

# Field oriented Control of an IPM

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## Introduction

Design of the drive systems of electric machines requires both an accurate model of the machine as well as the ability to simulate systems with different time constants (e.g., PWM and electromagnetic time constants). The machine model must be able to take saturation effects into account, carry out load and speed driven simulations, support scaling properties (for design iterations) of the system, in addition to being able to interface with the drive simulator. Using a 70 KW Interior permanent magnet (IPM) motor, designed using the MotorSolve BLDC software from Infolytica Corporation, a field oriented control of an IPM is presented in this document which shows a realistic drive simulation.

## IPM Motor Specifications

The IPM used in this example has the following specifications;

- Frame size : 190 mm (max.), round or square
- Drive type: Sine wave
- Voltage : 650 VDC (288 VDC + DC-DC Boost)
- Power output: 70 KW (4000 RPM -10000 RPM)
- Rated speed: 10000 RPM
- Rated torque ~ 65 to 70 Nm
- Peak Torque ~ 175 Nm starting to 4 Krpm
- Ambient Temp. 70 deg C
- Insulation class Class C (or better)
- Duty cycle : 10% at peak torque
- Cooling: 70 deg C 50-50 Glycol

As per specification, an 8 pole 48 slot IPM has been designed using the MotorSolve BLDC software. Details of the design steps are not given here. However, a summary of motor performance at 10000 RPM is given in Table 1.

Input power (KVA)	88.8	Core Mass (Rotor) (Kg)	8.71
Output power (KW)	86.4	Magnet Mass (Kg)	1.57
Efficiency (%)	97.3	Core mass (Stator) (Kg)	15.3
Av. Torque (Nm)	82.5	Ld (mH)	.341

Air gap stress (psi)	6.13	Lq (mH)	.82
Kt (Nm/A peak)	.395		
Ke (C.rad.sec peak)	.646		
Copper mass (Kg)	4.71		

Table 1: Performance summary @ 10000 RPM (92 A RMS, Gamma 45 degrees E)

This motor has been driven using a field oriented control (FOC) scheme using SIMULINK and a FEA based equivalent model of the machine, derived from the MotorSolve BLDC software. This exported model and its integration with SIMULINK for drive simulation and results are presented below.

### System Model Generation (SMG) of the IPM

A finite element analysis based equivalent model of the IPM consists of the system equations, the coefficients (the phase resistances, inductance matrix, back emf, etc.) of which are computed by solving the model using MotorSolve BLDC. A model of the IPM is exported as a \*.rsm file (an intrinsic format) which can be opened in SIMULINK using a MotorSolve-SIMULINK dll. The dll interface is shown below. The scaling properties, output controls etc. of the dll, all supported by this link are seen in this figure.

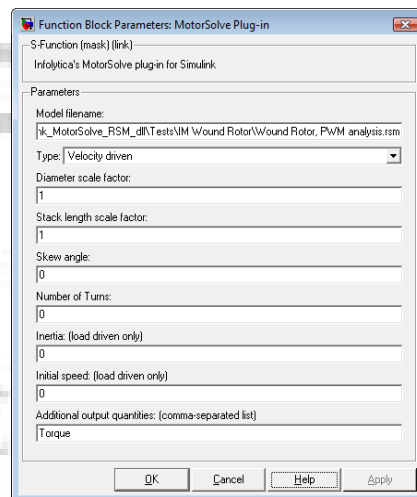


Figure 1: MotorSolve-SIMULINK interface dll

## Field Oriented Control (FOC)

The motor is driven by a 3 phase H-bridge circuit shown in Figure 2. In the actual model, the RL branches are replaced by the phase windings of the machine.

To control the motor dynamics, a simple PI control scheme is implemented in SIMULINK. The control strategy, based on closed loop velocity feedback determines the desired d and q axis voltages for the phase windings. The system block including the equivalent model and PI control block of this system is shown in Figures 3 and 4, respectively.

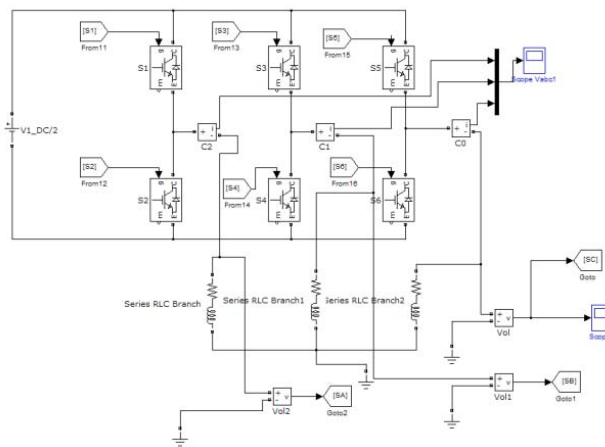


Figure 2: Standard 3-phase H-bridge simulation circuit

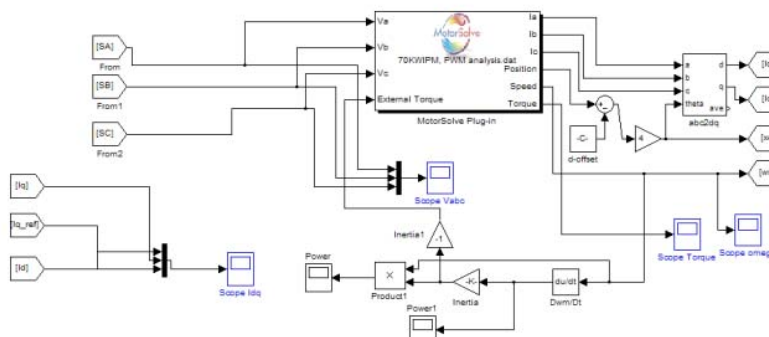


Figure 3: Response surface model of IPM and interface to SIMULINK



## Results

An arbitrary speed-time profile, similar to that used for portions of Urban Drive Simulations Standard (UDSS) was simulated to test the implementation of the scheme described here. The performance of the PI control system is shown in Figure 6. It is clear that the drive simulations are able to track the desired velocity versus time profile quite accurately. Also shown, in Figures 7 and 8, respectively, are the torque versus time and the d-q axis currents versus time of the simulations.

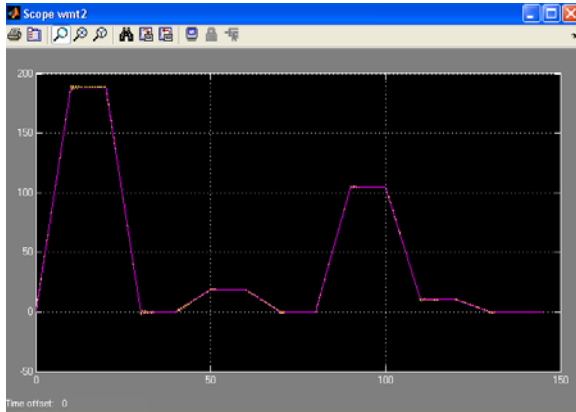


Figure 6: A test profile of speed vs. time

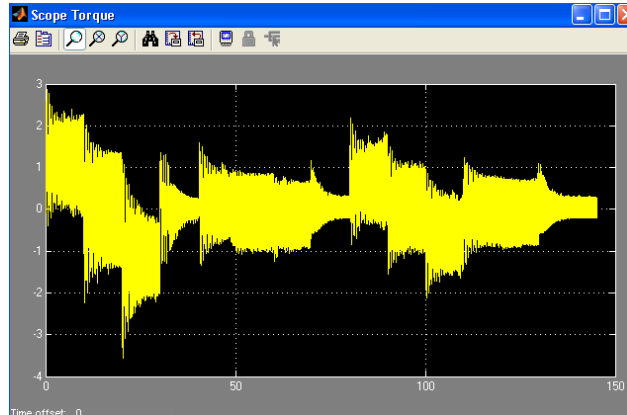


Figure 7: Torque versus time

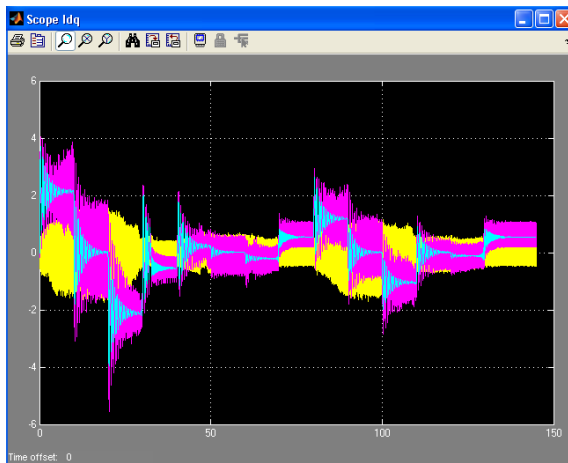


Figure 8: d and q axis currents versus time