A low-cost dual programmable power source based on a three-leg inverter

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Abstract

A low-cost dual power source solution suitable for several applications is presented. The power source is based on the common 2-level three-leg inverter which is one of the most popular topologies and is commercially available in low-cost power package modules. Although sharing the same topology, the two power sources are completely independent and programmable in term of desired waveform and control. A software tool was also developed to facilitate the dual power source configuration. The control techniques and power drives were designed to satisfy static and dynamic performance of several equipments such as electric machinery or demanding laboratory experiments which make it a very attractive solution to educational and investigation projects, among many others. Each power source are internally self-protected against short-circuits. Although not fully tested in all aspects, the implementation of this dual power source solution prototype allowed experimental confirmation of the expected performance.

Key words: power source, inverter, PWM, voltage control, current control.

1. Introduction

The electrical energy allowed, in the last century, a marked development of countries in various areas.
However, progress has led to the diversity of available receptors fed with different voltage levels and/or different frequencies. Due to advancements in Power electronics many works were developed and focused on the AC voltage and frequency regulation.
Application of microcontrollers and digital signal processors (DSPs) in high-performance power electronic systems has been a long term pursuing goal in development of control solutions for power converting systems. Today such digital devices can be effectively used to realize advanced control schemes. Most DSP instructions can be accomplished within one instruction cycle and complicated control algorithms can be executed with fast speed.

This paper proposes a DSP-controlled power source solution combined with a microcontroller device to provide a PC USB connection, allowing an easy configuration. The implementation of a dual programmable power source, with independent reference voltages or reference currents, allows an easy connection between the available power and the receptor even though their different characteristics. Besides the obvious usefulness to do laboratory tests, the dual source allows feed a device with two inputs or two receptors in accordance with some criterion for exploration. This flexibility shall be provided by a cheap power source.

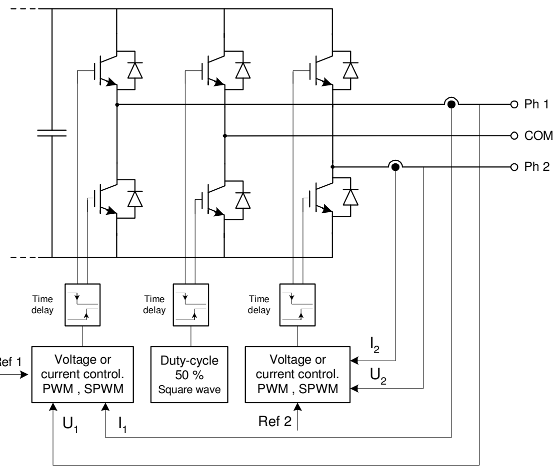


Fig. 1. Power source diagram using three-leg inverter.

2. Power Source

It is shown in this section, the implementation, control and possible applications of a dual power source capable of following, independently, two voltage references, or one voltage reference and another reference current or two current references.

A. *Implementation*

The power source is based on the common 2-level three-leg inverter (Fig. 1) that is fed with direct voltage or a rectified alternating voltage.
The switches of one leg are operated with constant switching frequency of 10 kHz, with a duty-cycle of 50%. The middle point of this leg behaves as a zero reference voltage [1, 2]. The dsPIC outputs are the PWM command signals to the semiconductors of the inverter legs.
The output PWM signals to other inverter legs have a maximum switching frequency of 5 kHz. Isolated gate drives are also included in the power converter board. This board is internally self-protected against short-circuits.
Figure 2 presents the developed dual power source prototype during experimental performance tests.

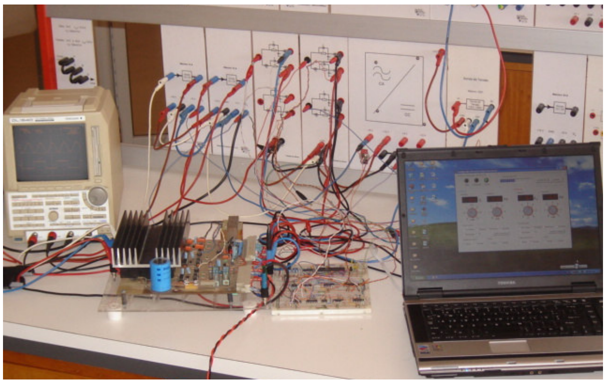


Fig. 2. Dual source prototype during experimental performance tests.

B. *Control*

The dual power source is DSP-controlled by a single device (dsPIC30F4011) which receives analog values from current and voltage sensors and generates internally the sigma-delta PWM output command signals [3, 4] to control independently each power source. The current control scheme is based on a simple hysteretic comparator (Fig. 3). The voltage control scheme is based on a PI voltage controller which is not so simple to control due to output filter delays (Fig. 4). In this dual power source prototype several 2nd order output filters were developed according with the desired output frequency. Improvements must be done to design a unique output filter with ability to adapt to different frequencies.

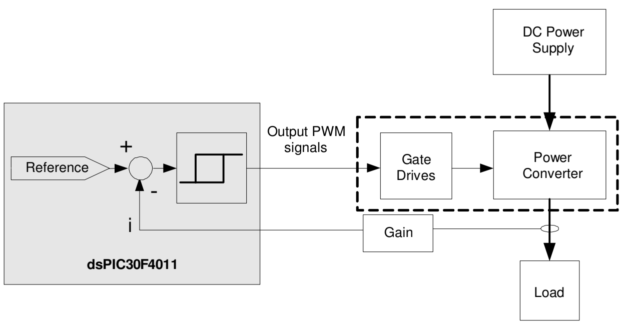


Fig. 3. Hysteretic current controller diagram.

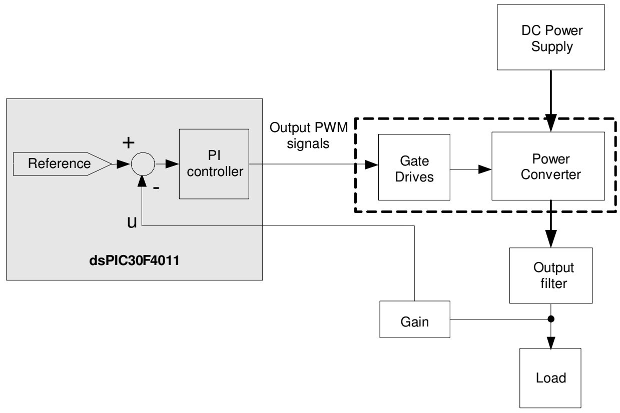


Fig. 4. PI voltage controller diagram.

The control board is also composed by an 8-bit microcontroller (PIC18F4550) connected in a master-slave architecture with the dsPIC device. The data communication between them is accomplished by an SPI (Serial Peripheral Interface) bus [5-9] available in both devices. The micro master (PIC18F4550) device is responsible for digital data communication between the control board and a computer through a plug and play USB interface. This device is also responsible to record the configuration parameters of the dual power source. The configuration parameters will be record in the internal EEPROM of the master device and sent to the slave device also through the SPI bus after the USB detachment. The control board is also composed by an analog and digital signal conditioning circuit to adapt the current and voltage sensors feedback from the circuit load. The dual power source control can be performed in open or closed loop but connection of current sensors is essential to provide additional current load protection. An LCD display is also available to show configuration parameters and error messages.
A general overview of the control board diagram is presented in Fig. 5.

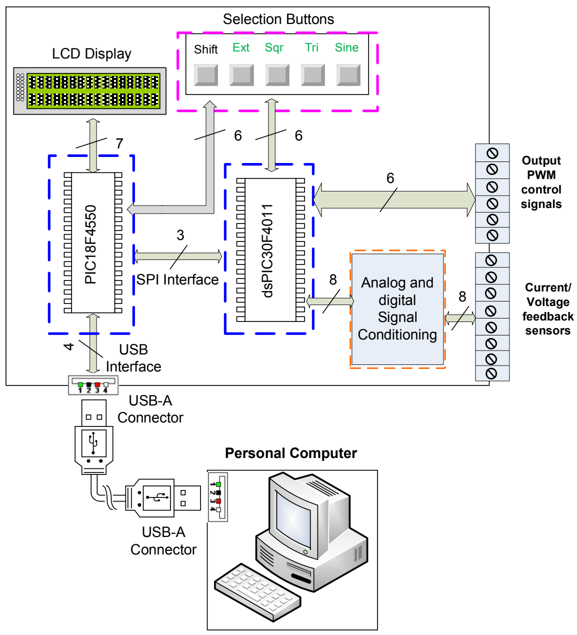


Fig. 5. Control board diagram.

To facilitate the dual power source configuration, specific software was developed. *Microsoft Visual Basic (VB) 6.0* was the object-oriented language used to create the software application. *Visual Basic* was considered as a powerful and flexible development platform, which includes many useful tools for graphical interface and data communications [10, 11].

Figure 6 presents a sample screen of the software tool developed to program the dual power source. Using this software becomes simple and flexible to choose between internal (generated internally in the dsPIC device) and external references, voltage or current mode and respective peak to peak values, DC or AC waveforms, frequencies, closed or open loop control options.

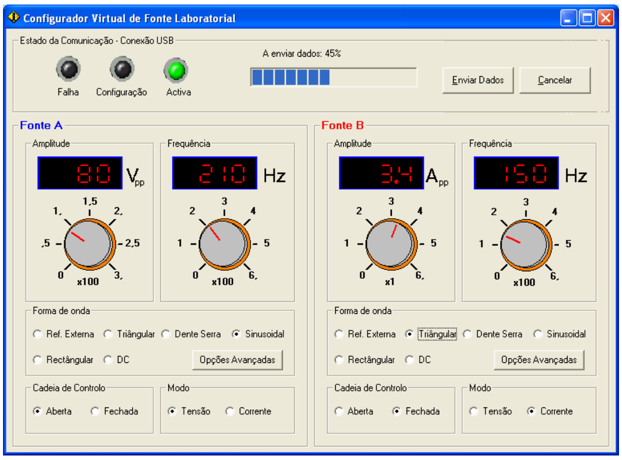


Fig. 6. Sample screen of the software tool developed for fast configuration of the dual power source.

C. *Applications*

The concept of dual power source has been used with two windings induction machines [1-3] and, seldom, with direct current machines [2], however, its study must be thorough and its application should be expanded to the receptors whose feeding needs some voltage or current control because it has a cheap and easy implementation. These characteristics make it very attractive to educational and investigation projects.
It is presented a not exhaustive list of applications:

1) *Single-phase induction motor. The main and the auxiliary windings work always together, without centrifugal switch or any capacitor;*
2) *DC motor. The field excitation and armature voltage or current are independently controlled.*
3) *Two permanent magnet DC machines (PMDC) can be controlled with different references and can be included in wheelchairs or carriers of luggage or others objects;*
4) *Thermo-fans. A variable voltage can be applied on an only resistance heating whilst the fan motor can be have a regulated speed;*
5) *Dual battery chargers. There are various charging algorithms to obtain three or four stages (bulk, absorption, equalization and float). Some stages can be implemented with constant current and the others with constant voltage;*
6) *Telecommunication equipments. There are several equipments in this application field that demand different DC voltages, such as 12, 24 and 48V;*
7) *Laboratory experiments. Current rms value (comparing thermal effects of various shapes of the current), electrical machines under unusual voltages, transformer behaviour fed with several frequencies, electrochemical effects;*
8) *Avionics application field. This dual power source can meet the evolving needs and capabilities of a broad range of aircraft equipments, ground support and test equipment considering the 400Hz standard alternating current.*

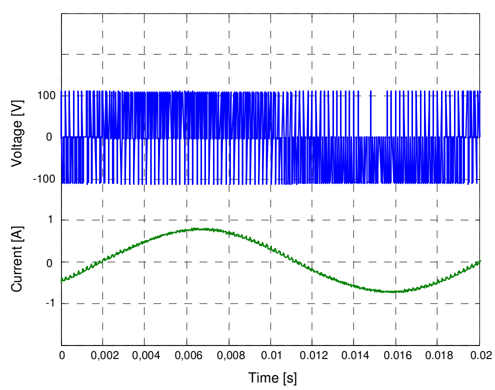
There are also some limitations using this solution:

1) *Due to inverter topology and control scheme, only half of the DC bus voltage is available to apply on the loads;*
2) *Nominal rms current supported by the switches of the leg that operates at high frequency square wave, with a duty-cycle of 50 %, must be equal to the rms/average current sum of both power sources;*
3) *Designed to maximum waveform frequency of 500Hz;*
4) *Care should be taken to avoid current or voltage dependence between loads in open loop control mode. This can lead to significant disturbances.*

This power source prototype is not optimized up till now to provide energy with quality requirements that some equipments and standards claim but there are improvements in progress to solve this.

3. Simulation and Experimental Results

The simulation results presented were implemented in Matlab/Simulink software using the Power System Blockset. Fig. 7 shows the simulation and experimental results of an open loop current control using a sinusoidal reference voltage (55 Hz) applied to a single RL load.



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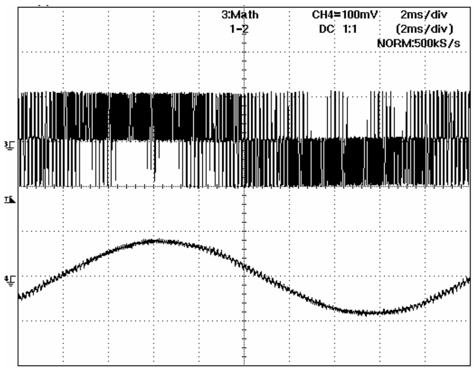
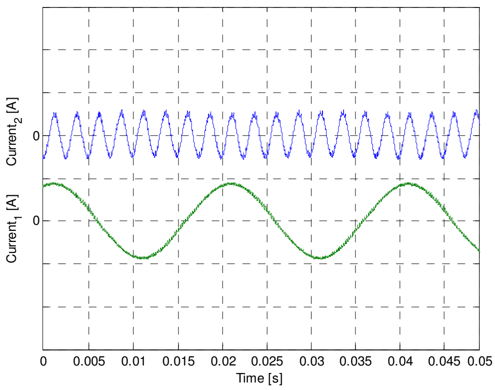


b)

Fig. 7. Open loop current control. Sinusoidal voltage reference of 55Hz, single RL load, one power source: a) Simulation; b) Experimental.

Figure 8 presents the simulation and experimental results of an open loop current control using two sinusoidal reference voltage (50 Hz and 400 Hz) in two identical RL loads (dual power sources).



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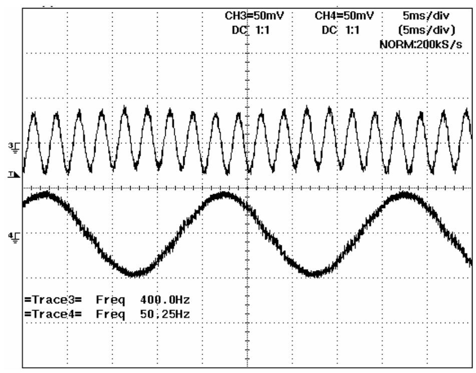

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Fig. 8. Open loop current control. Sinusoidal voltage reference of 400Hz and 50Hz, identical RL loads, dual power sources: a) Simulation; b) Experimental.

Figure 9 shows the harmonic spectrum of a current obtained with a single power source. A strong fundamental frequency and low harmonic content can be seen.

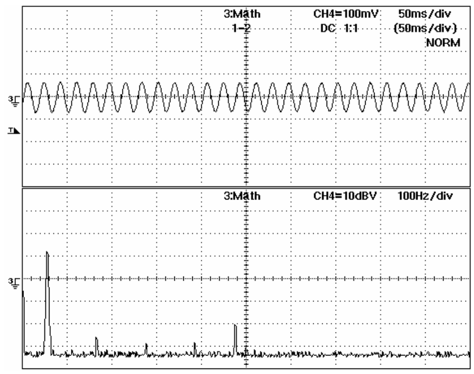
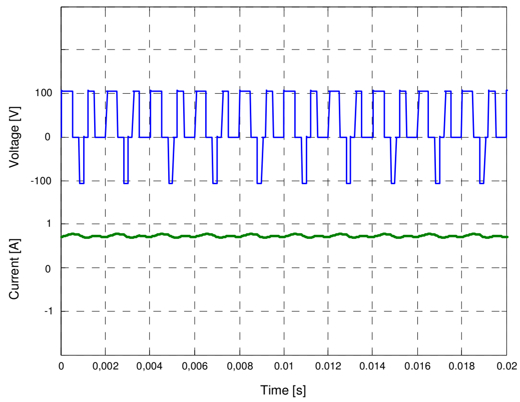


Fig.9 . Harmonic spectrum of a typical current waveform obtained in open loop control.

Figure 10 shows the simulation and experimental results of an open loop current control using a DC reference voltage applied to a single RL load.



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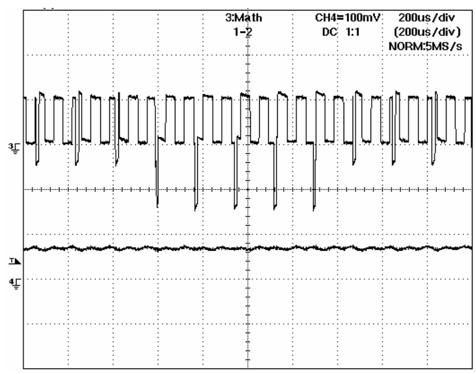
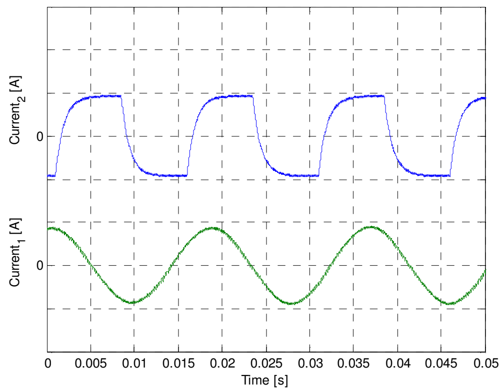


b)

Fig. 10. Open loop current control. DC voltage reference applied to a single RL load, one power source: a) Simulation; b) Experimental.

Figure 11 shows the simulation and experimental results of an open loop current control using a square wave (65 Hz) and a sinusoidal wave (55 Hz) using two identical RL loads (dual power sources).



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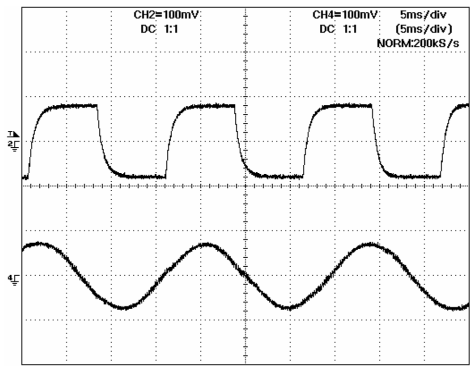
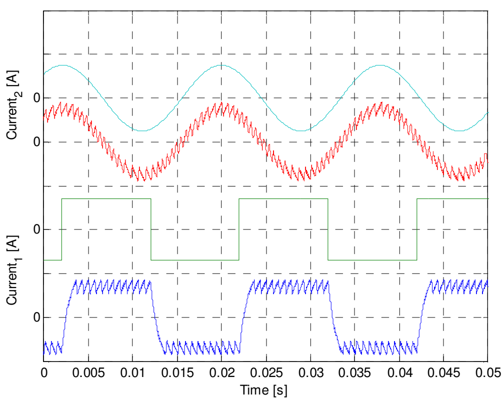


b)

Fig. 11. Open loop current control. Square wave voltage reference of 65Hz and sinusoidal reference of 50Hz, identical RL loads, dual power sources: a) Simulation; b) Experimental.

Figure 12 shows the simulation and experimental results of a hysteretic closed loop current control using a sinusoidal and square wave reference current with nearly 50Hz, applied to identical RL loads. In this result, the low switching frequency is due to high hysteretic bandwidth. This was purposely done to show details about current waveforms. Hysteretic bandwidth is typically very narrow.



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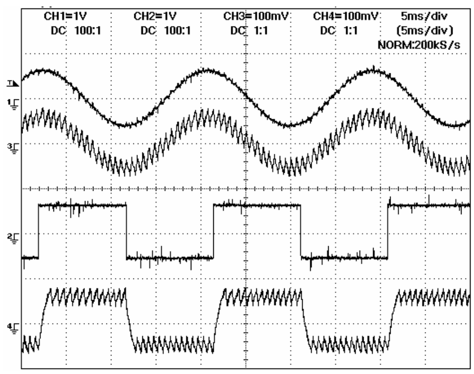

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Fig. 12. Hysteretic closed loop current control. Sinusoidal reference and square wave voltage reference of nearly 50Hz, identical RL loads, and dual power sources: a) Simulation; b) Experimental.

4. Conclusion

The flexibility of the proposed dual power source prototype makes it suitable for many applications. Considering the harmonic content, and comparing reference signals and the respective obtained waveforms it can be concluded that the performance of the dual power source is good. The developed software is a useful tool to fast configure the dual power source.

This paper also demonstrates that is possible to take advantage of three-leg bridge inverters usually optimized for three-phase applications to create solutions with potential for other applications. In this case, a three-leg bridge inverter has become a combination of two independent programmable power sources. It is advisable to use a low cost three-leg inverter to reduce the final cost.

The main drawback of this solution is that only half of the inverter voltage is available to apply on the loads, and the rms/average current sum of both power sources cannot exceed the nominal rms current supported by the switches of the leg that operates at high frequency square wave, with a duty-cycle of 50 %. Improvements must be done in the prototype to design a unique output filter with ability to adapt to different frequencies.

References

[1] D.G. Holmes, A. Kotsopoulos "Variable Speed Control of Single and Two Phase Induction Motors Using a Three Phase Voltage Source Inverter" IEEE Industry Applications Society Conference, vol 1, pp: 613-620, Toronto, Canada, 1993.

[2] S.S.Wekhande, B.N.Chaudhari, S.V.Dhopte, R.K. Sharma"A Low Cost Inverter Drive For 2-Phase Induction Motor" IEEE 1999 International Conference on Power Electronics and Drive Systems, PEDS'99, July 1999, Hong Kong.

[3] Young, C. M; Liu, C. C; Liu, C. H; ”New Inverter-driven design and control method for two-phase induction motor drives”, IEEE Proc. Electr. Power Appl. Vol. 143, Nº6, November 1996.

[4] Do-Hyun Jang ”PWM Methods for Two-Phases Inverters” IEEE Industry Applications Magazine, pp. 50-61, Mar/Apr 2007.

[5] Jordan, J., Serial Networked Field Instrumentation, Wiley, 1995.

[6] Microchip, “Using the PICmicro SSP for slave I2C communication”, Application Note–AN734, 2000.

[7] Pereira, F., Microntroladores PIC: programação em C., Ed. Érica-3ª Edição, São Paulo, 2004. ISBN: 85-7194-935-2.

[8] Microchip, “Serial Communications using the dsPIC30F SPI Module”

[9] Microchip, “Using the MSSP Module to Interface SPI™ Serial EEPROMs with PIC18 Devices”, Application Note–AN1000, 2005.

[10] Grier, R., Visual Basic – Programmer’s Guide to Serial Communications, Mabry Publishing, Stanwood, February 10, 2000, ISBN – 1-890422-25-8.

[11] Petroutsos, E; Hough, Kevin; “Visual Basic 5.0 Developer’s HandBook”, ISBN-0-7821-1985-9, Sybex – 1998.