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Digital Signal Processor Programming using MATLAB Simulink Embedded Coder

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Abstract. In this work, a computer tool developed in Matlab is presented for process control in real time. The Matlab/Simulink Embedded Code toolbox allows the programming of different commercial acquisition and control cards. In addition, it is easy to supervise the practical cases implemented both from the cards commercial interfaces and from Matlab/Simulink. This work shows how to use the Texas Instruments TMS320F28335 card, the installation of the required software to program the card and the development of a practical case to prove its performance. Thus, the way of generating a sinusoidal voltage waveform using a power DC/AC converter controlled by the PWM (pulse-width modulation) modules card, is presented. This method can be used for teaching and researching purposes, and it is also used for the electric power system management.

Key words. Simulation platform, Matlab/Simulink, TMS320F28335, Embedded Code.

1. Introduction

Nowadays, the smart control applications are very widely in all the engineering fields. To make the code development easier in these systems, the different simulation applications started to develop automatic code generation by means of digital models. Thus, the development of the proposed control and the verification in the simulation model allows to obtain the code to be used in physical control systems implemented in labs. This method has direct applications in the teaching and researching field, [1],[2].

In this wide framework, this work is focused on the analysis of the computer tool developed jointly by MathWorks and Texas Instruments (TI) to generate the microcontrollers' code for the TI C2000 series. These real time controllers allow the digital signals processing in industrial applications, being especially indicated for the control of power devices. The central processing unit (CPU C28X) uses a 32 bits core with a speed of 300 MIPS ("Microprocessor without Interlocked Pipeline Stages" is the family of RISC architecture microprocessors developed by MIPS Technologies). This chip has different peripherical adapted to the control applications, including communication modules. The micro is on the acquisition and data control card, the TMS320F28335 in this work, [3]-[5].

The entire process involves the design of the desired control model in the Embedded Coder Simulink within MATLAB, the automatic generation of a C code for TI microcontrollers through an Embedded Coder and the C code compilation to an executable program to be included in the microprocessor. This last task is achieved by means of another software compatible with Matlab, which in this case is Coder Composer Studio software. If a malfunctioning is detected, the easiest way of solving it would be to make an adjustment in the Matlab program and quickly generating another code C, saving programming time.

As it has already been mentioned, there are a large variety of control system applications. In this work, one of those applications is presented as well as the code generation tool, which is presented and used to generate a sinusoidal voltage waveform through a power inverter to supply an electric isolated micro-grid, [6]-[8]. In micro-grids connected to the grid, a current wave would have to be generated to provide the power generated by renewable energy sources. In these case a loop-closed control could be implemented, [9]-[11].

In section 2, the DSP hardware and the necessary software to build an executable control program is presented. In section 3, the installation process of all the required computer tools to make a control program and build an executable code from it, to be used in a microcontroller that works in a real physical system, is detailly presented. In section 4, a practical case developed in the lab is described. A power inverter control program is developed, detailing the building of the control program in Simulink, the automatic generation code and the execution of the program in real time, as well as the use of the tool which allows the analysing the system behaviour.

2. System description

In this section, the hardware and software requirements to work with the tool of Matlab generation code is presented. In summary, the hardware includes a computer and a control card, whereas the software includes, apart from the basic Matlab software, the required packages to communicate with the control card and the required software to translate the C language to the Matlab generated code, to compile the program and to create the executable program exportable to the control card.

A. Digital Signal Processor, DSP TMS320F28335

An embedded system is a combination of software and hardware in an electric or mechanic device that does not require the continuous intervention of the user to work. An embedded control system includes the system required to be controlled, the controller, the sensors to detect the state system and the actuators to operate it. The rapid prototyping is a technique to elaborate test control systems that allow to validate the designed algorithms, executing them directly in the plant, in a simulation model or in a model that combines part of the plant and part of its model. The objective is to know the behaviour of the controller before implementing it in a physical system.

The quick prototyping products of MathWorks automate the exportation of models and control algorithms developed within Matlab/Simulink over software to execute them in real time, allowing the focus attention on its evaluation, instead of in the required modifications of the programming code to adjust its performance.

The technological progress achieved in the digital integrated circuits creation has allowed the implementation of signals processing systems. For the processing, the physical signals are obtained through transducers and they are digitalized by means of analogical-digital converters. The DSP (digital signal processor) are microprocessors with special architecture to accelerate the intensive calculations required in embedded systems in real time. A microprocessor has two basic units to handle signals, read operations from a data memory, read new data in the memory and update the output modules. They are the control unit and the central processing unit CPU, figure 1.

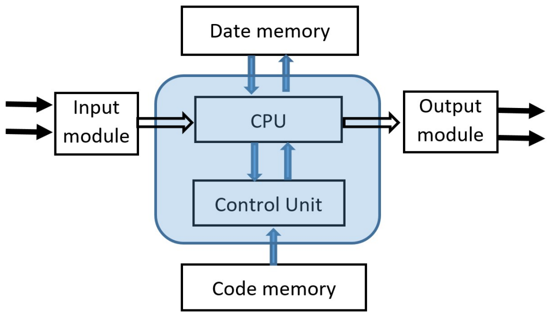


Fig.1. Microprocessor basic operation scheme

One of the main DSP manufacturers is Texas Instruments Company. The TMS320 processor series includes the C2000 family, the cheapest one, and it has an optimized core to execute complex algorithms and high-performance peripherals.

The used TMS320F28335 DSP in this work is included in the embedded processors group of 32 bits created for high performance in real time control applications. Some of its features are that it has a 32 bits CPU with Harvard architecture and floating-point arithmetic, the work speed of 150 MHz and its communication peripherals. Other useful features for the power devices control are the PWM modules with 18 outputs, 16 analogical-digital conversion channels of 12 bits and 80 kHz, SCI serial communication interface and 88 input/output pins for general purpose. Figure 2 depicts the card integrated in an experimental module, the TMS320F28335 kit, which is the used in this work. The card microprocessor is highlighted in the figure.

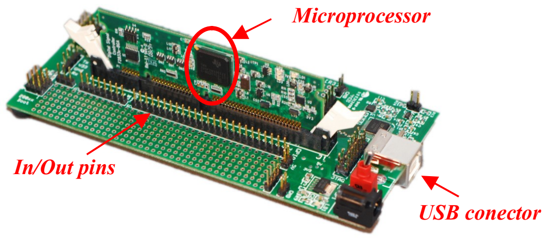


Figure 2. TMS320F28335 Experimental Kit with control card

The card has 6 peripherals for the improved pulse width modulation, ePWM, each one with two outputs, essentials for the control of the power electronic devices. The only requirement is to indicate the duty cycle which allows the generation of the PWM signal at the desired frequency. The synchronization is feasible with the card readings to prevent wrong readings. With high resolution modules (HRPWM), it is possible to work with frequencies higher than 200 kHz. In this work, conventional modules are used since the maximum frequency required is about 20 kHz.

B. Coder Composer Studio

The applications for the power devices of the different Texas Instruments processors and microcontrollers families are developed using the Code Composer Studio (CCS) software tool. CCS is a platform with integrated development and compilers for each device, source code editor, projects creation environment, simulators and operation systems in real time. It is based on open code software and it can be executed in Windows and Linux.

Simulink is a simulation platform with an interactive graphical environment and libraries configurable by the user. This software allows to design, simulate and evaluate, amongst others, signal processing systems, control systems and communication systems. Thus, the Simulink environment can generate a prototype of any control system, taking into account the models.

The Simulink Embedded Coder tool can automatically generate, from the designed program in Simulink, the code for the required hardware. Embedded Coder is a programming interface for applications to generate C code and optimize it to be used in embedded processors and/or rapid prototyping cards, like the one used in this work. The way of using this tool is detailed shown in section 3 through a practical case. CCS has been developed by Texas Instruments and it is used to create software for DSPs and microcontrollers developed by this company. CCS can be used combined with Embedded Coder to compile and upload the designed code over the available hardware device. After uploading the code in the device and executing the program in real time, it is possible to achieve the microprocessor

information through Matlab/Simulink by means of the CCS link. Thus, the experiments can be supervised by the user while it is executing in the control card in real time.
The versions of the different software tools required to implement the algorithm developed in Matlab/Simulink in the DSP are the next:

- Matlab (including Simulink), version R2022b. Embedded Coder Support Package for Texas Instruments C2000 Processors, version 22.2.0.
- Code Composer Studio, version 11.0.0.

This control applications are also used to compile and execute the program on the microcontroller card. In section 3, the installation process of the software required by the different tools are detailed presented. To do this, the way of generating a sinusoidal waveform through with a power converter using the ePWM module of the control card is described.

3. Software installation

In this work, a 2022b version of Matlab/Simulink is installed from MathWorks web, including a compilator to generate the code required to be installed in the card microprocessor ("Embedded Code"), figure 3. In this case, the license is from the University of Huelva.

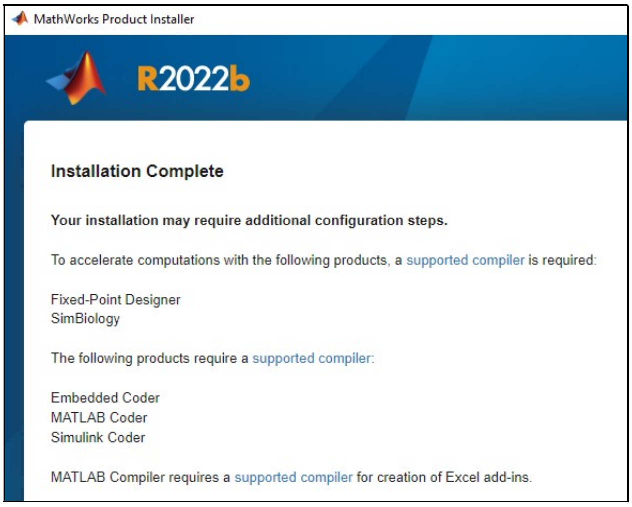


Fig.3. Matlab/Simulink and Embedded Coder installation

Once Matlab/Simulink is installed through the option "Get Add-Ons", the software that allows the connection to the control card is downloaded (in this case "Embedded Coder Support Package for Texas Instruments C2000 Processors"). This package is installed choosing the available controller card (in this case TI Delfino 2833), figure 4. This computer package needs another software to translate the Matlab code to C language, and to generate from C the executable code to be installed in the microcontroller. This software is the Code Composer Studio (CCS). In this case, the version 11.0 was installed by means of the CCS web with the standard installation. Figure 5 shows details about the installed software from Matlab through the Add-Ons option. As figure 5 depicts, the controlSuite software from TI is also required to create the code to make possible the inclusion of drivers and additional libraries.

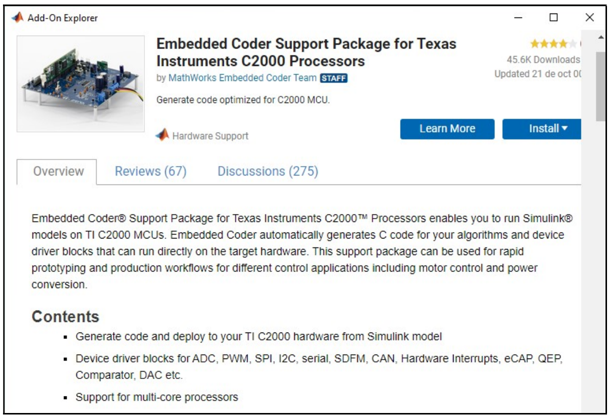


Fig.4. Embedded Coder Support for Texas Instruments C2000 Processors installation

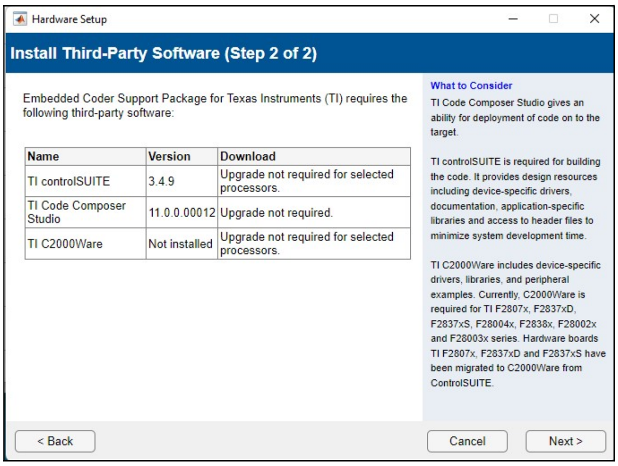


Fig.5. CCS and controlSUITE installation

4. A practical case: a power inverter control

To develop the control program to be implemented in the card, it is required to specify in Matlab/Simulink by means of the "Modelling Setting" option the type of the card that is going to be used, figure 6.

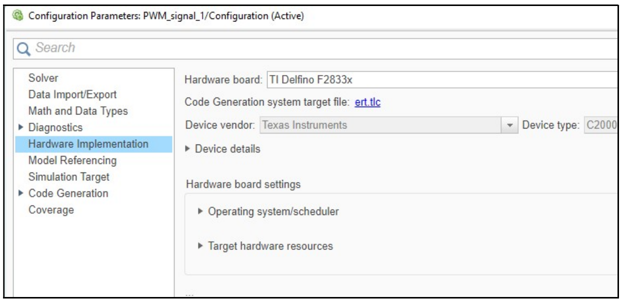


Fig.6. Control card selection

The first option to generate a PWM signal is using an external reference. In this case, a function generator has been used to create a reference sinusoidal voltage of 50 Hz. This signal is read by an analogical input pin from the card. The developed control program uses an ADC (analogue digital converter) that selects the analogical input and convert it to a digital signal of 12 bits (this provides a value that ranges from 0 to 2^{12}=4096). In the developed program, this signal is multiplied by 5 to achieve a value that ranges from 0 to 20480. This value has been used to configure the period of the ePWM module, figure 7. The ePWM module enables the start of the analogical conversion (clicking the “event trigger/enable ADC start” option) to synchronize the data reading with the output signals, which are the trigger signals to be sent to the power electronic devices.

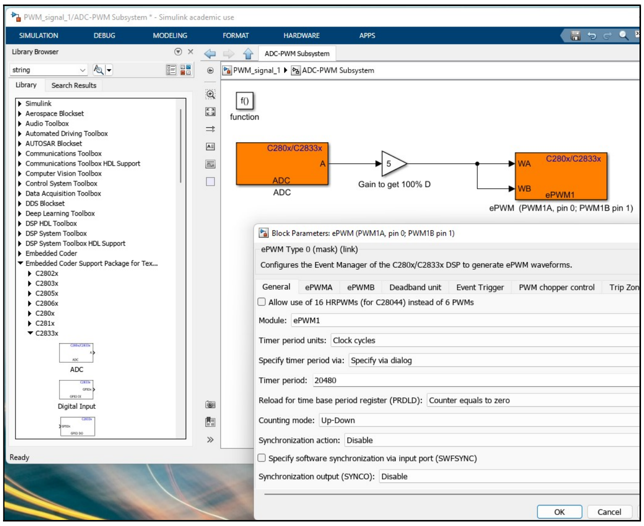


Fig.7. Data reading and generation of the output PWM signal

This simple reading and the PWM output signals generation program needs to be included in a “function” block, figure 8. The block “hardware interruption” has been configured so that the program is executed with the updated data and according to the software options, once the conversion is complete. Each interrupt is described by a CPU interrupt number, a PIE (program interruption element) interrupt number, a task priority and a preemption flag. The CPU and PIE interrupt numbers together uniquely specify a single interruption for a single peripheral or peripheral module. The Matlab help enables these codes, being CPU=1 and PIE=1 in the used card.

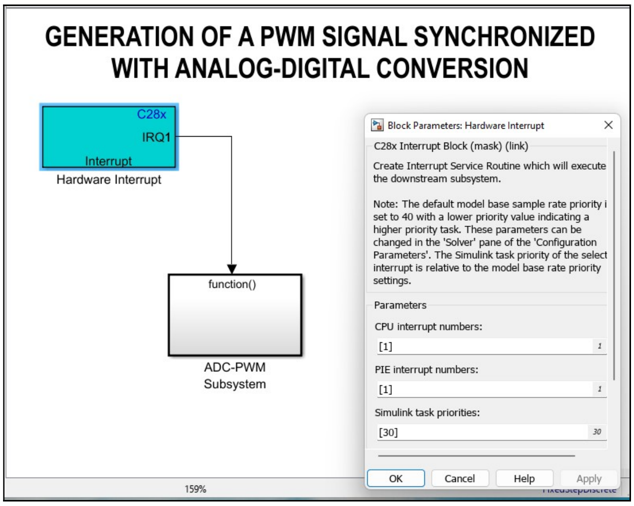


Fig.8. Program developed in Simulink with the interrupt configuration

The reference waveform logically can be generated by the own controller. In this case, it is not necessary to synchronize the PWM module with the analogical-digital converter that reads the external reference input.

Figure 9 presents the simple program that achieves the synchronization. In this work, the PWM duty cycle has been fixed in function to the clock cycles, figure 7. Thus, the program gain must be fixed according to the sampling time corresponding to the discrete sinusoidal waveform used as reference.

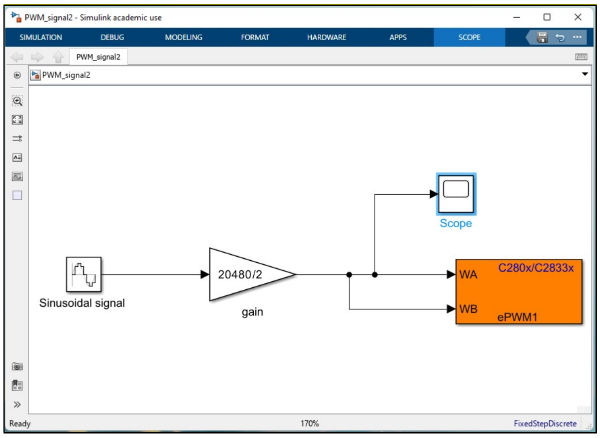


Fig.9. Program to internal reference generation

Once the program has been developed in Simulink, through the “Hardware/Build,Deploy&Start” option and thanks to the installation of CCS, the C code is automatically generated and the executable program is built. Then, the program is exported to the microcontroller via USB connection and automatically executed. Another option is to create and execute the program through the “Hardware/Monitor&Tune” option. In this case, it is possible to supervise and interact with the experiment in real time from the screen of Simulink, visualize the desired signals using the Scope blocks or even change the program parameters while the executable program is running in the card.

Figure 10 depicts the experimental platform used in this work. In the figure, it is highlighted the generated waveform as reference and the used control card.

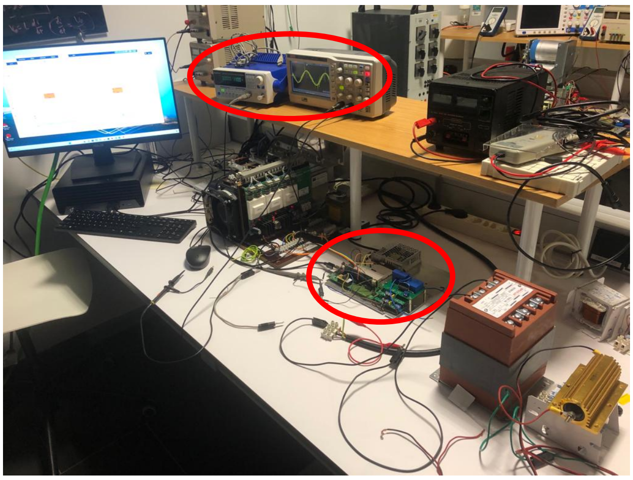


Fig.10. Experimental platform in the lab

In figure 11, the generated reference signal as well as the PWM signal at an output pin of the card is shown. This

PWM voltage signal is used in this work as the power inverter switching devices trigger signal. Thus, in this case, it is used a single-phase complete half bridge inverter, which is constituted by an only branch with two IGBTs supplied with a continuous voltage of 48 V. In figure 10, it is also shown the power inverter used in the experiment, in the middle of the figure, and the resistive (R) and inductive (L) load supplied by the power converter, at the bottom right of the figure.

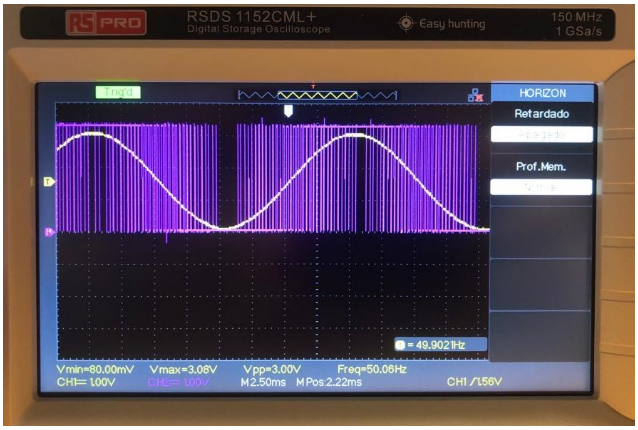
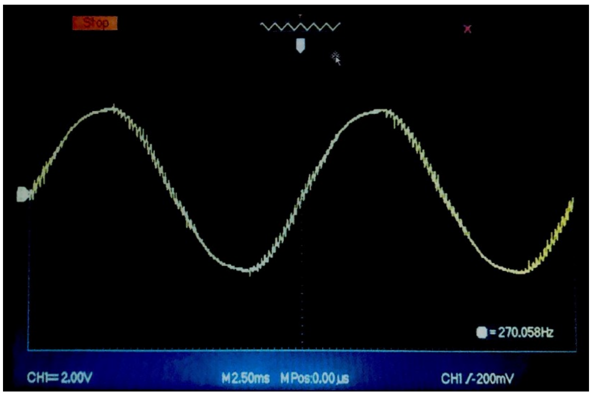
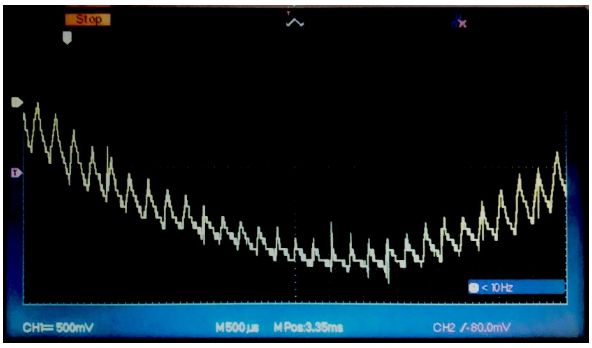


Fig.11. Reference signal and generated PWM

The PWM signal shown in figure 11 is used as the trigger signal of the IGBTs, implementing a voltage control in open loop. The current that flows by the RL branch is shown in figure 12, whose ripple depends on the values of R and L.



a)



b)

Fig.12. Measured current in the load resistor, a) complete period, b) zoom to see the signal ripple

5. Conclusions

In this work, a computer tool has been presented to control the process in real time, Embedded Code from Matlab Simulink. The way of installing the different applications required to program and use the Texas Instruments TMS320F28335 control card is described. In addition, the way of developing a program in Simulink to automatically generate the code with Embedded Code which is executed in the card in two different ways is also presented. The first way represents an autonomous execution in the card and the second one corresponds to an execution in the card supervised from Simulink.

A practical case has also been presented in this work, which is the development of a program to generate a sinusoidal waveform by means of a power inverter. It has been used to prove the validity of the used software for the signals processing and for the generation of control programs in real time. An additional advantage proved is that the programming of the microprocessor and the updating of the control is easier than with the card direct programming.

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