Center for Embedded Systems
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Embedded Controller for Reduction of Switching Harmonics and Torque Oscillations in a PMSM

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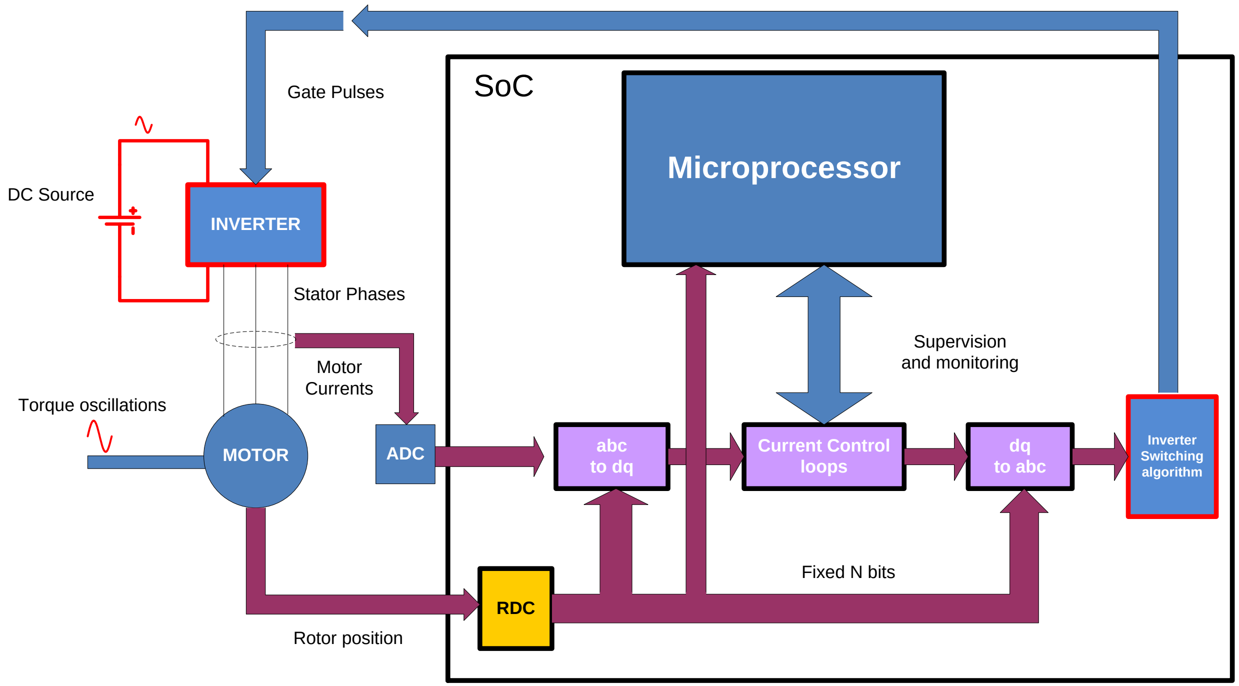
Project Overview and Description

- Design a control loop for an SoC embedded motor controller to:
  - Reduce overall switching harmonics and EMI.
  - Reduce motor torque pulsations.

- This project extends the work of two previous projects aimed at developing an SoC embedded controller for the PMSM:
  - Position resolving
  - Speed regulation
  - Low order harmonic current cancellation.

Project Overview and Description



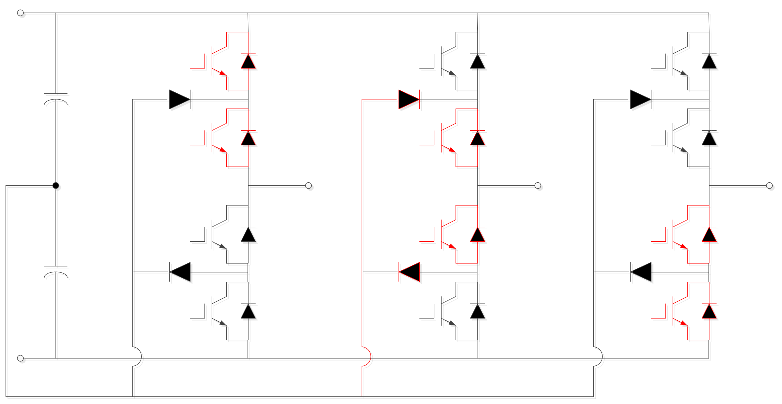
Problems:

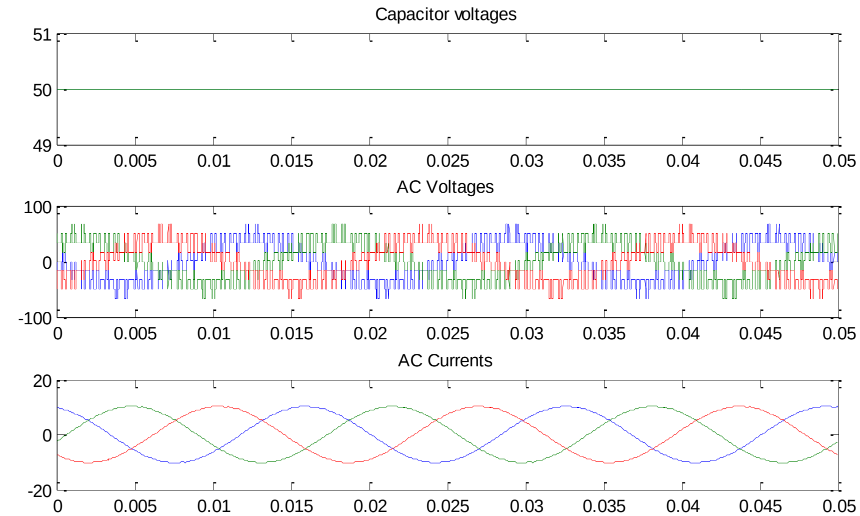
- The motor of interest is the trapezoidal PMSM with an inherently distorted back emf.
  - ❑ This creates low order harmonics on the stator currents and on the torque.
- The switching action of the 2-level inverter creates high magnitude switching harmonics.
  - ❑ Increases EMI and filter size.

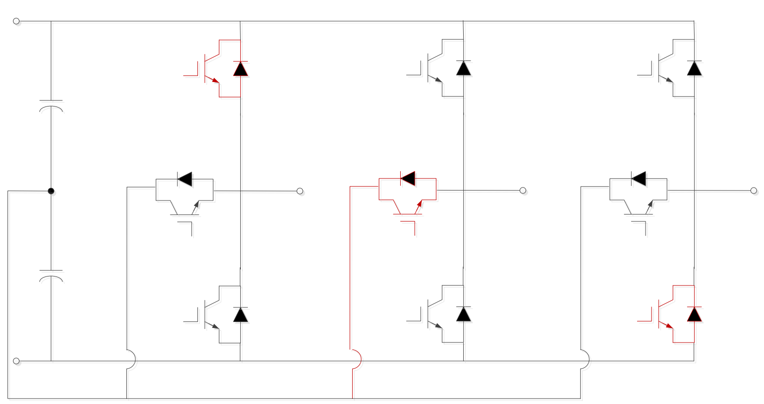
Approach

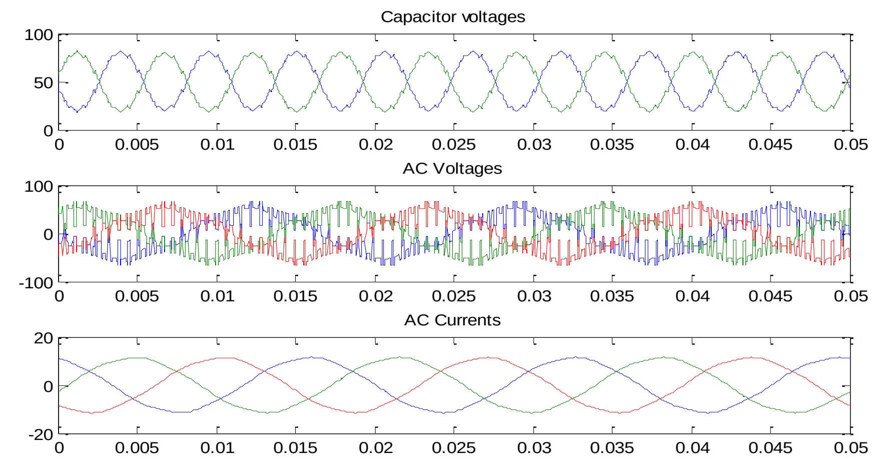
- Extend the harmonic cancellation methods developed in the previous project to address the torque pulsation.
- Investigate the application of the 3-level inverter to provide a smoother control of the motor decreasing the switching harmonics.
- The potential benefits from this project include an improved control of the PMSM and a reduced hardware size by embedding the control functions into a single chip.

Three-Level Inverter Arrangements







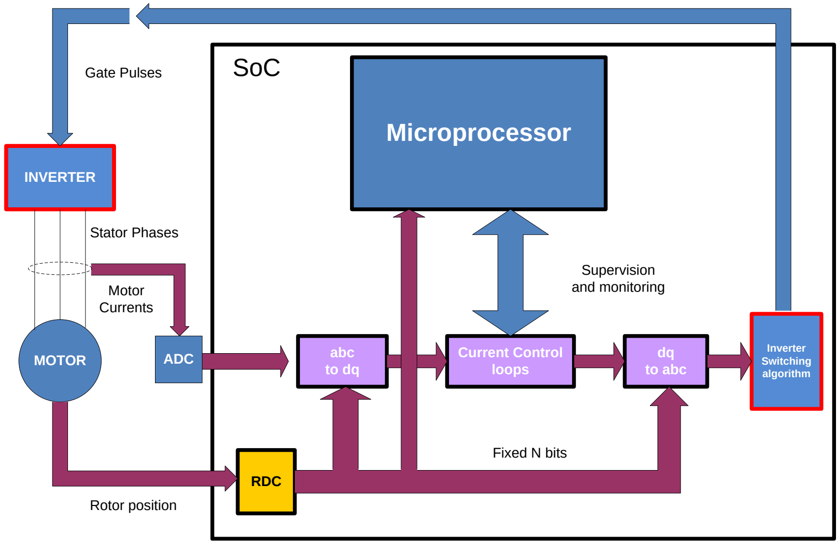


Project Tasks/ Deliverables

	Description	Date	Status
1	Literature review	Aug to Dec	
2	Development of methods	Dec to April	
3	Method testing	April to May	
4	Development of the deliverables (reports, models, programming).	May	
5			
6			

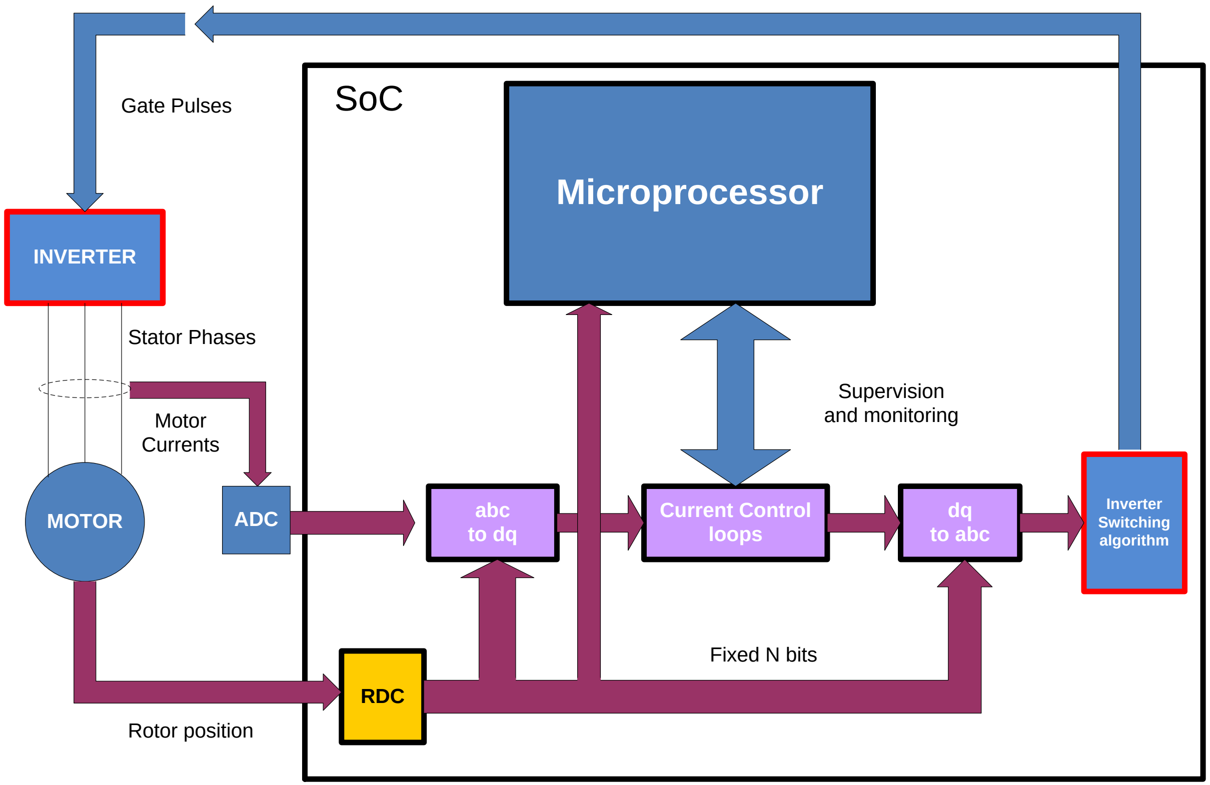
Executive Summary

- **The PMSM controller is embedded into a SoC**
- **The controller has multiple functions**
  - Speed regulation
  - Position resolving
  - Harmonic cancellation
- **The project will**
  - Investigate new inverter topologies for smoother control
  - Investigate techniques for decreasing torque harmonics.

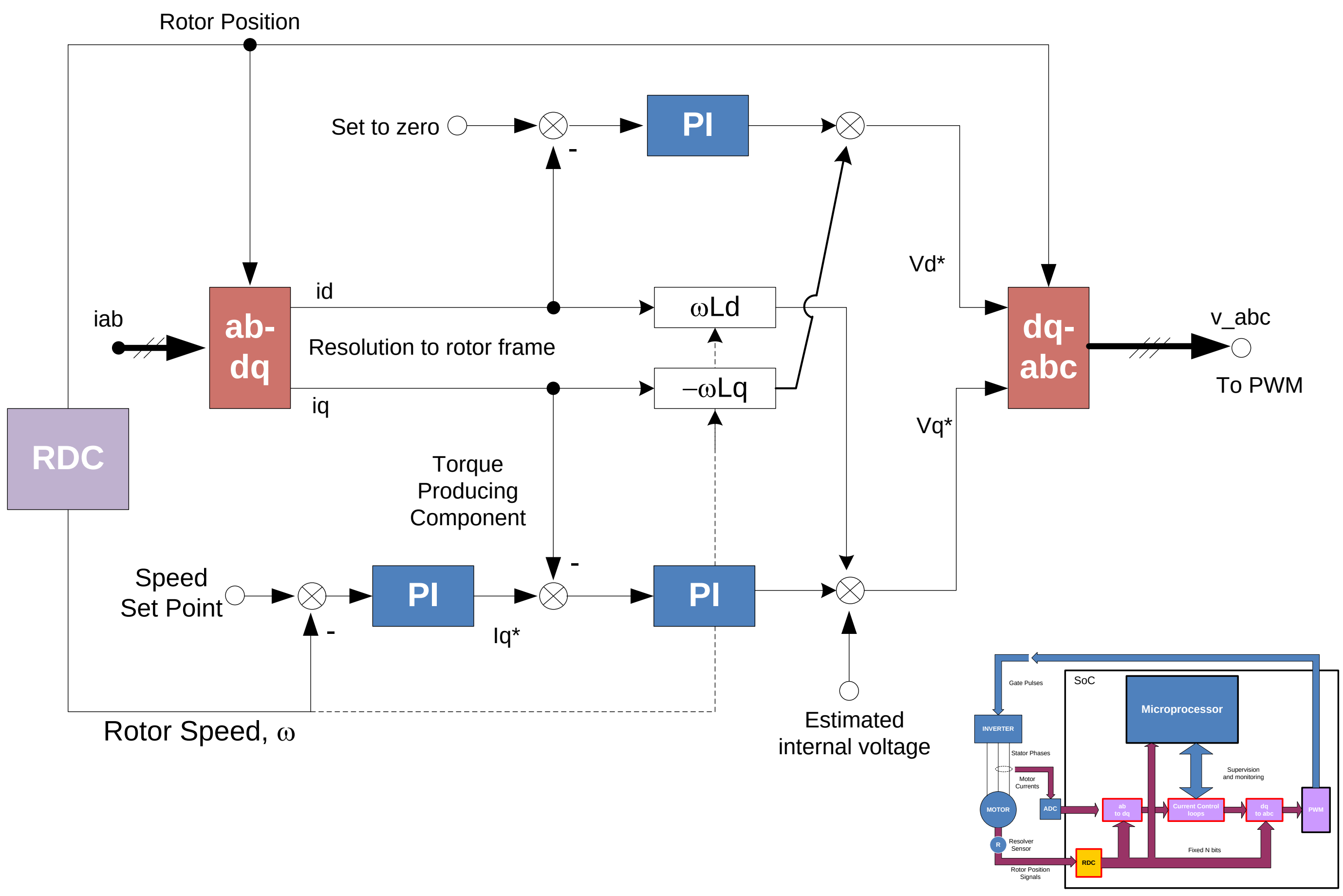


Approach

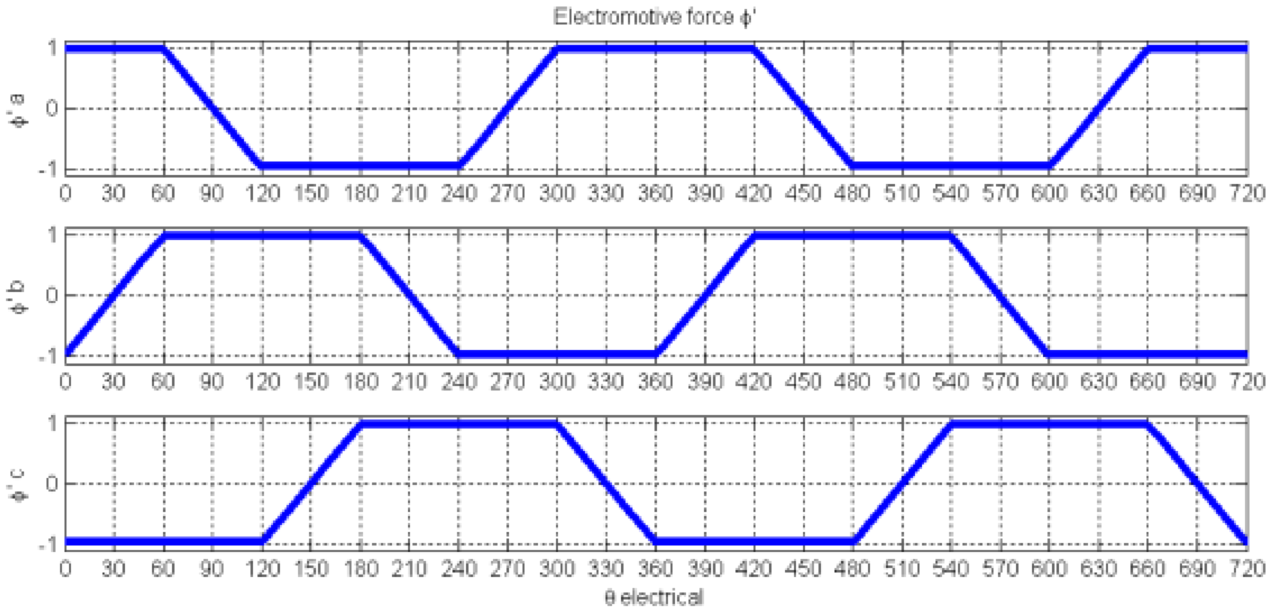
- **Embedded Controller Structure**
  - RDC
  - FOC
  - Switching Generator



Detail: The Decoupled FOC



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

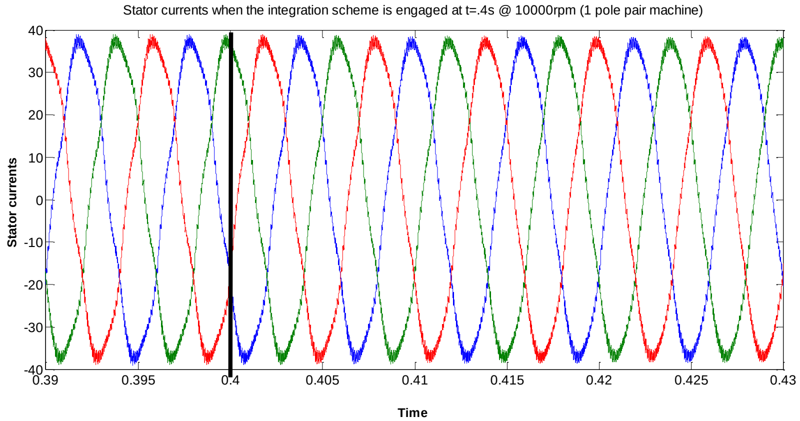
- The torque can be represented in terms of fundamental and harmonics as follows:

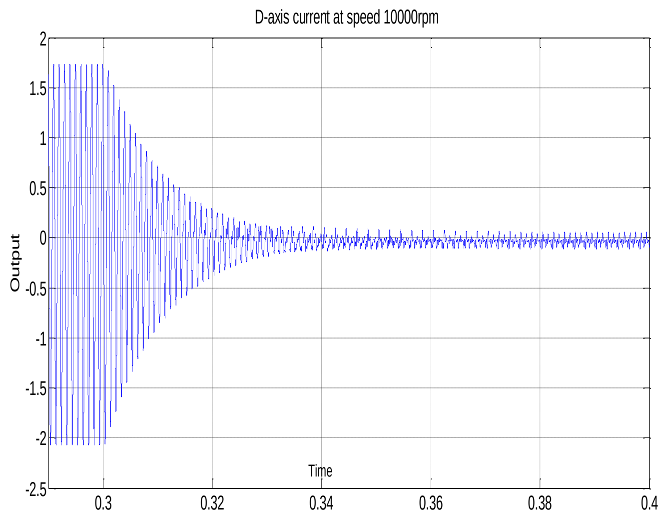
$$T_0 = \frac{3P}{2}[\psi_f I_{q0} - \frac{1}{2}(\psi_{d6} I_{q6} + \psi_{q6} I_{d6})]$$
$$T_6 = \frac{3P}{2}[\psi_f I_{q6} - \psi_{d6} I_{q0}]$$
$$T_{12} = \frac{3P}{4}[\psi_{q6} I_{d6} - \psi_{d6} I_{q6}]$$

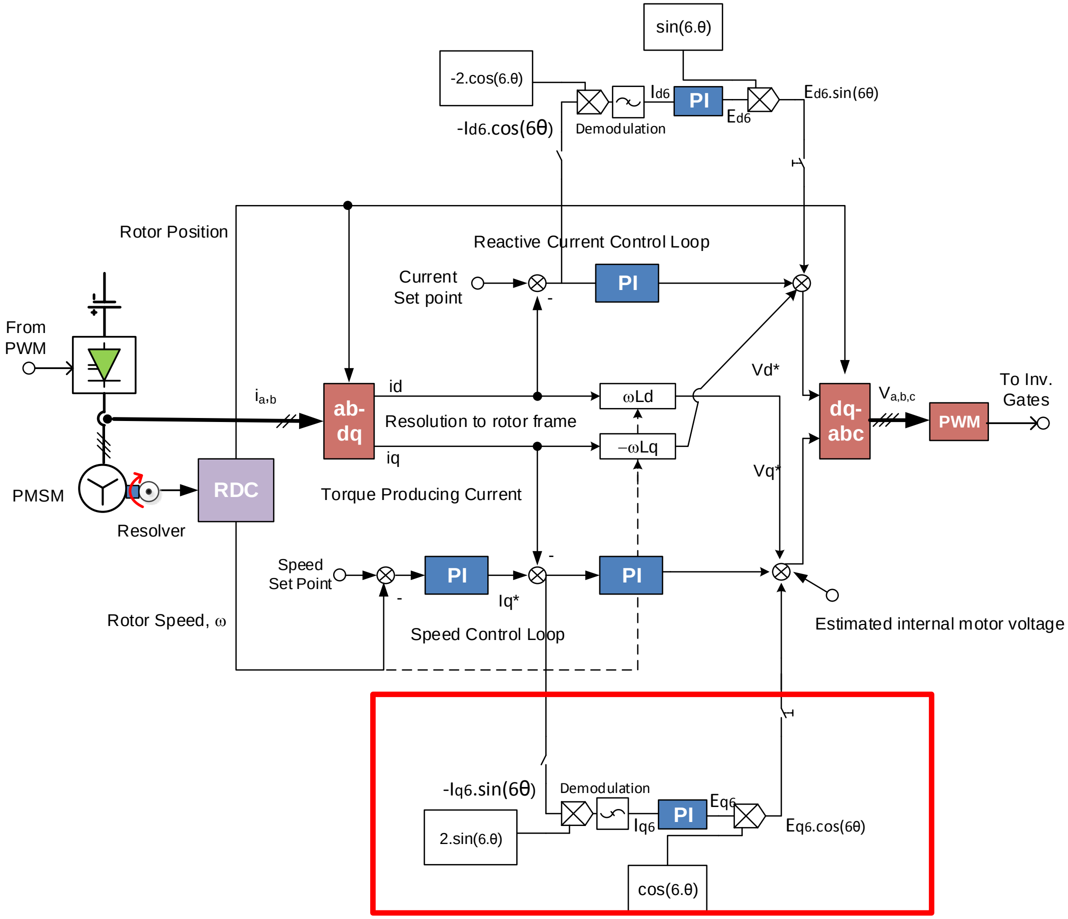
- If the objective is to eliminate the torque harmonics, I_{d6} , I_{q6} should be controlled as:

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

Harmonic Cancellation through Closed Loop Control







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.