

Real-time Simulation and Experiment Platform for Switched Reluctance Motor

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Abstract: This paper presents a dSPACE-1104 based real-time simulation and experiment platform for switched reluctance motor, meanwhile a demo experiment with MATLAB/Simulink diagram and its results are given.

INTRODUCTION

As a new type of electrical drive, switched reluctance motor (SRM) drives are finding extensive applications in industrial fields due to simple and robust structure, low rotor inertia, high power ratio per unit volume, reliability and low cost. SRM is a promising device for the replacement of the DC motor or induction motor. The constructions and operating principles are well documented [1]. The performance of an SRM drive can be customized to suit several applications through appropriate control. The literature suggests that SRM drives have been found to be suitable for automotive applications, household goods, electric vehicles (EVs) and hybrid electric vehicles (HEVs), compressors, etc.

Operation of SRM requires a complicated control system. Generally, computers or microprocessors are used for the control system for reducing hardware cost and to avoid the need for designing complicated hardware circuits. In the past, speed of computers and microprocessors were low, and could not provide a high frequency operation environment for the machine. In the past few years, performance of digital signal processors (DSPs) has been much improved and the cost much lowered. DSPs have been commonly used in the market. Because of their high speed, they can operate in high frequency. Nowadays, switched reluctance motor controllers are often based on DSPs for providing better performance. Soft-switching techniques are suitable for high frequency operation. Applying these techniques in SRM drives to improve efficiency is a great concern[2].

Currently the researches in SRM drives are focused on torque ripple minimization, and elimination of position sensors. All these rely on relatively complicated control algorithms. Generally, when a new idea of algorithm come up, it will be firstly simulated and adjusted in MATLAB[3], then translated or encoded into the microprocessor to implement. The progress is inconvenient, and the distortion is possibly introduced. During the simulation progress, the SR Motor is often described as a linear or nonlinear model. Although the simulation results are perfect, when they applied to the physical motor, unimaginable phenomena occurs.

Considering an academic environment, the implementation of real-time simulation provides a high degree of realism, and the effects of system variations are readily observed. This paper presents a dSPACE-1104 based real-time simulation and experiment platform for switched reluctance motor, meanwhile a demo experiment with MATLAB/Simulink diagram and its results are given.

DS1104 R&D CONTROLLER BOARD

The Simulink/Real-Time Workshop based dSPACE real-time simulation system is a famous development kit in electronic mechanical industry, and many international automobile manufacturers have adopted this system. The platform in this paper adopts DS1104 R&D controller board[4] and its resources is described in Figure 1.

DS1104 R&D Controller Board is a cost-effective system for controller development. It connects to the PC machine through PCI bus, all the real-time calculation is implemented in DS1104. The real-time hardware based on PowerPC technology and its set of I/O interfaces make the controller board an ideal solution for developing controllers in various fields, such as drives, robotics, aerospace and automotives. ControlDesk, dSPACE's well-established experiment software, provides all the functions to control, monitor and automate experiments and make the development of controllers more efficient.

The DS1104 upgrades your PC to a powerful development system for rapid control prototyping. Real-Time Interface provides Simulink® blocks for graphical configuration of A/D, D/A, digital I/O lines, incremental encoder interface and PWM generation, for example. The board can be installed in virtually any PC with a free 5-V PCI slot.

Real-Time Interface (RTI) is the real-time realization software for dSPACE system, which extend the real-time C-code automate generate software Real-Time Workshop, seamlessly intergrates the dSPACE system's Real-Time Kernel and I/O hardware model, automatically build, compile, link, download and execute the real-time C-code from simulink model[5]. Further more, RTI generate a variables file according to signals and parameters, and ControlDesk will access these variables and edit the parameters[6]. With Real-Time Interface (RTI), you can easily run your function models on the DS1104 R&D Controller Board. You can configure all I/O graphically by dragging RTI blocks and reduce the implementation time to a minimum.

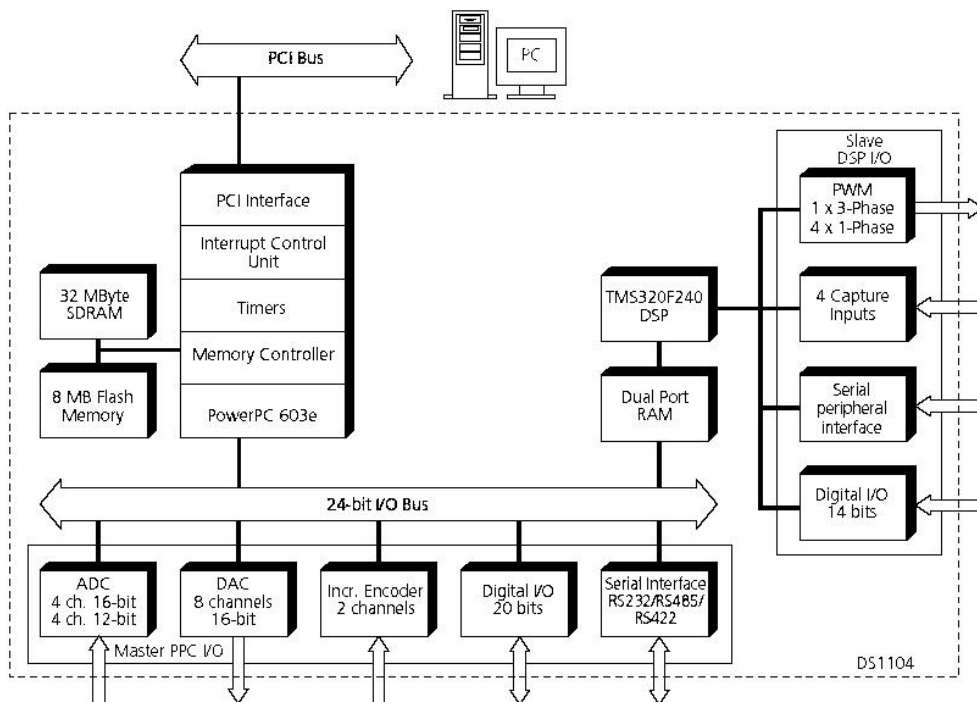


Fig1 Block Diagram of DS1104 R&D Controller Board

REAL-TIME SIMULATION AND EXPERIMENT PLATFORM FOR SRM

A. Structure

Fig2 shows the structure of real-time simulation and experiment platform for SR motor. The laboratory experimental setup consists of a dSPACE DS1104 digital signal-processor (DSP)-board-based motion controller, a Pentium III 500-MHz personal computer (PC) with Windows 2000, a 8/6 SR motor, a driver board, a torque transducer, and oscilloscope.

The DS1104 board is installed in the Pentium III PC. The control program is written in SIMULINK environment combined with the Real-Time Interface (RTI) of the DS1104 board and is implemented by the main processor 603 PowerPC running at 250MHz of the DSP DS1104 in realtime. A self-made dSPACE Connector panel provides easy access to all

input and output signals of the DS1104 board.

The IGBT converter board is a 2(n+1)-switch controller circuit[1] with 2 current transducer. The controller circuit uses one upper switch between each pair of phases in the 4-phase drive, giving a total of 6 IGBTs. The chopping IGBTs are connected to phase A&C and B&D respectively. The LEM current transducer of type LN25-NP is set to the conversion ratio KN of 3/1000.

The logic drive & signal shaping board convert the DS1104-output TTL level logic signal into the desired PWM drive signals using gate chips and opto-couplers. The output drive signal will be blank off in case of over current. The position signal and start/stop command signal are shaped to TTL level as the digital bit input of DS1104.

The DC power supply board provides separated DC voltage of 15V or 5V or -15V for the above boards.

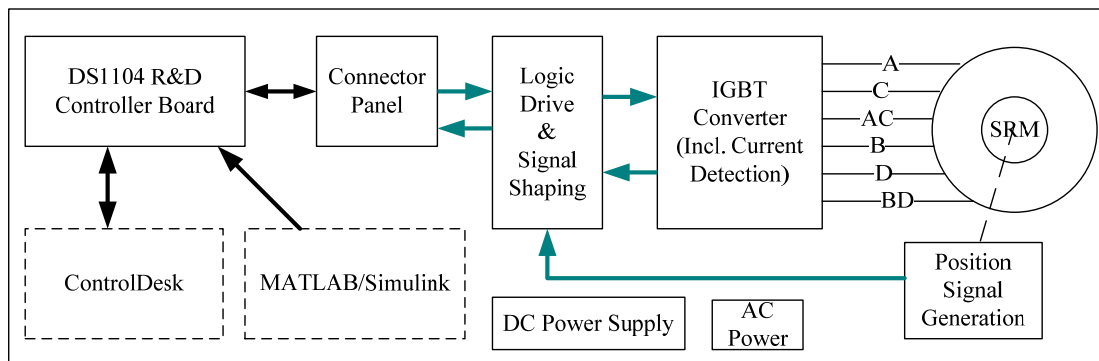


Fig2: Structure of Realtime Simulation and Experiment Platform for SR Motor

B The SR Motor

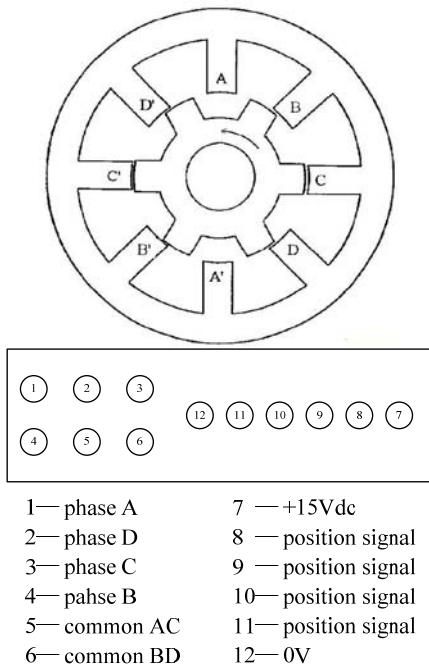


Fig3 OULTON 8/6 SR Motor and its Terminal Definition

Switched reluctance motor is a kind of brushless motor and reluctance motor. Definition of reluctance motor is that it is an electric motor in which torque is produced by the tendency of its moveable part to move to a position where the inductance of the excited winding is maximized[1]. Fig 3(upper) shows a 4 phases SRM with 8 stator poles and 6 rotor poles(8/6 SRM). When the phases of the motor are energized in the sequence A, B, C, D..., the rotor then rotates anti-clockwise, which we define as positive direction. The terminals of the OULTON 8/6 SRM used in our platform are shown in Fig.3(lower). According to the predefined positive direction, the terminal 1, 2, 3 and 4 are tested and determined to be one of the two ends of phase A, D, C and B respectively, terminal 5 and 6 are common end of phase A and C, phase B and D respectively.

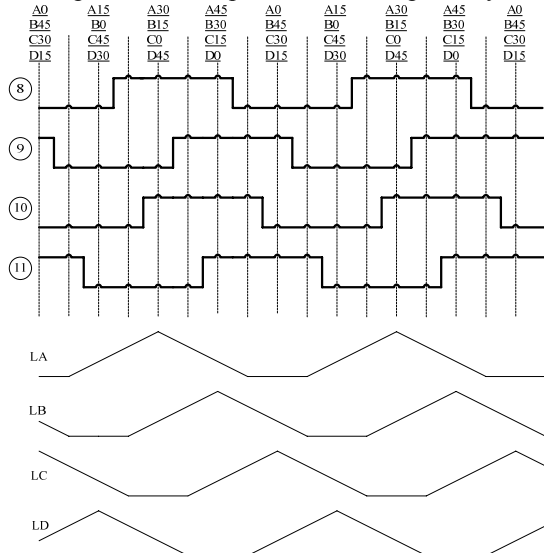


Fig4 Position Signals and each Phase Inductance

Terminal 7 to 12 are power and signal ends for rotor position sensor. When a certain phase is energized, the rotor pole will stop at the aligned position for this phase (defining 30°), then the levels for the signal ends are measured. Fig.4 shows the levels for terminal 8, 9, 10 and 11 when the rotor at different position, and the approximate curves for phase inductance L_A

to L_D are given also.

C Connections

Table 1 summarizes the connection relationship of the drive circuit and the DS1104 board pins.

Table 1 CONNECTIONS

the drive circuit	DS1104 PIN
Start/Stop	(57)IO11
Sensor signal 8	(53)IO15, (18)SCAP1
Sensor signal 9	(54)IO14, (16)SCAP2
Sensor signal 10	(50)IO18, (14)SCAP3
Sensor signal 11	(49)IO19, (12)SCAP4
Current Feed Back AC	(100)ADCH1
Current Feed Back BD	(99)ADCH2
Over Current	(58)IO10
PWM output	(23)ST2PWM
Drive Out D	(61)IO7
Drive Out C	(63)IO5
Drive Out B	(65)IO3
Drive Out BD	(66)IO2
Drive Out A	(67)IO1
Drive Out AC	(68)IO0
Analogue GND	AGND
Digital GND	DGND
Power	(19)(20)VCC +5V

DEMO EXPERIMENT

To illustrate how this platform works, here we take a simple open-loop voltage PWM hard chopping control scheme (Fig.5) as example in which the duty cycle d , the turn-on angle θ_{ON} and the dwell θ_D can be regulated respectively. More complicated system may be constructed based on this model without needing of any additional hardware.

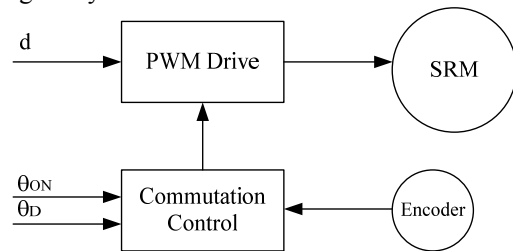


Fig5 SR motor open-loop control scheme

A Starting Method

Here two phases are conducted at the same time to start up the motor. When positive startup, the level of ⑩ and ⑪ determine the phases to be energized, as shown in Table 2. When negative startup, the level of ⑧ and ⑨ determine the phases to be energized, as shown in Table 3.

Table 2 positive startup

⑩	⑪	A	B	C	D
0	0	1	1	0	0
0	1	1	0	0	1
1	0	0	1	1	0
1	1	0	0	1	1

Table 3 negative startup

⑧	⑨	A	B	C	D
0	0	0	1	1	0
0	1	1	1	0	0
1	0	0	0	1	1
1	1	1	0	0	1

B. Online Control

As analysis of the position signals in Fig.4, we can get that when positive rotation the falling edge of ⑨ corresponds to the angle of B-11.25°, the rising edge of ⑨ corresponds to the angle of D-11.25°, the falling edge of ⑧ corresponds to the angle of A-11.25°, and the rising edge of ⑧ corresponds to the angle of C-11.25°. Hence we take the edges of these two signals as the reference point for angle calculation to control their corresponding phase. The IGBT will switch on at $\theta_{on}+11.25$ degrees after the reference, then turn off when θ_D pass. Calculation of the angles bases on the integration of real time speed in timer interrupt service program.

When negative rotation, the falling edge of ⑩ corresponds to the angle of B-11.25°, the rising edge of ⑩ corresponds to the angle of D-11.25°, the rising edge of ⑩ corresponds to the angle of A-11.25°, and the falling edge of ⑩ corresponds to the angle of C-11.25°. Hence we take the edges of ⑩ and ⑩ as the reference point for angle calculation to control their corresponding phase.

Fig.6 shows the real-time simulation blocks for positive rotation. In the following section, we take phase A as the example to explain the principle. As shown in Fig.7, the falling edge of the position signal ⑧ corresponds to the angle of A-11.25°, the control cycle is possible to divide into three sections according to this for a beginning.

(1) Within the angle from -11.25° to θ_{ON} , the timer interrupt service routine computes the time when to turn on the switches. The falling edge of the position signal ⑧ pass through the S-R trigger[7] MySRa1 to set the 'ONcal' flag, then accumulates the product of the instantaneous speed and the timer interrupt interval. When the accumulated amount reaches $\theta_{ON}+11.25^\circ$, the interrupt routine outputs a 'ONclr' signal into S-R trigger MySRa1 to reset the flag of 'ONcal', at the same time, the output 'OFFset' pass through S-R trigger MySRa2 to turn on phase A and set the 'OFFcal' flag.

(2) Within the angle from θ_{ON} to θ_{OFF} , the timer interrupt service routine computes the time when to turn off the switches. Since the 'OFFcal' flag is true, when the amount for the accumulation of the product of the instantaneous speed and the timer interrupt interval exceed the value of θ_D , the interrupt routine outputs a 'OFFclr' signal into S-R trigger MySRa2 to turn off phase A and clear the 'OFFcal' flag.

(3) Within the angle from θ_{OFF} to the next -11.25°, the timer interrupt routine does not integrate the speed because both the flag of 'ONcal' and 'OFFcal' are false.

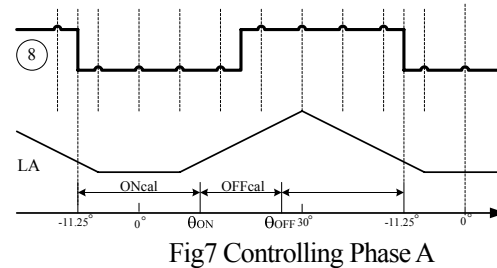


Fig7 Controlling Phase A

C Related Blocks

The dSPACE provides a slave DSP square-wave signal measurements related RTI block DS1104SL_DSP_F2D to measure the frequency of square wave signals on up to 4 independent channels, and the block outputs the signal frequency specified in Hz. In this paper, four position signals is connected to SCAP1~SCAP4, and their average frequency f (Hz, electrical cycles per second) is measured by DS1104SL_DSP_F2D block, then the speed is obtained as $60f$ (°/s).

The slave DSP provides four output channels for 1-phase PWM signal generation, and use the slave DSP PWM signal generation related RTI block DS1104SL_DSP_PWM to generate standard PWM signals with variable duty cycles. The Simulink input 0~1 corresponds to the duty cycle 0~100%. As shown in left lower corner of Fig.6, the PWM signal is produced by DS1104SL_DSP_PWM, then output to AND the phase drive-out signals.

The dSPACE also provides the Timer Interrupt block lets you use these timers as interrupt sources in a Simulink model. In this demo, the interval for timer interrupt is 20us, and the turn on /off time is computed in the timer interrupt service routine.

D Experiment Results

The following experiment results are under the DC voltage of 24V, duty of 100%, with the turn-on angle $\theta_{on} = 5^\circ$ and the dwell $\theta_D = 15^\circ$.

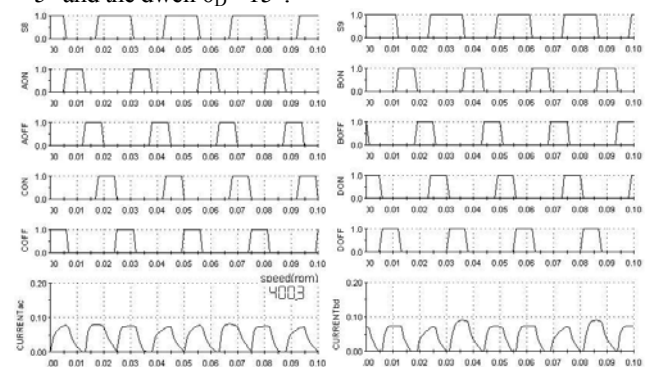


Fig8 four phases in service(400rpm)

In Figure8, S8 and S9 are the position signal ⑧ and ⑨ respectively. The xON/xOFF stand for the flag that the timer interrupt service routine is computing the time when to turn on/off the switches for phase x. The lower are current curves. All of the four phases are in service here, and the speed is around 400 rpm.

From Figure9 to Fig11, when the number of phases in service are cut down with the unchanged load, the speed decreases.

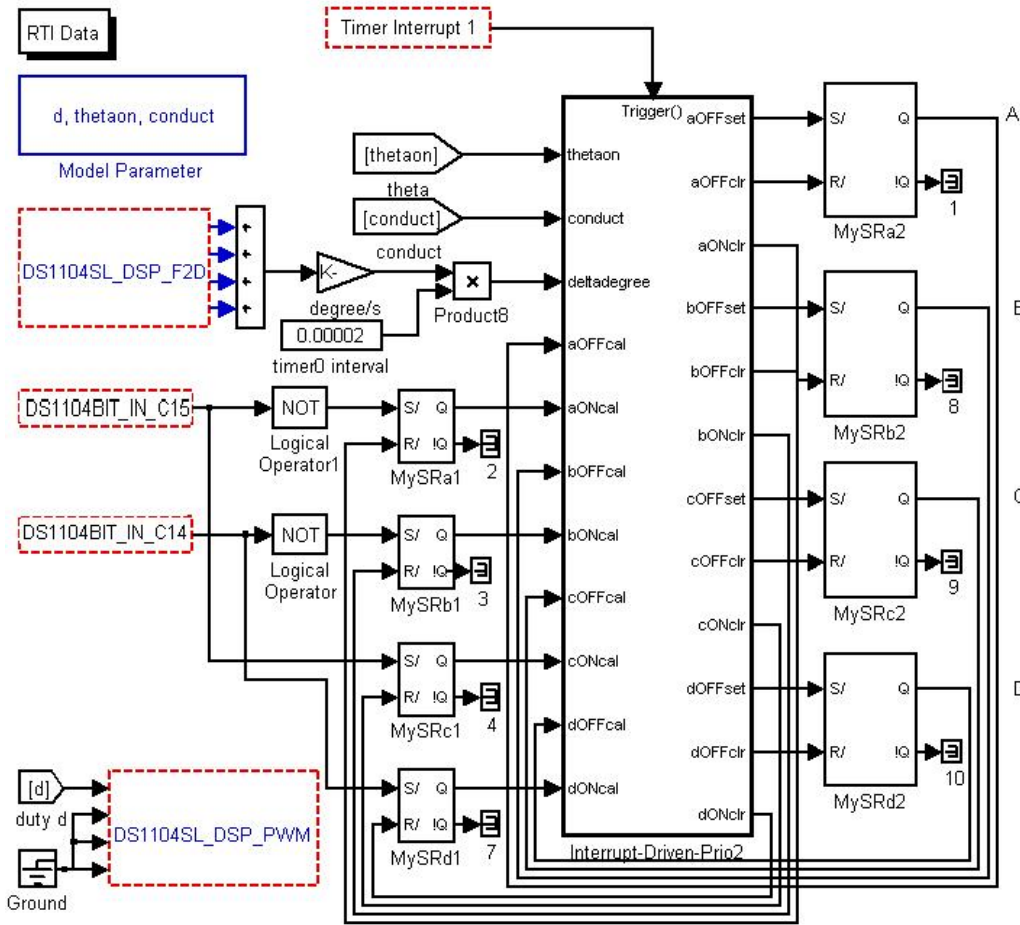


Fig6 Real-time Simulation Blocks for Positive Rotation

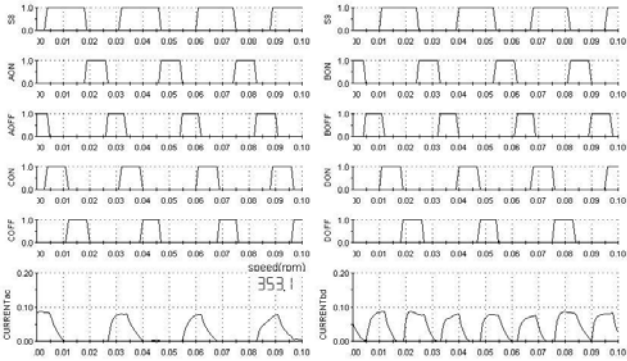


Fig9 three phases in service (ABD,350rpm)

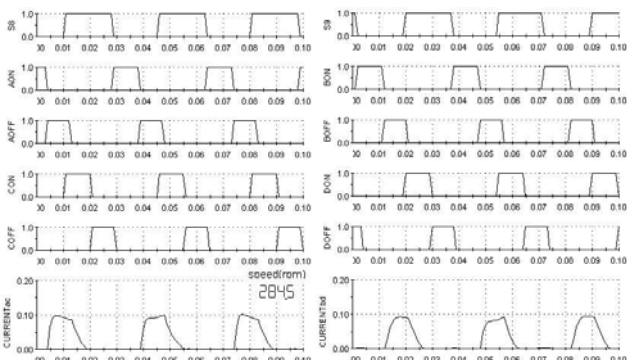


Fig10 two phases in service (AB, 285rpm)

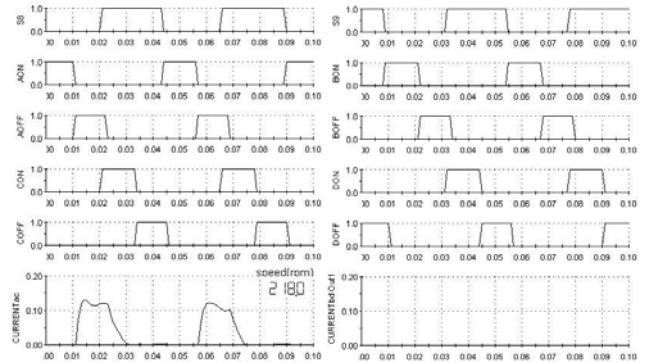


Fig11 only one phases in service (A, 220rpm)

CONCLUSION

A dSPACE-1104 based real-time simulation platform for SR motor is presented in this paper. A simple demo experiment on the platform is implemented in the environment of MALTAB/simulink, which is previously used for pure simulation research. Although the structure is very simple, it is easily to be extended to more complicated system, and to carry out various kind of real-time investigation of SRM.

The platform is likely to be used in the area of sensorless control of the SRM. Discrete position sensors increase the problems of reliability and cost of SRM drives. To implement the sensorless control, a proper method must be found to accurately model nonlinearities in SRM drives. The fuzzy logic and genetic algorithm, as artificial intelligent (AI) techniques,

are widely applicable to effectively solve nonlinear problems in science and engineering, such as nonlinear control and nonlinear optimization. As we know, MATLAB has provided abundant tools on these AI area, they will show their predominance in the platform.

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