Speed Controlled Industrial PMSM Servo Drive with Model Based Embedded Coder: Code Performance Analysis and Comparison

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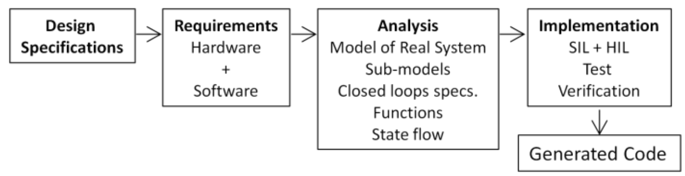
***Abstract*—This paper presents the design of speed controlled industrial permanent magnet synchronous machine (PMSM) servo drive via model based (MATLAB/Simulink) embedded coder with performance analysis and comparisons of the generated code. Design aspects in MATLAB/Simulink side for stable code generation are investigated and reported. Critical settings and code optimization strategies are suggested. Detailed comparisons have been made by deriving alternative scenarios. Also, generated code from MATLAB/Simulink is compared with ready to use code provided by Texas Instrument - Code Composer Studio. Designed field oriented control (FOC) based, speed controlled model is implemented on Texas Instruments C2000 Design Drive Development Kit for Industrial Motor Control (TMDXIDDK379D), TMS320F2837xD Dual Core Microcontroller and 400W Siemens Simotics S-1FL6 PMSM servo motor.**

***Index Terms*—Embedded Software, Automatic Code Generation, Programmable Control, Servo Systems, Velocity Control.**

I. Introduction

EMBEDDED systems have become an essential in many technological products that we can define as automatic. Automatic motor control and drive applications are most common in electromechanical designs. The more functions (linear or non-linear) of the electromechanical system, the more complex the software becomes. In this case, programs that generate embedded code through visual design have become more attractive than directly writing thousands of lines of code one by one. However, in model-based designs, it is important to pay attention to the harmonious design of subsystems such as sampling time of them, closed loop bandwidths (synchronization), modulation frequencies, transaction/calculation complexity, interrupt timings, filters and compensators.



In the literature, the simulation program MATLAB/Simulink is the most widely used model-based design program. It saves time and money in creating model of control structures of DSP or FPGA based electromechanical systems [Hercog - radim]. This simulation environment supports both the motor models, the driver and the control elements found on the market or custom designed [nourdine – Bogdan alecsa]. In fact, it is possible to design the basic mathematical equations that model the dynamics of the discrete time system to be designed in blocks and to translate this design into an embedded software language with "Embedded Code Generation" packages [morkoc-mehta-kivanc].

But we do not know how efficient these packages produce code or what are their technical advantages over handwritten code.

II. Mathematical Models

Control and drive of the system are managed by using electrical and mechanical mathematical model of the PMSM servo. Control operation is done by using linear PID controllers and dead time compensator. Driver side is working with respect to Field Oriented Control (FOC) principle and space vector PWM (SVPWM) technique.

A. *PMSM Mathematical Model*

There are two types PMSM as known as surface mounted magnet (SPMSM, $L_d = L_q$) and internal mounted magnet (IPMSM, $L_q > L_d$). The general electrical equations with respect to stationary rotating $d-q$ reference frame are given in eqs. (1-2).

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$$\frac{di_d}{dt} = \frac{1}{L_d}\left(v_d - r_s i_d + \frac{P}{2} L_q i_q w_r\right) \tag{1}$$

$$\frac{di_q}{dt} = \frac{1}{L_q}\left(v_q - r_s i_q - \frac{P}{2}\lambda_m w_r - \frac{P}{2} L_d i_d w_r\right) \tag{2}$$

The state space representation of PMSM equation set is given in eqs. (3-4)

$$\frac{d}{dt}x = Ax + Bu \rightarrow \quad \frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = A\begin{bmatrix} i_d \\ i_q \end{bmatrix} + B\begin{bmatrix} v_d \\ v_q \\ \lambda_m \end{bmatrix} \tag{3}$$

$$A = \begin{bmatrix} -\dfrac{r_s}{L_d} & -\dfrac{P}{2}\dfrac{L_q}{L_d}w_r \\ -\dfrac{P}{2}\dfrac{L_d}{L_q}w_r & -\dfrac{r_s}{L_q} \end{bmatrix} \quad B = \begin{bmatrix} \dfrac{1}{L_d} & 0 & 0 \\ 0 & \dfrac{1}{L_q} & -\dfrac{P}{2}\dfrac{w_r}{L_q} \end{bmatrix} \tag{4}$$

The mechanical mathematical model of PMSM is given in eqs. (5-6)

$$\frac{dw_r}{dt} = \frac{1}{J}\left(T_e - T_L - Bw_r\right) \tag{5}$$

$$T_e = \frac{3}{2}\frac{P}{2}\left(\lambda_m i_q + \left(L_d - L_q\right) i_d i_q\right) \tag{6}$$

Where, the used parameter definitions are given in following Table 1.

TABLE I
SERVO DRIVE SYSTEM MAIN PARAMETERS

Electrical Parameters	**Mechanical Parameters**
r_s : Series resistance	T_e : Electromech. torque
L_d : d-axis inductance	T_L : Load torque
L_q : q-axis inductance	J : Rotor and load inertia
λ_m : PM flux linkage	B: Viscous friction coefficient
P : Pole number ($P/2$: Pole pairs)	

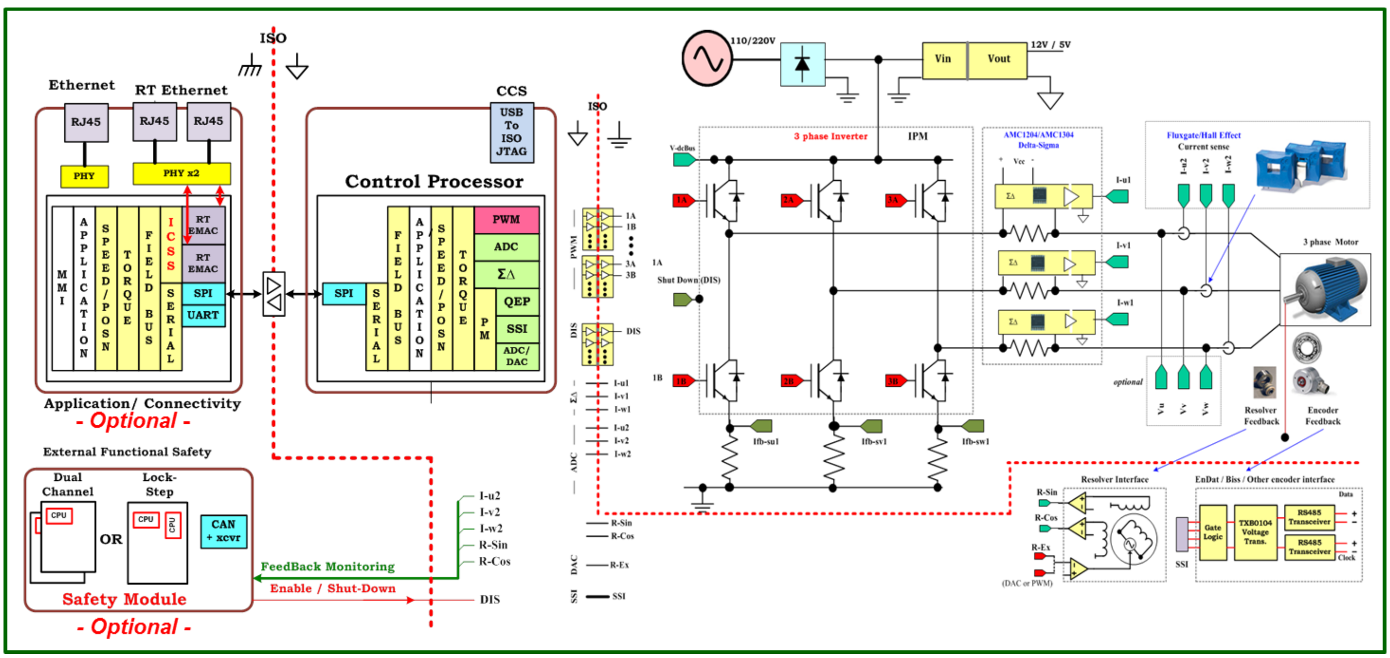


Fig. 1. IDDK controller and driver architecture

B. *Controller and Driver Structure*

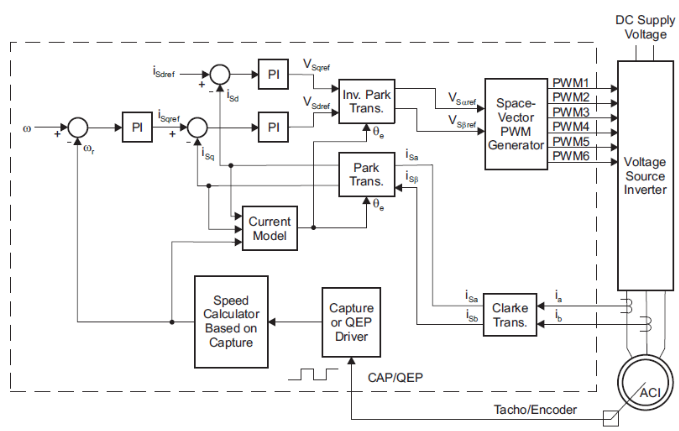
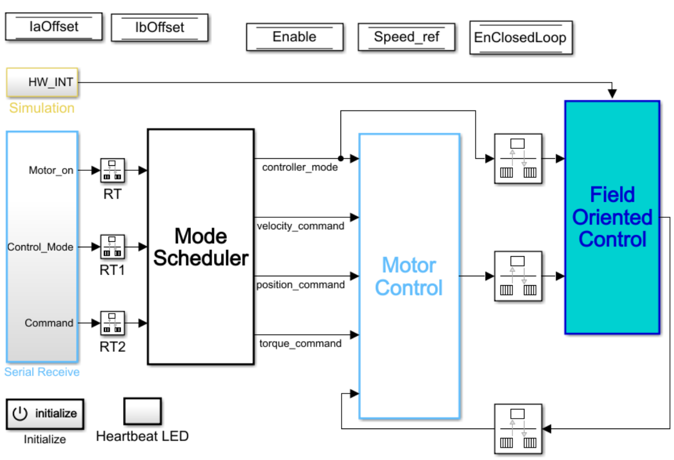


Figure 9. Overall Block Diagram of Indirect Rotor Flux Oriented Control

Fig. 2. TI IDDK and 379D DSP board

III. Controller and Drive in MATLAB/Simulink



A. Equations

Number equations

IV. Hardware Architecture

Use either

V. MATLAB/Simulink Embedded Coder Aspects

in accordance with the standard MISRA C (2012)

- Execution Efficiency
- ROM and RAM Efficiency
- Traceability
- Safety Precaution
- Debugging

2 scenarios for MATLAB/embedded coder:

1- Standard designed code
2- Optimized code vs. TI ready to use code

VI. Code Performance and Comparisons

A. Code Performances

The following list emphasizes the code performance of the industrial servo drive.

TABLE I
Code Performance Results

Performance Measurements	TI ready to use code	MATLAB/Embedded code
PWM measurements		
Phase Currents/Volts		
DC link		
Thermal stress on DSP		

B. Code Comparisons

Figures compiled

TABLE 2
Code Comparison

Compared Parameter/ Variable	TI ready to use code	MATLAB/Simulink Standard Embedded code	MATLAB/Simulink Optimized Embedded code
Code Size			
Lines of Code			
Complexity			
Execution time			

VII. Conclusion

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion.

Appendix

Appendixes, if needed, appear before the acknowledgment.

Acknowledgment

The 2244 project Tübitak

References

J. K. Author, "Title of chapter in the book," in *Title of His Published Book*, *x*th ed. City of Publisher, (only U.S. State), Country: Abbrev. of Publisher, year, ch. *x*, sec. *x*, pp. *xxx–xxx*.

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