# EE462 & EE464 Project: Design of a SM-PMSM Variable Frequency Drive with Matlab/Simulink


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## Contents



## Introduction

The aim of project is to design a SM-PMSM Variable Frequency Drive with respect to given parameters below by using matlab Simulink program.

$Pnominal$ = 80 $kW$

$Tnominal$ = 300 $Nm$

$nmax$ = 7000 $rpm$

Pole number: p=8

$Flux\ linkage$: $\lambda PM$ = 0.2 Vs (Wb-t)

$Ld$ = $Lq$ = 500 uH

$Inominal$ = 250 $A$ (peak)

Phase resistance $Rs$ = 50 mOhm

Equivalent inertia of the system: $Jeq$ = 10 kg m2

Ignore windage and friction losses.

The available supply is a three-phase AC source (50 Hz, 400Vl-l) and the PM is a surface-mount motor. Assume a 3-phase full-bridge diode rectifier is connected to the grid.

## Part A: Pre-design Stage

**1)** Calculation of the rated speed and torque of the PMSM.

$$Wbase = \frac{Pnominal}{Tnominal} = \frac{80\ kW}{300\ Nml} = \ 266.67\ rad/sec\ , Nbase = 2546.48$$

$$T = \frac{3}{2} * pp * \ \lambda PM * iq \ \ Where\ nomimal\ base\ Torque\ condition, \qquad \dot{I}q = \dot{I}nominal \ = 250\ A\,,$$
$$\dot{I}d = 0$$

Then T=1.5*4(pp)*0.2*250 = 300Nm where it is also given in parameters.

**2)** Calculation of the maximum applied electrical frequency and choose a switching frequency for your inverter

$$We = 2 * \pi * f \ \ , then\ frequency = \frac{We}{2 * \pi}$$

$$where\ from\ part\ a\ We(max) = \frac{7000rpm * 2 * \pi}{180}\ \ is\ found\ 733\ rad/sec,$$

$$fmax = \frac{733}{2 * \pi} = 116.67\ Hz$$

Selected Switch frequency=10kHz

**3)**

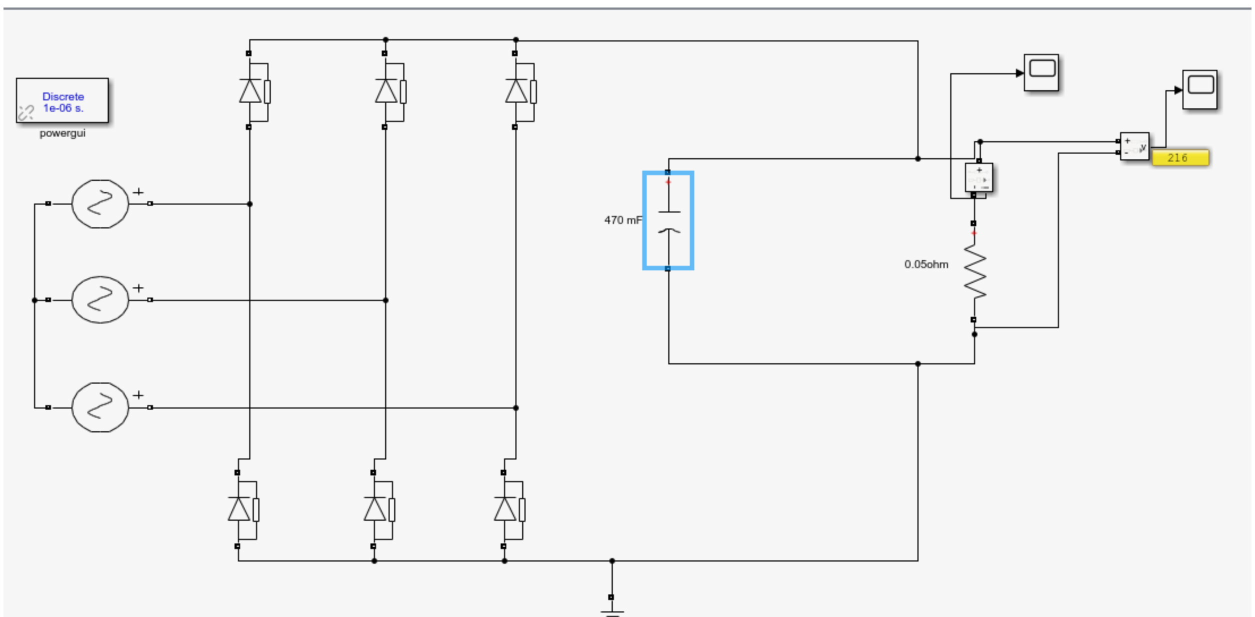


*Figure 1:Design of DC-link filter for the rectifier block*

We select the capacitor as 100 mF in order to decreases the voltage ripple.

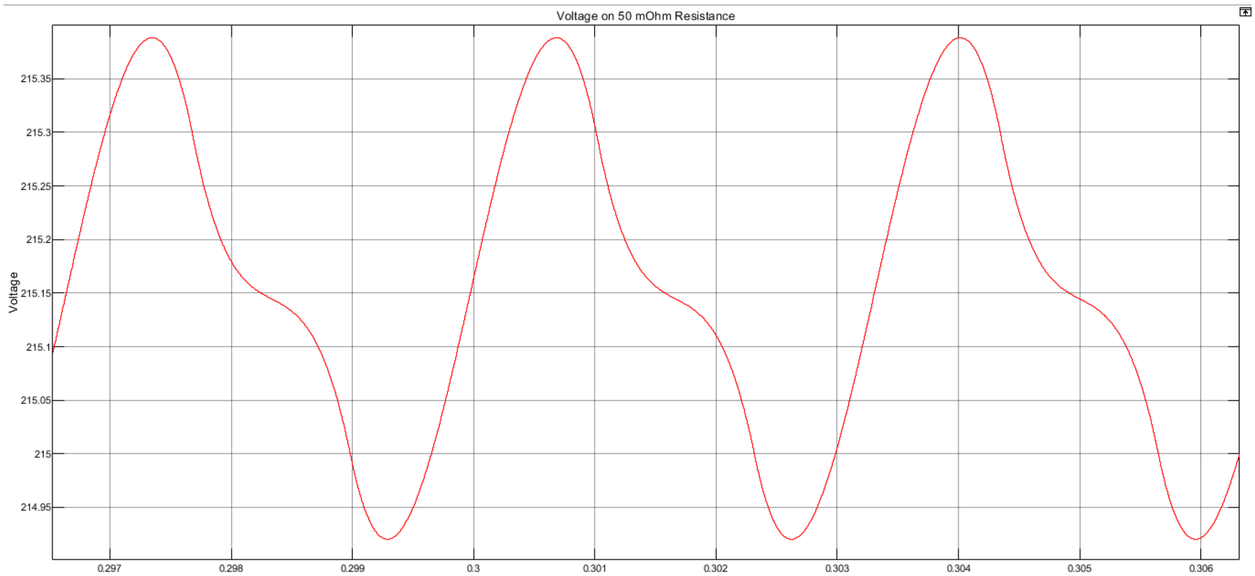


*Figure 2: Plot of  the DC-link voltage waveform by connecting a resistive load equivalent to motor.*

As seen figure 2. Voltage ripple is about 0.4 V. Avarage DC-link voltage as 215.15 .

Then, Ripple = 100*$\frac{0.4}{215.15} = \%0.2$ , This is so efficient result for our design.

# Part B: SPWM Design

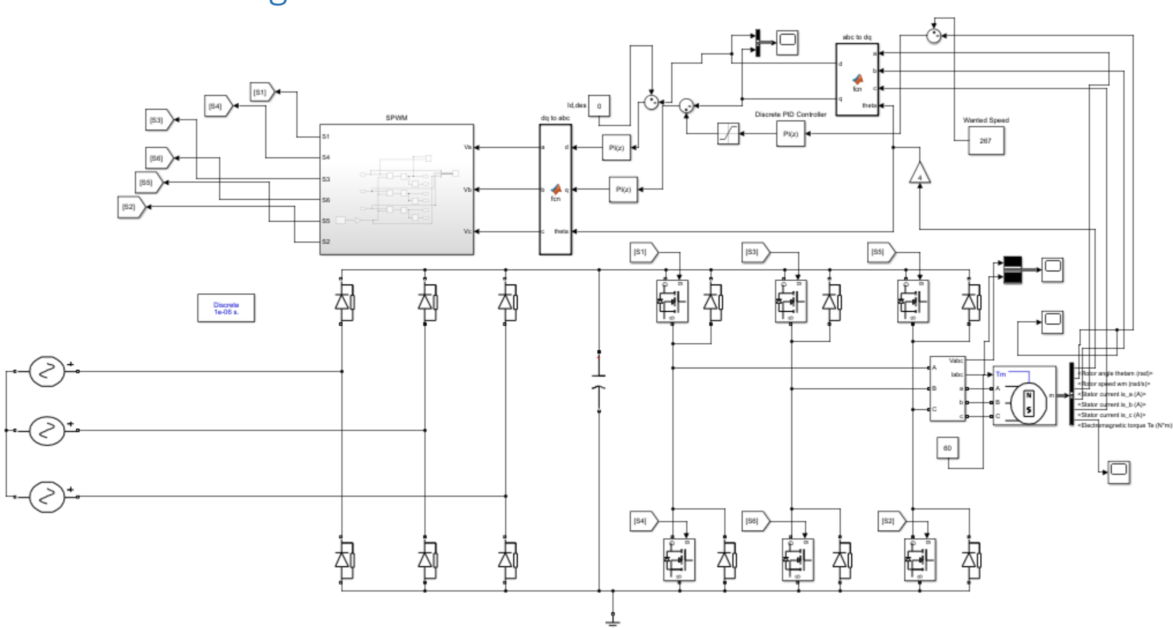


*Figure 3. Overall System*

**1)** Graphs are given below;

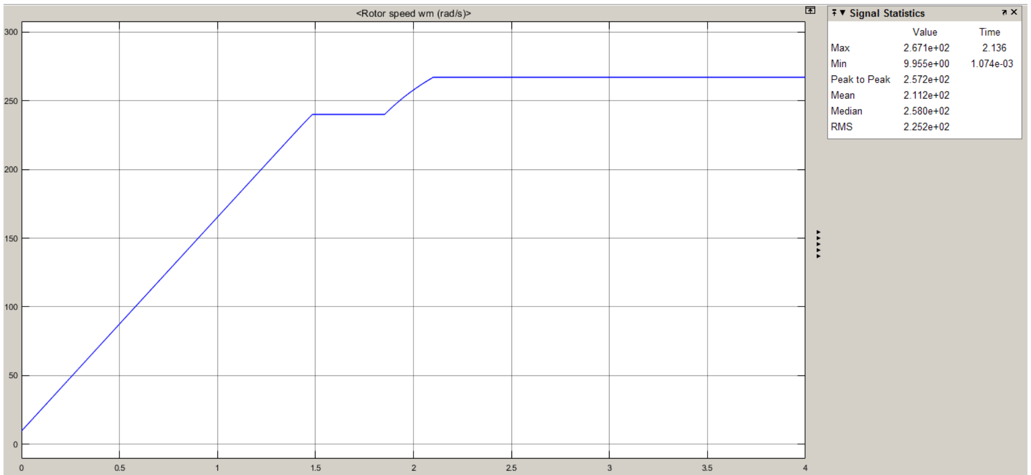


*Figure 4. 90% Rated Speed(240 rad/s) to Rated Speed*

We had given 240 rad/s first to the reference speed and reach that value and after some milliseconds, we made the ref speed rated speed.

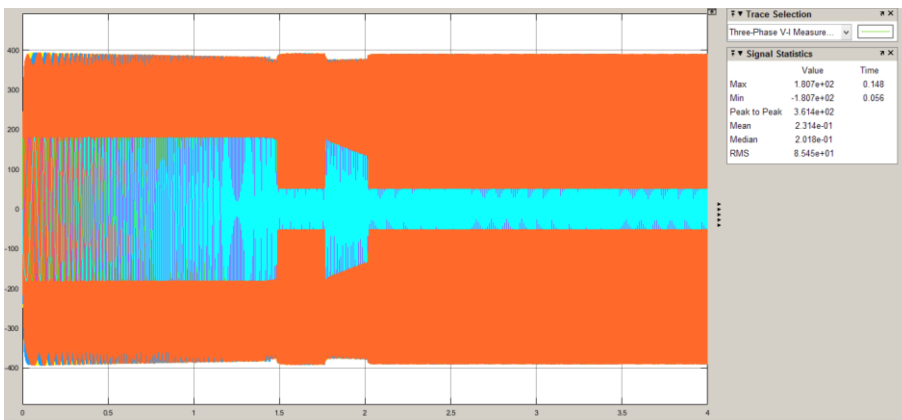


*Figure 5.Vl-l and Iph Waveforms*

The phase current is around 180 Apeak until the speed is stable at wanted speed. Then at stable condition, Iph ,peak = 40-50 A,peak. Vl-l does not differ much around the time of stable and switching sequences.

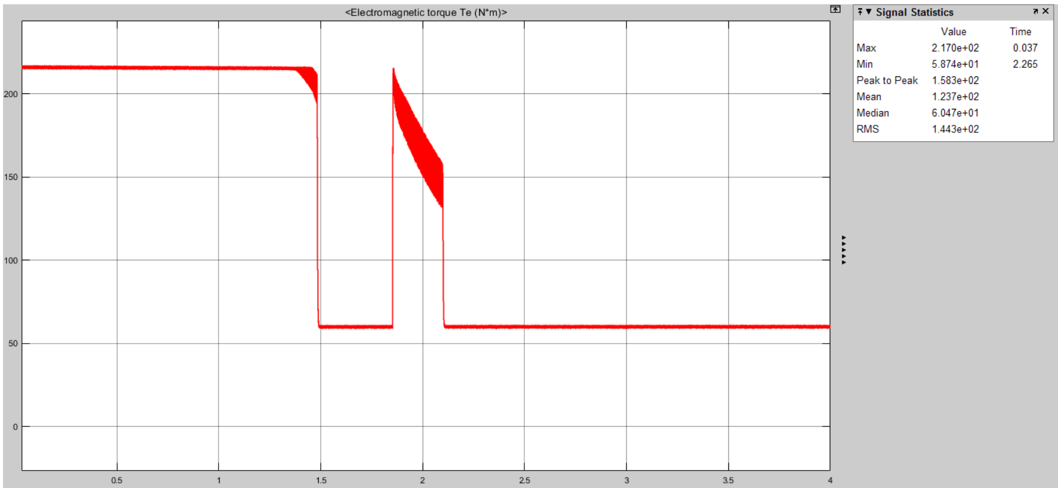


*Figure 6. Torque vs. Time*

Torque is around 220 Nm at the operation of transient time and then decreases to 60 Nm.

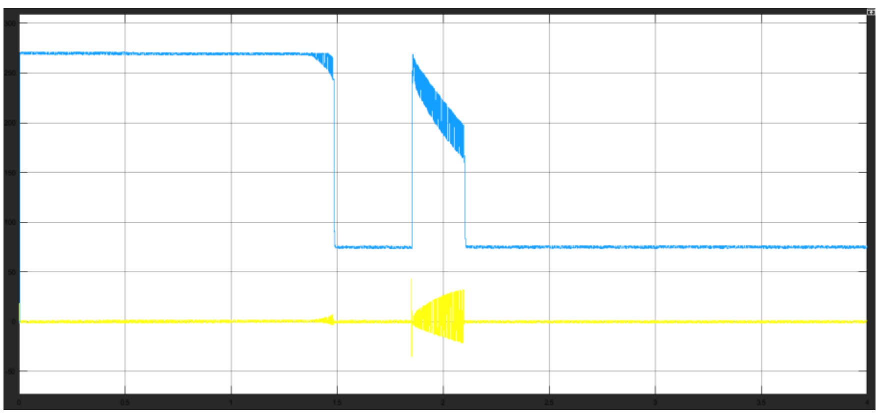

*Figure 7. Iq(blue) and Id(yellow) Waveforms*

Notice how Iq waveform is similar to Torque waveform and also observe how id changes and oscillates around the rated speed and id begins to be a non-zero value.

**2)** Load is unloaded around t = 1.9 sec;

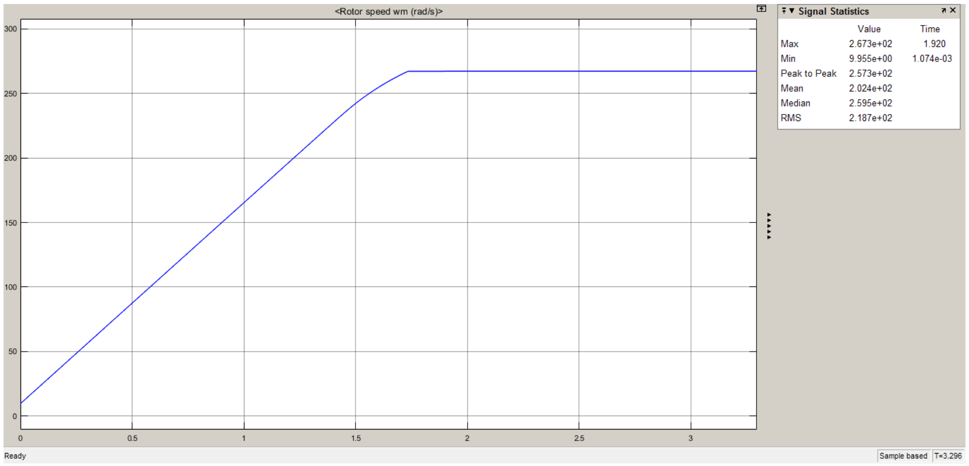


*Figure 8. Speed vs. Time*

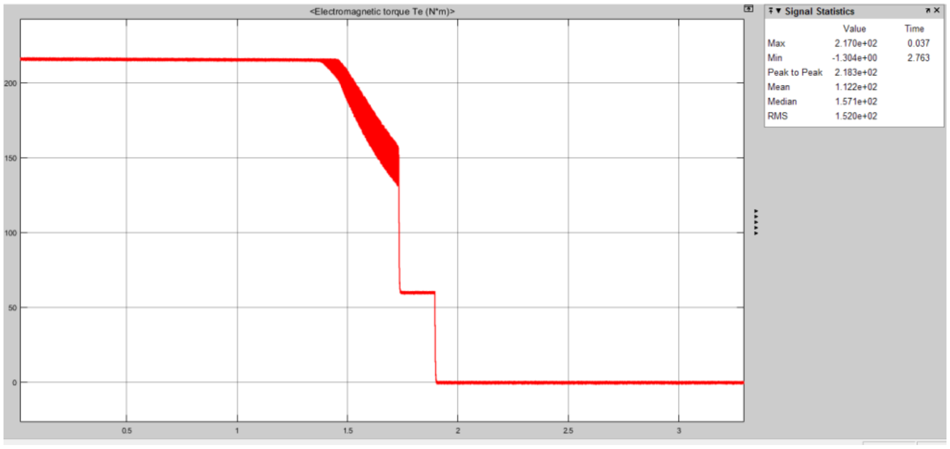


*Figure 9. Torque vs. Time*

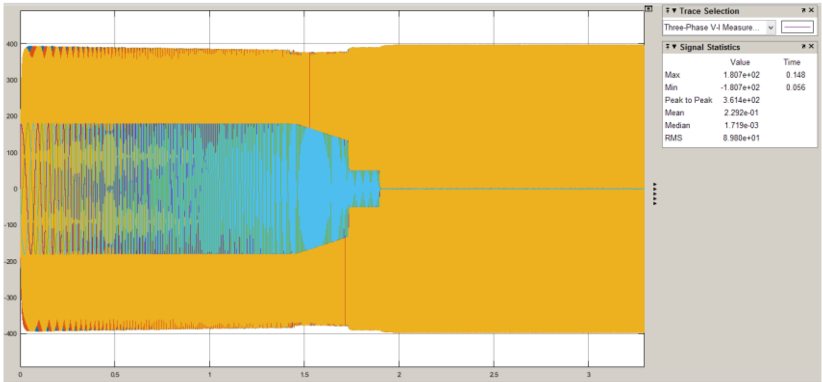


*Figure 10. Iph and Vl-l*

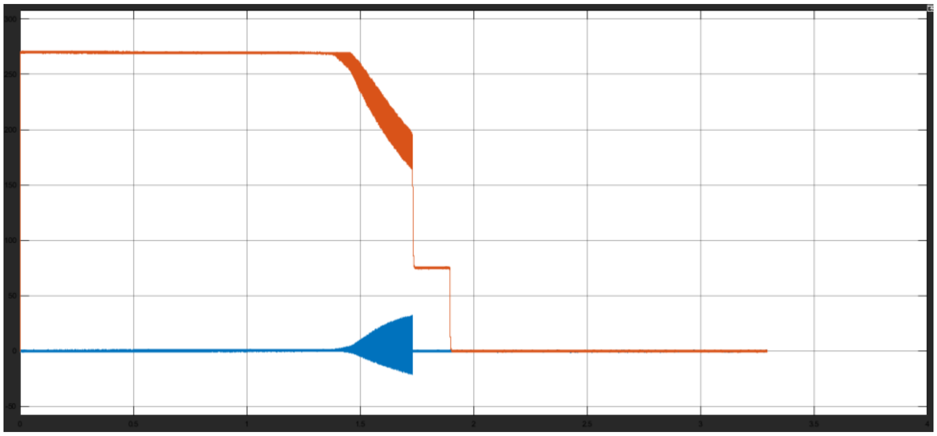

*Figure 11. Iq and Id*

According to these figures, motor speed stays the same after the system is unloaded but Id and Iq values, Iph and also Torque of the system decreases to zero.

**3)**

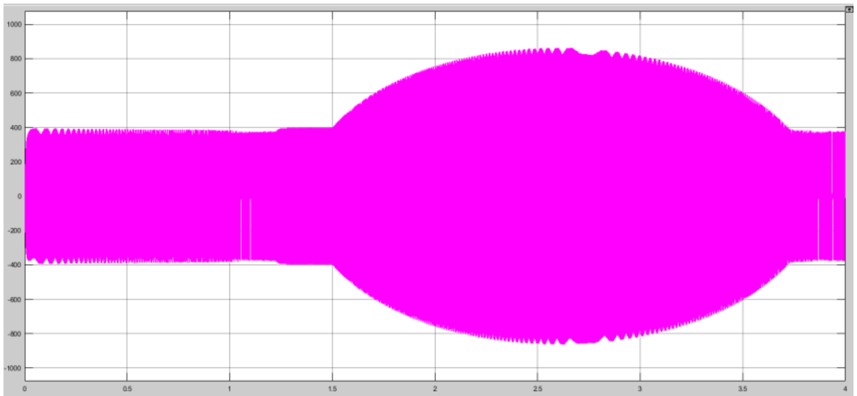

*Figure 12. Vl-l Waveform*

As it can be seen here, line to line voltage value increases over 800 Volts,peak and this can be dangerous.

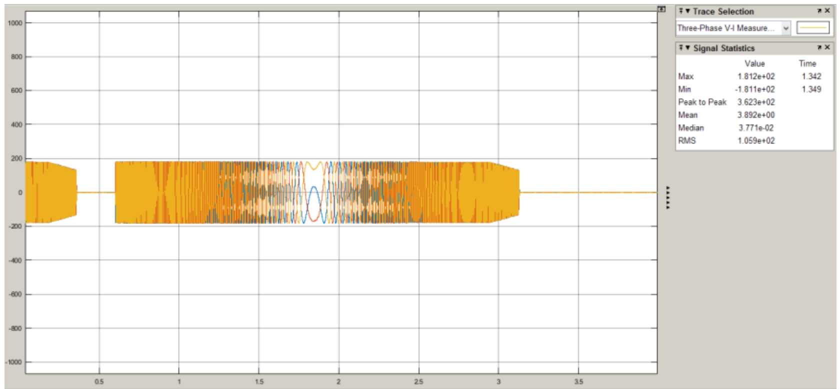


*Figure 13. Iphase vs. Time*

Irms = 127 Arms;

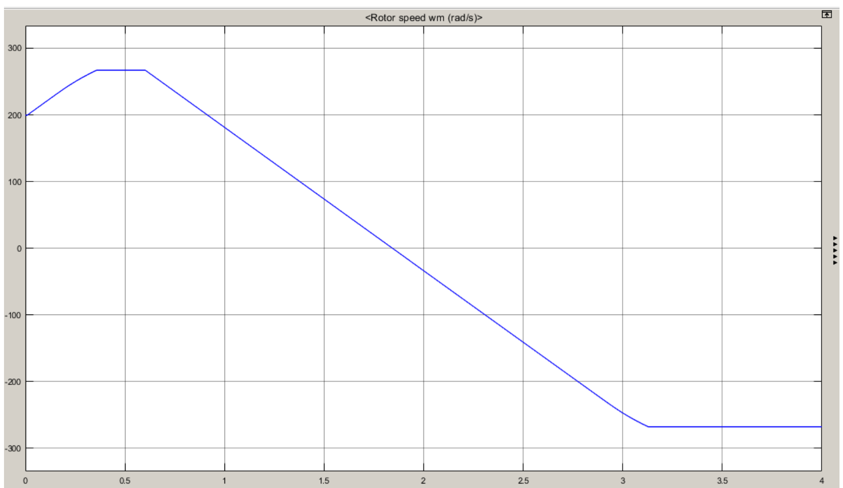


*Figure 14. Speed vs. Time*

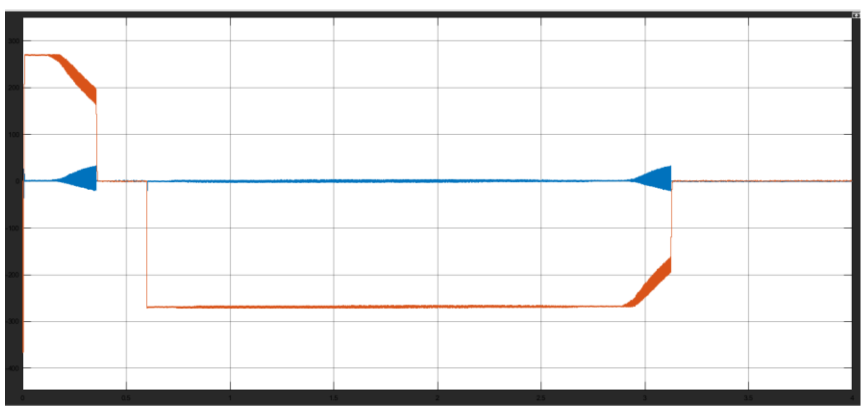

*Figure 15. Iq and Id Currents*

When the speed of the motor decreases to zero in inverse speed operation,

**4)**

We must use field weakening here to lower the K*flux value because in this region motor's power is constant and in order to change increase the speed, we must lower the K*flux value.

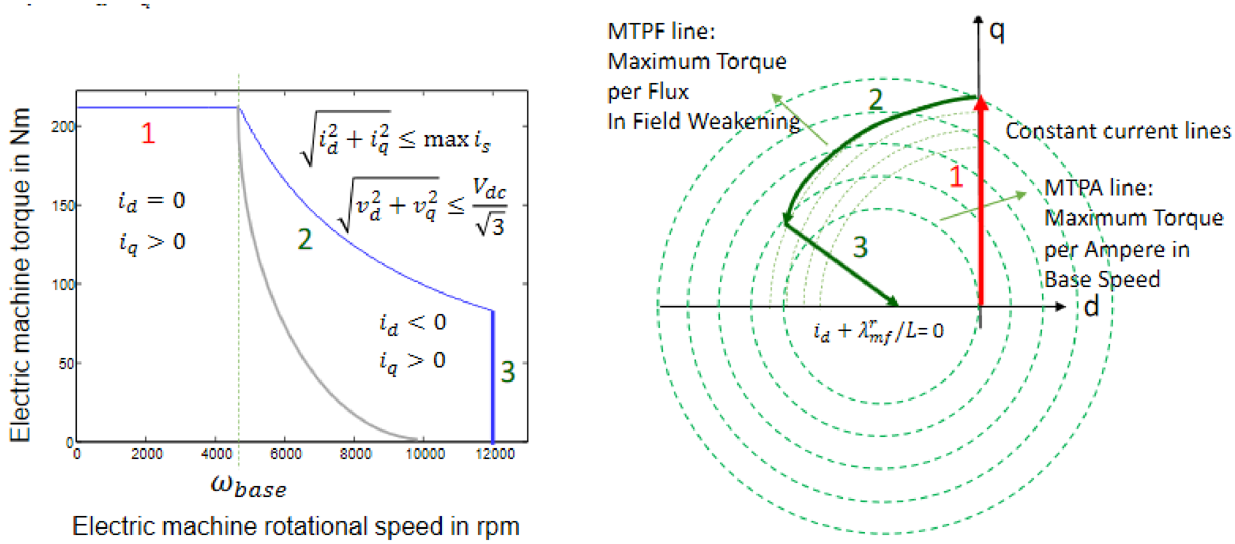


*Figure 16. Torque vs. Speed and q-d Coordinates for the Motor Operation*

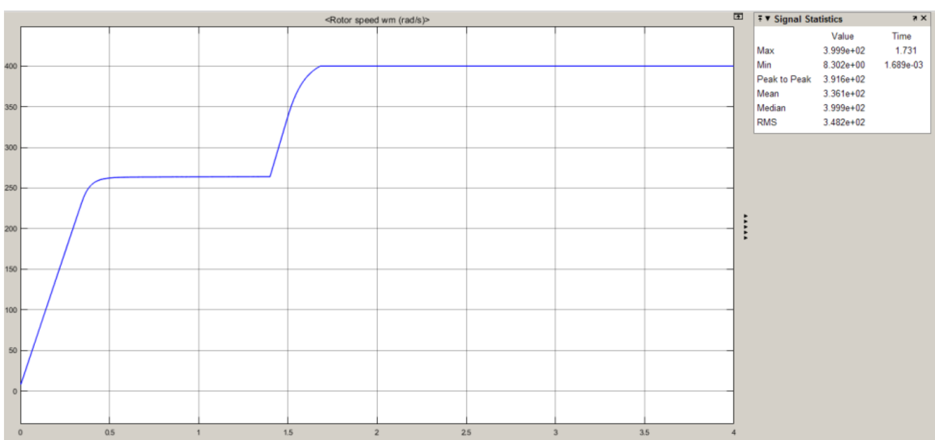


*Figure 17. Speed of the Motor after the Controller Operation*

In order to get into the field weakening mode, we need to increase the Id value. We observed that when we get the value of the Id to -300, we go straight to 400 rad/s which is 150% rated speed of the motor.

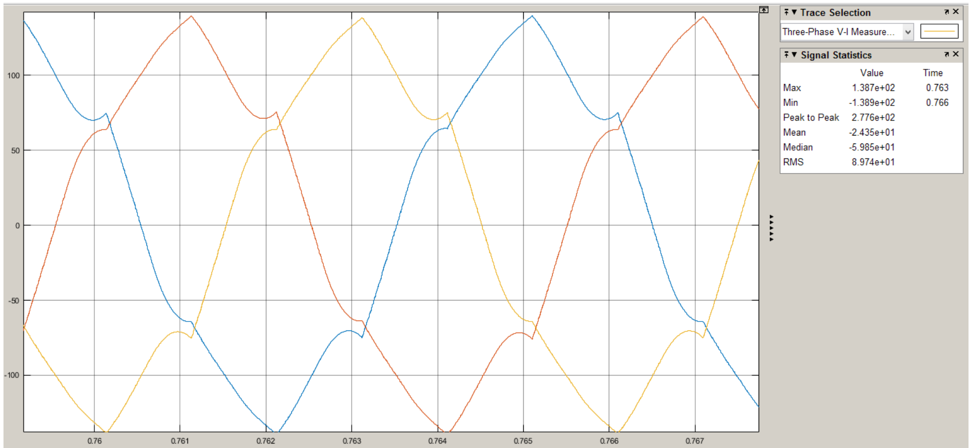


*Figure 18. 3-Phase Current When at Rated Speed*

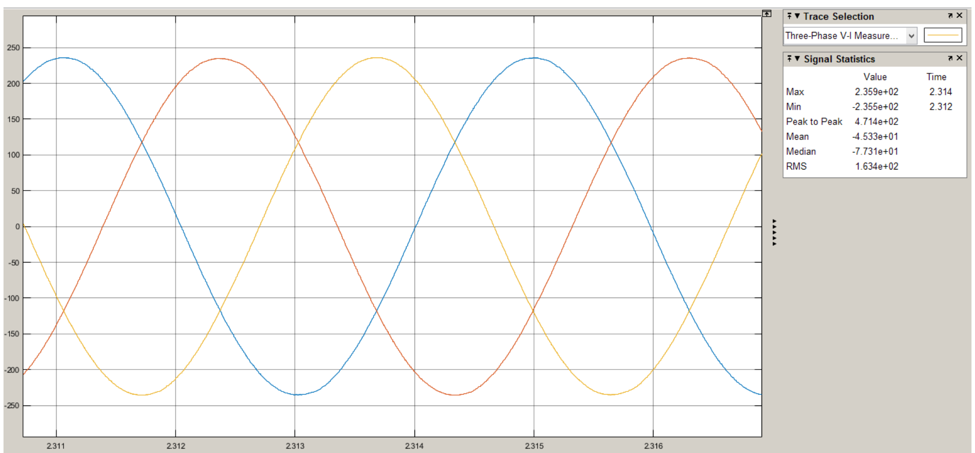


*Figure 19. Iphase when at 150% Rated Speed*

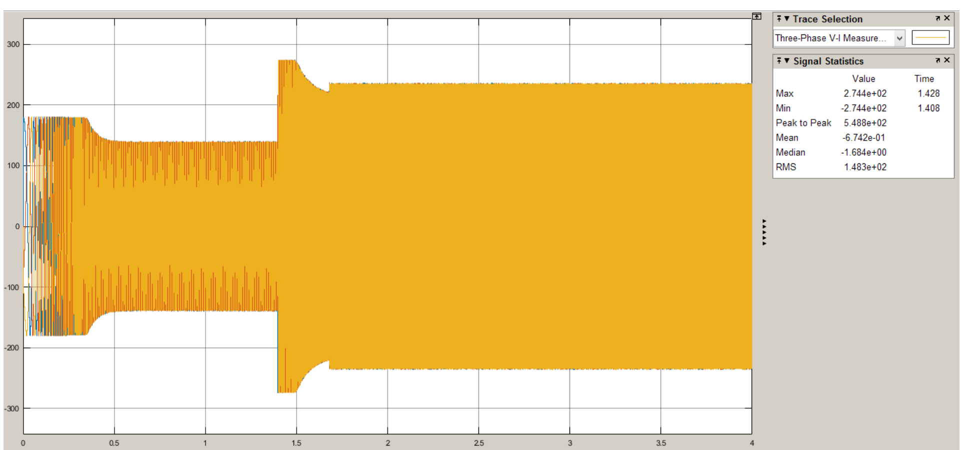


*Figure 20. 3-Phase Current Waveforms*

As it can be seen from the Figure 19, Iphase,peak = 236 Apeak which is below rated current.

## Part D: Component selection and verification

**1)** As specified in part b, 3rd question of the project briefing, We will have a braking resistance which will limit our DC-Link voltage at the inverter at most to 600 Vdc so our Mosfets and Diodes must have a voltage rate higher than this voltage value. Also our rated current is 250 Apeak.

For 3-Phase Full Diode Rectifier, we managed to find a high current diode rectifier which is not a 3-Phase Rectifier but still gets the job done if 6 of it bought. MDO500-12N1 High Current Diode Rectifier is chosen for the 3-Phase Diode Rectifier. This rectifier has a 1200 Volt and 560 Amps Rated values. Datasheet can be found at the end of this report.

For the DC Link capacitor, C44UOGT7200G5SK was used with a 900 Volts capability.

For the inverter, a FF150R17KE4 IGBT was used which has 1700 Volt rating and 150 A, as for inverter's current for each IGBT was around 80-100, this choice was sufficient.

Loss in DC Link Cap is equal to 0.2 Watt which we will ignore.

All of these product's datasheets can be found at the end of the page.

**2)** For IGBT, 102 mJ per cycle was lost in total of switch on and off which results in approximately 1020 Watt for 10kHz switching freq and with. Formula for the loss calculation ;

$$P_{sw.IGBT} = \left(E_{On} + E_{Off}\right) \times f_{sw}$$

*Figure 21. Switching Total Power Loss Calculation Provided by Dynex Semiconductors*

Also conduction losses must taken into account for IGBTs and others. Vce,sat = 2.35 V in IGBT and Ic was approx. 87 Amperes so, 2.35 * 87 = 204.45 Watts. For the whole 1224.45 *6 = 7346.7 Watt Losses for IGBTs.

For diode rectifier, Vfor = 1 Volt and considering approx. 203 Ampere,RMS dissipates through diodes, 203 Watt loss per diode rectifier results in a 2.6 kW loss for both using in rectifier and inverters makes it 13 diodes with the added diode in the Braking Resistance.

All in all at overall 10 kWatts are lost for this system coming from the semiconductor devices which takes away 12.5% away from the total power.

**3)** Loss in here is almost same as in the part 2, not much of a detail given about PMSM that's why we said that copper and core losses can be ignored and Rs loss is 0.05 * 250 = 12.5 Watt which is ignored.

Efficiency = 87.5 % for our simulation but we can say that this is definitely not the case when a real PMSM machine comes in, this efficiency will be much smaller.

## References


Help for the loss calculations taken from here:
https://www.dynexsemi.com/assets/downloads/DNX_AN6156.pdf

**Datasheets**

**IGBT:** https://eu.mouser.com/datasheet/2/196/Infineon-FF150R17KE4-DS-v02_03-EN-219268.pdf

**Single Diode Rectifier:** https://eu.mouser.com/datasheet/2/240/MDO500-12N1-1549412.pdf

**DC Link Capacitor:** https://eu.mouser.com/datasheet/2/212/kemet_10262015_C44UOGT7200G5SK-1173033.pdf