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Soft Starting of Three-Phase Induction Motor Using DSP Auto Coding and Power System Controllers (Digital Motor Controllers)

By

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Abstract:

Since the rapid development of the digital controller, such as Micro-Controllers (MC) and Digital Signal Processor (DSP), to replace the traditional analogue controller, their applications in the power system control are growing in fast pace. Several algorithms have been developed to achieve the best utilization of the digital controller. This is considered a major barrier facing the power engineers. Auto coding is a term used to express the translation of the high level model, which power engineer are familiar with, to a low level assembly code targeting a specific controller. In this paper, the authors present their experience dealing with the auto coding tools from MatLab targeting Digital Signal Processor (C2000 Family). Moreover, this paper walks through the steps and the most famous mistakes for converting the power system MatLab model to an assembly code for the DSP-C2000. The paper is using an induction motor controller as an example along with the practical laboratory results.

Keywords:

Voltage/ Frequency Control, DSP, Power Inverter, Soft Starting, Autocoding

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## 1. Introduction:

It is a challenge to implement the space vector control technique of induction motor using the traditional hardware that completely complex therefore, Digital Signal Processor (DSP) was born because of the intense computation for coordinate transformation and flux mode calculations [1]. Thus a few years ago due to the limit of the hardware, the researchers oriented their research to develop advanced control algorithm by using the DSP or the microprocessors [2]. The practical implementation of the space vector control technique is complex and Computationally intensive requiring the use of high-speed microcontrollers or digital signal processors (DSPs).

It is obvious that for a given digital controller, the computational burden will decrease as the fastest DSPs are used but too often design engineers are confronted with cost limitations. Then, the use of the fastest DSPs may not be cost effective. Most of the work reported on DSP implementations of the space vector control technique has mainly concentrated on the control technique [3-6].

Most of the motor controllers use the DSPs to generate PWM for driving the inverter IGBTs and to management the input/output control signals. Soft starting should be considered to comply with source power quality and additionally to avoid damaging of the IGBTs due to starting current that apply reduced voltage/frequency to the motor. By using the soft starting, the starting current surge can be reduced remarkably and many advantages like smooth acceleration control and energy savings with a light load can be available [7].

Figure 1 presents the soft starting with DSPs comparing with full voltage start with the traditional starting curve. It is clearly seen that a small reduction in voltage produces a considerable drop in starting torque, which may cause the motor with a load failure to start. Some soft starters have additional functions such as kick-start, but it cannot meet the need of enough starting torque of induction motors in Some conditions, e.g. a conveyor system. This implies that the traditional soft start method has limited applications where the starting torque requirement of the mechanical load is not high and the mechanical load is a function of speed, such as with fans or pumps.
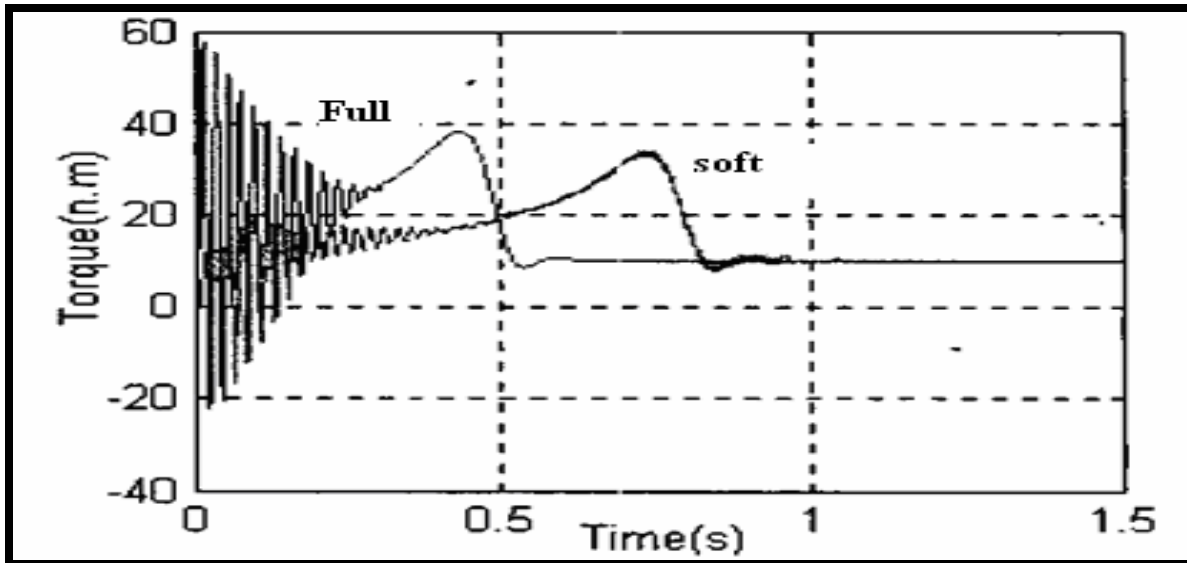
Figure (1): *Soft start using DSP comparing with full voltage start*
System Configurations

 Unfortunately, many induction motor applications have heavy loads at startup and the motor need to start with full loads. The traditional soft start method is a nonviable solution to such starting problem. The present paper investigates the different steps and some proposed solutions for the most famous mistakes for converting the Voltage/ Frequency 3-phase induction motor control algorithm using MatLab/Simulink model to an assembly code for the DSP- TMS320F2407A. Since the DSP-TMS320F2407A can operate at 40 MHz,

- it is possible that all the algorithms can be done easily within 20 KHz sampling frequency

- it improves the   ability of real-time current control, eliminates the noise produced by switching of the IGBT

- it reduces the effect of delay to the drive system

The paper is using an induction motor controller (DMC1500) as an example along with the practical laboratory results. The test bench is integrated inside the high voltage laboratory in the University of Waterloo using one DSP-TMS320F2407A evaluation module, DMC 1500 Power inverter and Balder Motor of 2 hp. The specifications of the DSP-TMS320F2407A and the DMC 1500 are shown in Table 1.

TABLE (1): DSP and DMC1500 Specifications

DSP-TMS320F2407A specifications:	DMC 1500 specifications:
128K words of external on-board SDRAM.	Compatible with the F240, F243, LF2407 DSKs, or EZDSP LF2407A from Spectrum Digital
On-board, 4-channel, 12-bit digital-to-analogue converter (DAC). XDS510 TM /XDS510PP emulation port	Allows development of algorithms for AC Induction, DC Brushless or Switched Reluctance Motors
Three 16-bit, 6-mode, general-purpose timers	Rated for Bus voltages of 350VDC
12 pulse-width modulation (PWM) channels A quadrature encoder pulse interface (QEP)	Rated current is 5 amps continuous and 10 amps Peak Onboard control power supply (115-230 VAC)
Dual 10-bit, 8-channel analog-to-digital converters (ADCs)	Onboard bus supply (Bridge + Capacitors + Voltage Doubler)
544 words of dual access RAM (DARAM)	Optically isolated digital I/O and Optically isolated RS-232 port

2. DSP Auto Coding Problems:

DSP auto coding is considered as an automatically software developer that converters high-level, hardware-independent language (graphic-based"Matlab/Simulink"), and translates this specification to lower-level, hardware-specific code (C-Code) control algorithms. Figure 2 presents a simple presentation of the main concept of the DSP auto coding versus the traditional coding. In spite of considering the DSP Auto Coding is simple in its applications, it needs a full knowledge and awareness of the different parameters of the applications under considerations. Specifically, here some of the

main tricks and the famous mistakes that could face some of the control algorithms developers will be focused on and on how to eliminate these tricks.
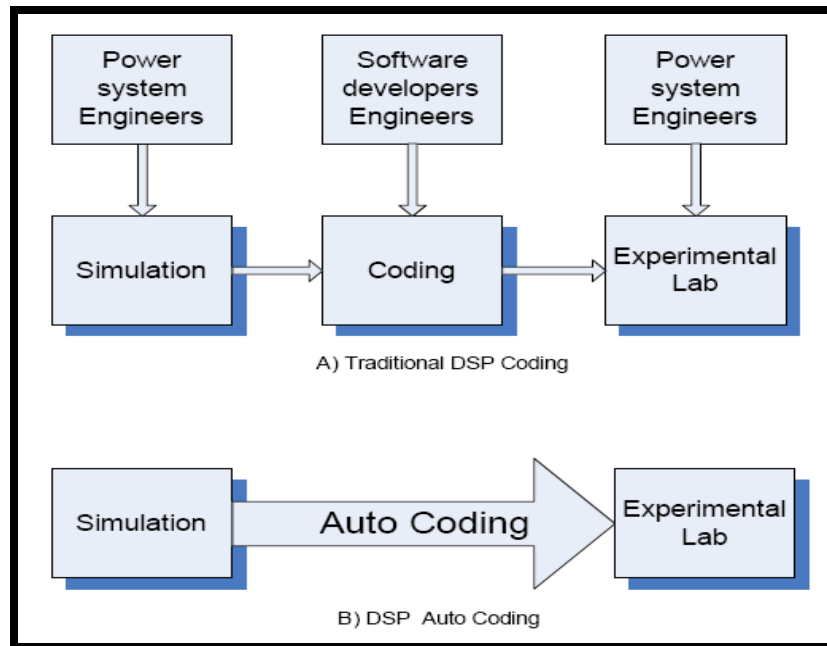

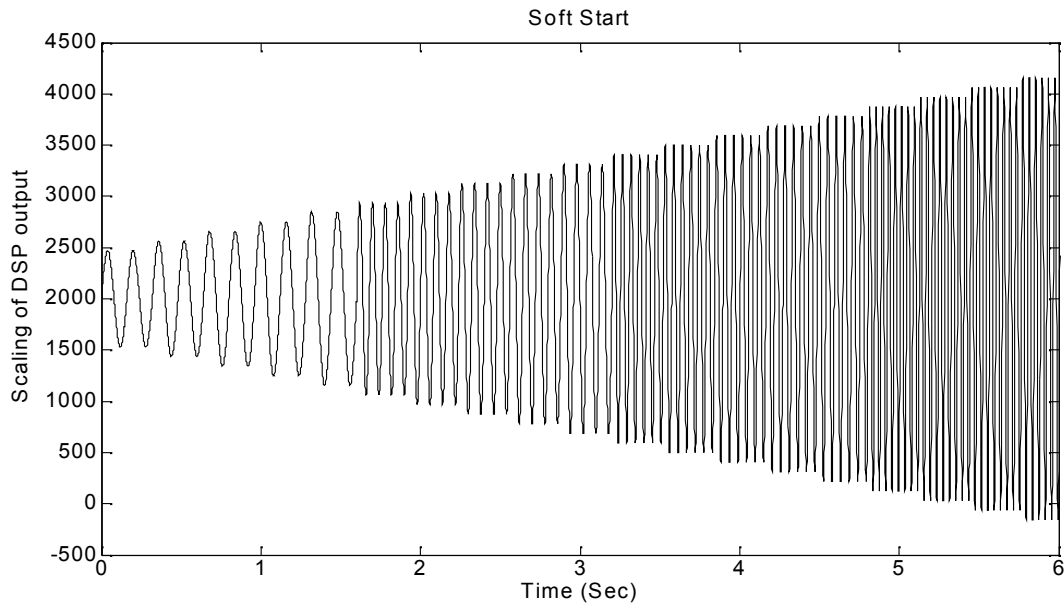*Figure (2): Traditional coding and auto coding steps.*

3. Auto Coding Algorithm and Results:

Voltage/Frequency control algorithm is developed to control the speed of a 3-phase induction motor with 2 HP, 1725 RPM and rated voltage of 230V. Figure 3 shows a simple presentation of the developed algorithm. Figure 4 present the typical developed simulink model which used to drive the inverter IGBT's gates. The used DSP was F2407 eZdsp. It can be noted that the acceleration pedal signal is processed with its integrated delay and feeding the lookup tables then compared with the ADC gain value and then added to the shift value for scaling then feed to the PWM generator feeding the different IGBT's gate drives. The results and the recommended steps to avoid any damage or to know exactly what is going inside the DSP black box will be investigated below

Algorithm steps:

For building algorithm using the DSP, the developer should be aware with the DSP full information as the DSP in this stage is considered as a black box. The major steps and the main tricks that should be considered during the coding are summarized as:

Figure (3): *Simple presentation of the developed algorithm*

Figure (4): *Typical presentation of the developed algorithm*

Soft starting:

Figure 5 presents the algorithm output result for the soft starting. It can be noticed that the DSP will generate increasing output signal that will control the power inverter output line voltage to avoid any sudden line voltage application. During the first six second the line voltage will increase according to the frequency increasing as shown in Figure 5

Figure (5): *DSP signal to increase the power inverter line voltage gradually*

Scaling:

As well known that the DSP signal changes from 0 to 5 volt, so to generate alternating scaling signal, a scaling factor should be considered. Figure 6 shows power inverter scaling factor to control the increasing of the power line voltage. The most famous mistakes and tricks and its solutions recommendations that could face the algorithm's developers are summarized in Table 2.
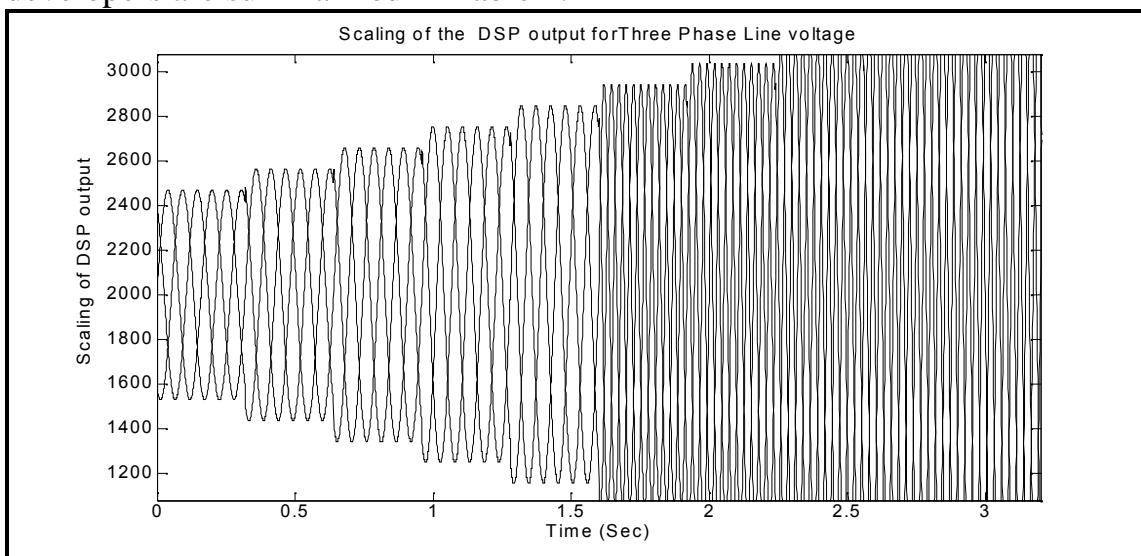
***Figure (6):*** *Frequency increasing to control the power inverter line voltage gradually*

TABLE (2): Algorithm Tricks and recommended solutions

| Algorithm Tricks	Recommended Solutions
Motor Parameters	Should be full known and adjusted in the algorithm to avoid any oscillation due to the transient response period
Math Resolutions	Should be adjusted to 16 or 32 bit as the DSP
Soft Starting	Should be added to avoid high starting torque/current
External Enable	Should be added to avoid any sudden injecting the PWM across the IGBTs gates.
Limits of the applied Voltage/Frequency	To put the limits of upper and lower voltage limits to avoid any risks comes from the DC Bus voltages
Speed Ramp	V/F ratio should be gradually increased to avoid sudden full load current
Scaling	Should be considered to get -/+ sine wave half cycles.
Dead Band	Should be adjusted to avoid short circuits across IGBTs in the same limb.

Dead Band:

Figure 7 presents the output result that should be delivered to the IGBT's gate drive circuits. It is monitored using four-channel Oscilloscope. As can be noticed that each pair of gate signal is fed to each Limb in the power inverter so there is no noticeable overlap between each of them. Therefore, the dead band should be considered carefully to avoid any short circuits in the power inverter. Figure 8 presents the inverter output line voltage and current. It is monitored using four-channel Oscilloscope. As can be noticed that the output voltage is close to be sinusoidal and the line current is as well.
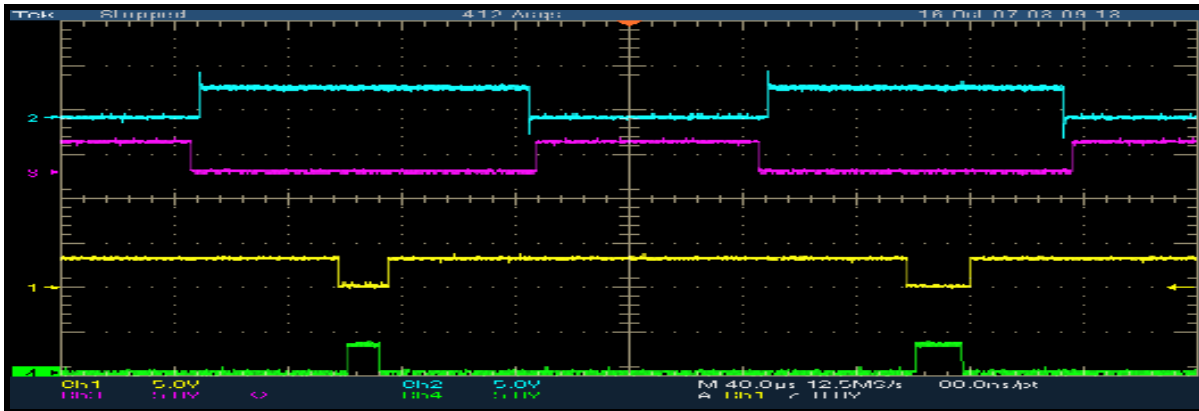
Figure (7): *The DSP output for the IGBT's gate drive circuits for each limb in power inverter (shown two limbs only).*
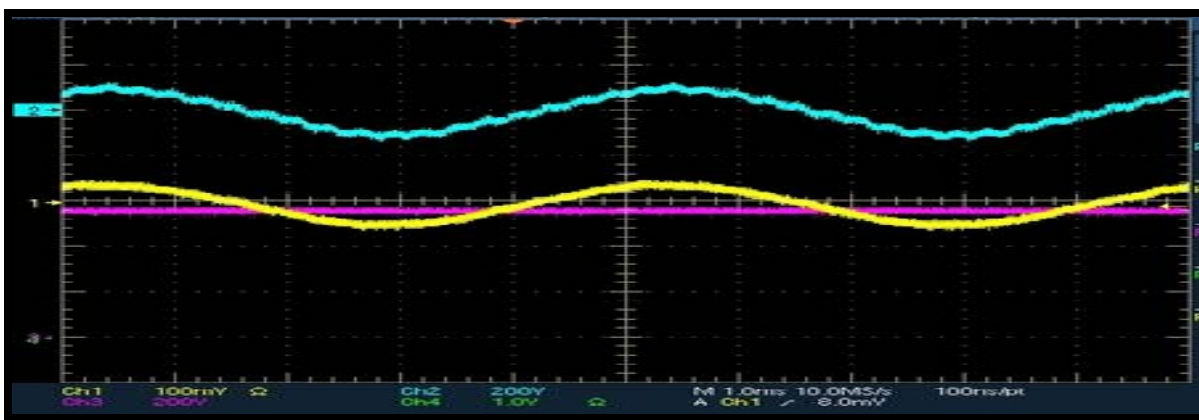
Figure (8): *The inverter output line voltage and current based on the DSP output feeding the inverter control circuit of the IGBT's gates.*

4. Conclusions:

A model for a Voltage/Frequency control algorithm used in EV using Matlab/Simulink is achieved to control the soft starting of three phase induction motor which is the major element in the electric drive system in the electric vehicles. The developed control algorithm was trained and test in a test bench model. The implementation and integration of the DSP and the DMC1500 was fully succeeded using the Pulse Width Modulation (PWM) techniques. The model gives a good result during starting up drive cycle. This model is effective and simple in use to investigate the DSP applications for three phase induction motor speed control. Moreover, the solutions of some famous Mistakes and tricks were presented.

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