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Testing of Control Signals for a Voltage Source Inverter

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ABSTRACT
In this work, the control signals that feed a voltage source inverter (VSI) are shown and analyzed. These signals were generated using a NXP® FRDM-KL46Z Microcontroller and are used to power the gates of an inverter's transistors. Control signals are generated with a PWM technique. Tests of complementary signals, frequency and dead times are made. The voltage at the output of the inverter depends on these control signals; this voltage is used to feed the load.

KEYWORDS: *Control Signals,PWM,Complementary Signals, Dead Time, Inverter, Gate Driver.*

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I. INTRODUCTION

Electric machines currently play an important role in the industry and in the daily life of the human being. As you know, an electric machine converts mechanical energy into electric and vice versa. As for the supply voltage, electric machines are divided into two types, alternating current (AC) machines and direct current (DC) machines. The AC machines in turn are divided into synchronous machines and induction machines.

One of the most used machines today is the AC induction motor. The induction motor is a rotary machine designed to operate with a three-phase alternating voltage source. The most common type of induction motor is the squirrel cage rotor. In this type of rotors the aluminum conductors or bars are short-circuited at each end by rings.

Much of the engines used in modern industry operate at varying speeds. These machines require precise speed control to achieve adequate productivity, good completion of the manufactured product or ensure the safety of people and the equipment itself. Currently, the variable speed of induction motors is achieved with *Variable-Frequency Drive (VFD)*. The *VFD*is a type of control for AC motors that energizes, protects and allows varying the speed. The main advantage of the drives is that they reduce the consumption of electric energy in the processes they control, resulting in considerable decreases in operating costs.

It can also achievespeed control and drive AC motors by developing own control schemes with the help mainly of power converters, gatesdriver, sensors and of course with the development and advancement of Microcontrollers; these allow the implementation of very precise control algorithms. Today, these control algorithms can use different *Pulse Width Modulation* (PWM) *Techniques* for this purpose.

One of the most used power converters for the drive and speed control of AC motors is the Inverter. The inverter is an electronic circuit that converts a DC voltage to AC voltage. With the inverter, voltages can be generated at certain amplitudes and frequencies by using a PWM technique.

Inverters can be basically classified into two types:
• Single phase inverters
• Three Phase Investors
And these in turn in:
• Voltage Source Inverters (VSI)
• Current Source Inverters (CSI)

The three-phase inverter consists of three branches or legs of half-bridge where the upper and lower switches are controlledcomplementarily. Since the device's off time is longer than the on time, a dead time must be inserted between the turnoffone of the transistors and the turn on of the other.Most of the power transistor devices used in the inverter in motor control applications are*IGBT's* or *MOSFET's* (*Insulated Gate Bipolar Transistor and Metal Oxide Semiconductor Field-Effect Transistors respectively*).

The PWM control technique for switching the inverter IGBT's can be generated by different methods. For example, in the sinusoidal technique, a triangular wave is compared with a sine wave of fundamental frequency, and the intersection points determine the breakpoints of the inverter's power device.

Current techniques and control algorithms to vary the speed of AC motors are programmed from the computer and loaded in the microcontroller, which generates the control signals. Microcontrollers currently have the necessary tools and peripherals, as well as the memory to implement modern control algorithms.

II. MOTOR DRIVES

To drive AC motors in variable speed applications, as mentioned, an inverter is required to vary the frequency and output voltage. In the design of an inverter speed variator, the implementation of control techniques and algorithms is also necessary. This implementation can be done using a Microcontroller and an interface that allows communication between the control and power modules. The scheme consists mainly of anAC-DC converter (rectifier), a DC-AC converter (inverter) and the control block; which can be composed of a gate driver, optocouplers, current and temperature sensors, among others. Figure 1 shows the block diagram of one of the schemes that are required to vary the speed of an induction motor. The power interface is part of this scheme. The scheme consists mainly of the following modules:

- *Rectifier*
- *Inverter*
- *Control Block(Driver, Optoacopladores, Sensors, Microcontroller, etc.)*
- *Load*

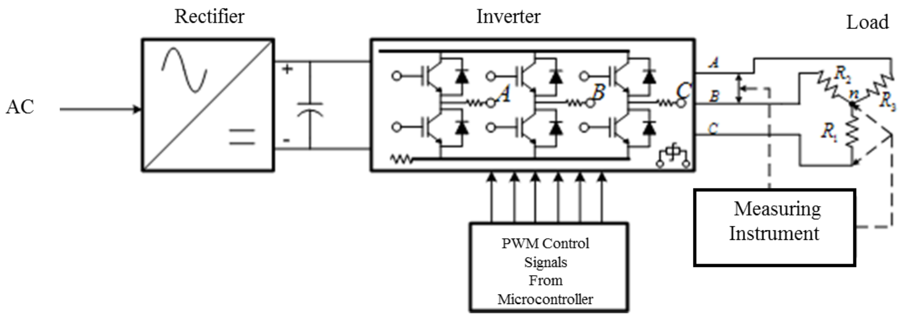


Figure 1.Block diagram of the main elements to vary the speed of AC motors.

As can be seen in the scheme in Figure 1, power converters are the main modules that make up the speed control scheme. For the control or conditioning of electric power, it is necessary to convert it from one form to another, and that the switching characteristics of the power devices allow those conversions. Power converters perform these functions and are basically classified into five types:

1. AC-DC converters (diode rectifiers and controlled rectifiers)
2. AC-AC converters (AC voltage controllers)
3. DC-DC converters (DC converters)
4. DC-AC converters (inverters)
5. Static switches

In this work we are going to focus on the inverter because the signals that are going to be generated feed the gates of the inverter's transistors, in which the tests will be done.

III. MICROCONTROLLER

The use of microcontrollers for this type of implementation is important because it facilitates and gives speed to the solution of industrial problems. The development board used is from the Kinetis L series KL4x MCU family built on *the ARM® Cortex ™ -M0 + processor*. The programming environment or development interface is *Mbed OS*. Mbed is a platform and operating system for devices connected to the internet based on this type of microcontrollers.

The microcontroller has an online compiler which directly uploads the programs to the cloud via the Internet, the advantages provided by compiler are:

- *Code update from any computer.*
- *Debugging the code.*
- *Open and free platform.*
- *Facilitates the storage medium of the algorithms.*

The development board used is the *FRDM-KL46Z* designed by *NXP-FREESCALE®*, which has a low-cost development platform; the programming environment is flexible to implement the developed algorithms. Theboard peripherals are shown in Figure 2.

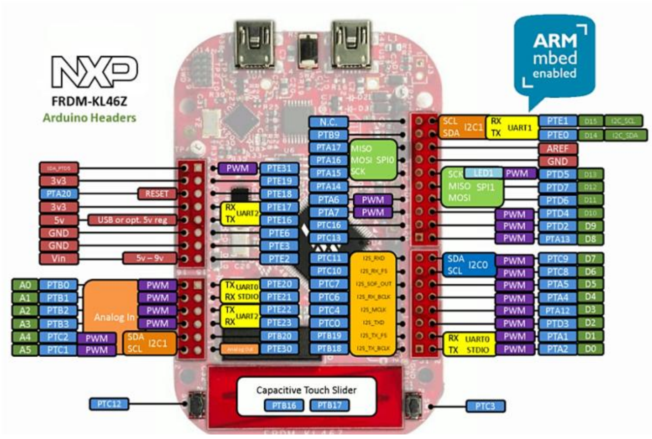


Figure 2.Peripherals of the development board FRDM-KL46Z [7].

The development of the PWM technique is done by comparing a control signal (sinusoidal signal) and a carrier signal (triangular signal), in this comparison when the control signal is greater than the carrier signal, it will produce a high pulse with a corresponding duty cycle. The PWM frequency will be set while the duty cycle varies between *0* and *100%*.

IV. TEST AND RESULTS

The tests are made at the outputs of the Microcontroller (board pins), Optocoupler and Gate Controller. It is checked that the control signals at the output of the mentioned devices are *complementary;the programmed operating frequency* and *the dead times* between them are verified too. Figure 3 shows the block diagram of each stage of the power interface and the control scheme.

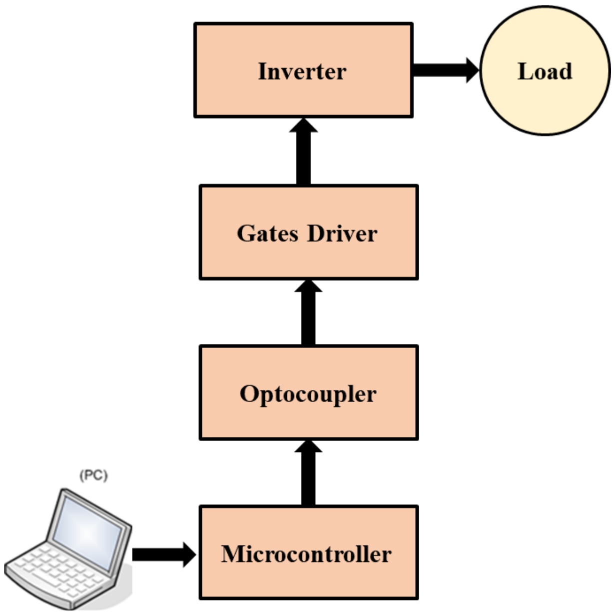


Figure 3.Block diagram of the control scheme.

Complementary Signals and Frequency Test at the Output of the Microcontroller

Below the results obtained on the output pins of the microcontroller after running the program with the PWM control techniqueare shown. As a first test, it was checked that the control signals were complementary, figure 4; this means that when the above transistor of the same leg of the inverter is turn on the transistor below must be turned off and vice versa. Also, a dead time was programmed between them. These two tests are done in order to avoid a short circuit in the legs or branches of the inverter, since they must not be turn on two transistors of the same leg at the same time.

The frequency of the PWM signals was programmed at *16kHz* with a *dead time* (*DT*) of *3µs*. In this test it was possible to check this programmed frequency and it can be seen in figure 4. The control signals at the output of the microcontroller are approximately *3.3V*. The channels 1 and 2 of the oscilloscope are at *5V* per division. This voltage is what was expected since the microcontroller gives an output voltage of *3.3V*.

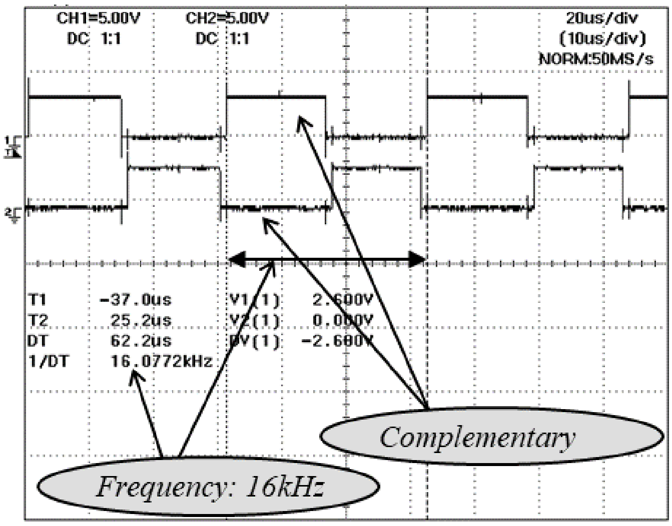


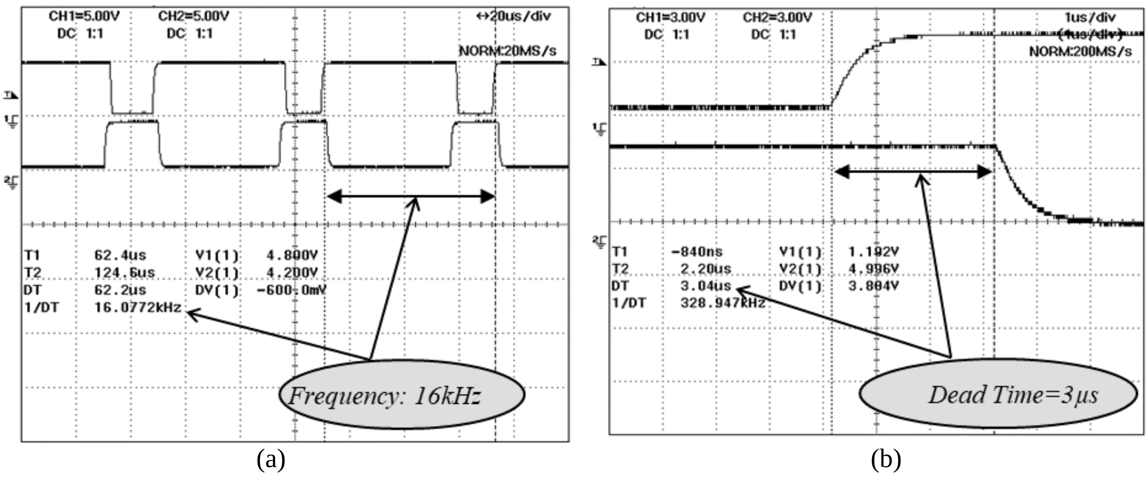
Figure 4.Control signals at the output of the development board.

With this test it was possible to verify that the control PWM signals were complementary and the programmed frequency were adequate for the drive of the transistor gates of the inverter module.

Dead Timeof Control Signalsat the Output of the optocouplers

In the optocouplers output, tests of dead time were carried out to the complementary signals, in order to ensure adequate switching between each transistor of each leg of the inverter, that is, when a transistor of the same leg is turning off, a time for the other transistor of same leg must be given to turn on. This time is known as dead time; during this interval neither of the two transistors of the same branch must be on, otherwise the inverter will be short-circuited.

The dead time programming is done by software. Figure 5 (a) shows the control signals at the output of the optocouplers for one leg of the inverter. The same signals are shown in Figure 5 (b) but making a zoom in at one of the ends. It can check the programmed dead time from the microcontroller by measuring the signal cycle with the oscilloscope, in this case *3µs*.



(a) (b)

Figure 5.Signals at the exit of the optocouplers: (a) PWM Complementary Signals, (b) Zoom in: Dead Time between them of *3µs*.

Complementary Signals and Frequency Test at the Output of the Gates Driver

In this test, it was found thatthe signals sent to each transistor of each leg of the inverter were complementary to *15V*, at a frequency of *16kHz*, as can be seen in Figure 6. The volts-divisions of the oscilloscope can be seen in 5V, with a scale of 1: 1, from it can see that the signal is approximately *15V*. It can also see that the magnitude of voltage increases from *3.3* to *15V* approximately. This is because the output voltage of the gate driver is *15V* due to the requirements of the inverter's transistors.

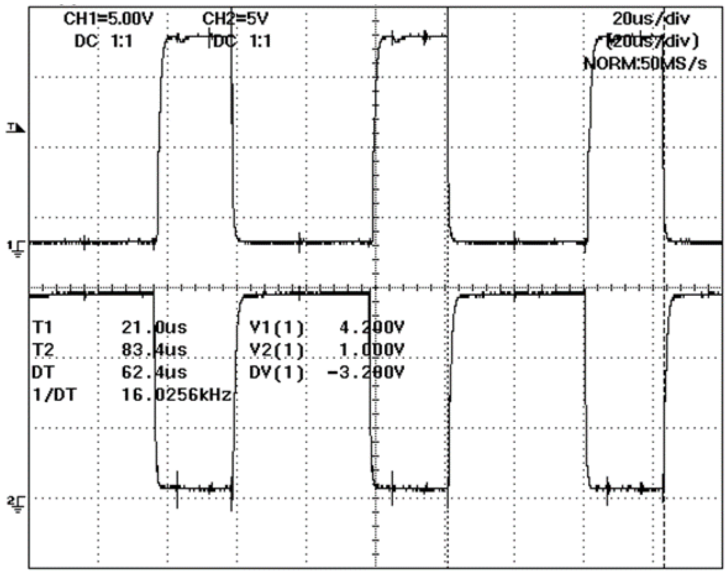


Figure 6.Complementary signals at the gate driver output.

Dead Timeof Control Signalsat the Output ofthe Gates Driver

The dead time test was performed at the gatesdriver output, figure 7. A dead time of *1.5µs* was programmed from the microcontroller. It was possible to verify that the gatesdriver introduces a dead time of *0.3µs* as indicated by the device data sheet, so that the output of the driver has a total dead time of *1.8µs*.

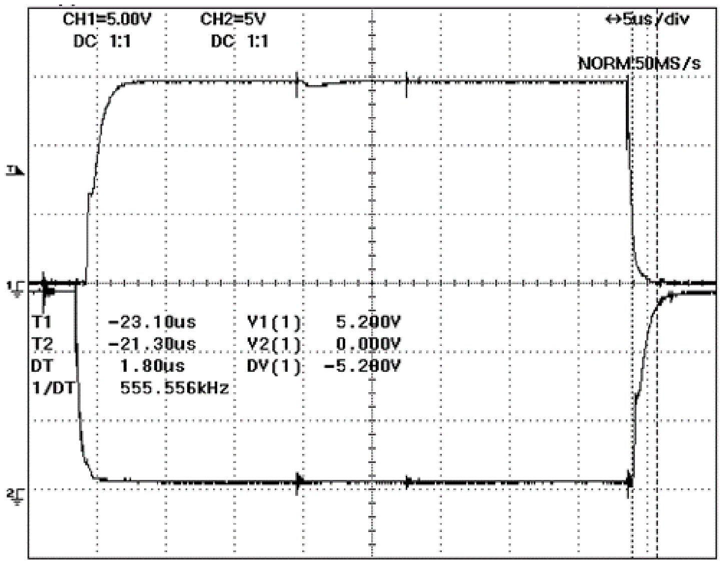


Figure 7.Dead time of complementary 15V signals at the gate driver output.

With this test it is verified that the dead time can be worked from *0.3µs*, time that the gate driver introduces, up to the time required by the application, programmed from the microcontroller.

V. CONCLUSIONS

The design of an AC motor drive scheme with a microcontroller allows different control techniques to be implemented. In addition, it allows to vary the dead times between the control signals, unlike when the dead times are introduced by hardware. When dead times are entered by hardware they are fixed.

Complementary signals and dead times are important for the proper switching of inverter transistors. If the signals are not complementary, the inverter module is short-circuited and its internal circuit is destroyed.

The previous tests indicate that the control signals are adequate to be implemented in an inverter. This allows the inverter to be operated in a safe manner. You also have the flexibility to vary the dead times and the frequency through the program from the computer.

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