

Based on FPGA Method to Design and Implement for Induction Motors Drive System



Shyh-Shing Perng¹, Ter-Feng Wu¹, Maoh-Chin Jiang¹, Chih-Wen Li¹, and Yi-Ru Jiang²

¹Department of Electrical Engineering, National Ilan University
Yilan 260, Taiwan, ROC
{ssperng, tfwu, mcjiang, cwli}@niu.edu.tw

²Taipei Municipal Muzha Vocational High School
Taipei 116, Taiwan, ROC
p0141004@ms.niu.edu.tw

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Abstract. Induction motor is currently the mainstream in industrial motion control and is frequently used in industrial mechanics, precision automation, electric vehicles, etc. The global market scale of induction motor drive industry has reached billions of dollars and is increasing with an annual growth rate of 15%. In response to industrial needs, it is a trend for universities to establish theoretical and experimental lectures of motor drive control, in order to nurture domestic talents. “Control of Electrical Drives” is a subject that combines Electrical Machinery, Power Electronics, Control Systems, Sensor Technology, Applications of Microprocessor and System-on-chip. Since it contains so many different disciplines, it is difficult for students to absorb. One crucial factor that determines the learning result is the construction of suitable teaching materials and experiment devices. The experimental platform constructed in this article is a digital motor drive system based on FPGA (Field Programmable Gate Array). All the experiments of electrical drives are proceeding in the environment of SIMULINK. The results can be directly copied and used by various control icons of different functions, making it easy to test and verify the theories and experiments of motor controls. Thus, the barriers to learning can be reduced and the time for students to debug can decline.

Keywords: FPGA, induction motors, SIMULINK

1 Introduction

Control of Electrical Drives is the mainstream of the current industrial motion control. It can be seen in general industrial machinery, precision automation machinery, electric cars, railway, etc. So far, the business opportunity of global motor drive industry has reached billions of U.S. dollars, with an annual growth rate of 15%. In response to the industrial demands, it is the trend to set up the control of electrical drives theory and experiment courses in colleges and departments of electrical engineering [1]. If the undergraduates of department of electrical engineering could receive related implement training at school, it would significantly reduce the costs of R & D and personnel training for companies.

For students of electrical engineering, who have had the basic knowledge of control of electrical drives, the greatest difficulty lies in the realization that meets the industrial demand. In some circumstances, with a chosen DSP chip and completed hardware, students still don't know how to implement. In order to do so, students need to understand and apply central processing unit, memory allocation, peripheral components, interrupt mechanism, time series planning, assembly language, development environment, linking, etc. However, students can only access to information like the English website of the chip manufacturers, manuals, and the project-based textbooks published by the domestic publishers. These resources are all difficult to absorb, which leads to the result of ineffective learning. The graduate students can do the time-consuming exploration on their own, but this method is rather impossible for the

undergraduates. Consequently, “Control of Electric Drives” became a daunting discipline for students.

“Control of Electrical Drives” is a subject that integrates electrical machinery, power electronics, control systems, sensors and transducers, application of microprocessor and single chip. Since it covers multiple disciplines, the teaching materials should be carefully selected and integrated. The experiment equipment should also be properly developed. The commonly seen laboratories in Departments of Electrical Engineering are electrical machinery lab, power electronics lab, microprocessors lab and system-on-chip lab. However, for these laboratories, it is difficult to construct a motor drive control experiment system with control software. This is the main obstacle that universities are facing when setting up the “Control of Electrical Drives ” course.

In order to solve this difficulty, multiple literatures are contributed to the improvement of equipment for the lessons and curriculum planning. For example, Mok showed how to construct a DC motor drive system by utilizing 3D simulation software to provide a more accurate and interesting learning environment [2]. Ayasun used the MATLAB / SIMULINK software to simulate the three-phase induction motor in a no-loaded and blocked experiment, in order to obtain the parameters of single-phase equivalent circuit model [3]. Blanque established an experimental platform of the reluctance motor drive system, together with the theoretical and experimental curriculum planning [4]. Montesinos came up with the experimental platform of a DSP-based, brushless DC motor drive system, and the related curriculum planning [5]. Rodriguez-Resendiz has implemented a servo system laboratory course in a LabVIEW environment [6]. Anand. has developed a “Power Electronics and Drives Experimental Bench” (PEDEB). By using the PEDEB, we can observe and learn an induction motor drive [7].

In the last decade, with the progress and development of ultra large scale integrated circuits (ULSI), the synthesized analog circuit has gradually been replaced by the more flexible microprocessor (μ P) and digital signal processing (DSP). Sometimes, it is even replaced by the Embedded Development Kit (EDK) based on FPGA chips [8], to implement the high-performance motor drive system control. This provides the programmable hardware and software which have better flexibility. Students, who study the DSP and FPGA chip of motor drive control system, would need to verify the feasibility and system performance. Generally, they would apply the motor drives which include the inverter, motor, sensors and load system, as shown in Fig. 1.

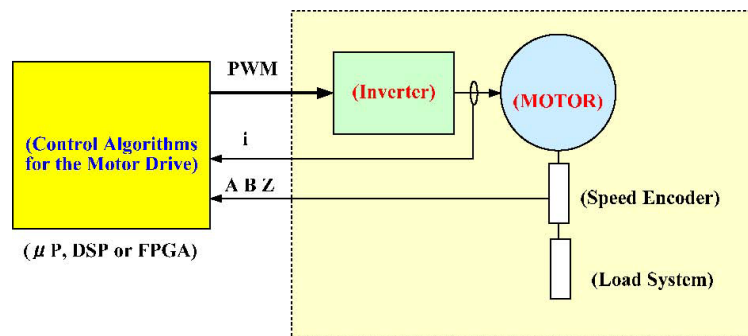


Fig. 1. Simplified block diagram of motor drive control system

FPGA can dramatically reduce processing time and effectively increase the performance and practicality of the digital control system. Therefore, in recent years, FPGA is often used as the hardware foundation of the motor drive systems. Lots of papers proposed various control algorithms or programs to be applied in the design of FPGA. For example, Zhao substituted FPGA for expensive DSP to accomplish the control of SRM [9]. Milivojevic implement the space vector pulse width modulation (PWM) method by a FPGA chip [10]. Nekoei use the FPGA chip to complete the induction motor vector control [11], and Sutikno utilize the FPGA chip to complete the Direct Torque Control (DTC) [12].

Address to these issues, this paper constructs an induction motor drive system experimental platform. It is a digital motor drive system based on FPGA. By using the S-function in the SIMULINK environment to create a block diagram, we can carry out all adjustment of parameters of the module program and system testing in the human-computer interface. It can significantly simplify the design process of the induction motor drive system.

2 The Experimental Platform of Induction Motor

The control of electrical drives experimental platform, constructed in this paper, uses the FPGA chip as the control center. We created a complete digitized induction motor drive system. It can be divided into four main parts as shown in Fig. 2. Fig. 3 shows the appearance of the experimental platform for the motor drive system.

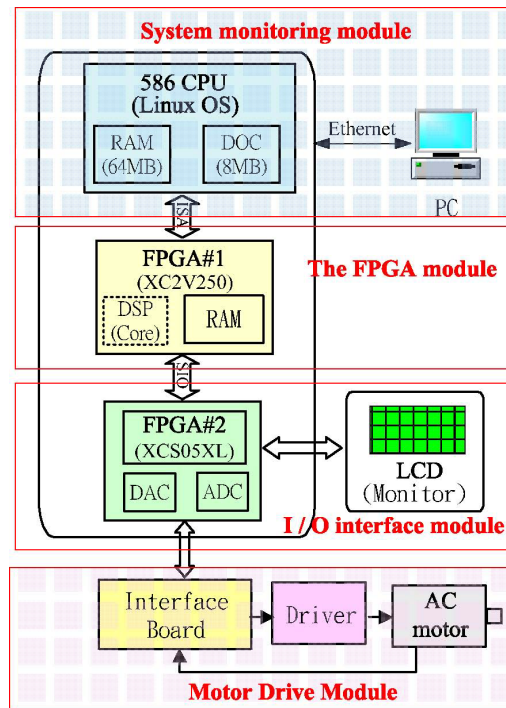


Fig. 2. Induction motor drive system experimental platform block diagram

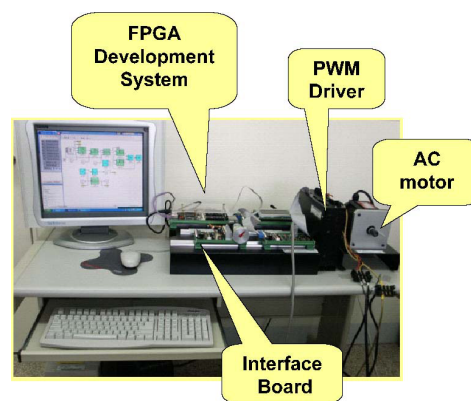


Fig. 3. Photo of the induction motor drive system experimental platform appearance

2.1 System Monitoring Module

It includes 586CPU, 64MB of memory RAM and an 8MB disk-on-chip (DOC). Thus, the platform can be connected with PC through the Internet to execute programs, monitoring and managing.

2.2 The FPGA Module

The FPGA module is the control center of the motor drive system experimental platform. It consists of a large-scale programmable logic gate FPGA # 1 which uses the Xilinx product XC2V250 of Virtex-II series. Any application, written in VHDL language on a PC, can be downloaded into the FPGA for

implementation testing and verification. This experimental platform has implanted a 16-bit DSP core in the FPGA, responsible for real-time control. This DSP core, constructed by software, is designed for controlling. Thus, the assembly language concisely plans 29 instructions according to different controlling conditions. By using these 29 instructions in programming, we can eliminate the traditional DSP chips in applications. The DSP core and the 586CPU are directly connected by dual-port memory, with the sampling frequency up to 32 KHz. All data and programs within DSP can be read, wrote, setup and managed by 586CPU.

2.3 I / O Interface Module

The I / O interface module contains eight channels of 12-bit ADC, four channels of 12-bit DAC and a smaller FPGA # 2, which satisfies the requirement of analog output in the interface design for the system. Induction motor experiment module can only be connected with the FPGA # 2. Thus control of I/O interface of FPGA # 1 must be done through FPGA # 2.

2.4 Motor Drive Module

The motor drive modules include servo interface, power driver, and motor, as shown in Fig. 2. The servo interface can generate six sets of PWM control signals, in order to control six power switches in the driver. It includes the switch protection and startup protection in order to control the motors. The current sampling signals of A / D and angle feedback signal both maintain 12-bit resolution.

3 Data Structural of Induction Motors Drive System

Generally, the motor drive system design can be divided into two categories, the software method or the hardware method, according to the implementation of digital control programming. For the software method, we first design the DSP core in FPGA [13]. Then, we design the motor driver control software for the DSP core. The controlled method is implemented by software execution. Another method is the direct implementation of hardware circuit. We directly design logic circuits in FPGA to implement the motor drive. In comparison, the software method has more flexibility since the control structure and internal parameters are easier to be modified. The hardware method is relatively more rigid, due to the restriction that any control framework changes must also include the modification of the hardware circuit. Thus, in a control structure that is not yet confirmed, it is difficult to design a hardware circuit. Our experiments will base on software design. We will use S FUNTION in the SIMULINK environment to generate block diagrams, so that all adjustments of parameters in the module program and system testing can be carried out in the man-machine interface provided by SIMULINK. This would greatly simplify the motor control experiment design process, as shown in Fig. 4. All data in DSP core is saved in the memory. Via reading, writing, operating and managing the memory, we can control the entire operation of the DSP core. Through the connection interface between the FPGA # 2 and servo interface, we can input signals of the servo interface feedback current, motor speed, etc. into a specific memory. Once the system program is compiled, we can download the circuit file into the FPGA # 1 and FPGA # 2. We also download the machine code and microcode file into the DSP core of the FPGA # 1. Then, we can start testing and monitoring the system. In addition, through the ISA-bus, 586CPU can both read and write all data in the DSP core, I/O interface area, data area, program area, micro-code and stack information in FPGA # 1, for testing and monitoring the digital data of the experiment system. Also, we implanted oscilloscope and logic analyzer functions in the LCD monitor module, which can monitor real-time waveform of the experiment system action.

4 Building the Motor Drive Control Box Module

SIMULINK is a simulation tool established under the MATLAB environment, which provides multi-graphic function blocks. Users can conveniently link to or establish a control system block diagram, for the simulation or experiment. This can significantly simplify the design process, and reduce designers' burden. The most important feature is that, we can establish a user-defined function block with a strong scalability by using the S-FUNCTION. At the same time, we could be able to communicate with

applications of file type *.dll, to achieve integration and application. In this paper, we use the S-FUNCTION to establish the corresponding block, so that the links of the system programs, the adjustment of parameters of the module program and system testing and monitoring can all be completed in the man-machine interface provided by SIMULINK.

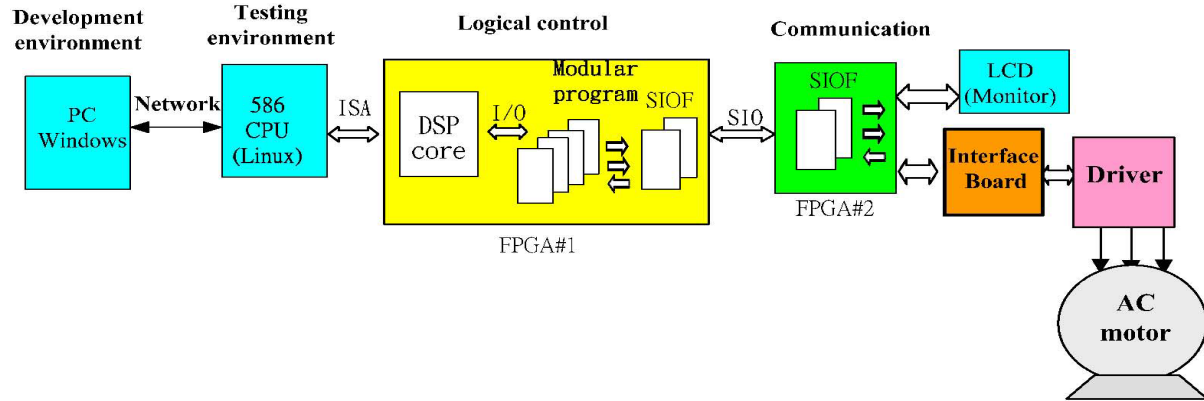


Fig. 4. Data structural of the induction motors drive system

4.1 The Module Program for Constructing Control box

The module program of each control block is written in assembly language. The data structure of the modular program is shown in Fig. 5, which each program is a subroutine structure and end with the RET instruction. When the system executes real-time control program after links to multiple modules, it will automatically calls the relative procedures by turns. After all modules have been executed, the system would then return control power to other programs. Fig. 6 shows a flow chart of the module program for the system to perform real-time control.

```

@global  .... ;           // Defines the public variable
@local   .... ;           // Defines the modular variable
@data    .... ;           // Defines the segment length of modular variable
@table   .... ;           // Defines the database table
@initial: ....           //@initial subprogram, setup initial parameter values
RET;     //The RET instruction terminates the subprogram
@stop:   ....           //@stop subprogram, set security shutdown
RET;     // The RET instruction terminates the subprogram
@timer:  ....           //@timer subprogram, periodic real-time control process
RET;     // The RET instruction terminates the subprogram
@doloop: ....           //@doloop subprogram
RET;     // The RET instruction terminates the subprogram
    
```

Fig. 5. Simplified block diagram of motor drive control system

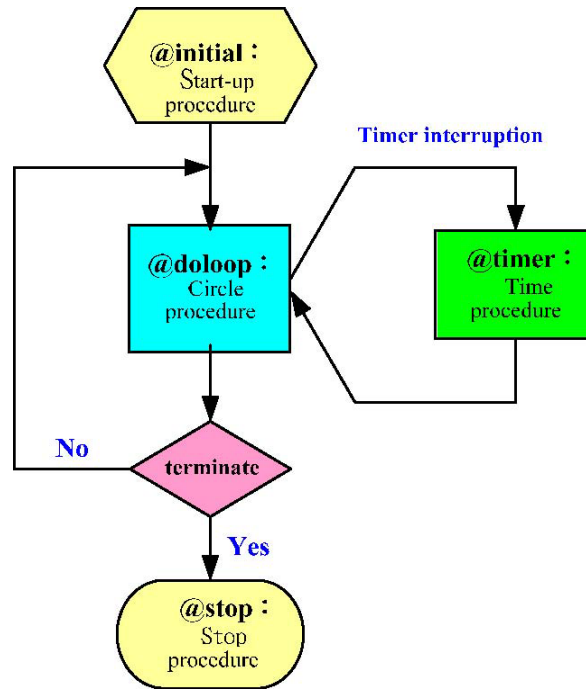


Fig. 6. Flow chart of the real-time control of module program

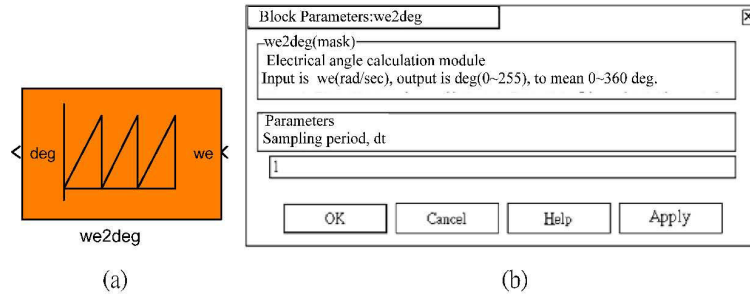
4.2 Create a Module Program Corresponding to the SIMULINK Control Block Diagram

Programs completed according to the data structure of the modular design mentioned above, uses S-FUNCTION to create corresponding graphical box. Fig. 7 shows an example of graphical block module program. Fig. 7 (a) is the corresponding control block diagram of S-FUNCTION. Fig. 7 (c) is the window for the parameter adjustment and Fig. 7 (c) shows the original assembly language of module program. This module function is for the calculation of the motor rotation angle, where the input signal is the motor angular velocity and the input signal is the motor rotation angle. We use an integer from 0 to 255 to represent the motor rotation angle from 0 to 360 degrees. Transforming the formula above to a discrete relationship can be expressed as, in which is the discrete sampling time.

The motor control block diagrams, of various functions constructed under the SIMULINK environment, can be shown in Fig. 8. In the SIMULINK environment, we can select the desired control block diagram, complete the input and output connection of the system and control parameter settings. After that, we can conduct the system testing, making the motor-driven experiments as easy and convenient as circuit simulation.

5 Implementation of FPGA-Based Induction Motors Drive System

Generally, current high-performance induction motor drive system uses the vector control technology [14]. Fig. 9 is a block diagram of the AC induction motor vector control. The basic concept of the AC induction motor vector control technology is to transform the current signal of the motor to a coordinate system of the synchronous speed by using coordinate transformation. Then, through the decoupling control, it can divide into two equivalent and mutually perpendicular current component. One is equivalent to the field current, and the other is equivalent to the torque current. We can control the magnitude of the magnetic field current component and torque current component by adjusting the magnitude, phase and frequency of the induction motor three-phase stator current. Moreover, we can control the rotation speed and output torque of the AC induction motor to achieve high performance similar to the control of DC separately excited motor.



```

File : we2deg.asm

@local we R0 IP gnd; //Input point, electrical angular frequency we(rad/sec)
@local out R1 OP; // Output point, electrical angle deg(0~255) to mean(0~360° )
@local dt R2 1; // Sampling time
@local prd R3; // Internal variable
@local tmp R4; // Internal variable
@local sumL R5; // Internal variable
@local sumH R6; // Internal variable
@local rad R7 333; //Constant variable (rad=65536*0.000125*255/(2*pi)=333)
@local gnd R8 0; // The ground point
@data 9; // Length of module variable
@initial: //***** Starting program *****
RD #0; WR out; WR sumL; WR sumH; WR prd,#1; RET;
@timer: //***** Real-time control program *****
SUB prd,#1; JNZ b9; //if (-prd>0) return
RD dt; WR pr d; //prd=dt
MUL rad; WR tmp; //tmp=dt*333
RD (we); SGN; SFR 6;MUL tmp; // we (Q6=2^6 )
ADD sumL; WR sumL; //sumL=(we)* tmp +sumL
RD.H; ADC sumH; //sumH+=sumL
AND #255; WR sumH; WR out; //out=sumH
b9: RET;
    
```

(c)

Fig. 7. Under the SIMULINK environment, (a) establish the control block diagram corresponding to S-function, (b) parameter adjustment window, (c) the source assembly language of module program

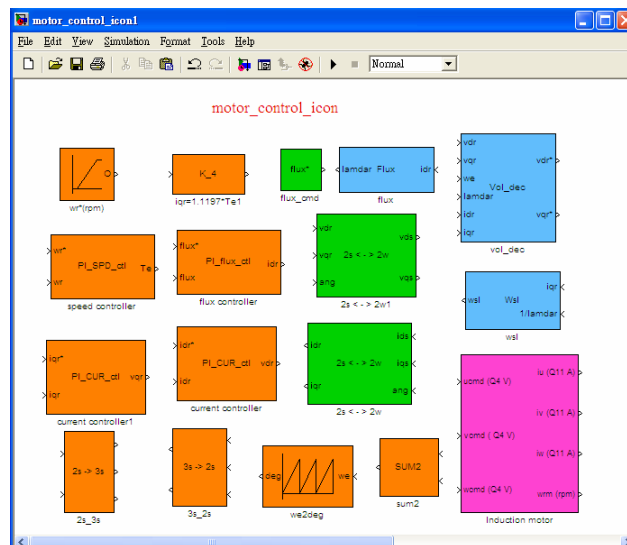


Fig. 8. The motor control block diagrams constructed under the SIMULINK environment

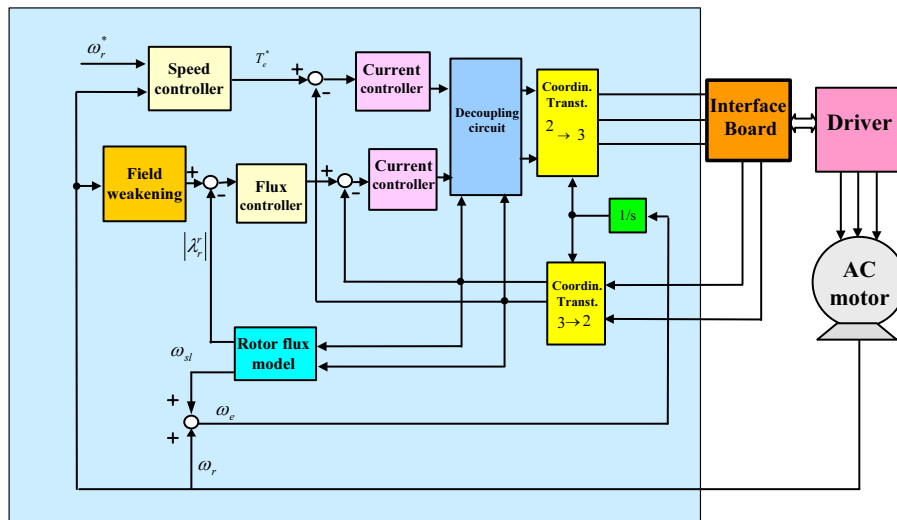


Fig. 9. Block diagram of the AC induction motor vector control

Fig. 10 is the system block diagram of induction motor vector control experiment, designed and accomplished under the SIMULINK environment. The system uses the 16-bit integer arithmetic and powers of two scaling, also known as radix point-only scaling [15]. The voltage signals use the Q4 mode, the flux and current signals use the Q10 mode, and the speed signals use the Q6 mode.

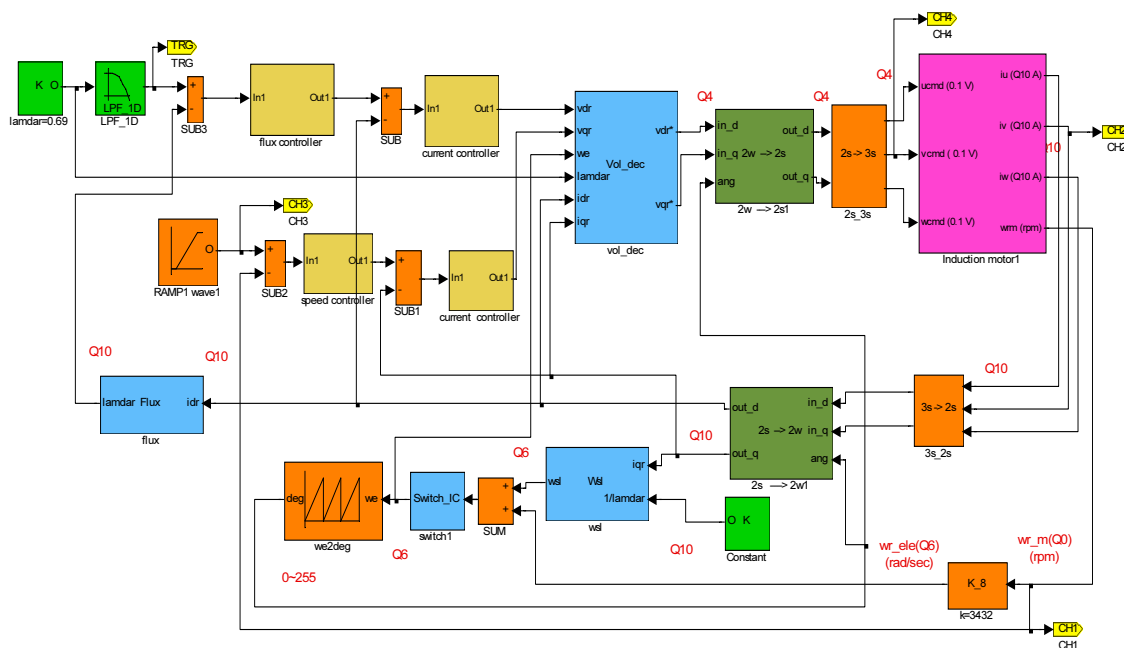


Fig. 10. The induction motor vector control experiment system designed and accomplished under the SIMULINK environment

The controlled motor used in the experiment is the TECO 220V, 1Hp, three phase AC induction motor, system power-level DC Bus voltage is 280V, and the work sampling frequency is 8KHz. After started, the system first establishes magnetic flux of the d-axis, and adds the 500RPM the speed command at the 0.5 seconds. Fig. 11 shows the experiment result waveform of induction motor vector control. Fig. 12 shows the response waveform of simulation results. According to the simulation and experimental results, we found that the measured current and speed waveforms were almost identical to the simulation results. We can conclude that the theoretical and experimental results perform mutual authentication.

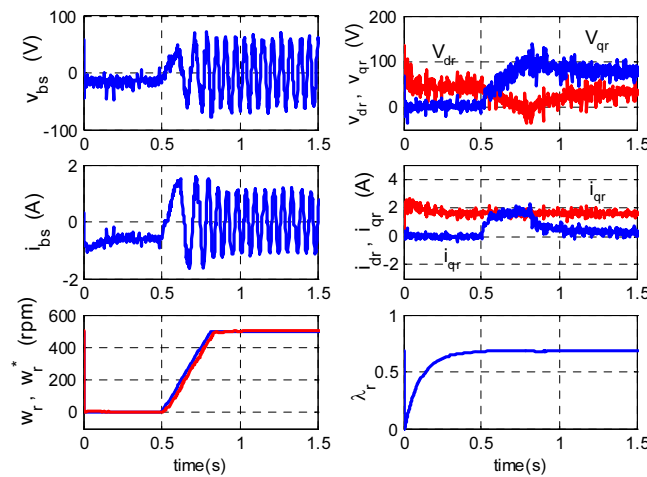


Fig. 11. The experiment result of induction motor vector control

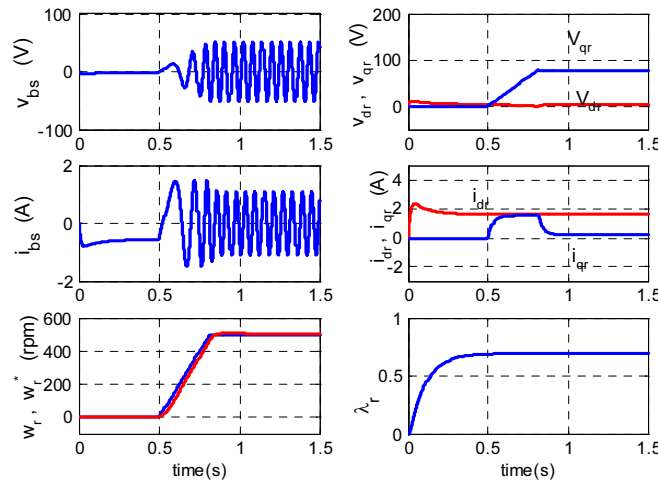


Fig. 12. The simulation result of induction motor vector control

5 Conclusion

The induction motor drive system experimental platform, established in this article, is a digital motor drive system based on FPGA. The advantage of this experimental platform is that all the motor drive control experiments are completed in the SIMULINK environment, where the implemented control block with various functions can be directly copied and used. It makes the verification of motor drive control theories and experiments simple, and reduces debug time for beginners. Meanwhile, in the SIMULINK environment, we can easily see the direction of signals by the system block diagrams, which help the students to debug and deepen the understanding of the theory. It can be used in universities to verify control of induction motor drives experiments with theories. It can also provide reference for R & D personnel devoted to the FPGA chip design for control of induction motor drives.

Acknowledgement

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References

- [1] C.M. Chan, Control of Electrical Drives Theory and Experiments, New Wun Ching Developmental Publishing, Taiwan, 2003.
- [2] H.S. Mok, J.H. Lee, G.H. Choe, S.H. Kim, D.J. Yun, 3D education system of DC motor drive using RecurDyn and CoLink, in: Proc. Power Electronics, ICPE'07, 2007.
- [3] S. Ayasun, C.O. Nwankpa, Induction motor tests using MATLAB/SIMULINK and their integration into undergraduate electric machinery courses, IEEE Transactions on Education 48(1)(2005) 37-46.
- [4] B. Blanque, P. Andrada, J. Lopez, An education and research prototyping platform for switched reluctance motor drives, in: Proc. the Power Electronics and Applications, 2007.
- [5] D. Montesinos, S. Galceran, A. Sudria, O. Gomis, A laboratory test bed for PM brushless motor control, in: Proc. the Power Electronics and Applications, 2005.
- [6] J. Rodriguez-Resendiz, G. Herrera-Ruiz, E.A. Rivas-Araiza, Adjustable speed drive project for teaching a servo systems course laboratory, IEEE Transactions on Education 54(4)(2011) 657-666.
- [7] S. Anand, R.S. Farswan, B.G. Fernandes, Unique power electronics and drives experimental bench (PEDEB) to facilitate learning and research, IEEE Transactions on Education 55(4)(2012) 573-579.
- [8] C.M. Chan, C.H. Yeh, S.S. Perng, Design of VHDL-based electrical drive simulator on chip, in: Proc. the 27th Symposium on Electrical Power Engineering, 2006.
- [9] K. Zhao, L. Su, W. Wang, M. Wang, Arithmetic and implementing on indirect position detecting of SRM based on FPGA, International Conference on Computer Engineering and Technology 3(2010) V3-96-V3-99.
- [10] N. Milivojevic, M. Krishnamurthy, Y. Gurkaynak, A. Sathyan, Y.J. Lee, A. Emadi, Stability analysis of FPGA-based control of brushless DC motors and generators using digital PWM technique, IEEE Transactions on Industrial Electronics 59(1)(2012) 343-351.
- [11] F. Nekoei, Y.S. Kaviani, A. Mahani, Three-phase induction motor drive by FPGA, in: Proc. Conference on Electrical Engineering, 2011.
- [12] T. Sutikno, N.R.N. Idris, A.Z. Jidin, M.Z. Daud, FPGA based high precision torque and flux estimator of direct torque control drives, in: Proc. IEEE Applied Power Electronics Colloquium, 2011.
- [13] P.Z. Tang, DSP Core Design in FPGA, Jun-Yuan Technical Company, 2003.
- [14] P. Vas, Vector Control of AC Machines, Clarendon Press, Oxford, 1990.
- [15] The MathWorks, Fixed-Point Blockset User's Guide, The MathWorks, Natick, 1999.