GENERIC GENERATOR OF THREE-PHASE PERIODIC SIGNALS FOR APPLICATION IN AC POWER SOURCES

Joselito A. Heerdt, Neomar Giacomini, Jonathan D. Sperb, Marcello Mezaroba, Alessandro L. Batschauer
Laboratório de Eletrônica de Potência, Laboratório de Eficiência Energética de Sistemas Motrizes - Departamento de Engenharia Elétrica, Universidade do Estado de Santa Catarina - UDESC
Campus Universitário Prof. Avelino Marcante s/n, Bom Retiro, Joinville, SC, Brasil, CEP: 89223-100
E-mails: jaheerdt@joinville.udesc.br, neomar@ieee.org, jonathan@joinville.udesc.br, mezaroba@joinville.udesc.br, batschauer@joinville.udesc.br

***Abstract* – This paper presents a Generic Three-Phase Signal Generator based on the Fourier mathematical series, which uses a Digital Signal Controller (DSC) to manage several capabilities that include serial communication, liquid crystal display and keyboard user interface. The main idea of this generator is to allow the user to create its own periodic signal with the necessary harmonics or to recreate signals with proceeding data from power line harmonic analysis or simulation results. The developed system was tested on a 4.5kW power amplifier with characteristics that allow the generation or the reproduction of power lines.**

***Keywords* - AC Power Source, Digital Signal Controller, Fourier Series, Generic Signal Generator, Harmonic Distortion, Undeland Snubber.**

I. INTRODUCTION

With the evolution of the electronics on the last decades, mainly regarding the energy processing, several problems began to appear due the new driving techniques and new developed circuits. Among the most common problems we can mention the generation of electromagnetic noises of the most varied frequencies that circulate in the power lines and can cause damages to the other systems connected to it. Willing to assure the correct operation of commercial equipments, there were created standard that demand tests for the certification of its correct operation, where they are fed by a power line in adverse conditions.

With the objective of assisting the demands described by those standards, several works have been published in the sense of developing power sources with the capacity to create such conditions [1],[2],[3]. In the same sense, we noticed the need to design a three phase generic signal generator that would makes possible the emulation of power lines, by simply supplying the coefficients of the Fourier Series of the desired signal. Taking advantage of such system, it is possible to test equipments using real power lines parameters from power lines all around the world without the need of taking the equipment under test to other testing facilities. Specific operational conditions can also be easily reached improving tests duration.

This paper presents a complete system of a three-phase generic signal generator aiming at the freedom in the construction of periodic signals provided by the Fourier Mathematical Series. Along the paper is presented the signal generation methodology, the local and remote human-machine interfaces, tests with an amplifier, pictures of the developed system and the analysis of the obtained results.

II. GENERATION SYSTEM

The functional structure of the proposed generator is presented in Figure 1. It has 3 major subsystems: Local Human-Machine Interface (LHMI), the Reference Signal Generator and the Virtual Remote Human-Machine Interface (VRHMI). The local interface has a keyboard, a liquid crystal display (LCD) and signalizations, allowing the introduction and management of the generated waveforms. The Generic Signal Generator consists of a TMS320F2812 Digital Signal Controller (DSC), digital to analog converters (DAC) and filters used to obtain the average level of pulse width modulated (PWM) signals. The remote interface allows the manual preparation of the desired signals or the usage of data originated from power line analyzers, circuit simulators or oscilloscopes through the import function. The prepared signal is then sent to the DSC using the remote interface communication link.

This system can be used to obtain an AC Power Source just with the addition of a Three Phase Power Amplifier responsible for the amplification of the reference signals to the desired levels [4]-[8].

A. Characteristics of the system

The characteristics of the proposed system were chosen focusing its handy operation and flexibility on the signal creation process, resulting on the following specifications:

- Generation of periodic generic signals;
- Voltage excursion on the reference output from 0 to 16V (peak to peak);
- Fixed output reference resolution of 8bits;
- Amplitude control using 16 bits resolution;
- Fundamental frequency from DC to 500Hz;
- Harmonics addition until the 51st harmonic of 60 Hz, with individual amplitude and phase control;
- Individual adjust of the DC level for all the three phases;
- Possibility of imposing amplitude and phase unbalances;
- Real time adjustment of the amplitude and frequency of the signals under generation;

- Local interface containing a 20x4 LCD and a 20 keys keyboard used for data insertion and control;
- Isolated RS232 communication link;
- A Remote virtual interface containing data import functions and functions for the remote control of the system;
- Capacity to locally store at least one signal setup for further usage.

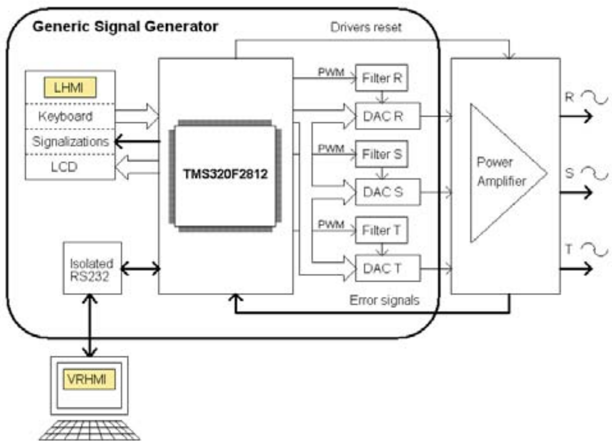

Fig. 1. Block diagram of the proposed generator.

III. REFERENCE SIGNAL GENERATOR

The development process of the Reference Signal Generator system has two major blocks, software and hardware, as presented in this section.

A. Hardware of the Reference Signal generator

Based on the characteristics previously presented, it was used a TMS320F2812 DSC to manage the LHMI, the communication link to the RVHMI and the reference signal generation. The main characteristics of this controller are:

- 150MHz clock (6,67ns per instruction);
- 32 bits CPU;
- 36KB RAM + 256KB FLASH;
- 3 Timers of 32bits;
- SCI and SPI Serial Interfaces;
- CAN Interface;
- 16 PWM outputs with 16 bits resolution;
- 16 AD multiplexed channels;
- 56 GPIO (Shared with peripherals);
- 45 multiplexed interruption sources.

The LHMI DSC is used to read a 4x5 matrix like keyboard, the LCD management with contrast adjustment that is done through a filtered PWM signal, the error signals monitoring and the control of the signalizations.

The communication with the VRHMI is done through and isolated bidirectional RS232 link. The isolation is obtained using optocouplers with an isolated ±12V power supply.

To obtain three independent generic signal output channels the system uses a single 8 bits data bus connected to three high speed digital to analog converters (TLC7524) that are controlled through their chip-select pins. The circuits used to eliminate the DC levels on the DAC outputs are the one recommended by its manufacturer on the datasheet and can be verified on [9].

Even using an 8 bits fixed resolution on the digital bus, the 16 bits amplitude control is obtained through the variation of the reference voltage of the digital to analog converters. It is done using second order filtering of PWM channels.

The storage of a signal under generation can be done using the external 16 kbytes SPI EEPROM. Using a specific function on the LHMI the signal can be restored and used on further tests.

Since this generator should be connected to an amplifier that is usually obtained using switched power converters, it is expected a high incidence of electromagnetic noise that could cause malfunction due to Electromagnetic Interference (EMI). To minimize those effects the printed circuit board (PCB) design should follow some basic rules [10]. Tracks length and board size reduction, power supply decoupling, the insertion of ground planes and the elimination of loops that could result on noise induction are some examples of the details the designer should care about.

Thinking about those and many others requirements it was proposed the usage of a 4 layers FR4 PCB with massive ground plane and surface mount technology (SMT) assembly. By this way the PCB size was drastically reduced improving EMI immunity.

B. Software of the Reference Signal generator

The embedded software developed to manage the signal generation was coded including serial communication routines containing error-detection and error-correction functions in such way the final communication protocol is error free granting secure control and data exchange. Through the communication link it is possible to send to the DSC commands like “Iniciar Geração” that will start the generation process, “Parar Geração” to stop it and “Confirmar Sinal”. The last command is necessary to be executed after the data was inserted/sent. It will ask the CPU to recalculate the output data vector samples.

Figures 2 and 3 present simplified flow charts of the most important routines in the embedded software that were coded using C language.

The left side flowchart presented in Figure 2 is the simplified main routine. During the startup process it initializes all the necessary peripherals and variables and then cyclically executes three functional blocks: “Keyboard routines”, “Keyboard data and commands management” and “LCD refresh”. The first one read the keyboard using filters by software and turbo functions, the second executes the functions related to the data or command previously inserted and the third block call the functions responsible for refreshing the LCD.

The right side flowchart presented in Figure 2 shows the routine responsible for refreshing the output data vector samples in the generator output channels. It is executed on fixed intervals which duration depends on the desired fundamental frequency.

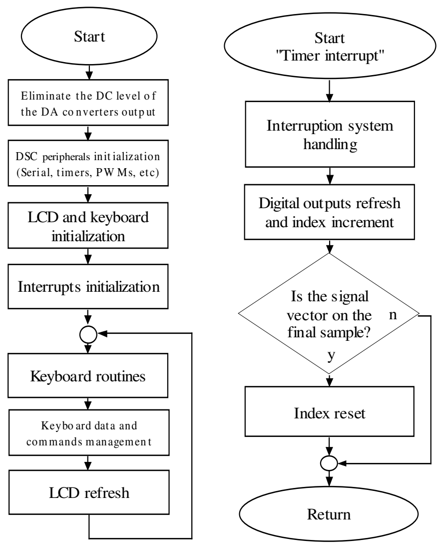

Fig. 2. Main routine and timer interrupt software flowcharts.

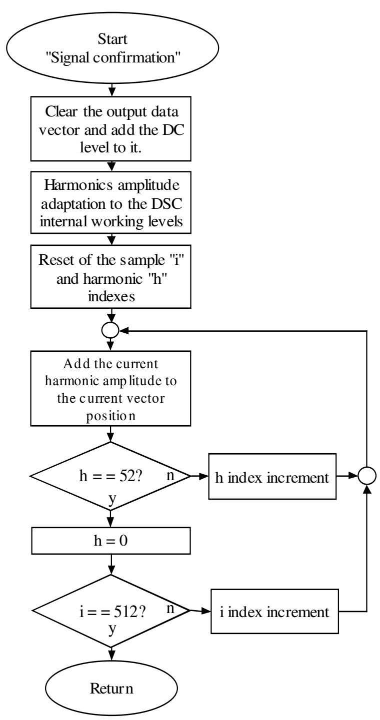

Fig. 3. Flowchart of the output data vector samples calculation routine.

Figure 3 presents the “Confirmar Sinal” routine flowchart which is responsible for the calculation of the output data vector samples that are calculated using 51 harmonics as will be further explained. This routine is executed three times, once per output channel. The results are 512 samples for each channel that are stored on individual vectors.

C. Signal Construction

Aiming the reconstruction of signals analyzed by most of the engineering measurement equipments such as oscilloscopes, power line analyzers and also from circuit simulators, the authors studied the equations used during the harmonics analysis by the equipments available in the involved laboratories. The equation presented in (1) is used by PSpice simulators, by the FLUKE 43 power analyzer and also by the Tektronix WaveStar software used to obtain the harmonic analysis from data files saved using Tektronix oscilloscopes. All these three data sources were used during the studies and experimental tests.

$$f(t) = dc + \sum_{n=1}^{51} a_n \cdot sen(n \cdot \omega \cdot t + phase_n) \quad (1)$$

Where:

- dc : DC level of the signal;
- n : Harmonics number;
- a_n : Amplitude of the n^{th} harmonic;
- ω : Fundamental frequency;
- t : Time;
- $phase_n$: Phase of the n^{th} harmonic.

Based on equation (1) and using the data previously introduced by the user for the mentioned parameters, the CPU recalculates all the three phase signals samples values. Since the data is independent for each phase, except for the fundamental frequency, the systems allows the creation of signals with different DC levels, amplitudes and harmonic content for each phase. The only difference on the equations for each phase is the addition of the natural 120 electrical degrees delay between them.

To facilitate the generator operation, the embedded software allows the user to control all the functions through the LHMI keyboard. It is possible to start and stop the generation, to change the amplitude and frequency while operating, to select pre-defined signals such as sinusoidal and triangular waveforms and the insertion of all the mentioned parameters.

IV. VIRTUAL REMOTE HUMAN MACHINE INTERFACE (VRHMI)

Aiming at to facilitate the operation on the part of the users, a Virtual Remote Human Machine Interface (VRHMI) was developed, in such way to make possible to import and to export data. Figure 4 presents the proposed remote interface, designed with LabVIEW 8.0. It should be given attention to the columns of the amplitude and phase values of the harmonics and to the fields "Valor CC" and "Frequência" because these are the coefficients of the Fourier series that will be sent for DSC through serial communication. The values of those parameters can be typed directly in the corresponding field or they can be imported through the reading of files saved previously.

The signals that will be generated as a result of the coefficients introduced in the table can be visualized by the user pressing the "Gráfico" button, according to display the Figure 5.

Still in the Figure 4, in the superior left corner it is possible to access the data table of all the phases. A copy function was designed to allow easy replication of signals among the phases.

Fig. 4. Virtual Remote Human Machine Interface (VRHMI).

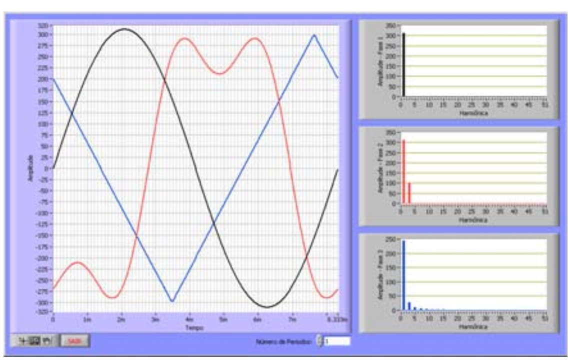

Fig. 5. Signals visual confirmation, where the first is a sinusoidal signal, the second is a sinusoidal signal with third harmonic and the third is a triangular signal, with many harmonics.

V. THREE-PHASE POWER AMPLIFIER

The block diagram of the switched power converter used as amplifier can be observed in Figure 6.

The input of the system consists of a three-phase full-bridge rectifier and capacitive filters, responsible for obtaining a DC link of 540Volts. That bus feeds the power inverter, composed by discrete Insulated Gate Bipolar Transistors (IGBT), commanded by optical isolated drivers. The commutation is defined by the voltage controllers, based on the input reference signals supplied by the generic signal generator and on the voltage feedbacks from the outputs.

The amplifier uses Pulse Width Modulation (PWM) with a switching frequency of 50kHz and it has a bandwidth of 3kHz. The described amplifier has a voltage gain of 50 times and is able to supply an output power of 4.5kW. It uses a modified Undeland snubber circuit together with a Buck-Boost converter for the reduction of the switching losses. The complete operation of that circuit is not the focus of this work and it can be found in [11] and [12].

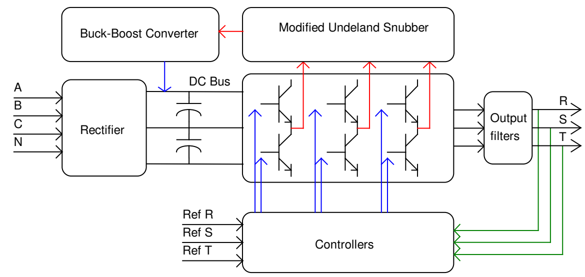

Fig. 6. Block diagram of the three-phase amplifier used.

VI. EXPERIMENTAL RESULTS

Figure 7 presents the developed Generic Signal Generator developed. The processor is under the display and practically all the components are SMT technology. For the development of the layout the position of the components was carefully studied, separating the digital circuits of the analogical ones and growing up different ground planes. This board was built using a four layers FR4 printed circuit board (PCB), facilitating the connections of the components and the creation of the ground planes and power supply.

Figure 8 shows the power converter, used to amplify the generated signals. In this illustration the control board can be observed, located in the frontal part, the isolated drivers, the capacitors and inductors of the output filters can also be observed on the top of the converter and behind it, respectively.

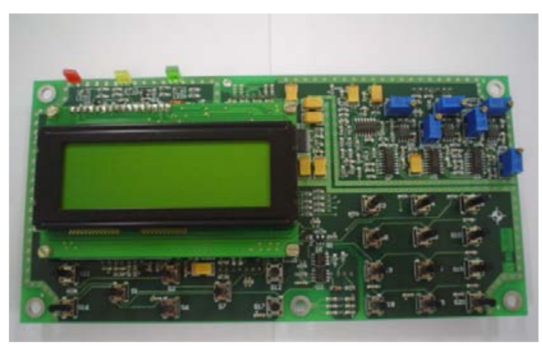

Fig. 7. Three-Phase Generic Signal Generator developed.

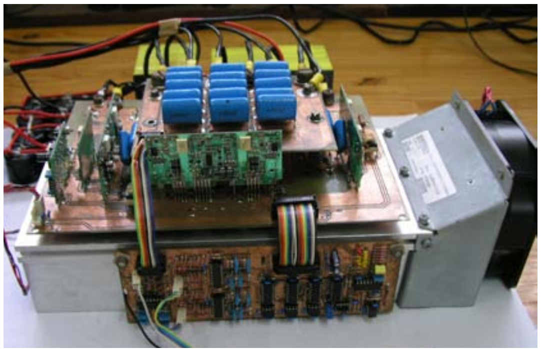

Fig. 8. Three-phase generic signal amplifier.

The developed system was tested using the same parameters previously presented in the Figures 4 and 5. The waveforms theoretically presented were also obtained experimentally and are presented in Figures 9 and 10. Figure 9 present the signals in the outputs of the signal generator and Figure 10 in the amplifier outputs.

Observing Figures 9 and 10 great similarity among the waveforms can be observed, a result of the low distortion inserted by the amplifier.

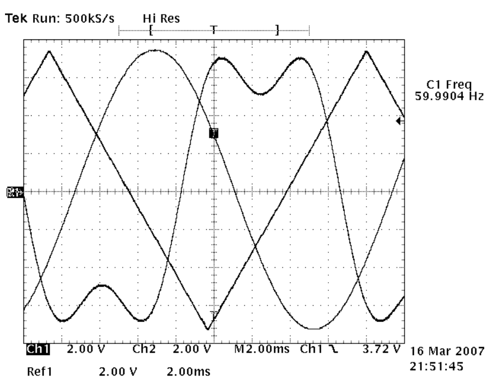

Fig. 9. Generic signals in the generator outputs – Fundamental frequency of 60Hz.

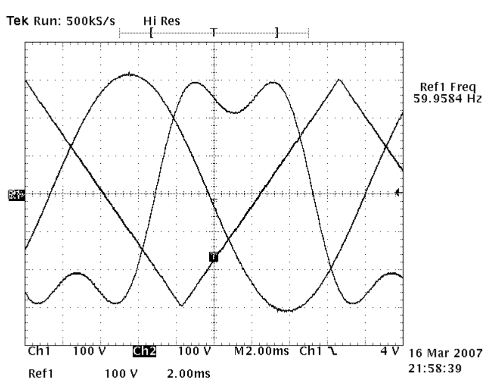

Fig. 10. Generic signals in the amplifier outputs – Fundamental frequency of 60Hz.

Figure 11 shows a comparison among the harmonic analysis of the phase with triangular waveform and the theoretical one, the one available in the output of the signal generator and the waveform in the amplifier output. In this figure a percentual comparative of the amplitude of the harmonics until the 30rd one are presented. Higher orders harmonics were omitted due to their very little contribution on the total harmonic distortion. We can notice a great similarity among the harmonic contents of the three signals confirming the correct operation of the proposed system

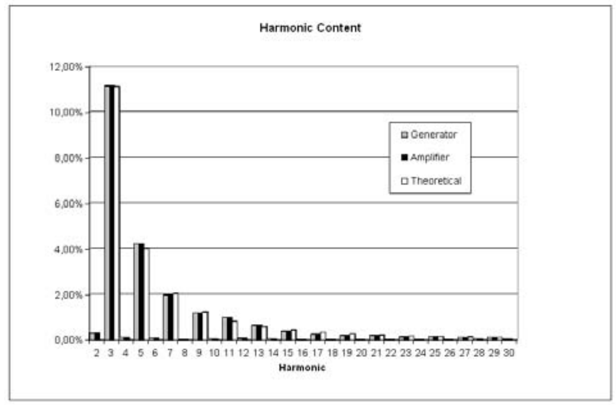

Fig. 11. Comparative analyzes of harmonics of the triangular signals: theoretical, output of the generator and output of the amplifier.

VII. CONCLUSION

In agreement with the presented results it’s verified that the system of sinusoidal generation with addition of harmonicas reproduces with great fidelity the requested signals, allowing this to be used in a wide range of electro-electronics equipments tests as well as in emulations of power lines.

With this system it can be generated three phase sinusoidal balanced signals, unbalanced signals in amplitude and in phase and still signals with different harmonic contents in the three phases, choosing their amplitudes and the phases freely. The user still can to introduce different DC levels to the phases.

The possibility of serial communication with the virtual interface and the transference of parameters of simulation results, of analyzers of energy or oscilloscopes revealed very useful and easy to use.

The generation of three-phase generic signals reference with fundamental frequency from 1 to 500Hz, in 8 bits resolution, was possible of being implemented with relative easiness with DSC TMS320F2812. However, for the generation of reference signals with larger resolution and frequency the optimization of the code in Assembly language or the choice for a processor of larger capacity is necessary, as of the C6000 family of the same manufacturer. This fact is related to the necessary output sampling rate to construct the signal, for example, 512 samples per period in 500Hz it will have 256kS, duplicating to each additional bit.

ACKNOWLEDGEMENT

We thank Centrais Elétricas Brasileiras S.A. - ELETROBRAS who through the National Program of Electrical Energy Conservation (PROCEL) is financing the implantation of the Energy Efficiency of Motor Systems Laboratory in the University of the Santa Catarina State (UDESC) and scholarships for graduation students and masters degree.

We also thank the Texas Instruments for the donation of the development kit for DSC TMS320F2812 and the Digital-Analogical Converters used in this project, as well as the University of the Santa Catarina State, for the financing scholarship.

A special gratefulness the Supplier Indústria e Comércio Ltda for the donation of several materials and electronic components.

REFERENCES

[1] A. L. Batschauer, J. A. Heerdt, M. Mezaroba, N. Giacomini, “Gerador de Sinais Periódicos Genéricos para Utilização em Fontes de Alimentação CA”, in Proc. of CBA 2006, pp. 643-648, 2006.
[2] A. L. Batschauer, J. A. Heerdt, M. Mezaroba, “Conversor CC-CA para amplificação de formas de onda genéricas empregando snubber regenerativo”. VII INDUSCON, Recife – PE, 2006.
[3] W. Komatsu, A.R. Giaretta, L. Matakas Jr., “A Didatic Microcontrolled Three-Phase Signal Generator”, *in Proc. of COBEP 2005*, pp. 169-174, 2005.
[4] H. Van der Broeck, P. Lurkens, “Programmable AC power source”, Fifth European Conference on Power Electronics and Applications, pp. 255-260, vol.3, 1993.
[5] K. S. Low, “A DSP-based variable AC power source”, IEEE Transactions on Instrumentation and Measurement, Volume: 47 , Issue: 4 , Aug. 1998; Pages:992 – 996.
[6] K. S. Low, “A DSP-based single-phase AC power source”, IEEE Transactions on Industrial Electronics, Vol. 46 , Issue 5, pp. 936 – 941, 1999.
[7] Shih-Liang Jung, Hsiang-Sung Huang, Meng-Yueh Chang, Ying-Yu Tzou, “DSP-based multiple-loop control strategy for single-phase inverters used in AC power sources”, Power Electronics Specialists Conference, PESC '97 Record., 28th Annual IEEE, pp. 706-712, vol.1, 1997.
[8] Ying-Yu Tzou, Rong-Shyang Ou, Shih-Liang Jung, Meng-Yueh Chang, “High-performance programmable AC power source with low harmonic distortion using DSP-based repetitive control technique”, IEEE Transactions on Power Electronics, Vol. 12, Issue 4, pp. 715-725, 1997.
[9] Texas Instruments, “TLC7524 8 bits Multiplying Digital do Analog Converter”, http://www.ti.com , 1999.
[10] M. I. Montrose, “EMC and the printed circuit board: Design, theory and layout made simple”, IEEE Press Editorial Board, New York, USA, 1999. ISBN 0-7803-4703-X.
[11] J. D. Sperb, M. Mezaroba, “Snubber de Undeland regenerativo com comutação ZVS para o conversor auxiliar”, in Proc. of CBA 2006, pp. 655-660, 2006.
[12] A. Péres, “Uma Nova Família de Inversores com Comutação Suave Empregando a Técnica de Grampeamento Ativo”. Doctor’s Thesis - INEP – UFSC, Florianópolis – SC, 2000.