

UNIVERSITY OF TECHNOLOGY, SYDNEY  
Faculty of Engineering and Information Technology

**DEVELOPMENT OF FPGA BASED CONTROL  
ARCHITECTURE FOR PMSM DRIVES**

by

**Quang Nguyen Khanh**

A THESIS SUBMITTED  
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## **Certificate of Authorship/Originality**

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## ABSTRACT

### **DEVELOPMENT OF FPGA BASED CONTROL ARCHITECTURE FOR PMSM DRIVES**

by Quang Nguyen Khanh

The rapid advancement of the very large scale integration (VLSI) technology and electronic design automation techniques in recent years has made a significant impact on the development of complex and compact high performance control architecture for industrial motion systems.

Specific hardware with the field programmable gate array (FPGA) technology is now considered as a promising solution in order to make use of the reliability and versatility of controllers. Indeed, FPGAs have been successfully used in many control applications such as power converter control and electrical machines control. This is because such an FPGA-based implementation can offer an effective reprogrammable capability and overcome disadvantages of microprocessor-based or digital signal processor-based embedded systems.

This thesis aims to provide a proof-of-concept for the control-system-on-chip and a prototype for a fully-implemented FPGA control architecture for permanent magnet synchronous motor (PMSM) drives. In this thesis, a special focus is given on analytical effects, design procedure, and control performance enhancement for PMSM drives under sensor/sensorless vector control using a number of control techniques.

The control schemes include FPGA-based intelligent control and robust cascade control for single axis and multiple axis tracking with PMSMs. An important contribution of this thesis rests with a convincing demonstration of high performance estimation schemes, using sliding mode observers and extended Kalman filters, in terms of accuracy and robustness against noisy and/or perturbed currents for sensor-

less PMSM control based on the FPGA technology. In addition, a sequential finite state machine is developed in this work to result in less logic gate resources, leading to a faster processing time.

Significance of this thesis contribution includes in providing a feasible and effective solution for the implementation of complex control strategies to fully exploit the FPGA advantages in power electronics and drive applications.

## List of Publications

1. **Nguyen Khanh Quang**, Nguyen Trung Hieu, Q. P. Ha (2014), *FPGA-Based Sensorless PMSM Speed Control Using Reduced-Order Extended Kalman Filters*, IEEE Transactions on Industrial Electronics, vol.61, no.12, pp.6574-6582.
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3. **Nguyen Khanh Quang**, Doan Duc Tung and Q. P. Ha (2015), *FPGA-Based Sensorless PMSM Speed Control using Adaptive Extended Kalman Filter*, The 11th IEEE Int. Conf. on Automation Science and Engineering (CASE2015), Gothenburg, Sweden, to be published 2015.
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13. **Nguyen Khanh Quang**, Y.-S. Kung, and Q. P. Ha (2011), *FPGA-Based Control Architecture Integration for Multiple-Axis Tracking Motion Systems*, IEEE/SICE International Symposium on System Integration (SII2011), Kyoto, Japan, pp.591-596.
14. Y.S. Kung, **Nguyen Khanh Quang** and Le Thi Van Anh (2009), *FPGA-based neural fuzzy controller design for PMLSM drive*, The 8th Int. Conf. on Power Electronics and Drive Systems (PEDS2009), Taipei, Taiwan, pp.222-227.

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# Contents

Certificate	ii
Abstract	iii
Publications	v
Acknowledgments	viii
List of Figures	xiv
List of Tables	xviii
Notation	xix
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	1
1.2 Research Objectives . . . . .	2
1.3 Thesis Structure . . . . .	3
<b>2 FPGA Technology, Finite State Machine, and Model-Sim/Simulink Co-simulation: An Overview</b>	<b>6</b>
2.1 Introduction . . . . .	6
2.2 FPGA Technology . . . . .	7
2.2.1 FPGA Programming Technologies . . . . .	7
2.2.2 Architecture of FPGA . . . . .	9
2.3 Computation using Finite State Machine Method . . . . .	10
2.3.1 Sum of Product Computation . . . . .	11
2.3.2 Computation of the Polynomial Equation . . . . .	12
2.3.3 Exponential Function Computation . . . . .	14

2.4	ModelSim/Simulink Co-simulation Method . . . . .	16
2.4.1	Introduction of ModelSim/Simulink Co-simulation . . . . .	16
2.4.2	Simulation Work . . . . .	19
<b>3</b>	<b>A Brief Survey on PMSM Drives</b>	<b>22</b>
3.1	Introduction . . . . .	22
3.2	Overview of PMSM [82] . . . . .	22
3.3	Current Vector Control of PMSM Drives . . . . .	25
3.3.1	Coordinate Transformations . . . . .	26
3.3.2	Space Vector Pulse Width Modulation . . . . .	27
3.4	Digital Circuit Design of Current Vector Control . . . . .	30
3.4.1	Current Controller and Coordinate Transformations . . . . .	30
3.4.2	Circuit of SVPWM Generation . . . . .	33
3.5	Review on Control Techniques for Motion Axis Control Systems . . . . .	35
3.6	Review on Sensorless PMSM Estimation Techniques . . . . .	38
3.6.1	PMSM Drive Model . . . . .	39
3.6.2	Survey on Model-based Estimation Methods . . . . .	39
3.6.3	Remarks . . . . .	46
<b>4</b>	<b>FPGA-based Intelligent Control for Multiple Axis Tracking Motion System</b>	<b>49</b>
4.1	Introduction . . . . .	49
4.2	System Description and Neural Fuzzy Controller Design . . . . .	51
4.2.1	PMLSM Drive Model . . . . .	52
4.2.2	Neural Fuzzy Control Design . . . . .	53
4.3	Hardware/software Co-design of Motion Control . . . . .	57
4.4	Experimental Results on One Axis of Motion System . . . . .	61
4.4.1	Experiment Set-Up . . . . .	61

4.4.2	Experimental Results . . . . .	61
4.5	Computer Simulation of Multiple Axis Tracking Motion System . . . . .	65
4.5.1	Quartus II and Nios II based Simulation . . . . .	65
4.5.2	Trajectory Planning . . . . .	67
4.5.3	Simulation Results and Discussion . . . . .	69
4.6	Chapter Conclusion . . . . .	70
<b>5</b>	<b>Observer-based Integral Sliding Mode Control for Sensorless PMSM Drives using FPGA</b>	<b>73</b>
5.1	Introduction . . . . .	73
5.2	Observer-based Integral Sliding Mode Control Design . . . . .	74
5.2.1	Motor Drive Model . . . . .	75
5.2.2	Improved SMO based Rotor Flux Position Estimation . . . . .	76
5.2.3	Integral Sliding Mode Control Design in Speed Loop . . . . .	78
5.3	FPGA based Sensorless Control Implementation . . . . .	79
5.3.1	Control Architecture . . . . .	79
5.3.2	Design procedure for SMO . . . . .	80
5.3.3	Algorithm Implementation . . . . .	81
5.4	Results and Discussion . . . . .	85
5.5	Chapter Conclusion . . . . .	86
<b>6</b>	<b>FPGA Sensorless PMSM Drive with Adaptive Fading Extended Kalman Filter</b>	<b>91</b>
6.1	Introduction . . . . .	91
6.2	Extended Kalman Filter based Rotor Flux Position Estimation . . . . .	93
6.2.1	Extended Kalman Filter Algorithm . . . . .	93
6.2.2	Adaptive Fading Extended Kalman Filter Algorithm . . . . .	95
6.3	Control Architecture and Implementation of AF-EKF . . . . .	98

6.3.1	Design Procedure of AF-EKF Algorithm . . . . .	98
6.3.2	Algorithm Implementation of AF-EKF . . . . .	100
6.4	Results and Discussion . . . . .	103
6.5	Chapter Conclusion . . . . .	106
<b>7</b>	<b>FPGA-Based Sensorless PMSM Speed Control using Adaptive Extended Kalman Filter</b>	<b>107</b>
7.1	Introduction . . . . .	107
7.2	Adaptive Extended Kalman Filter . . . . .	108
7.2.1	Adaptive Algorithm . . . . .	108
7.2.2	Design Procedure of Adaptive EKF . . . . .	110
7.3	FPGA Realization of Sensorless Control Design . . . . .	111
7.3.1	Controller Architecture . . . . .	111
7.3.2	Algorithm Implementation . . . . .	111
7.4	Co-Simulation and Results . . . . .	114
7.5	Chapter Conclusion . . . . .	115
<b>8</b>	<b>Reduced-Order Extended Kalman Filters-based Sensorless PMSM Speed Control using FPGA</b>	<b>117</b>
8.1	Introduction . . . . .	117
8.2	Reduced-Order Extended Kalman Filter for Sensorless PMSM Drive .	118
8.2.1	PMSM Decoupled Dynamics . . . . .	118
8.2.2	Parallel Reduced-Order EKFs . . . . .	120
8.2.3	Design Procedure of Reduced-Order EKF . . . . .	121
8.3	FPGA Control Architecture and FSM Implementation . . . . .	122
8.3.1	FPGA Architecture for Sensorless PMSM Speed Control . . .	122
8.3.2	EKF Complexity and Implementation with FSM . . . . .	124
8.3.3	Sensorless Control Timing Diagram . . . . .	127

8.4	Computer Simulation . . . . .	128
8.4.1	ModelSim/Simulink Co-simulation . . . . .	128
8.4.2	Estimation and Speed Control: Simulation Results . . . . .	129
8.4.3	Resource Consumption and Execution Time Analysis . . . . .	131
8.5	Implementation and Results . . . . .	132
8.5.1	Laboratory Set-Up . . . . .	132
8.5.2	Experimental Results . . . . .	133
8.6	Chapter Conclusion . . . . .	134
<b>9</b>	<b>General Conclusion</b>	<b>137</b>
9.1	Conclusions . . . . .	137
9.2	Thesis Contributions . . . . .	139
9.3	Future Works . . . . .	140
	<b>Bibliography</b>	<b>141</b>

## List of Figures

2.1	General structure of FPGA . . . . .	9
2.2	Configurable logic block . . . . .	10
2.3	Sum of product computation . . . . .	11
2.4	State diagram of an FSM for describing the polynomial equation . . .	13
2.5	Simulation result of polynomial equation computation in Quartus II .	14
2.6	The result of exponential function with the ninth order in MATLAB .	15
2.7	Simulation result of exponential function computation in Quartus II .	16
2.8	EDA Simulator Link software [56] . . . . .	17
2.9	Linking MATLAB with HDL simulator [56] . . . . .	18
2.10	MATLAB and ModelSim co-simulation structure [56] . . . . .	18
2.11	Connection between ModelSim and Simulink via network port 4449 [56]	19
2.12	The Simulink/ModelSim co-simulation architecture for sensorless speed control system . . . . .	21
3.1	Cross-section of PMSM (a) Surface mounted PMSM, and (b) Interior PMSM. . . . .	23
3.2	Block diagram of current loop . . . . .	25
3.3	Transformations between stationary and synchronously rotating axes	26
3.4	3-phase power converter and AC motor . . . . .	27
3.5	Basic vector space and switching patterns . . . . .	28
3.6	State machines for describing the CCCT . . . . .	32
3.7	Circuit of SVPWM generation . . . . .	33

3.8	State machines for describing SVPWM circuit . . . . .	34
4.1	Motion control system for X- and Y-axes . . . . .	51
4.2	The symmetrical triangular membership function of $e$ and $de$ , fuzzy rule table, fuzzy inference and fuzzification . . . . .	55
4.3	Self-adjusted RBF NN schema . . . . .	57
4.4	FPGA architecture of the motion control system . . . . .	58
4.5	State diagram of an FSM for describing the neural fuzzy controller . .	60
4.6	Experiment set-up photograph . . . . .	62
4.7	Membership functions, fuzzy rule table and surface for step responses	63
4.8	Rule table after adjustment and the control effort surface . . . . .	63
4.9	Step response at 0 – 10 $mm$ to 20 – 30 $mm$ square wave command under case of (a) FC without external load (b) FC with 11 $Kg$ external load (c) NFC with 11 $Kg$ external load . . . . .	64
4.10	Implementation diagram for on-chip simulation . . . . .	67
4.11	Window motion trajectory . . . . .	69
4.12	Window trajectory response by using FC for case 1: (a) Window tracking (b) Position tracking (c) Control efforts (d) Tracking errors in X and Y-axis. . . . .	71
4.13	Window trajectory response by using FC for case 2: (a) Window tracking (b) Position tracking (c) Control efforts (d) Tracking errors in X and Y-axis. . . . .	72
4.14	Window trajectory response by using NFC for case 2: (a) Window tracking (b) Position tracking (c) Control efforts (d) Tracking errors in X and Y-axis. . . . .	72
5.1	The proposed speed control system for a sensorless PMSM drive using SMO . . . . .	75

5.2	Rotor flux angle estimation based on the conventional SMO . . . . .	77
5.3	The proposed speed ISMC controller for a sensorless PMSM drive . .	80
5.4	State diagram of an FSM for the speed controller using ISMC . . . . .	83
5.5	State diagram of an FSM for an improved SMO-based rotor position estimation algorithm . . . . .	84
5.6	Flux angle (FA) waveforms obtained by the conventional SMO method using the signum function . . . . .	87
5.7	Flux angle (FA) waveforms obtained by the improved SMO method using the saturation function . . . . .	87
5.8	Simulation result when PI controller is used while sensorless PMSM operated at normal load condition . . . . .	88
5.9	Simulation result when PI controller is used while sensorless PMSM operated at light load condition . . . . .	88
5.10	Simulation result when PI controller is used while sensorless PMSM operated at heavy load condition . . . . .	89
5.11	Simulation result when ISMC controller is used while sensorless PMSM operated at normal load condition . . . . .	89
5.12	Simulation result when ISMC controller is used while sensorless PMSM operated at light load condition . . . . .	90
5.13	Simulation result when ISMC controller is used while sensorless PMSM operated at heavy load condition . . . . .	90
6.1	The proposed speed control system for a sensorless PMSM drive using EKF . . . . .	92
6.2	State machine diagram of AF-EKF algorithm . . . . .	102
6.3	Actual and estimated rotor flux angle from standard EKF and AF-EKF under speed condition at low speed 100 <i>rpm</i> . . . . .	104



6.4	Speed responses by using standard EKF and AF-EKF under speed condition at low speed 100 <i>rpm</i> and inverse -100 <i>rpm</i> . . . . .	105
6.5	(a) Speed responses by using the standard EKF and proposed AF-EKF under varying external load; (b) Current responses with AF-EKF . . . . .	105
7.1	State machine diagram of the adaptive EKF algorithm . . . . .	113
7.2	Comparison between adaptive EKF and conventional EKF: (a) Rotor flux angle, (b) Rotor speed. . . . .	116
8.1	Proposed EKF based sensorless speed control IC circuitry . . . . .	123
8.2	State machine diagram of the parallel reduced-order EKF algorithm .	126
8.3	Timing diagram of the sensorless control system . . . . .	128
8.4	Speed 900 <i>rpm</i> : (a) actual and estimated rotor flux angle from SMO, full-order EKF and parallel reduced-order EKFs, (b) zoom-in responses	130
8.5	Speed pattern 0→90→600→900→1200 <i>rpm</i> : (a) actual and estimated rotor flux angle, (b) actual and estimated speed . . . . .	130
8.6	Responses with reduced-order EKFs: (a) $d - q$ currents, (b) three-phase currents . . . . .	131
8.7	Set-up photograph . . . . .	133
8.8	Estimated and measured flux angle when PMSM runs at 200 <i>rpm</i> . .	135
8.9	Estimated and measured flux angle with PMSM running from 1000 to -1200 <i>rpm</i> . . . . .	136
8.10	Speed step response of the sensorless PMSM drive . . . . .	136

## List of Tables

3.1	T1 and T2 in all specific sectors . . . . .	29
3.2	Assigning duty cycle to CMPx in any sector . . . . .	30
4.1	Comparison results between FC and NFC . . . . .	71
6.1	Utility Evaluation of Sensorless Control IC in FPGA . . . . .	101
6.2	Comparison of Estimation Algorithms in Control Implementation . . . . .	104
8.1	Complexity of EKF Algorithms . . . . .	124
8.2	FPGA Utility Evaluation for Sensorless PMSM Speed Control . . . . .	125

# Nomenclature and Notation

## List of abbreviations

- ADC : Analog digital converter
- ASIC : Application-specific integrated circuit
- CCCT : Current controller and coordinate transformation
- EDA : Electronic design automation
- EKF : Extended Kalman filter
- EMF : Electromotive force
- EPROM : Programmable read-only memory
- FC : Fuzzy control
- FPGA : Field programmable gate array
- FSM : Finite state machine
- HF : High frequency
- IDE : Integrated development environment
- IP : Intelligent property
- IR : Interrupt service routine
- LE : logic element
- LPM : Library parameterized module
- LUT : Look up table
- PLD : Programmable logic device
- PMSM : Permanent magnet synchronous motor
- PMLSM : Permanent magnet linear synchronous motor
- PI : Proportional integral controller
- QEP : Quadrature encoder pulse

- RBF : Radial basis function
- SoPC : System-on-programmable-chip
- SRAM : Static random access memory
- SVPWM : Pulse-width-modulation
- VHDL : Very high speed integrated hardware description language
- VLSI : Very large scale integration

### **List of symbols**

- $\theta$  : Rotor position
- $F_e$  : Motor thrust force
- $F_L$  : External load force
- $B_m$  : Viscous friction coefficient
- $K_t$  : Force constant
- $J$  : Inertia
- $\lambda$  : Permanent magnet flux linkage
- $p$  : Pairs of poles of a motor
- $\tau$  : Pole pitch
- $\omega_e$  : Electrical speed (*rad/s*)
- $r_s$  : Stator resistance
- $v$  : Voltage
- $i$  : Current
- $T_s$  : Sampling period
- $x$  : State space vector
- $u$  : Input vector
- $y$  : Output vector
- $\nu; \xi$  : The discrete forms of system and measurement noise
- $K$  : Kalman matrix
- $P; P_0$  : State error covariance matrix, Initial state error covariance matrix
- $Q; R$  : Covariance state noise and covariance measurement noise matrices

- $F; H; \Phi$ : Jacobian, output matrix, and state transition matrices
- $s$  : Laplace operator

### **Indexes**

- $d - q$  : Rotating reference frame indexes
- $\alpha - \beta$  : Stationary reference frame indexes
- $a; b; c$  : Three phase reference frame indexes
- $*$  : Reference quantity
- $\hat{\cdot}$  : Estimated quantity
- $n$  : Sampling index
- $n/n - 1$  : Predicted quantity
- $n/n$  : Optimal estimated quantity