Center for Embedded Systems (CES)
Request for Proposals Template – YEAR 7

DUE: Wednesday, April 1, 2015, by 11 p.m.

TITLE:	Embedded Controller for Reduction of Torque Oscillations in a PMSM				
PI:	C.J. Hatziadoniu	**EMAIL:**	hatz@siu.edu	**TEL:**	(618) 453-7036
DEPT:	ECE	**SCHOOL:**	Southern Illinois University Carbondale		

ABSTRACT: (250 OR FEWER WORDS)

The proposed project will be an extension of a series of previously funded by the center projects addressing the control of a permanent magnet synchronous motor (PMSM). The ultimate goal is to develop a multiple function controller that can be incorporated into an integrated system-on-chip (SoC), thereby reducing hardware size and complexity. In the previous projects, two controller functions were developed for the PMSM: a speed regulator and an adaptive scheme to cancel stator current harmonics. In this project, it is proposed to investigate the torque harmonics generated at low frequencies as a result of a non-sinusoidal flux distribution in the motor. Subsequently, it is proposed to design a control loop to reduce the torque harmonics. The additional function will be incorporated into an SoC along with the previously developed subsystems of the controller.

PROBLEM:

PMSMs generate harmonics due to the imperfect distribution of magnetic flux. Harmonic generation is particularly pronounced in trapezoidal flux motors. In these motors, the shape of the flux distribution induces high magnitude low order harmonic frequencies to the back emf of the motor. As a result, harmonic stator currents will develop. The interaction between these harmonic currents and the harmonic emf produces torque oscillations at related frequencies, [5].

In certain applications, torque oscillations at low frequencies induce mechanical vibrations that can be disruptive to a process. Therefore, it is important to eliminate or reduce these torque harmonics. In a PMSM with a nearly sinusoidal flux distribution, this can be achieved by eliminating the harmonics from the stator currents. In PMSM with a trapezoidal flux distribution, however, this does not suffice, since a sinusoidal stator current will still produce low order torque oscillations. In effect, minimizing stator harmonics for a trapezoidal PMSM will increase the harmonic torque oscillations and, vise-versa, minimizing torque oscillations will increase stator harmonics, [5].

The main challenge in designing a suitable algorithm is the dependence of the fundamental of the harmonic frequencies on the speed of the motor. Therefore, a conventional fixed frequency filter will not be effective. The approach must be based on adaptive filtering techniques. However, the complexity of the technique could impede implementation on an SoC, [1].

The proposed work will investigate adaptive methods for reducing the torque harmonics produced by a non-sinusoidal flux distribution in PMSM. The final algorithm will be optimized for implementation in a SoC in order to reduce hardware complexity.

RATIONALE:

Torque oscillations at low frequencies can present a problem in certain industrial applications. It is necessary to investigate the effectiveness versus the complexity of suitable adaptive harmonic elimination techniques in order to design an algorithm suitable to be implemented in a SoC.

APPROACH:

The main approach will consist in developing a suitable algorithm to counteract the torque oscillations due to the non-sinusoidal emf of the motor. The algorithm will be based on motor emf and torque estimation on-line [1, 3, 4]. The frequency content of the motor back emf varies with the motor speed. Adaptive algorithms have been already developed in a previous project for estimating the motor back emf [2]. Concerning the estimation of the motor torque harmonics, the proposed project will attempt to estimate the motor torque either based on direct dc current measurements or based on the stator current measurements. The estimated values of the back emf and torque will be used as feedback to counter modulate the stator voltage (through the motor inverter output).

Suitable models will be built for the trapezoidal PMSM using Simulink in order to test the effectiveness of the developed techniques for torque oscillation elimination.

NOVELTY:

The main novelty of the project is in the method to estimate the motor torque without requiring a mechanical sensor. Another novelty is the incorporation of a complete motor controller into an SoC.

POTENTIAL BENEFITS TO INDUSTRY MEMBERS:

The primary benefit to the industry is the potential to reduce torque oscillations and to reduce the size of needed hardware.

DELIVERABLES:

The main deliverables include:

1. the code for an SoC implementation;
2. a MATLAB models of the motor and the controller for using in studies and assessing effectiveness.

TIMELINE/MILESTONES: (PER QUARTER)

Term	Deliverable
August-December, 2015	Literature review and design of the main algorithm
January-May, 2016	Validation of the algorithm and integration of algorithm into the SoC

TECHNOLOGY TRANSFER:

The algorithm developed will be directly transferred onto the SoC at SIUC sight.

BUDGET:

The project requests $25k for the entire duration. The funds will support a graduate student and half of a month salary for the PI.

BIBLIOGRAPHY: (ATTACH IN IEEE CONFERENCE OR JOURNAL FORMAT)

[1] Vladan Petrovic´, Romeo Ortega, Aleksandar M. Stankovic´, and Gilead Tadmor, “Design and Implementation of an Adaptive Controller for Torque Ripple Minimization in PM Synchronous Motors”, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 15, NO. 5, SEPTEMBER 2000 871.

[2] Yasser Abdel-Rady Ibrahim Mohamed, and Ehab F. El-Saadany, “A Current Control Scheme with an Adaptive Internal Model for Robust Current Regulation and Torque Ripple Minimization in PMSM Vector Drive”, *IEEE Trans. In Energy Conversion, Vol. 23-1, 2008, pp 92-100.*

[3] Bodson, M.; Sacks, Alexei; Khosla, P., "Harmonic generation in adaptive feedforward cancellation schemes," *Automatic Control, IEEE Transactions on* , vol.39, no.9, pp.1939,1944, Sep 1994

[4] Messner, W.; Bodson, M., "Design of adaptive feedforward controllers using internal model equivalence," *American Control Conference, 1994*, vol.2, no., pp.1619,1623 vol.2, 29 June-1 July 1994

[5] Cho, K.-Y.; Bae, J.-D.; Chung, S.K.; Youn, M.J., "Torque harmonics minimisation in permanent magnet synchronous motor with back EMF estimation," *Electric Power Applications, IEE Proceedings* - , vol.141, no.6, pp.323,330, Nov 1994

PI INFORMATION: (ATTACH 2-PAGE CV)

CONSTANTINE J. HATZIADONIU, Professor, hatz@siu.edu
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Carbondale, IL 62901-6603

Education

Diploma in Electrical Eng., University of Patras, Greece, 1983
Ph.D. in Electrical Eng., West Virginia University, Morgantown, 1987

Professional Experience

- Professor of Electrical and Computer Engineering, Southern Illinois University Carbondale. Sept 1987-present.
- Teaching and Research Assistant. Department of Electrical Engineering, West Virginia University, Morgantown. August 1984-1987.
- Consulting engineer, Greece. August 1983-1984.

Research Interests

Power electronics, Energy harvesting devices, wind and photovoltaic energy systems, power system modeling and simulation; power system control and protection.

Recent Publications.

Nezar Abou Qamar, **C.J. Hatziadoniu**, Haibo Wang, "Speed error mitigation for a DSP-based resolver-to-digital converter using autotuning filters", IEEE Trans. On Industrial Electronics, Vol. 62-2, Feb 2015, pp 1134-9.

Hany A. Abdelsalam and **C.J. Hatziadoniu**, "A Robust Wide Area Controller of Multiple FACTS for Damping Oscillations in Multi-Area Power System Using the H∞ Method", Power System Conference 2011 PSC11, March 15-18, 2011 at Clemson University, Clemson, SC, USA.

A. Albanna and **C.J. Hatziadoniu**, 'Harmonic Modeling of Hysteresis Inverters in the Frequency Domain', IEEE Trans. on Power Electronics, Vol. 25, No 5, May 2010, pp.1110-4.

Ahmad Albanna, **C.J. Hatziadoniu**, "Harmonic Modeling and Analysis of Multiple Residential Photo-Voltaic Generators", Power and Energy Conference, University of Illinois Urbana-Champaign, February 2010.

Ahmed Albanna, **C.J. Hatziadoniu**, "Harmonic Modeling of Three-Phase Neutral-Point Inverters", Proceedings of the 2009 North American Power Symposium, Mississippi State University, Starkville, MS, Oct 4-6, 2009.

Ahmed Albanna, **C.J. Hatziadoniu**, "Harmonic Modeling of Single-phase Three-level Hysteresis Inverters", Proceedings of the 2009 North American Power Symposium, Mississippi State University, Starkville, MS, Oct 4-6, 2009.

C.J. Hatziadoniu, N.B. Harp, and A.J. Sugg, "Finite-Element Models for Open-Air Power Lines in Broadband PLC", IEEE Trans. On Power Delivery, Vol. 21, No. 4, Oct. 2006, pp. 1898-1904.

F. Pourboghrat, F. Farid, C.J. **Hatziadoniu**, M. Daneshdoost, F. Mehdian, M. Lotfalien, "Local Sliding Control for Damping Inter-Area Power Oscillations", IEEE Trans. On Power Systems, PES 19-2, May 2004, pp. 1123-34.

G. Chang, **C.J. Hatziadoniu**, W. Xu, P. Ribeiro, R. Burch, W.M. Grady, M. Halpin, Y. Liu, S. Ranade, D. Ruthman, N. Watson, T. Ortmeyer, J. Wikston, A, Medina, A. Testa, R. Gardinier, V. Dinavahi, F. Acram, P. Lehn, "Modeling Devices with nonlinear Voltage-current Characteristics for harmonic studies", IEEE Trans. On Power Delivery, Vol. 19, No. 4, Oct. 2004, pp. 1802-11.

Synergetic Activities.

- "Pilot Study of Energy Harvesting Devices towards the Development of a Prototype", (PI C.J. Hatziadoniu, Co-PI Tsuchin Chu and Fran Harackiewicz), NSF, I/UCRC for Embedded Systems August 2012-August 2013.
- "Resolver Sensor Conditioning Size Reduction", (PI C.J. Hatziadoniu, Co-PI W. Haibo), NSF, I/UCRC for Embedded Systems, August 2012-August 2013.
- "Distribution System Modeling for Power Line Communication", Research grant, AMEREN-UE, 2001-2002.
- "Software for the optimum operation and planning of high-data rate PLC Systems", Research grant, AMEREN-UE 2003-04.
- "Workstation Computer Program for Insulation Coordination of ac and dc Substations"
- Research grant (EPRI 1989-1992), RP 2323, with G.D. Galanos and M. Daneshdoost.
- "Advanced Voltage Systems", Research grant (EPRI 1990-1992), RP 4000-22, with G.D. Galanos and F. Pourboghrat.
- "Faraday's Law Electric Machine Laboratory", Equipment grant (NSF 1991), with G.D. Galanos, V. Feiste and M Daneshdoost.

Collaborators and Other Affiliations.

Collaborators: D. Takach, Ameren UE, Saint Louis, Missouri.
Graduate Advisor: Dissertation Advisor: G.D. Galanos, Department of Electrical and Computer Engineering, SIUC.
Thesis and Dissertation Advisor (recent): A. Albana (PhD), H. Ahmed (PhD), Dler Dler (MS), H. El-Hadji (MS), D. Schleeper (MS).

I/UCRC Executive Summary - Project Synopsis		Date: April 1, 2015
Project Title: Embedded Controller for Reduction of Torque Oscillations in a PMSM		
Center/Site: SIUC		
Principle Investigator: C.J. Hatziadoniu		**Type: (New or Continuing)** New
Tracking No.: (CES office to input)	**Phone ☹618) 453-7036**	**E-mail : hatz@siu.edu**
		Proposed Budget: $25k

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Rationale / Approach: The main approach will consist in developing a suitable algorithm to counteract the torque oscillations due to the non-sinusoidal emf of the motor. The algorithm will be based on motor emf and torque estimation on-line. The proposed project will attempt to estimate the motor torque either based on direct dc current measurements or based on the stator current measurements. The estimated values of the back emf and torque will be used as feedback to counter modulate the stator voltage (through the motor inverter output).

Novelty: The main novelty of the project is in the method to estimate the motor torque without requiring a mechanical sensor. Another novelty is the incorporation of a complete motor controller into an SoC.

Potential Member Company Benefits: The primary benefit to the industry is the potential to reduce torque oscillations and to reduce the size of needed hardware.

Deliverables for the proposed year: The main deliverables include:

1. the code for an SoC implementation;
2. a MATLAB models of the motor and the controller for using in studies and assessing effectiveness.

Milestones for the proposed year:

Term	Deliverable
August-December, 2015	Literature review and design of the main algorithm
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Progress to Date: **THIS SECTION TO BE UPDATED IN JANUARY**

Estimated Start Date: August 2015	**Estimated Knowledge Transfer Date**: May 2016