):

$$\frac{Vout(s)}{Vin(s)} = \frac{\frac{1}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}} \tag{2}$$

Where:
$$\omega = \frac{1}{\sqrt{LC}} \tag{3}$$

$$\zeta = \sqrt{\frac{L}{C}} * \frac{1}{2 * R} \tag{4}$$

Setting C=0.1µF, L=100mH, results in a cut frequency of f=1.59kHz. In order to always have ζ=0,7 or greater, one gets R=714Ω as maximum value, which has to be permanently attached to the output. Notice that this lossy filter implementation is done because the adopted inverter does not have voltage/current feedback capabilities. A dynamic ξ value change (according to ω) is under study.

IV. EXPERIMENTAL RESULTS

Tests were performed through waveforms acquisition and analysis for each of the possible generator configurations, for both analog and PWM outputs. Figures 7 to 18 show some representative waveforms. Figure 19 shows prototype picture with the signal generator and the power inverter board.

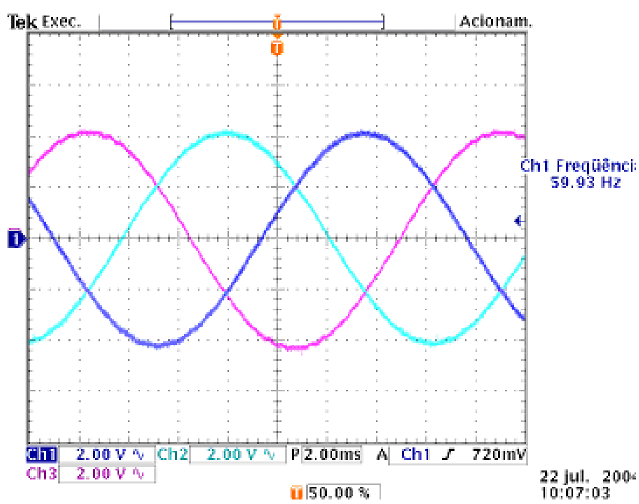

Fig. 7: Three sinusoidal signals, same amplitude, 120º displacement (analog output). Voltage and time scales indicated at the figure.

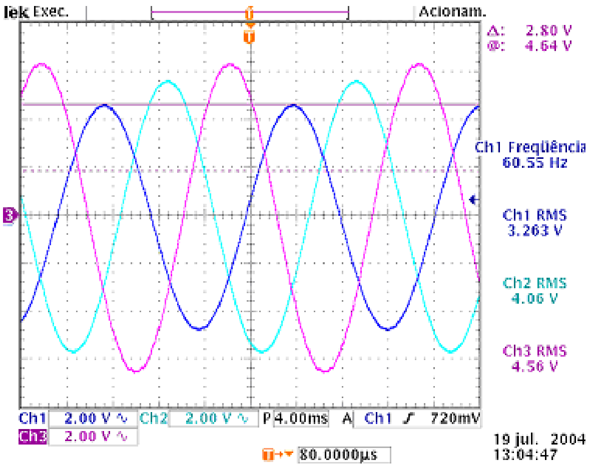

Fig. 8: Unbalanced system, 120º displacement (analog output). Voltage and time scales indicated at the figure.

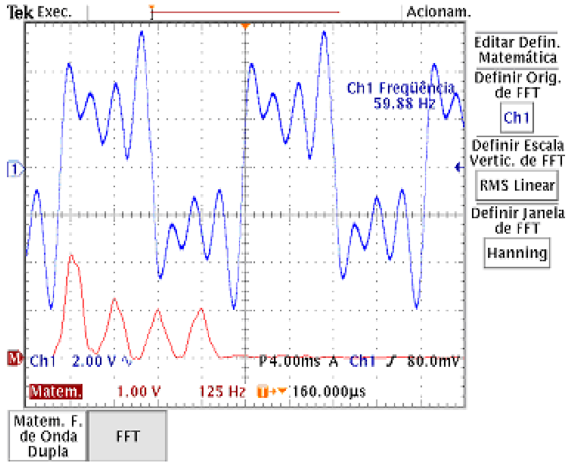

Fig. 11: Signal with 3rd, 5th and 7th harmonics included and its FFT (analog output). Voltage and time scales indicated at the figure.

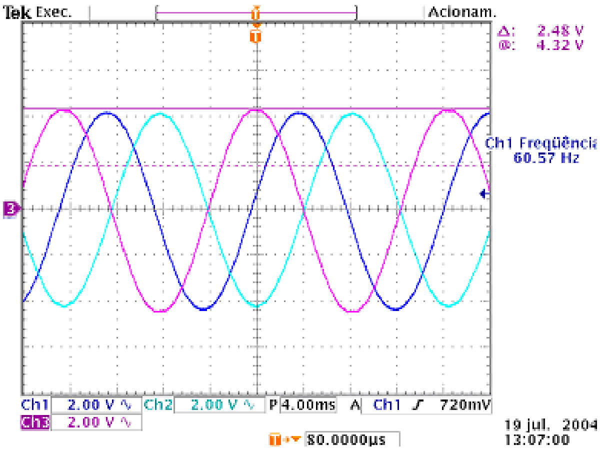

Fig. 9: Unsymmetric system, same amplitude (analog output). Voltage and time scales indicated at the figure.

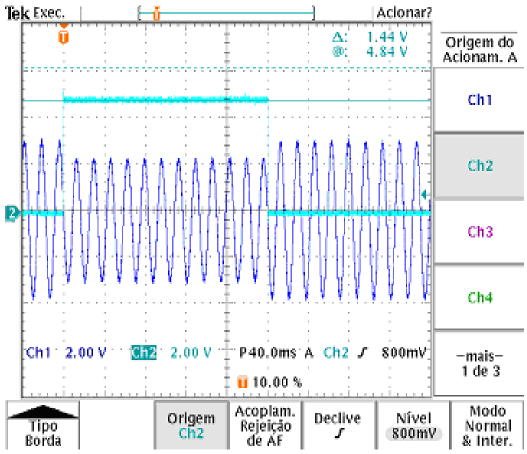

Fig. 12: Sinusoidal signal with sag to 75% for 12 cycles and trigger signal (analog output). Voltage and time scales indicated at the figure.

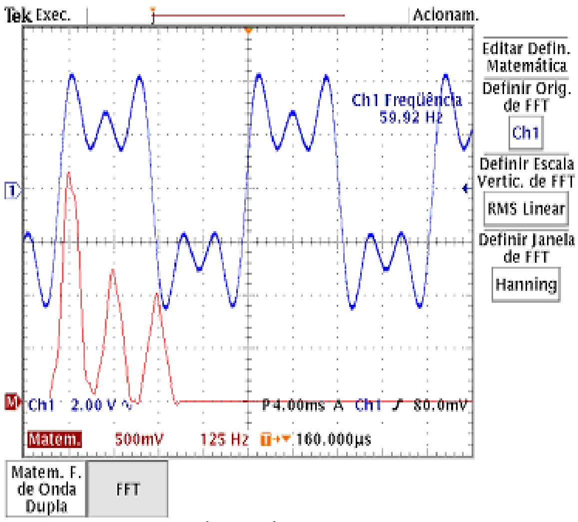

Fig. 10: Signal with 3rd and 5th harmonics included and its FFT (analog output). Voltage and time scales indicated at the figure.

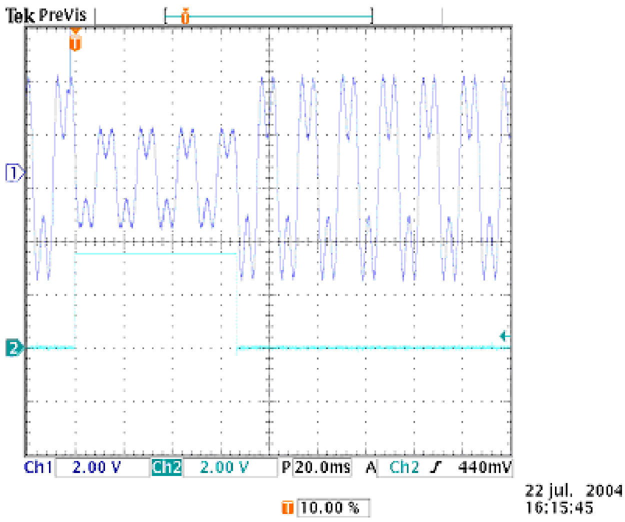

Fig. 13: Signal with 3rd harmonic 25% with sag to 50% (analog output). Voltage and time scales indicated at the figure.

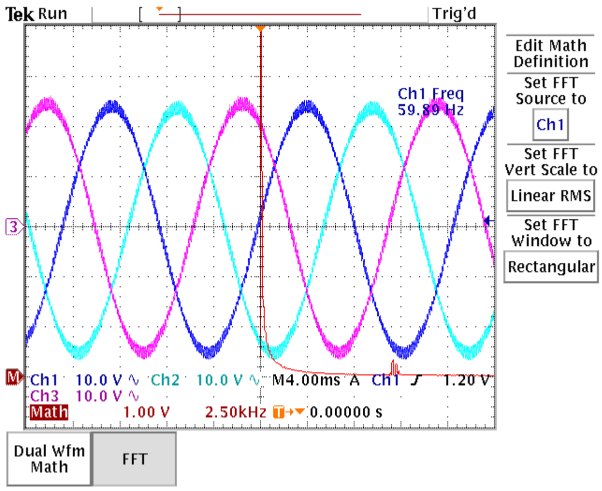

Fig. 14: Sinusoidal signal and its FFT (filtered PWM output of power inverter). Voltage and time scales indicated at the figure.

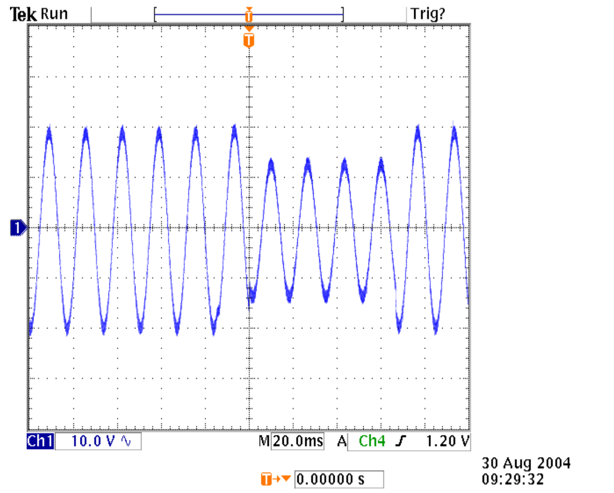

Fig. 17: Sinusoidal signal with sag to 70% for 4 cycles (filtered PWM output of power inverter). Voltage and time scales indicated at the figure.

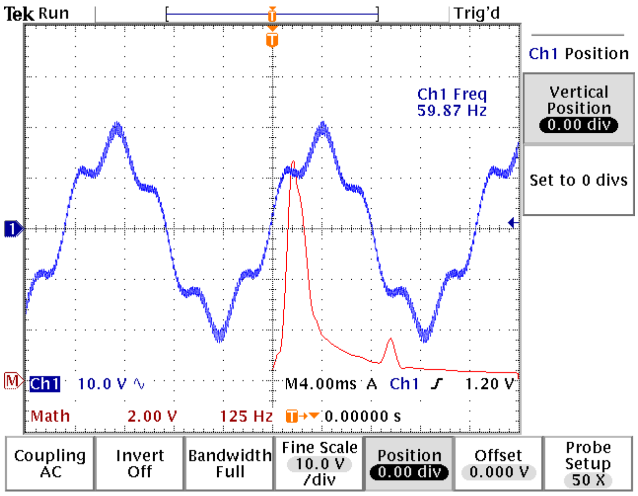

Fig. 15: Signal with 5th harmonic included and its FFT (filtered PWM output of power inverter). Voltage and time scales indicated at the figure.

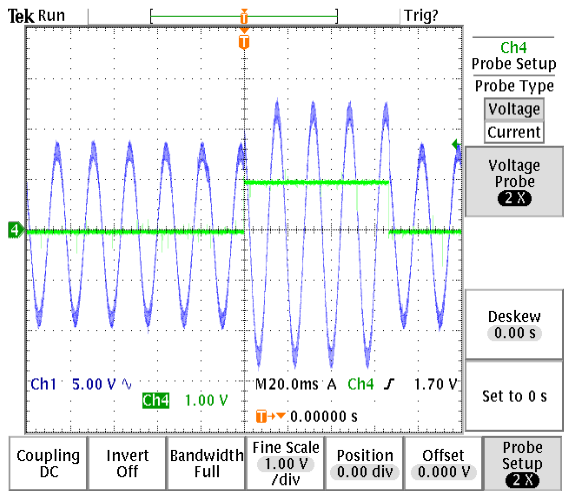

Fig. 18: Sinusoidal signal with swell to 125% for 4 cycles and its trigger signal (filtered PWM output of power inverter). Voltage and time scales indicated at the figure.

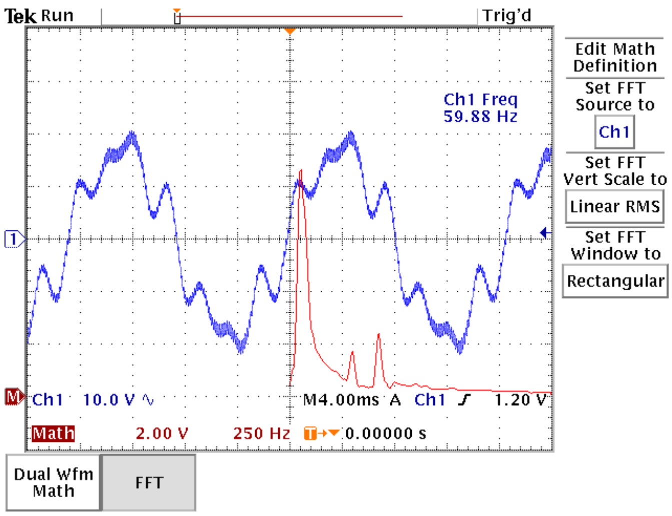

Fig. 16: Signal with 5th and 7th harmonics and its FFT (filtered PWM output of power inverter). Voltage and time scales indicated at the figure.

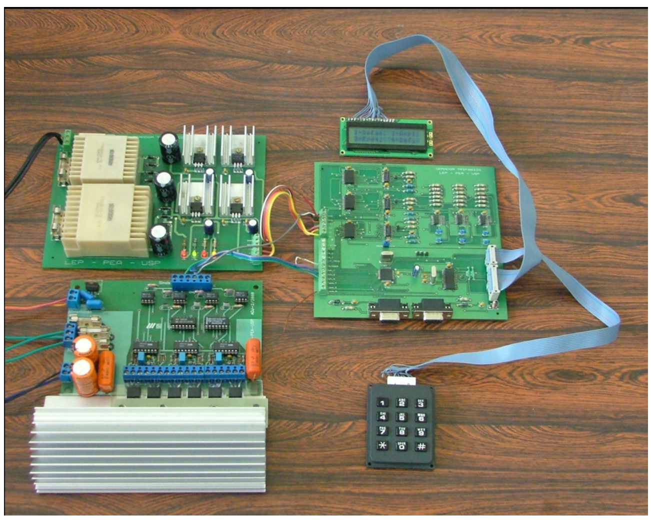

Fig. 19: Prototype picture with generator (right) and its keyboard and LCD display. The DC source board (above left) and the power inverter board (below left) are also shown.

V. FINAL REMARKS

This paper has presented a didactic microcontrolled three-phase signal generator and its associated switched power amplifier and power filter. It allows fundamental frequency and phase variation, independent phase amplitude control, inclusion of harmonics and application of programmed voltage sags and swells. A brief description was made, and experimental results were presented, showing the viability of an easy-to-use and low-cost system for power electronics and power quality education.

VI. REFERENCES

[1] California Instruments Inc. Available in: http://www.calinst.com (visited in 31/Aug/2004);
[2] Microchip Technology Inc. Available in: http://www.microchip.com (visited in 31/Aug/2004);
[3] Pereira, F. Microcontroladores PIC Técnicas Avançadas. Ed. Érica, São Paulo, 2003;
[4] Pereira, F. Microcontroladores Programação em C. Ed. Érica, São Paulo, 2002;
[5] Junqueira, A.D. Controle Digital de Conversores estáticos. Relatório de Iniciação Cientifica PIBIB/CNPq, PEA-USP 98/99.
[6] Junqueira, A.D. Controle Digital de Conversores estáticos. Relatório de Iniciação Cientifica PIBIB/CNPq, PEA-USP 99/00.
[7] Matakas Jr., L.; Junqueira, A.D., Komatsu, W. Digital Implementation of Three-Phase Rectifier with Deadbeat Controller. In: COBEP 2001, V.1, Florianópolis, 2001, SOBRAEP. p. 229-234.