Center for Embedded Systems
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Optimized Switching Pattern Generator For a SoC-Based Motor Drive

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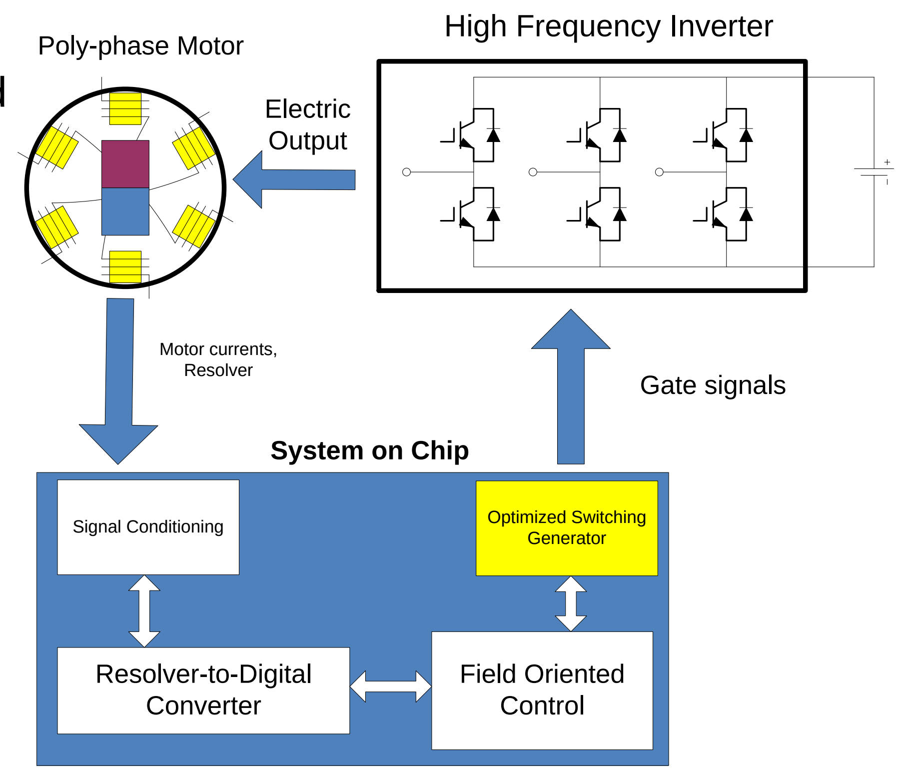
Project Overview and Description

- **Project Description**

Develop and integrate into an existing SoC-based motor drive system a switching pattern generator for the power inverter in order to reduce the harmonic currents of the motor.



- **Problem and Challenges**
- The non-sinusoidal flux distribution inside the motor causes low order harmonic currents.
- The main effect is to de-rate the motor capability and increase torque oscillations.
- A key challenge in the design of a switching algorithm for the inverter is the shifting of the frequency of the fundamental of these harmonic currents as the motor speed changes.
- The inverter band-with is sufficient to deal with the most severe of these harmonics at the low orders of 5^{th} and 7^{th}.The 11^{th} and 13^{th} orders present a greater challenge at high motor speeds.

Approach

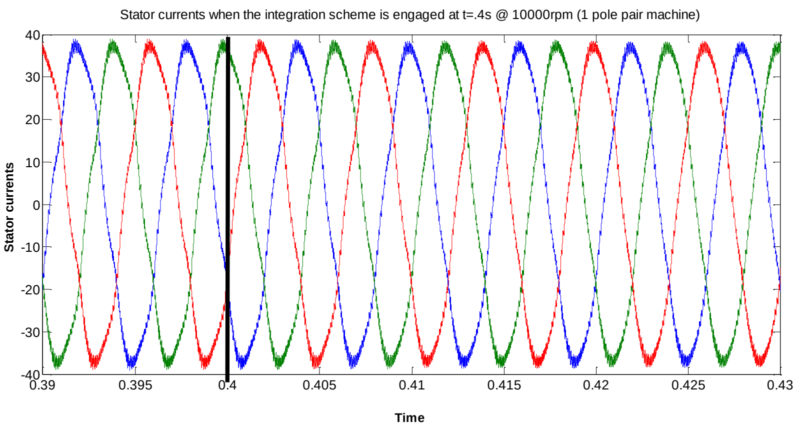
- **Approach:**
  - Develop an accurate model for the PM motor representing the flux distribution in the stator (the trapezoidally distributed flux).
  - Study harmonic cancellation techniques based on adaptive control applied to the inverter output (e.g. switching pattern generation).
- **Novelty:**
  - Integrate an efficient adaptive control system for the non-sinusoidal PM motor into an SoC.
- **Benefits:**
  - The proposed project will result in significant reduction of discrete components for the implementation of the controller, including inductive filters applied at the motor stator.
  - It will enable the nearly full use of the motor ratings.

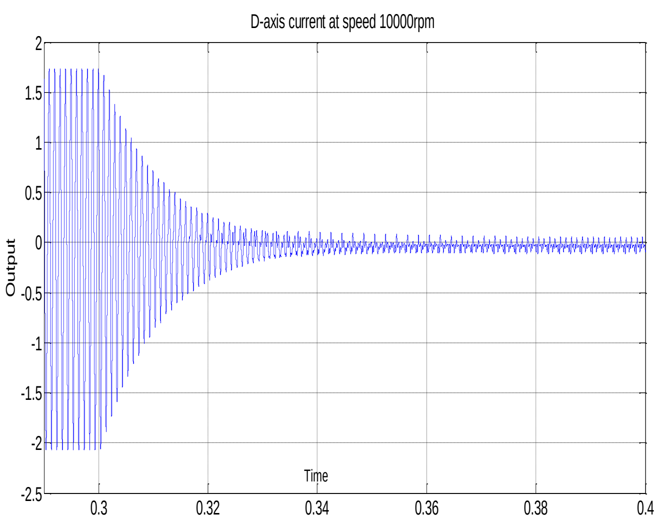
Project Tasks/ Deliverables

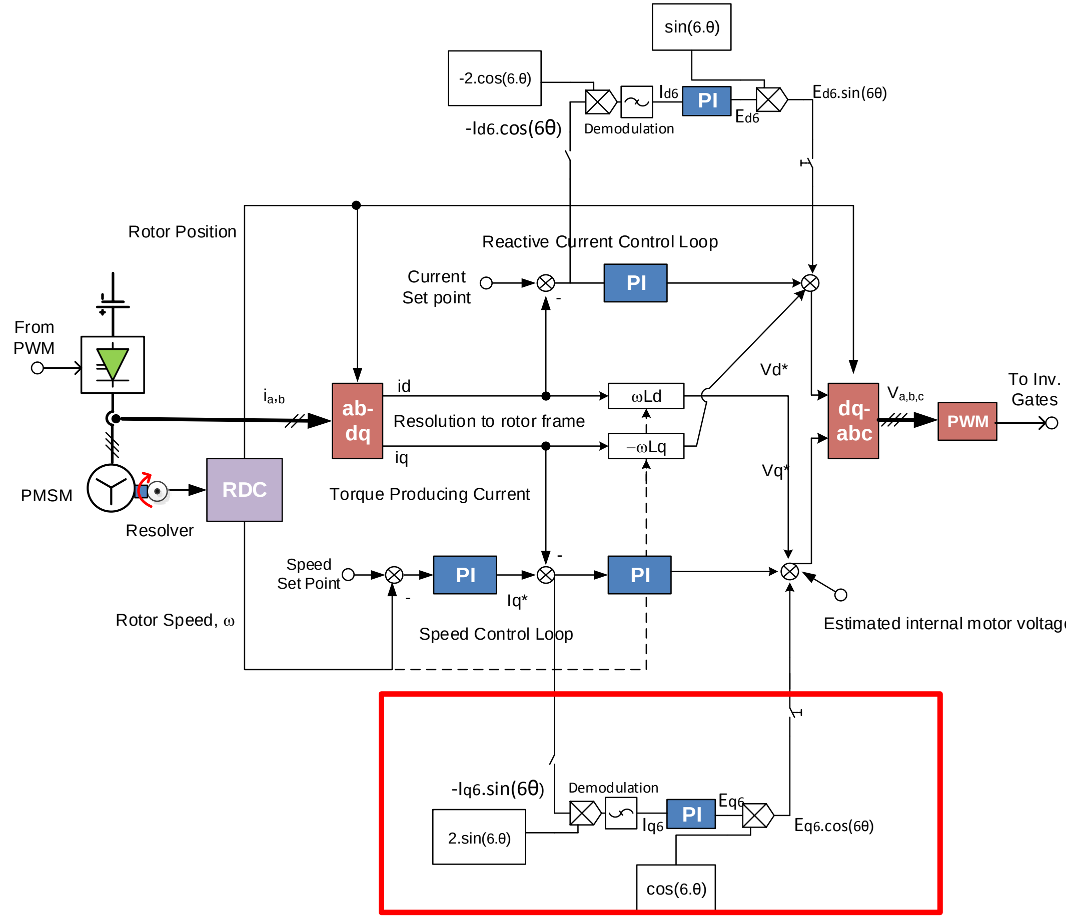
	Description	Date	Status
1	Researching of harmonic cancellation techniques	August	
2	Develop SIMULINK model	January	
3	Fabric programing	March	

- **Task 1:** **The research studies the most effective cancellation scheme for the motor.**
- **Task 2:** **A SIMULINK model is developed to assist in studying and optimizing the adaptive method.**
- **Task 3:** **The optimized method is programed into the SoC fabric.**

Harmonic Cancellation through Closed Loop Control



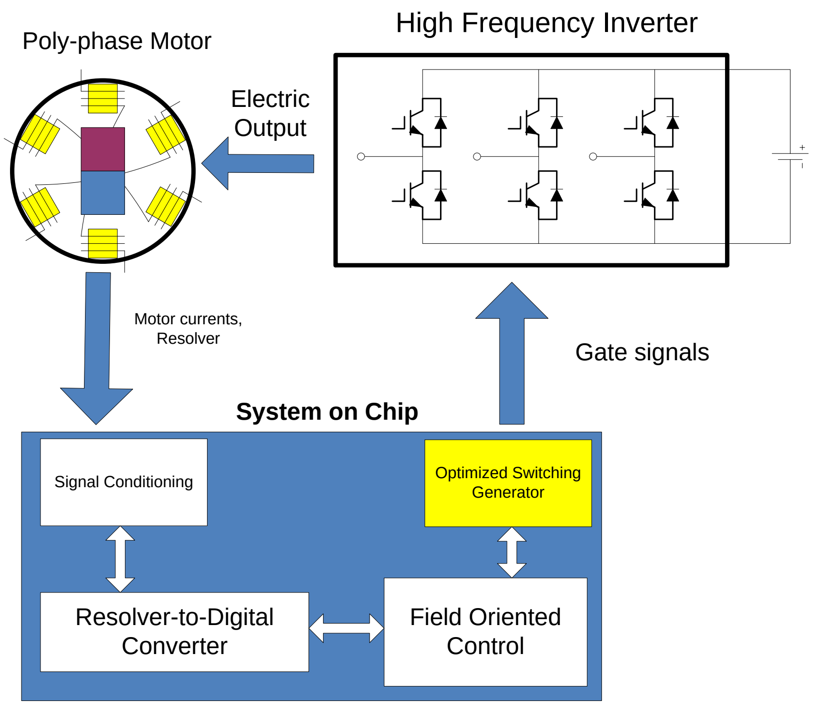




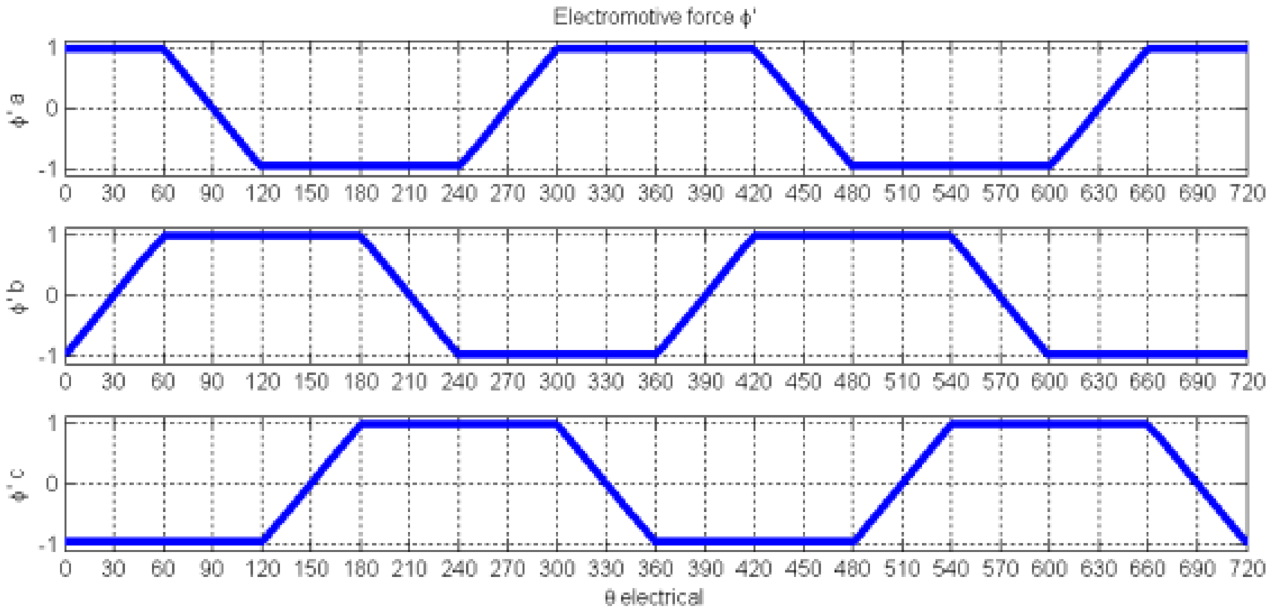
The cancelation loop converges quickly computing the correct components of the inverter output voltage that counter the harmonic back emf of the motor resulting in significant current harmonic cancellation.

Executive Summary

- Non-sinusoidal flux distribution in the PM motor causes low order harmonic currents.
- Typically an inductive filter is needed to reduce these currents.
- A optimized harmonic cancellation technique will reduce the current harmonics and eliminate the need of an inductive filter.
- The developed method will be embedded into a SoC. The SoC already includes the motor drive control.
- The project will create a complete motor-drive control integrated into a SoC.



Trapezoidal Motor Harmonic Profile



harmonic order	5000 (rpm) Mag., A	10000 (rpm) Mag., A	5000(rpm) %	10000(rpm) %
1	18.57	37.1	100%	100%
5	2.34	2.3	12.59%	6.2%
7	.57	.55	3.05%	1.48%
11	.13	0.12	.69%	.33%

Harmonic Currents and Harmonic Torque

- The motor torque is expressed as:

$$T_e = \frac{3P}{2}(\lambda_{ds} i_{qs} - \lambda_{qs} i_{qs}),$$

where $\lambda_{ds} = L_d i_{ds} + \psi_f - \psi_d cos6\theta_r$, $\lambda_{qs} = L_q i_{qs} + \psi_q sin6\theta_r$

- The torque can be represented in terms of fundamental and harmonics as follows:

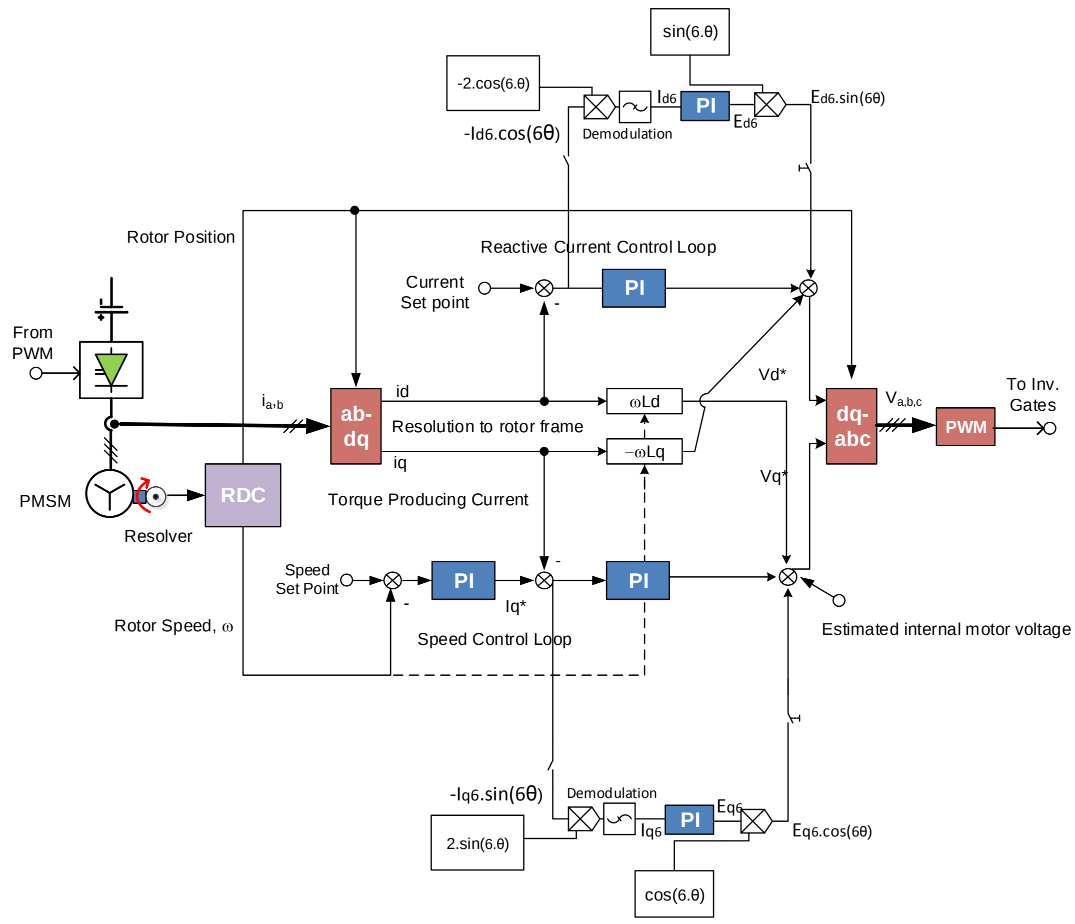
$$T_0 = \frac{3P}{2}[\psi_f I_{q0} - \frac{1}{2}(\psi_{d6} I_{q6} + \psi_{q6} I_{d6})]$$
$$T_6 = \frac{3P}{2}[\psi_f I_{q6} - \psi_{d6} I_{q0}]$$
$$T_{12} = \frac{3P}{4}[\psi_{q6} I_{d6} - \psi_{d6} I_{q6}]$$

- If the objective is to eliminate the torque harmonics, I_{d6} , I_{q6} should be controlled as:

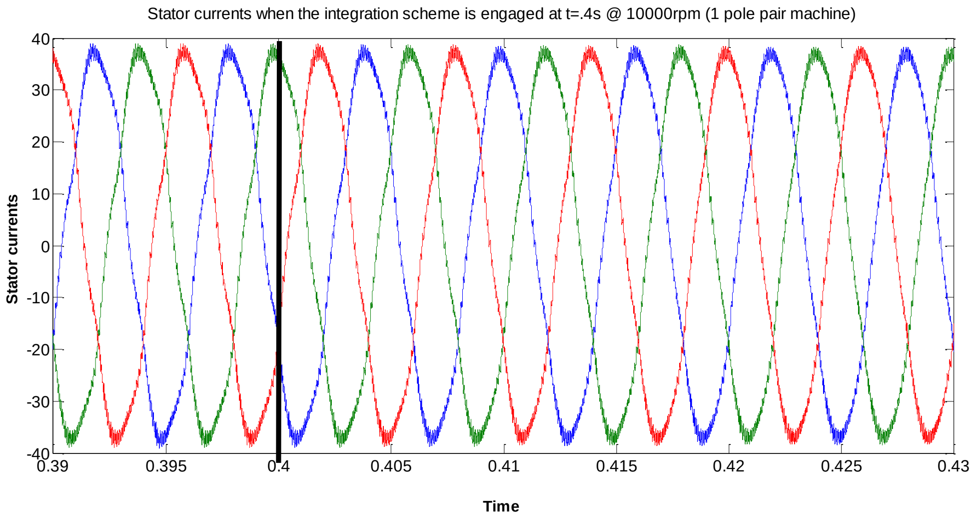
$$I_{q6} = \frac{\psi_{d6}}{\psi_f} I_{q0}$$
$$I_{d6} = \frac{\psi_{d6}}{\psi_{q6}} I_{q6} = \frac{\psi_{d6}}{\psi_{q6}} \cdot \frac{\psi_{d6}}{\psi_f} I_{q0} = \frac{\psi_{d6}^2}{\psi_{q6}\psi_f} I_{q0}$$

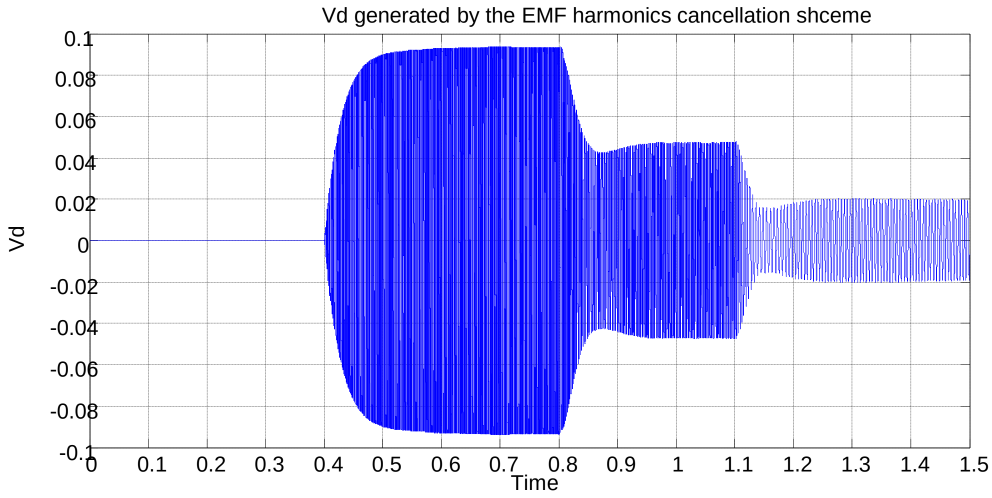
Harmonic Cancellation through Closed Loop Control

- Frequency demodulation
- The magnitude of the 6th order current harmonic is produced by demodulating the d-q currents.
- The output of the PI controller, which is the magnitude of the 6th harmonic back emf, is modulated to produce the 6th harmonic of the back emf.
- At low speeds the PI current controller is fast enough and the 6th harmonic back EMF compensation section is disconnected.



Results ABC stator currents





Results DQ stator currents