

Development of a Variable Frequency Power Electronics Inverter to Control the Speed of a Three-Phase Induction Motor

Pedro Nuno da Costa Neves and João L. Afonso
Universidade do Minho, Campus de Azurém, 4800 Guimarães - Portugal
pneves@dei.uminho.pt jla@dei.uminho.pt

Abstract. *This work presents the development and implementation of a variable frequency Power Electronics inverter to drive a three-phase induction motor. The inverter allows a user to control the speed and torque developed by the motor, as well as its rotating direction. The inverter's digital controller was implemented with a microcontroller. The inverter is fed from a rectifier with capacitive filter, which is connected to single-phase, 50 Hz power mains.*

Keywords. Power Electronics Inverter, Three-Phase Induction Motor, Speed Controller, Velocity/Frequency Controller.

1. Introduction

In order to control the rotating speed of a three-phase induction motor, a three-phase inverter is required.

Any other kind of motor needs extra means to produce a spinning magnetic field. Because of the nature of the power supply, three-phase induction motors are the only ones in which the rotating magnetic field is created naturally in the stator.

The rotating speed (in RPM) is given by equation (1).

$$n_s = 120 \times \frac{f(\text{Hz})}{p \text{ (number of poles per phase)}} \quad (1)$$

The equation above represents the mathematical expression that describes the variables and parameters on which the synchronous speed depends on. However, the induction motor is an asynchronous machine, which means that the rotor's speed will not reach that value. The rotating magnetic flux that takes place in the stator is induced in the rotor that will turn at the base speed, which is, normally about 0,5% slower than synchronous speed, if no load is applied to the rotor, and

100% if the rotor is stopped completely from turning, as described in equation (2) where s is the speed slip between the stator magnetic field (n_s) and the rotor speed (n).

$$s = \frac{n_s - n}{n_s} \times 100(\%) \quad (2)$$

The stator windings are powered from 3 voltages that differ in phase 120° of each other. The three-phase power mains act as a power supply, and most motors are made to combine their characteristics with the power mains to work at nominal rated values of voltage and speed. The major inconvenient of this power supply (besides not being portable) is that speed cannot be changed since the frequency is constant.

By means of an inverter, a single DC power supply can be modulated into three AC voltages at a frequency and amplitude set by the controller that drives the inverter.

2. The Induction Motor

Essentially, an induction motor is made out of two main parts: the stator (the stationary part) in which the system voltages are applied to the windings, and the rotor (the moving part) in which the magnetic flux is induced. Figures 1 and 2 present images of the stator and of the rotor of a typical squirrel cage induction motor, which is a very simple, robust and inexpensive type of motor [1].

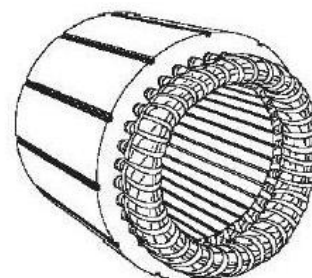


Figure 1. Typical induction motor stator

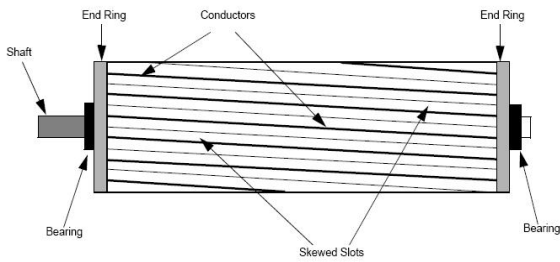


Figure 2. Typical squirrel cage rotor

The squirrel cage rotor is the most common type of rotors used in motors all over the world, because of its simplicity, low cost and robustness. Essentially, it is a cylinder with copper or aluminum bars assembled longitudinally and connected in the end with rings short circuited.

The three-phase power supply is connected to the stator windings, creating 2 poles for each phase, when there is only a winding for each phase (3 windings in total). When there are 2 windings for each phase (6 windings in total), 4 poles are created per phase. The magnetic field that results from all the poles, fed from the three-phases is a rotating magnetic field with constant amplitude, and with a constant rotating speed that depends on the power supply frequency, as shown in (1).

3. The Developed System

The developed variable frequency power electronics inverter to control the speed of a three-phase induction motor has several

fundamental components that are displayed as blocks in Figure 3.

Basically, from the single-phase power mains, the sine wave voltage is rectified, filtered and, by the inverter, turned into three sine wave voltages displaced of 120° between them, to feed the motor.

Each component has its own part in the inverter. The microcontroller is responsible for producing the PWM signals, which will determine the voltages applied to the three-phase induction motor. Different control and modeling techniques can be applied through the controller. The gate driver transforms the control signals generated by the microcontroller into gate signals which drive the switching semiconductors of the inverter.

Apart from the microcontroller, a PC based application has been built in order to have a complete and “easy to use” interface which allows the user to command and see some of the on going variables.

3.1. The inverter

The inverter block is constituted by six power switches (MOSFETs), with respective freewheeling diodes, as shown in Figure 4. The inverter switching frequency is equal to 20 kHz. The inverter produces three voltage waveforms, with a fundamental frequency component that ranges from zero to 120 Hz, which power the three-phase induction motor.

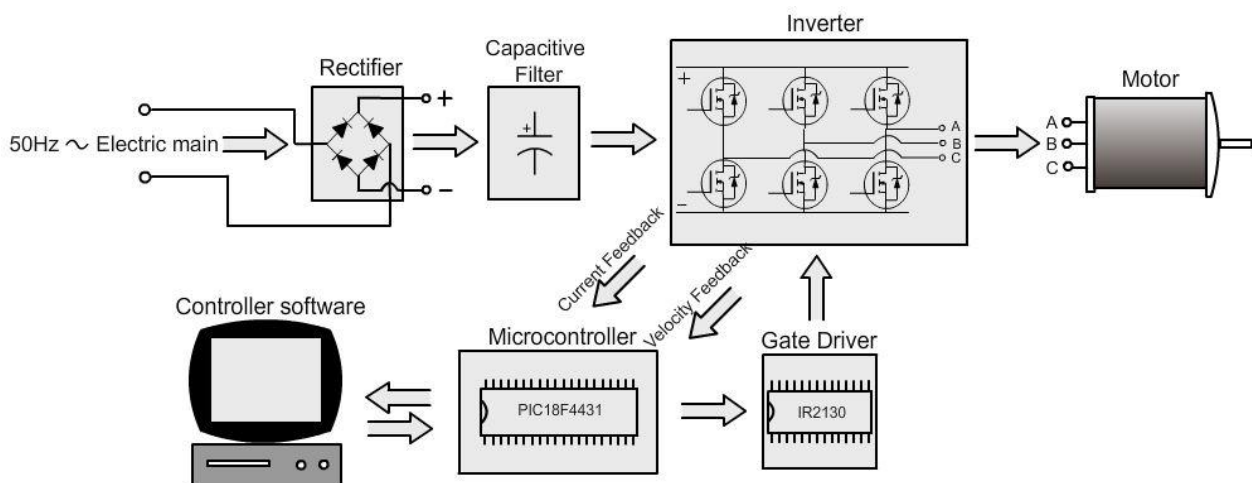


Figure 3. Developed system block diagram

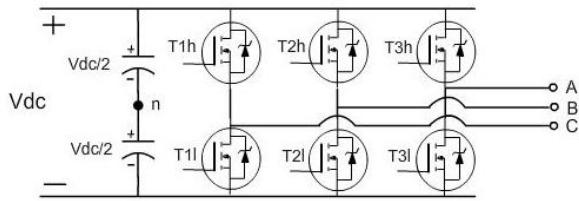


Figure 4. Three-phase inverter

The three-phase inverter can be seen as three complementary pairs or legs, in which the switching semiconductors of the same leg can never be in conduction simultaneously. So, one must be turned-off before turning-on the other, as shown in Figure 5, that presents the driving signals applied to two semiconductors of a same leg of the inverter.

Also, attention must be given to the fact that power switches take more time to turn-off than to turn-on. For this reason, a dead time has to be inserted between turning-off one of the switching semiconductors of a leg and turning-on the other.

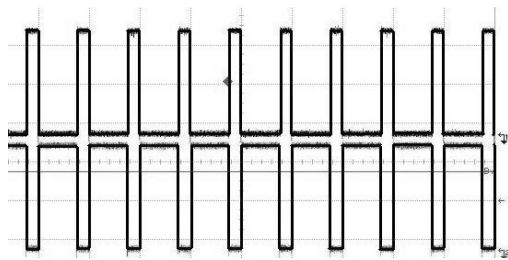


Figure 5. Complementary pair switching

Figure 6(a) shows the inverter output voltage V_{AB} , which is measured between the phases A and B of the inverter. Figure 6(b) shows the same voltage after a RC filter which has filtered the high frequencies produced by the inverter. Thus, basically this figure presents the fundamental frequency of the voltage applied to the motor.

Besides V_{AB} the inverter produces two other voltages, V_{BC} and V_{CA} . These three voltages are 120° shifted one from each other.

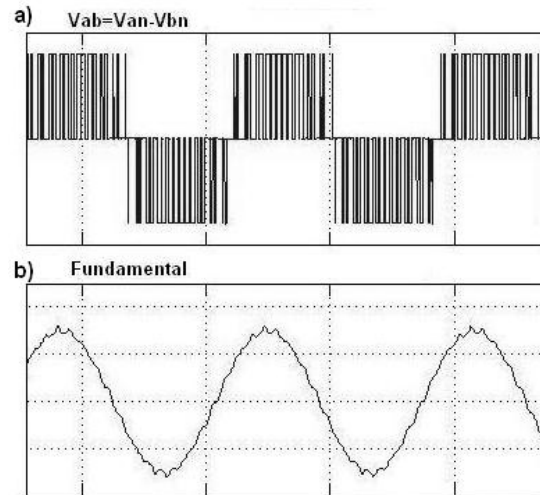


Figure 6. Vab voltage drop

3.2. The gate driver

The gate driver is an essential component to switch the semiconductors. Figure 7 displays a block diagram of the integrated circuit IR2130 from *International Rectifier* used to implement the gate driver [<http://www.irf.com/product-info/datasheets/data/ir2130.pdf>].

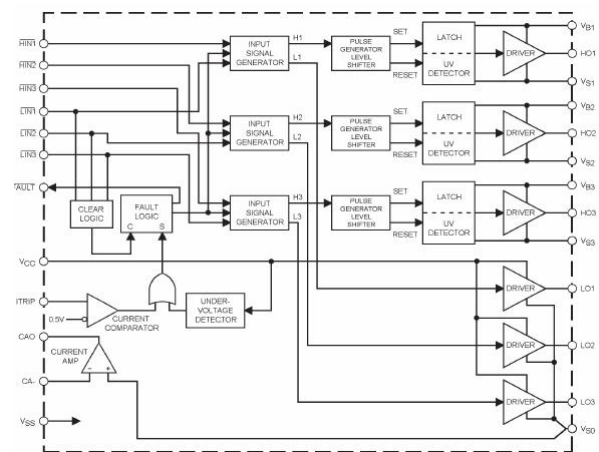


Figure 7. Gate driver block diagram

The PWM signals come from the microcontroller. The low side signals (applied to the 3 lower semiconductor switches of the inverter) are directly driven into the outputs. The high side signals (applied to the 3 upper semiconductor switches of the inverter), however, must be level shifted so that to the gate voltage is added to the voltage across the DC side of the inverter, otherwise the gate drive does not work properly.

3.3. The PWM signals

The PWM signals are obtained using the *Microchip* microcontroller PIC18F4431 [http://ww1.microchip.com/downloads/en/DeviceDoc/39616b.pdf]. The signals are produced with a fixed frequency of 20 kHz and with a variable duty cycle, which is shown in Figures 8 and 9, with PWM signals acquired at two different places in time.

In order to be commanded by a user, the microcontroller reads values of desired output velocity, desired running direction, stop or run commands, actual speed and current.

The produced voltages, with fundamental sine wave, is shaped by means of a continuously updated duty cycle.

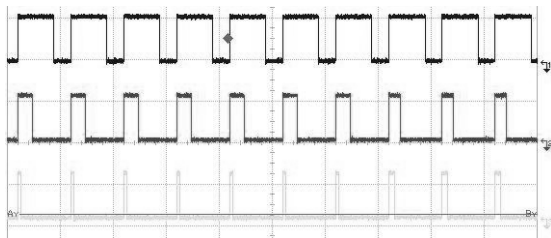


Figure 8. PWM signals

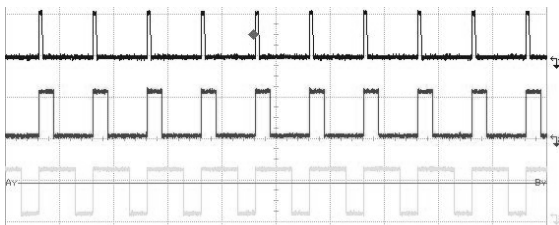


Figure 9. PWM signals with updated value

3.4. The software controller

National Instruments LabVIEW 7.1 was chosen as a tool to build a PC based controller and monitor. It is mainly an instrumentation tool that allows the construction of a user friendly interface, characteristics required for the application in hand.

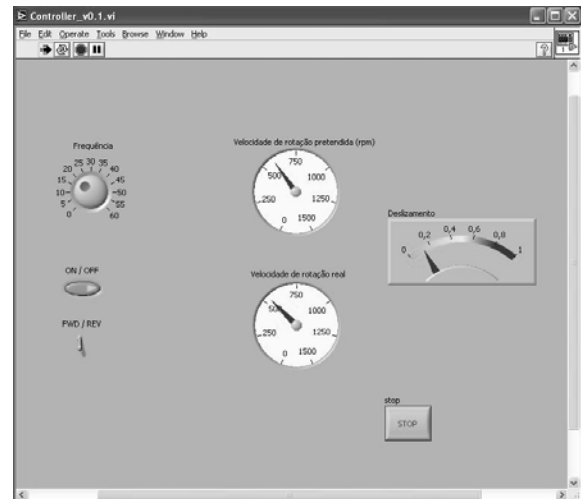


Figure 10. PC controller user interface

The software built for this purpose controls the PC parallel port output bits with a five bit resolution. These five bits are converted to an analog signal which can vary from 0 to 5 V. On/Off signal and Forward/Reverse buttons are also present with the use of a driver constituted by two transistors in a bipolar totem-pole configuration, so that no danger is held to the computer's communications port. Using this configuration, the two base-emitter junctions protect each other from reverse breakdown and the use of a schottky diode to prevent the reverse flow of current isn't necessary.

This software has also measurement and calculation features. By reading the real angular speed of the rotor, the slip is calculated and displayed. This is useful to draw conclusions from the working conditions of the motor. To make it possible, an encoder was attached to the motor's rotor and the information from it was sent to the computer's parallel port input pins, which are acquired by the application, and shown on screen.

By means of a simple switch, control capability can be changed between the computer application, or the on-board push buttons and potentiometer.

3.5. The electrical isolation

In power electronics appliances, there is normally isolation between controller module and power module. In order to be safe for a user to press the control buttons and potentiometer, optocouplers were used to send the signals from the microcontroller to the power module.

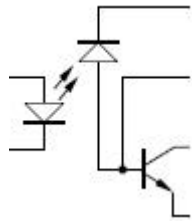


Figure 11. Optocoupler topology

Using these devices, the control signals are applied to the power module using a light source. Figure 11 shows basically how the optocoupler works. When a current is applied to the Light Emitting Diode, it sends light which is received by the photodiode on the secondary part polarizing the transistor.

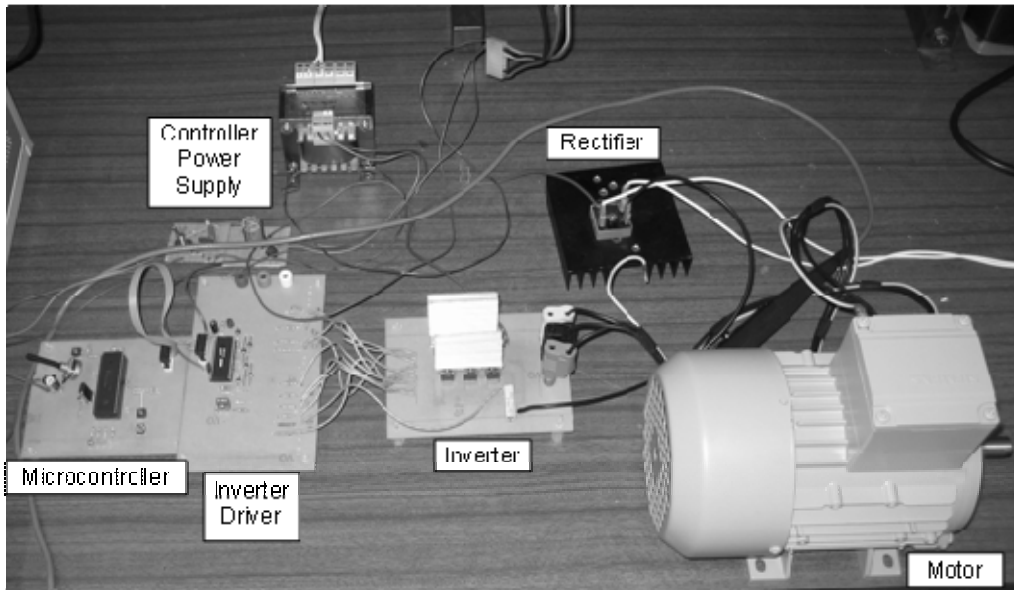


Figure 4. Developed circuit used to drive the motor

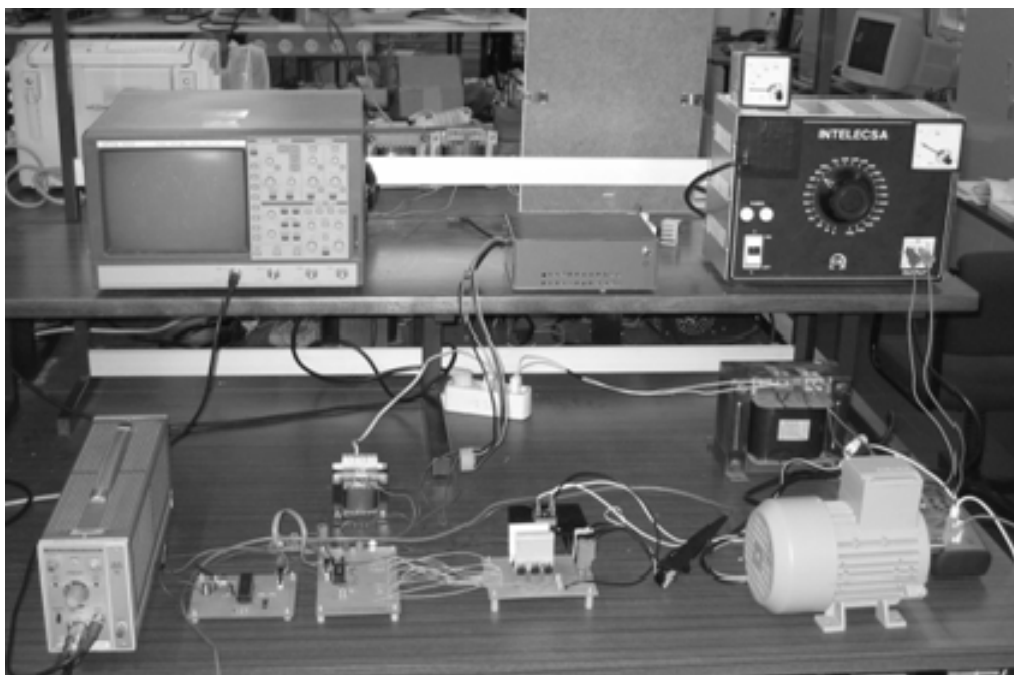


Figure 5. Circuit workbench, with power supplies and measuring instruments

4. Conclusion

This paper presents a developed variable frequency power electronics inverter used to control the value and the direction of the speed of a three-phase induction motor. The system is fed from single-phase power mains. The control system is based on a PIC18F4431 microcontroller, from *Microchip*. The inverter uses six IRFP460 MOSFETs from *International Rectifier*. The developed system presents an interface to a PC (Personal Computer), which allows controlling and monitoring the motor operation, through a user friendly interface designed with the software tool *LabVIEW 7.1*, from *National Instruments*.

5. Acknowledgements

This work was supported by the FCT (Fundação para a Ciência e a Tecnologia), project funding POCTI/ESE/41170/2001 and POCTI/ESE/48242/2002. The authors are also grateful to PRIME (Programa de Incentivos à Modernização da Economia) for funding the Project SINUS.

6. References

- [1] Rakesh Parekh, AN887, AC Induction Motor Fundamentals, Microchip Technology Incorporated, U.S.A., 2003.
- [2] N. Mohan, T. M. Undeland, W. P. Robbins, Power Electronics: converters, applications, and design, John Wiley and Sons, Inc., New York, 1995.
- [3] Jon Burroughs, AN900, Controlling 3-Phase AC Induction Motors Using the PIC18F4431, Microchip Technology Incorporated, U.S.A., 2004.
- [4] João L. Afonso, Jaime Fonseca, Júlio Martins e Carlos Couto, "Fuzzy Logic Techniques Applied to the Control of a Three-Phase Induction Motor", ISIE'97 - IEEE International Symposium on Industrial Electronics, Guimarães, Portugal, 7-11 Julho, 1997, pp. 1179-1184.
<http://www.ietf.org/internet-drafts/draft-ietf-avt-rtp-new-10.txt> [10/31/2001]