DEVELOPMENT OF FPGA BASED CONTROL ARCHITECTURE FOR PMSM DRIVES

by

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I certify that the work in this thesis has not been previously submitted for a degree nor has it been submitted as a part of the requirements for other degree except as fully acknowledged within the text.

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Quang Nguyen Khanh
ABSTRACT

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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


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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
- $\hat{}$: Estimated quantity
- $n$: Sampling index
- $n/n - 1$: Predicted quantity
- $n/n$: Optimal estimated quantity