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A Position Sensorless Control System of SRM over Wide Speed Range

Won-Sik Baik*

Abstract

This paper presents a position sensorless control system of SRM over wide speed range. Due to the doubly salient structure of the SRM, the phase inductance varies along with the rotor position. Most of the sensorless control techniques are based on the fact that the magnetic status of the SRM is a function of the angular rotor position. The rotor position estimation of the SRM is somewhat difficult because of its highly nonlinear magnetizing characteristics. In order to estimate more accurate rotor position over wide speed range, Neural Network is used for this highly nonlinear function approximation. Magnetizing data patterns of the prototype 1-hp SRM are obtained from locked rotor test, and used for the Neural Network training data set. Through measurement of the flux-linkage and phase currents, rotor position is able to estimate from current-flux-rotor position lookup table which is constructed from trained Neural Network. Experimental results for a 1-hp SRM over 16:1 speed range are presented for the verification of the proposed sensorless control algorithm.

Key Words : Switched Reluctance Motor, Position Sensorless Control, Neural Network

1. Introduction

The Switched Reluctance Motor (SRM) is considered as an attracting candidate for the variable speed motor drives due to its low cost, simple structure and high efficiency over a wide speed range. Moreover, the inverter of the SRM drive can prevent the shoot-through fault that exists in the induction and permanent magnet motor drives[1-2].

In order to produce motoring torque at any moment and for optimum performance, it is necessary to commutate the excitation current from phase to phase synchronously with the rotor position. This needs the use of a mechanical position sensor attached to the motor shaft. The problems associated with the mechanical position sensor are the poor reliability in a dusty environment, high cost of the sensor and the requirement of the extra space to accommodate.

Several sensorless control methods have been proposed in the literature over the past two decades[3-4]. Due to the doubly salient structure of the SRM, the phase inductance varies along with the rotor position. Most of the sensorless

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control methods utilize the functional relationship between the stator flux linkage or phase inductance, phase current, and rotor position to estimate the rotor position. In this paper, the rotor position is estimated from the current-flux-rotor position lookup table which is constructed from trained Neural Network. Experimental result for a 1-hp SRM is presented for the verification of the proposed sensorless control algorithm.

2. Switched reluctance motor drives

2.1 Basic principle of operation

The Switched Reluctance Motor drives are accomplished by switching the phase current on and off synchronously with the rotor position[5]. The voltage equations of the SRM can be described as followings.

$$v = Ri + \frac{d\psi}{dt} = Ri + L\frac{di}{dt} + \omega_m i\frac{dL}{d\theta} \qquad (1)$$

where v is the phase voltage, i is the current, R is the phase resistance, L is the phase inductance, ω_m is the rotor angular velocity and θ is the rotor position.

The instantaneous electric power which is the product of phase voltage and current is as followings.

$$vi = Ri^2 + Li\frac{di}{dt} + \omega_m i^2\frac{dL}{d\theta} \qquad (2)$$

The instantaneous electro-magnetic torque is given by the following equations.

$$T = \frac{1}{2}i^2\frac{dL}{d\theta} \qquad (3)$$

Motoring torque is produced when the phase winding is energized during the positive slope of the phase inductance variation. Fig. 1 shows the Inductance profile of the stator pole pair with respect to the rotor angular position and the phase current of the prototype 1-hp SRM. Accurate measurement of this magnetic characteristic is very important for verification of the motor design, performance prediction, and the development of a high-performance sensorless control algorithm. In the literature, several measurement methods of the magnetic characteristic have been proposed[6-7].

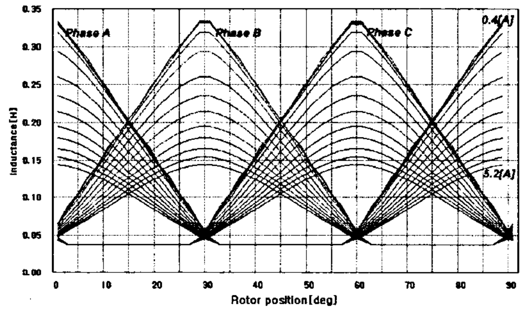


Fig. 1. Inductance profile of the prototype 1-hp SRM

2.2 Rotor position estimation

The rotor position of the SRM can be estimated based on the fact that the magnetic status of the SRM is a function of the angular rotor position. The variation of the magnetizing curves along with the phase current and rotor position for a 1-hp SRM are shown in Fig. 2. Magnetizing curves are obtained by measuring the instantaneous voltage and current for each rotor position. The phase current and rotor position are varied in a step of 0.4[A] and 2[deg] respectively. The flux-linkage is measured by the numerical integration of the phase voltage.

The highly nonlinear function of the magnetizing data can be approximated by Neural

Network[8-9]. Fig. 3 shows the block diagram of the designed Neural Network. The number of neurons of the hidden layer is 5 and sigmoid activation function is used. All the data patterns are normalized for more accurate function approximation. The bias source is connected to a fixed input of +1 which provides additional activation for each neuron. The designed Network is trained using Professional II/plus software package. Fig. 4 shows the output data patterns of the trained Neural Network. The per unit rotor position represents one electrical period.

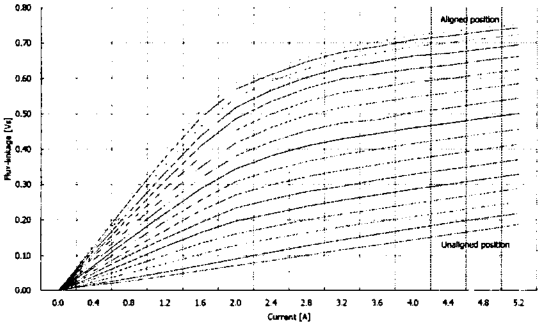


Fig. 2. Magnetizing curve of the prototype 1-hp SRM

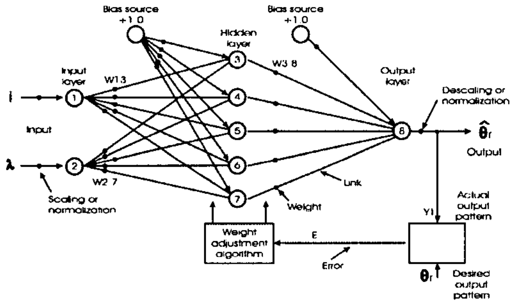


Fig. 3. Block diagram of the designed Neural Network

Through measurement of the phase flux linkages and phase current, the trained Neural Network is able to estimate the rotor position. Because of the Neural Network requires much calculation time and additional lookup tables for the activation functions, 2-D lookup table is generated using trained Neural Network for real application. Fig. 5 shows the design flow for the generation of 2-D look-up table which is used to estimate the rotor position from the flux-linkage and the phase current.

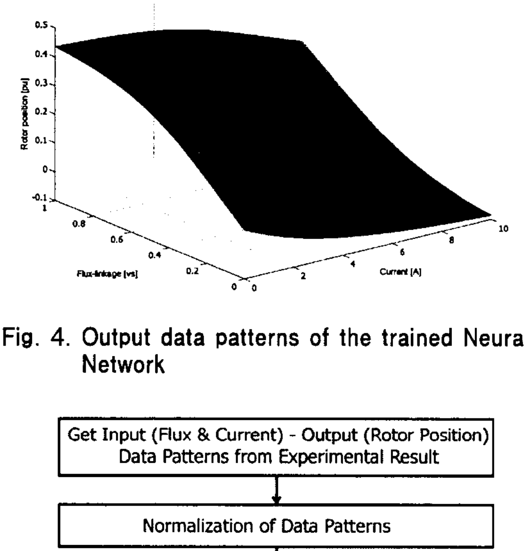


Fig. 4. Output data patterns of the trained Neural Network

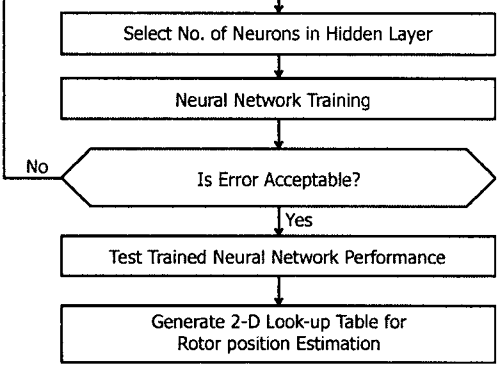
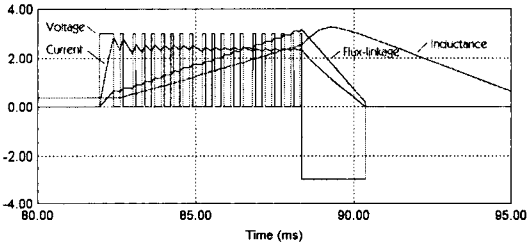


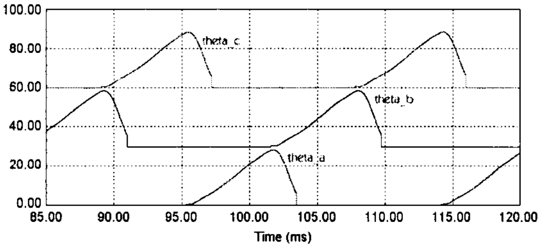
Fig. 5. Design flow of the Neural Network

Fig. 6 shows the simulation result at 800[rpm] and 1.2[Nm] using PSIM software package. Fig. 6

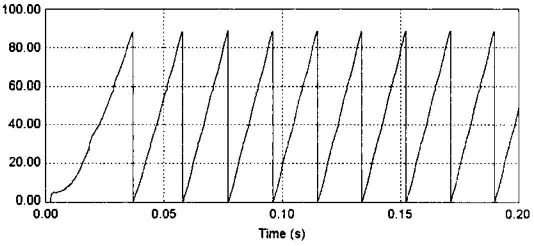
(a) shows the phase voltage (×10^{-2}[V]), phase current ([A]), phase inductance (×10^{1}[H]) and flux-linkage (×10^{1}[Vs]) of one stroke. In this figure, inductance is slightly increases according to the phase current decreasing at de-fluxing intervals which is the result of the nonlinearity consideration. Fig. 6 (b) shows the estimated rotor position from the flux-linkage and the phase current. Each individual estimated rotor positions are combined into one electrical period. Fig. 6 (c) shows the estimated rotor positions over one electrical period[10].



(a) Voltage, current, inductance and flux-linkage of one stroke



(b) Estimated rotor position



(c) Combined rotor position over 1-electrical period

Fig. 6. Simulation result at 800[rpm], 1.2[Nm]

3. Experimental results

3.1 System configuration

Proposed sensorless algorithm is realized using TMS 320F2812 DSP controller and 5-KVA asymmetric bridge converter. Fig. 7 shows the block diagram of the proposed position sensorless control system. In Fig. 7, the flux linkage is calculated from the DC link voltage, duty cycle and phase current data to consider the resistive voltage drop. Using calculated flux linkage and reference current data, the rotor position is estimated from 2-D look-up table. Fig. 8 shows the prototype 1-hp SRM and Table 1 shows the design parameters of the SRM. Fig. 9 shows the experimental setup.

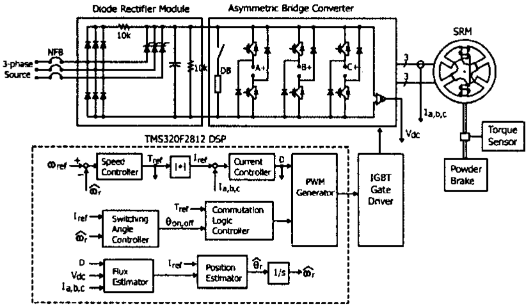


Fig. 7. Block diagram of the proposed position sensorless control system

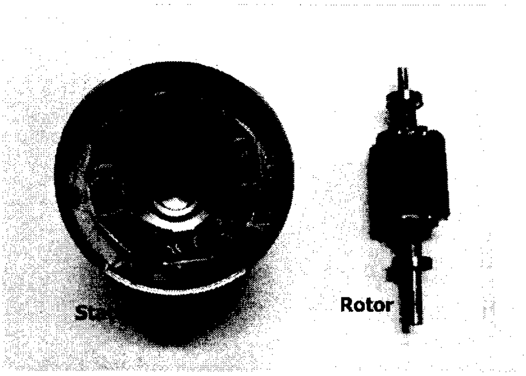


Fig. 8. Prototype 1-hp SRM

Table 1. Design parameters of SRM

No. of phase	3	Stator pole	6
Rated output	1[hp]	Rotor pole	4
Rated voltage	300[Vdc]	Stator pole arc	30[deg]
Rated speed	3000[rpm]	Rotor pole arc	32[deg]

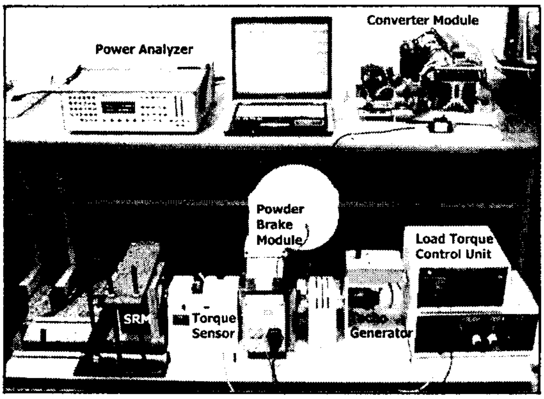


Fig. 9. Experimental system setup

3.2 Experimental results

Fig. 10 to 23 illustrates the experimental results of the sensorless algorithm for wide speed range. All the waveforms are generated using software drawing program based on the experimental data which obtained from the online data communication with DSP. Fig. 10 shows the calculated flux linkage of each phase, and Fig. 11 shows the estimated rotor position at 450[rpm] and 0.5[Nm]. The position waveforms are represented by per unit value which means one electrical period. Fig. 12~17 shows the speed, actual and estimated rotor position at different operating speed and load. Although some position errors are observed in the active phase changing interval, wide speed control range of 16:1 is accomplished. Fig. 18~21 shows the position estimation error according to the operating condition. Fig. 22 and 23 show the transient response of load torque variation.

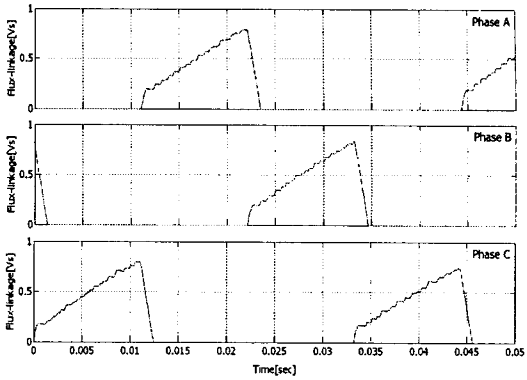


Fig. 10. Estimated flux-linkage at 450[rpm], 0.5[Nm]

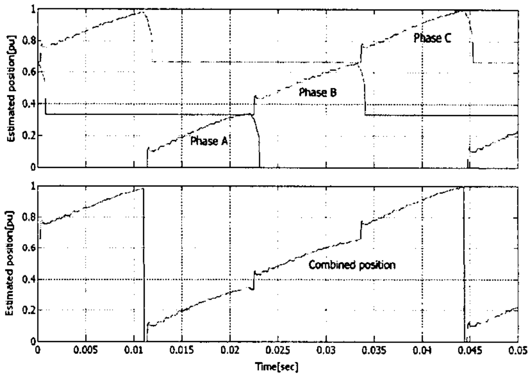


Fig. 11. Estimated rotor position at 450[rpm], 0.5[Nm]

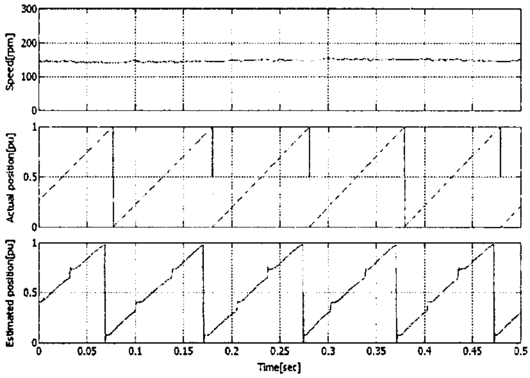


Fig. 12. Speed & rotor positions at 150[rpm], 0.5[Nm]

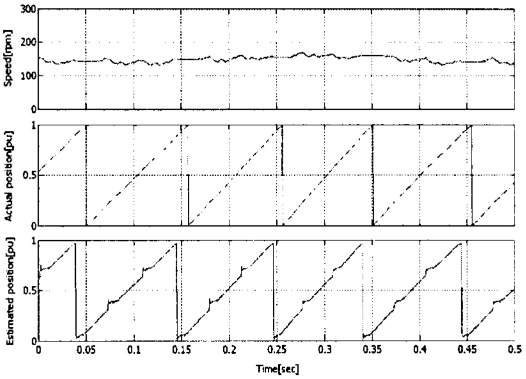


Fig. 13. Speed & rotor positions at 150[rpm], 1.5[Nm]

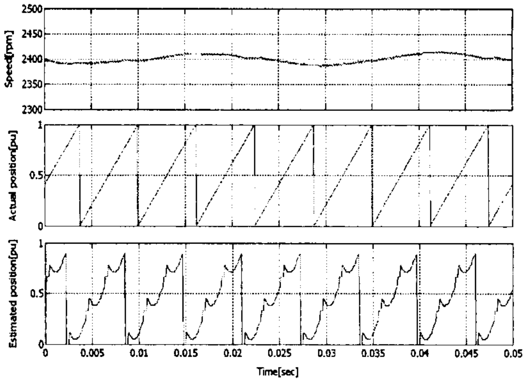


Fig. 16. Speed & rotor positions at 2400[rpm], 0.5[Nm]

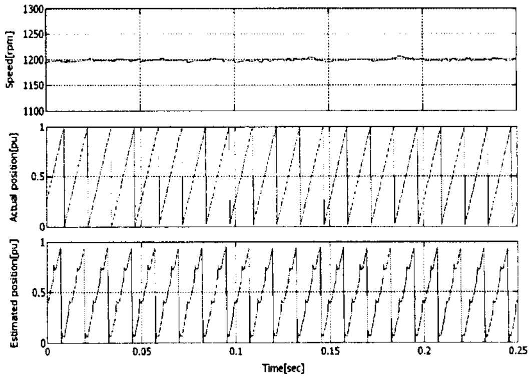


Fig. 14. Speed & rotor positions at 1200[rpm], 0.5[Nm]

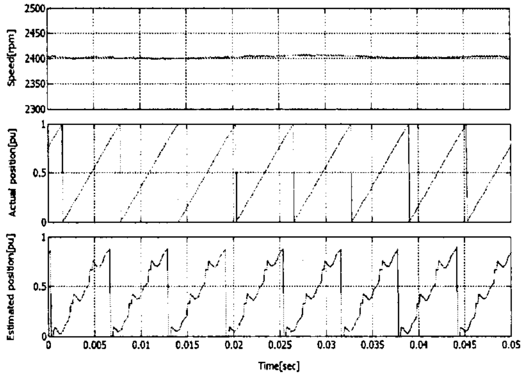


Fig. 17. Speed & rotor positions at 2400[rpm], 1.5[Nm]

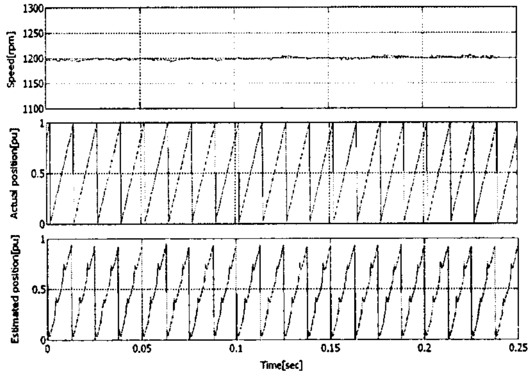


Fig. 15. Speed & rotor positions at 1200[rpm], 1.5[Nm]

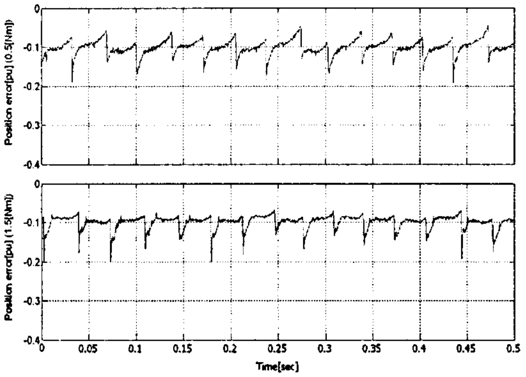


Fig. 18. Position estimation error at 150[rpm]

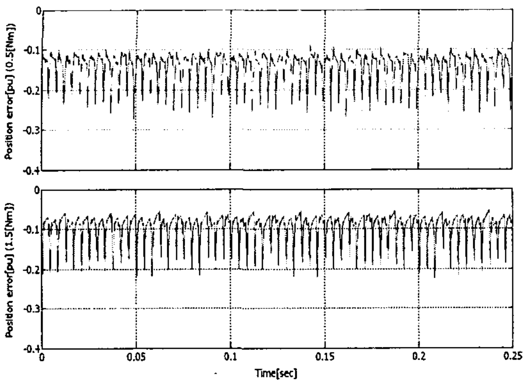


Fig. 19. Position estimation error at 1200[rpm]

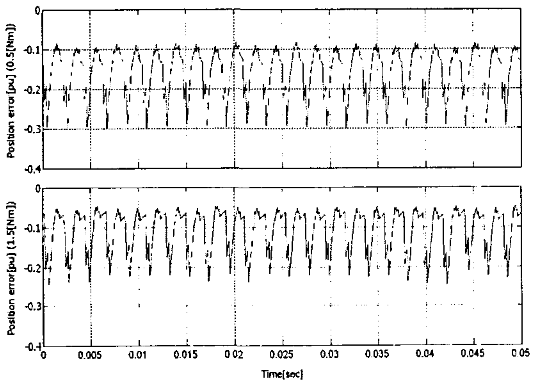


Fig. 20. Position estimation error at 2400[rpm]

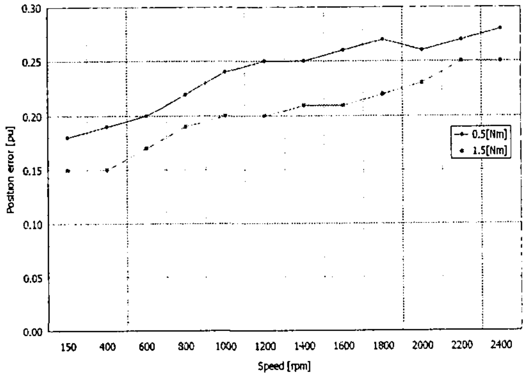


Fig. 21. Position estimation error according to the speed & load torque

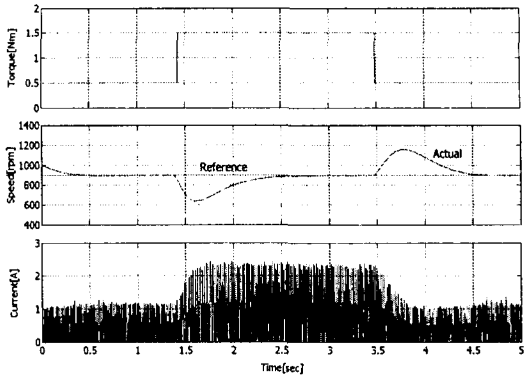


Fig. 22. Transient response at 900[rpm]

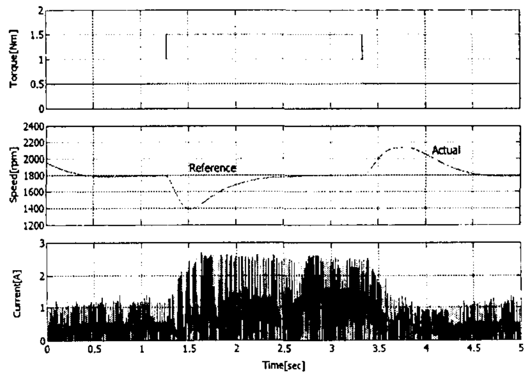


Fig. 23. Transient response at 1800[rpm]

4. Conclusion

In this paper, a position sensorless control system of SRM over wide speed range is presented. Neural Network is adapted to approximate the highly nonlinear function of the magnetizing curves. The 2-D current-flux-rotor position lookup table is generated by trained Neural Network. Through measurement of the flux-linkage and phase currents, rotor position is able to estimate from current-flux-rotor position lookup table. Experimental result for a 1-hp SRM is presented for the verification of the proposed sensorless algorithm. Although some position errors are observed in the active phase changing intervals, proposed algorithm is easy to realize and wide speed control range of 16:1 is accomplished.

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Biography

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He was born in Daegu, Korea, on October, 1970. He received the B.S. degree in Mathematics from Keimyung University in 1996. He received the M.S. and Ph.D. degrees in electrical engineering from Yeungnam University in 2002, 2007 respectively. Currently, he is a post doc. researcher at Department of Electrical Engineering in Yeungnam University. His research interests are a control system of motor drives and power electronics.