MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

EE 462-EE 464 COMMON PROJECT

Design of a SM-PMSM Variable Frequency Drive with MATLAB/Simulink

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1. Introduction

In this project, a variable frequency drive system for an SM-PMSM has been developed by using MATLAB/Simulink. To regulate the field of an SM-PMSM, the cascaded speed and current controllers have been used. The pre-design stage is the first section of the report. The essential and crucial parameters for the drive system design have been calculated in this part. The maximum applied electrical frequency parameters, as well as the motor's base speed and vehicle speed corresponding to base speed, have been determined. Then, based on the maximum applied electrical frequency, an appropriate switching frequency has been chosen for the drive system's Voltage Source Inverter (VSI). The designed motor drive system has been implemented using the Sinusoidal PWM method in the second part of the project. Under various situations, the performance of the proposed motor drive system using the Sinusoidal PWM method has been observed. The reaction of the drive system to changes in the speed reference has been examined. Following that, it has been observed how the drive system responded to changes in load torque relative to the reference speed. Moreover, the reaction and performance of the drive system to the speed reference reversal at half of the rated torque have been examined in this part. In addition, a method has been proposed to operate run the motor at 60 km/h without exceeding the rated currents, while the vehicle is driving at 40 km/h at half of the rated torque (assume a constant load torque and inertia of the load). The needed d and q currents have been calculated for both the initial and final conditions. Also, the suggested method has been implemented to simulate and analyze the performance of the drive system with the help of Simulink blocks.

2. Part A: Pre-design Stage

1.

We can calculate the base speed of the PMSM from the equation of as follows. We need to consider the power and torque limitation. So, to find the base speed, we should use the values of the nominal power and torque. The base speed equation is written as follows:

$$P_{nominal} = T_{nominal} * w_{base}$$

$$w_{base} = \frac{P_{nominal}}{T_{nominal}}$$

In addition, Sinusoidal-PWM modulation is applied to the system. This means that the output voltage is half of the DC voltage.

$$V_{an,peak} = \frac{V_{DC}}{2}$$

$$V_{an,peak} = \frac{420}{2}$$

$$V_{an,peak} = 210\,V$$

Moreover, the value of nominal power is given as shown below:

$$P_{nominal} = 120\ kW$$

Also, the value of nominal torque is given as shown below:

$$T_{nominal} = 350\ Nm \text{ (rated)}$$

So:

$$w_{base} = \frac{120 * 10^3}{350}$$

$$\boldsymbol{w_{base} = 342.857\ rad/s}$$

There is a gearbox in the system, with a ratio of 8.5. With the help of the following formula, the mechanical shaft speed which is referred to as the vehicle speed is found.

$$\frac{w_{base}}{w_{vehicle}} = 8.5$$

$$w_{vehicle} = \frac{342.857}{8.5}$$

$$w_{vehicle} = 40.336\ rad/s$$

In the project definition, vehicle speed is expected in km/h. Therefore, we must first multiply the velocity we found in rad/s by the radius. Then we have to multiply by 3600/1000.

$$V_{vehicle} = w_{base} * r * \frac{3600}{1000}$$

$$V_{vehicle} = 40.336\ * 0.3 * \frac{3600}{1000}$$

$$\boldsymbol{V_{vehicle} = 43.56\ km/h}$$

2.

The maximum speed of the motor is given in the project description.

$$n_{max} = 14000\, rpm$$

In order to find the maximum electrical frequency applied, we first need to find the mechanical frequency. So we need to find the maximum speed in rad/s.

$$n_{max} = \frac{14000 * 2 * \pi}{60}$$

$$n_{max} = 1466\, rad/s$$

Now that we have found the maximum speed in rad/s, we can calculate its frequency as shown below:

$$w_m = 2 * \pi * f_{max,mech}$$

$$f_{max,mech} = \frac{w_m}{2 * \pi}$$

$$f_{max,mech} = \frac{1466}{2 * \pi}$$

$$f_{max,mech} = 233\, Hz$$

As is known, the electrical frequency is greater than the mechanical frequency. The ratio between them depends on the pole pair. The electrical frequency is found as shown below:

$$f_{max,elec=}f_{max,mech} * pole\ pair$$

$$f_{max,elec=}233 * 4$$

$$f_{max,elec=}932\, Hz$$

The frequency modulation ratio should be chosen as an odd value that is not too high to reduce harmonic effects. In electric vehicles, this ratio is usually chosen between 8 and 12.

$$f_{s=}f_{max,elec} * (8 - 12)$$

As a result, choosing this ratio as 11 would be a good choice.

$$f_{s=}932 * 11$$

$$\boldsymbol{f_{s=}10.252\, kHz}$$

3. Part B: Sinusoidal PWM

In this part, we are expected to implement a motor drive using sinusoidal PWM (Sine-PWM), and implement a cascaded speed and current controller using $i_d - i_q$ parameters

1.

In this section , firstly , we need to calculate the equivalent inertia and the load seen at the electric machine shaft. Also, there is a single speed gear box connected between electric motor and wheels with 8.5 gear ratio.

$$\frac{w_{em}}{w_{wheels}} = 8.5$$

The equivalent inertia is found as follows :

$$J_{eq} = J_{rotor} + 4 * J_{single\ wheel\_em} + J_{M-em}$$

We know the inertia on the wheel. But this inertia is on the load side. Therefore, we need to transfer this to the electric machine side with the gear ratio. We can do this as follows:

$$J_{single\ wheel\_em} = \frac{J_{single\ wheel}}{gear\ ratio^2}$$

$$J_{single\ wheel\_em} = \frac{1}{8.5^2}$$

$$J_{single\ wheel\_em} = 0.0138\ kgm^2$$

Now we need to calculate the inertia of the vehicle. Since the result we found will be on the load side, we need to transfer it to the electric machine side with the gear ratio.

$$J_{M-em} = M * \left(\frac{radius}{gear\ ratio}\right)^2$$

$$J_{M-em} = 1500 * \left(\frac{0.3}{8.5}\right)^2$$

$$J_{M-em} = 1.868\ kgm^2$$

Since all inertia values are found and transferred to the electric machine side, the equivalent inertia is as follows:

$$J_{eq} = 0.5 + 4 * 0.0138 + 1.868$$

$$\boldsymbol{J_{eq} = 2.4232\ kgm^2}$$

The load characteristics of the vehicle are given in the project description. Here F_{load} is given as shown below.

$$F_{load} = 150 + 0.35v^2 \ N \ (v \ in \ m/s)$$

However, we need to calculate the load torque seen at the electric machine shaft. So, to obtain load torque expression, we should multiply the expression of the load force by radius.

$$T_{load} = F_{load} * radius$$

$$T_{load} = (150 + 0.35v^2) * 0.3$$

$$\boldsymbol{T_{load} = 45 + 0.105v^2 \ Nm} \ (v \ in \ m/s)$$

Figure 1 shows the speed, torque and dq current waveforms during the transition from 35km/h to 40km/h speed. The motor torque is the summation of load torque and the torque resulted from the equivalent inertia. The motor torque reaches the nominal torque of the machine during the transition. The limitation is determined with saturation block used for the i_q, quadrature axis current. The reason for reaching nominal torque of the machine is usage of step change of speed. If the reference speed were given with ramp function, the motor torque during the transition could be adjusted. The functionality of controller is sufficient. As seen in the Figure 1, the reference speed and the speed of the car matches after the transition period. Moreover, the reference of id current is given as zero since the motor operates in the base speed region. Hence, MTPA is applied. On the other hand, as shown in the figure below, the transition time is about 0.35 second.

The operating mode of the motor does not change before, after and during the transition. The machine operates in motoring mode.

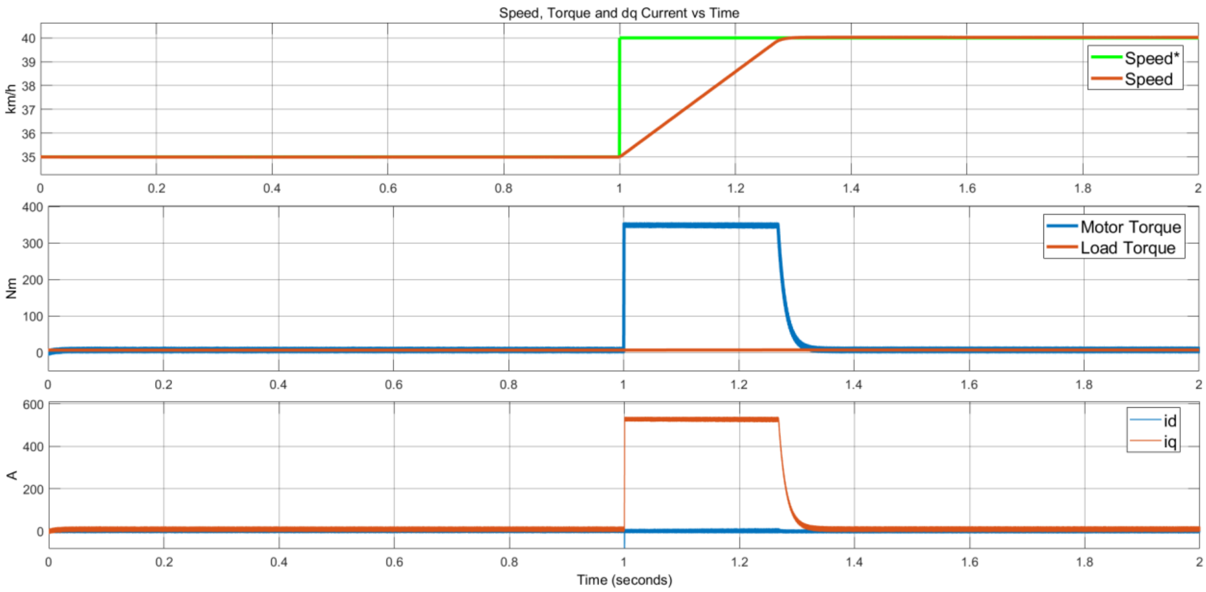

Figure 1 Speed, torque and dq currents waveforms for step change from 35km/h to 40km/h. $K_{P-speed}$=20, $K_{I-speed}$ = 0.8.

Figure 2 also shows the speed, torque and dq current waveforms during the transition from 35km/h to 40km/h speed. However, the K_P and K_I constants of speed controller are 2 and 0.8, respectively. For the sake of comparison for two different values of proportional constant, the change of K_P constant is applied. According to comparison of Figure 1 and Figure 2, the response time of the system slows down, and overshoot is observed for the case in which K_P is 2. As a result, the response time of the system is increased and observed overshoot is eliminated with respect to change of proportional constant, K_P.

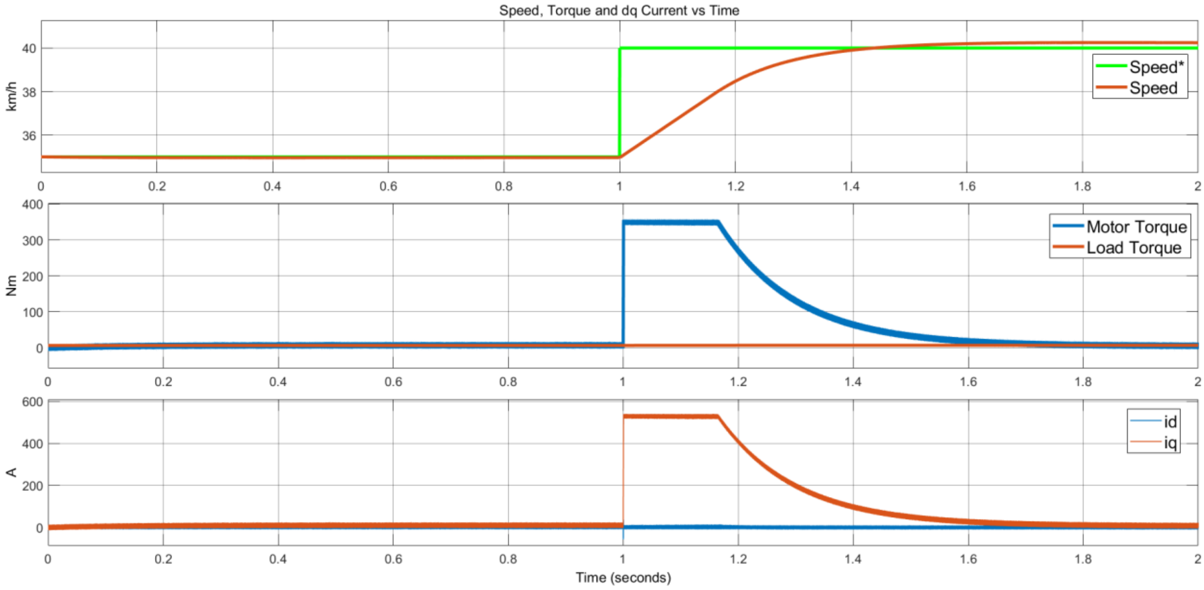

Figure 2 Speed, torque and dq currents waveforms for step change from 35km/h to 40km/h. $K_{P-speed}$ =2, $K_{I-speed}$ = 0.8.

Figure 3**Error! Reference source not found.** shows the line-to-line voltage waveforms of the motor. The peak-to-peak voltage value is equal to two times of the Vdc since the voltage measurement is applied between two phases. The peak-to-peak value of the line-to-neutral voltage measurement should be equal to Vdc for the sinusoidal PWM. Since the line-to-line voltage equals to difference of two line-to-neutral voltage, peak-to-peak voltage value of line-to-line measurement is two times of the DC-link voltage. The expected waveforms are shown in Figure 4 and the observed waveforms are matched.

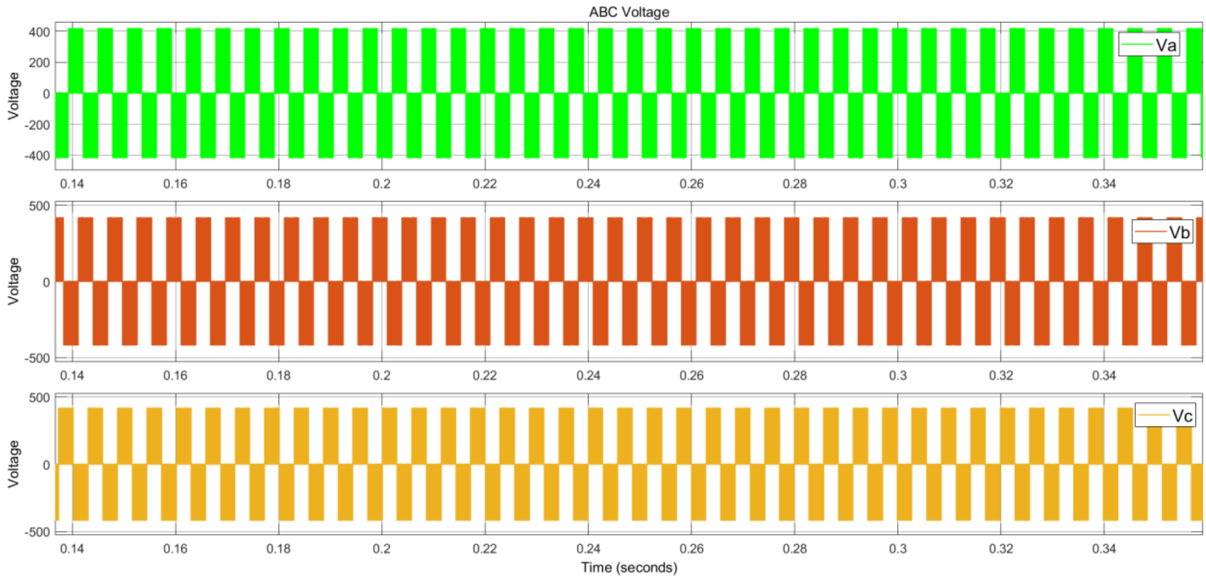

Figure 3 Line-to-line voltage waveforms for step change from 35km/h to 40km/h. $K_{P-speed}$=20, $K_{I-speed}$= 0.8.

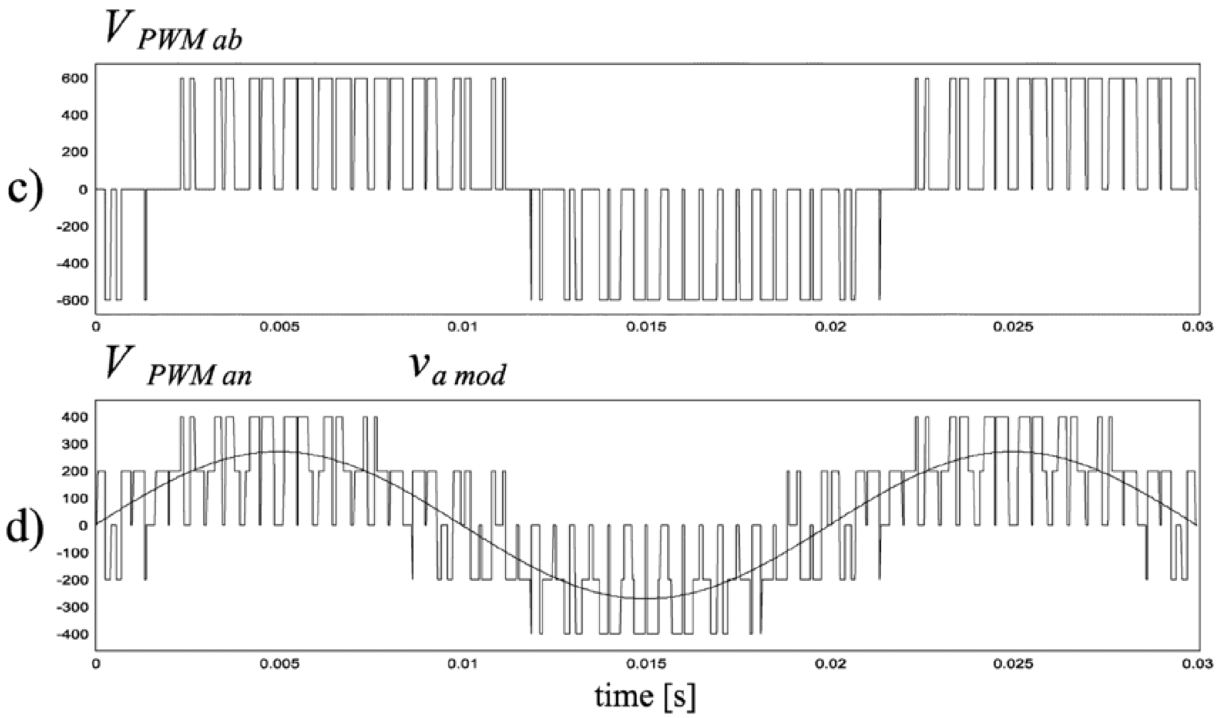

Figure 4 Example line-to-line and line-to-neutral voltage waveforms for sinusoidal PWM

Figure 5 shows the phase currents of the motor during the transition from 35km/h to 40 km/h. The increase in the current at time which equals to 1 second results from the inertia since the step change of speed is applied at that time. The maximum value of the phase current is equal to maximum value of quadrature current due to the amplitude invariant transformation. The waveforms are sinusoidal in Figure 5.

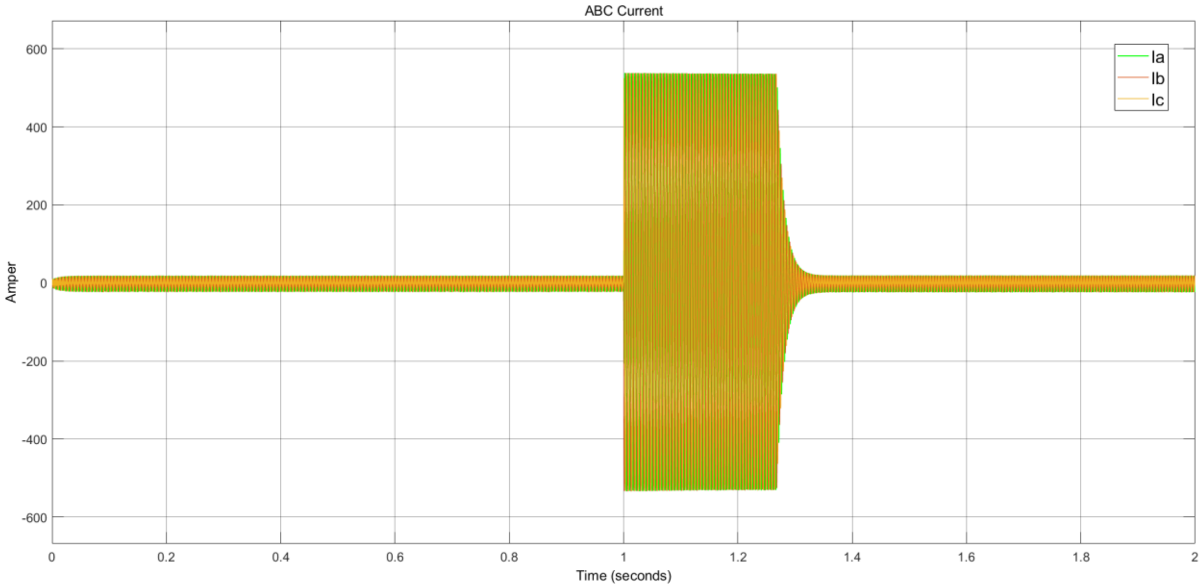

Figure 5 Phase current waveforms for step change from 35km/h to 40km/h. $K_{P-speed}$ *=20,* $K_{I-speed}$ *= 0.8.*

2.

Figure 6 shows the speed and dq current waveforms during the transition from 40km/h to -8km/h speed. Firstly, the machine works in motoring mode up to the time in which step change of speed is applied and the machine absorbs power in this mode. When the step change of speed is applied the quadrature current diminished from positive value to -530A, nominal current, which implies the machine works in the generating or braking mode. The machine speed is positive, and the torque is negative as implied from the i_q current in the 2nd current. In other words, applied voltage is positive and applied current is negative, which implies that the power is dissipated on the brake resistor or supplied to the grid. When the speed of the motor is equal to zero, the sequence of phase voltage changes and machine starts to work in reverse motoring mode. Hence, the power flow is from grid to the motor for reverse motoring mode. The operating modes of the machine for the step change from 40km/h to -8km/h can be seen in Figure 7.

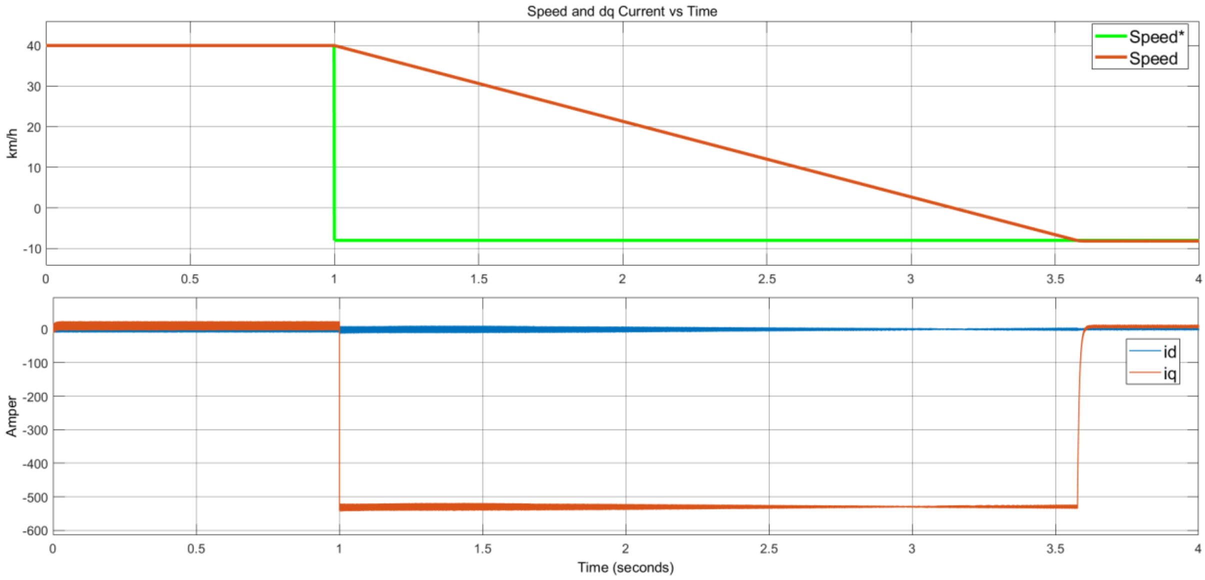

Figure 6 Speed, and dq currents waveforms for step change from 40km/h to -8km/h. $K_{P-speed}$=40, $K_{I-speed}$= 0.1.

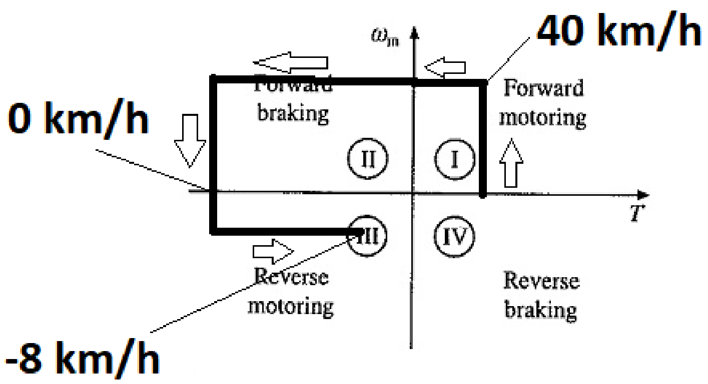

Figure 7 Operating modes of the machine for the step change from 40 km/h to -8 km/h.

Figure 8 also shows the speed and dq current waveforms during the transition from 40km/h to -8km/h speed. However, the K_P and Ki constants of speed controller are 20 and 0.8, respectively. For the sake of comparison for two different values of proportional constant and integrative constant, the change of K_P and K_I constants are applied. According to comparison of and Figure 6 and Figure 8, the response time of the system slows down, and overshoot is observed for the case in which K_P is 20 and Ki is 0.8. The elimination of the overshoot is succeeded with increase in K_P from 20 to 40 and decrease in Ki from 0.8 to 0.1. While increase in the proportional constant makes the system more responsive, decrease in the integrative constant eliminates the error coming from the summation of error between reference speed and measured speed.

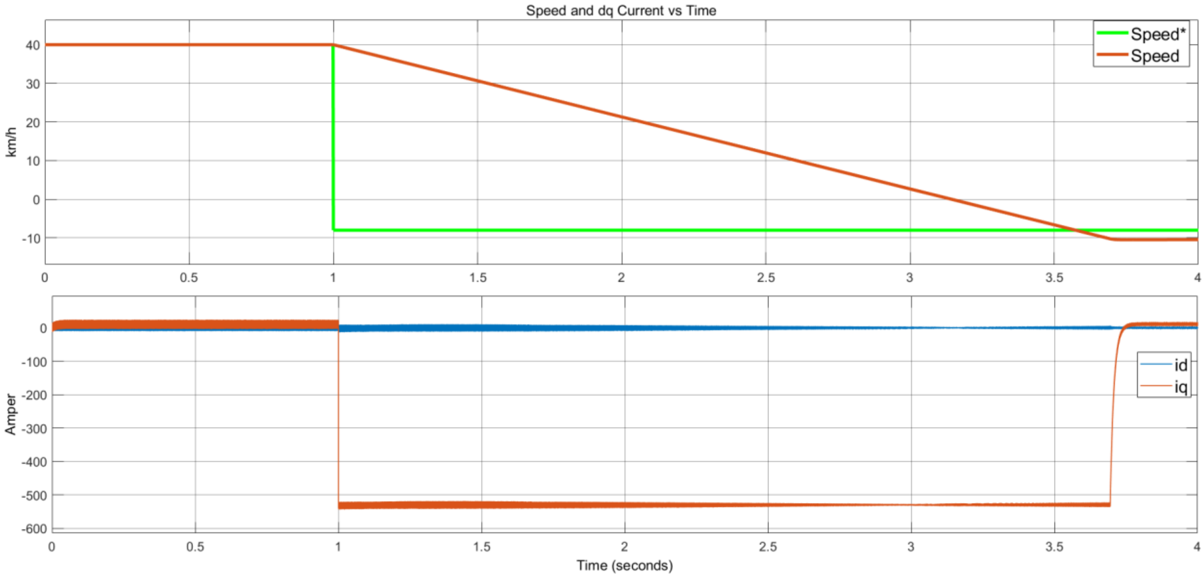

Figure 8 Speed, and dq currents waveforms for step change from 40km/h to -8km/h. $K_{P-speed}$ =20, $K_{I-speed}$ = 0.8.

Figure 9, shows the phase currents of the motor during the transition from 40km/h to -8km/h. The applied step change in speed at t equals to 1 cause that the quadrature current becomes negative nominal current. The negative i_q current and positive speed indicates that the braking is applied, which can be also seen by the density of the sinusoidal in Figure 9. As the motor slows down, the period of the phase current increases. When the speed equals to 0, the sequence of phase currents is flipped, and motor rotates in the negative direction. Hence, the machine starts to operate in reverse motoring region. Then, when the motor reaches to -8km/h, the torque due to the inertia becomes zero and the motor torque decreases to the 5.355 Nm.

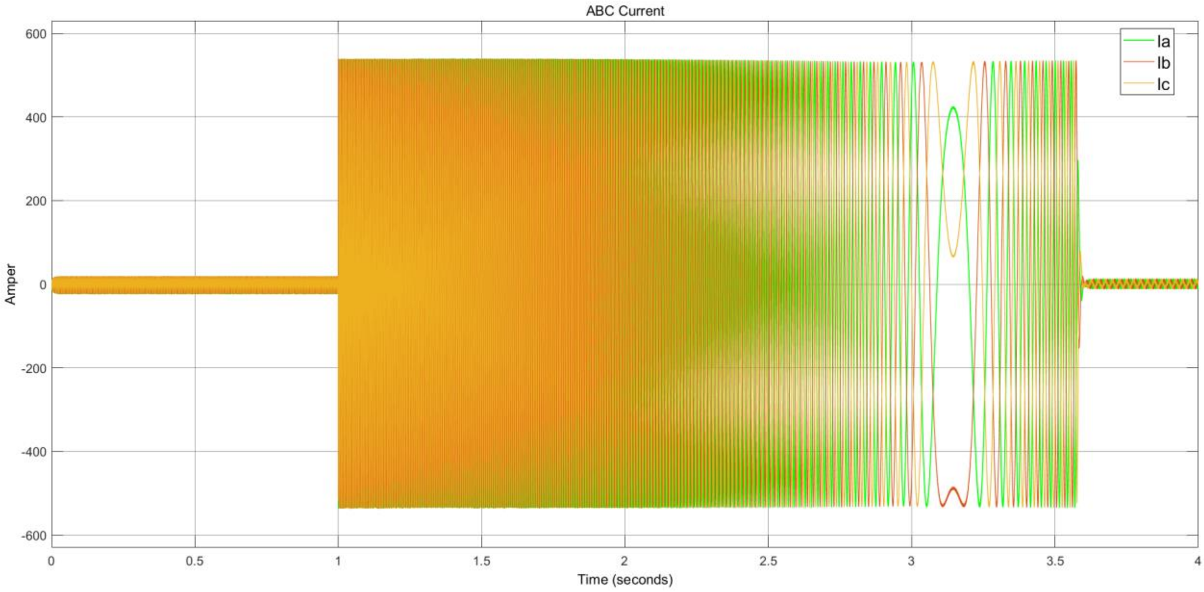

Figure 9 Phase current waveforms for step change from 40km/h to -8km/h. $K_{P-speed}$ =40, $K_{I-speed}$ = 0.1

Figure 10, shows the phase currents of the motor during speed reversal. As known for the rotational MMFs, the direction of rotation can be flipped with change of two-phase sequence, which can be illustrated in Figure 10. The speed reversal occurs approximately between 3.08 and 3.22 seconds. While the phase sequence is green-red-orange before the speed reversal, the sequence of phases changes to green-orange-red.

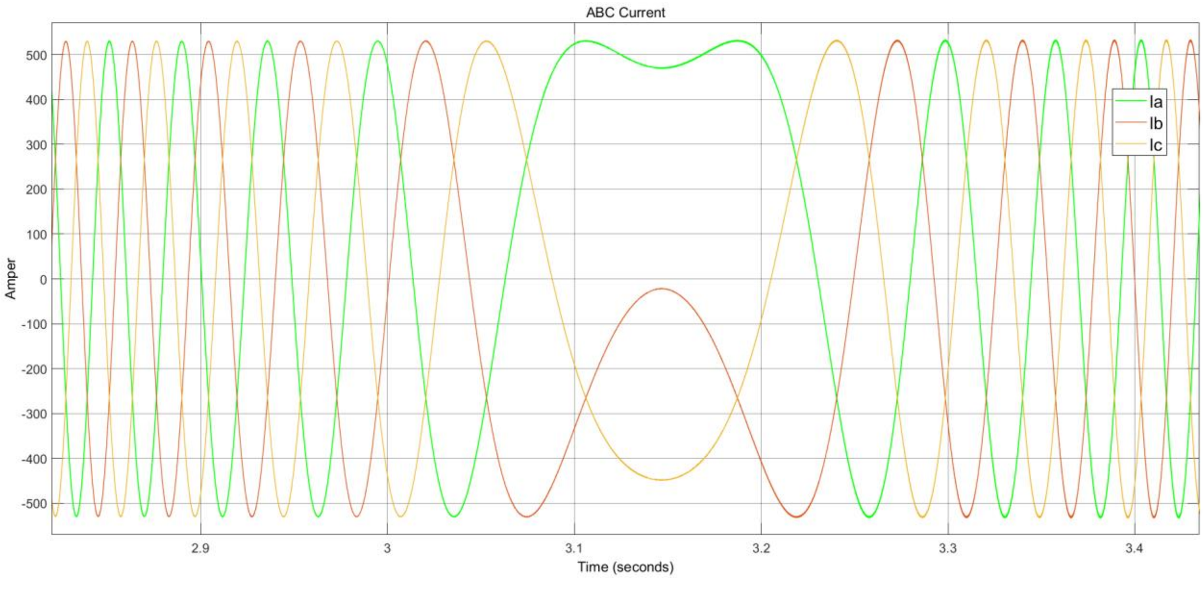

Figure 10 Phase current waveforms during speed reversal for step change from 40km/h to -8km/h. $K_{P-speed}$ =40, $K_{I-speed}$ = 0.1.

3.

In this part, first of all, we need to find out in which region our electric motor operates. First of all, we need to find the speed of the vehicle in rad/s and compare it with the base speed. In this way, we can determine in which region it works. If the speed of the vehicle is higher than the base speed, it means that it is operating in the field weakening region. If it is lower than the base speed, it means that it is working in the base speed region. Firstly, we need to convert the speed given in km/h to rad/s.

$$w_{vehicle} = V_{vehicle} * \frac{1000}{3600} * \frac{1}{radius}$$

$$w_{vehicle} = 60 * \frac{1000}{3600} * \frac{1}{0.3}$$

$$w_{vehicle} = 55.56\, rad/s$$

Now we need to transfer the speed we found to the motor side with the gear ratio.

$$w_m = w_{vehicle} * gear\ ratio$$

$$w_m = 55.56 * 8.5$$

$$w_m = 472.26\, rad/s$$

We previously calculated the base speed. The base speed we found is 342.857 rad/s. We found the speed of the motor as 472.26 rad/s. As it can be understood from here, the speed of the motor is higher than the base speed. Obviously motor is operating in a field weakening region.

$$w_m = 472.26\, rad/s \qquad w_{base} = 342.857\, rad/s$$

$$w_m > w_{base}$$

$$\boldsymbol{FIELD\ WEAKENING\ REGION}$$

Also, we can find w_e by multiplying w_m by the pole pair:

$$w_e = w_m * pole\ pair$$

$$w_e = 472.26 * 4$$

$$w_e = 1889.04\, rad/s$$

In other words, considering the given conditions, the engine must operate in the field weakening region in order for the vehicle to drive at 60 km/h. It will not be enough to apply only i_q current for the vehicle to drive at this speed. That's why we need to apply i_d current to the system. Since the i_d current is 0 in the base speed region, the vehicle will not be able to reach this speed. As a result, the motor operates in the field weakening region and by applying i_d current along with the i_q current in this region, we ensure that the vehicle drives at the given speed. As a result of this analysis we have done, we need to find i_d and i_q currents. As it is known, the vehicle here is driving at half of the rated torque. So the i_q current will also be halved. i_q current is as shown below.

$$i_q = \frac{I_{nominal}}{2}$$

$$i_q = \frac{530}{2}$$

$$i_q = 265\,A$$

We can also find the i_d current with the formula given below:

$$\frac{V_s}{w_e} = \sqrt{(\lambda_{PM} + L_s * i_d\,)^2 + (L_s * i_q)^2}$$

$$i_d = \frac{\sqrt{\left(\frac{V_s}{w_e}\right)^2 - \left(L_s * i_q\right)^2} \; - \lambda_{PM}}{L_s}$$

$$i_d = \frac{\sqrt{\left(\frac{210}{1889.04}\right)^2 - (165 * 10^{-6} * 265)^2} \; - 0.11}{165 * 10^{-6}}$$

$$\boldsymbol{i_d = -47.227\,A}$$

Considering the above analysis results and conditions, we apply 265 A as i_q current and i_d current in the opposite direction to the motor operating in the field weakening region, so that the vehicle can drive at the desired speed.

Figure 11 shows the proposed method for the speed transition from 40km/h to 60km/h without exceeding rated currents. Conceptually, we propose a method how to apply the calculated id* and how to adjust limitation on the i_q^***.** The above f(u) block provides the switch with calculated id current based on the phase limit equation. Then, if the calculated id is negative, switch output gives calculated id*. If not, switch gives zero as a reference. The below switch may be trivial, but it placed to make it understandable. Function of the below switch is determination of whether the speed is above or under the base speed. If above, the output of the above switch is given as i_d^*If not, id* becomes zero. The bottom f(u) block determines the maximum i_q^* with respect to calculated nominal current. For instance, if the i_q^* equals to zero, the limit of i_q^* is equal to nominal current, 530A. Moreover, the power is also considered not to exceed power limit. Power of the machine is calculated according to we, electrical speed of rotor and the torque. The MATLAB function block compares both values from the f(u) and gain block represents the inverse model of the torque. Then the smaller limit is provided as $i_{q-limit}$.

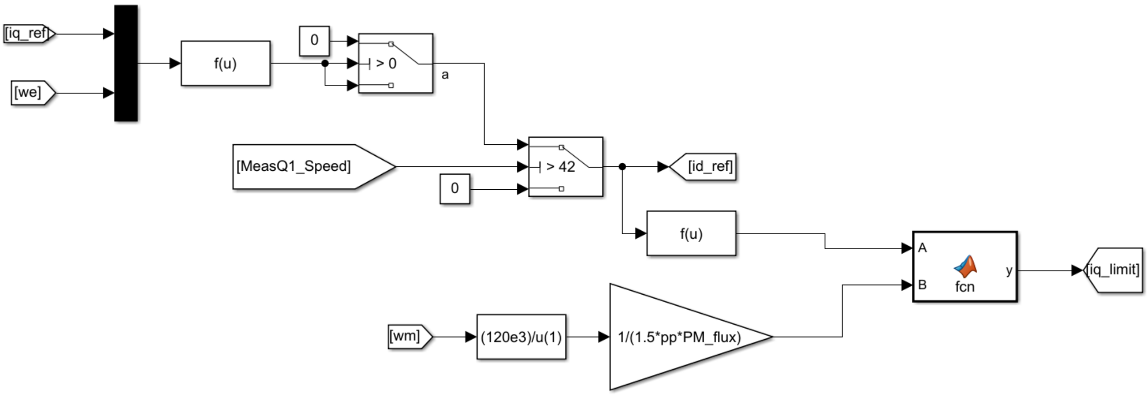

Figure 11 Simulink blocks for closed-loop control of speed transition from 40km/h to 60km/h with field-weakening

Figure 12 shows how the calculated $i_{q-limit}$ is applied to saturation block.

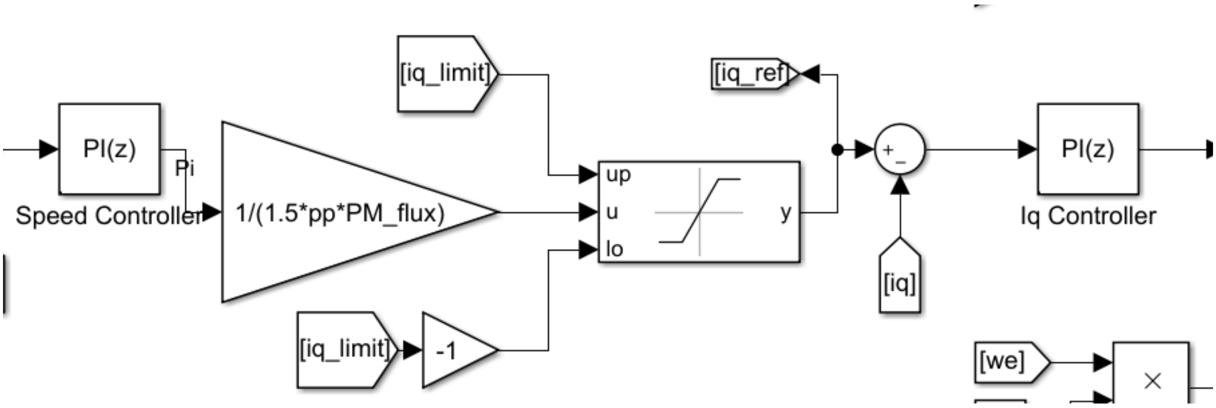

Figure 12 The method for applying $i_{q-limit}$ to saturation block of i_q.

Figure 13 shows the speed and dq current waveforms for the step change of 40km/h to 60km/h at the half of the rated torque, 175Nm. As expected, apply of negative id current is a must not to apply over-modulation. When the step change is applied at time equals to 1, the id* current is still given as zero since the rotor speed is smaller than the base speed. On the other hand, i_q reached to the nominal current when the step is applied. Then, the i_q current starts to decrease when the rotor speed is equal to the base speed for the sake of power conservation of the machine. The point id* becomes negative is calculated according to the formulation below. Then, the steady-state values of i_q and id current reach 265A and -47.23A as calculated above, respectively, which represents the current values final condition. The initial values of i_q and i_d is simply 265A and 0A. As we see, the id current has no contribution on torque for SM-PMSM.

$$i_d = \frac{\sqrt{\left(\frac{210}{\frac{49.96}{3.6*0.3}*8.5*4}\right)^2 - (165*10^{-6}*462.72)^2} - 0.11}{165*10^{-6}} = -2.81A$$

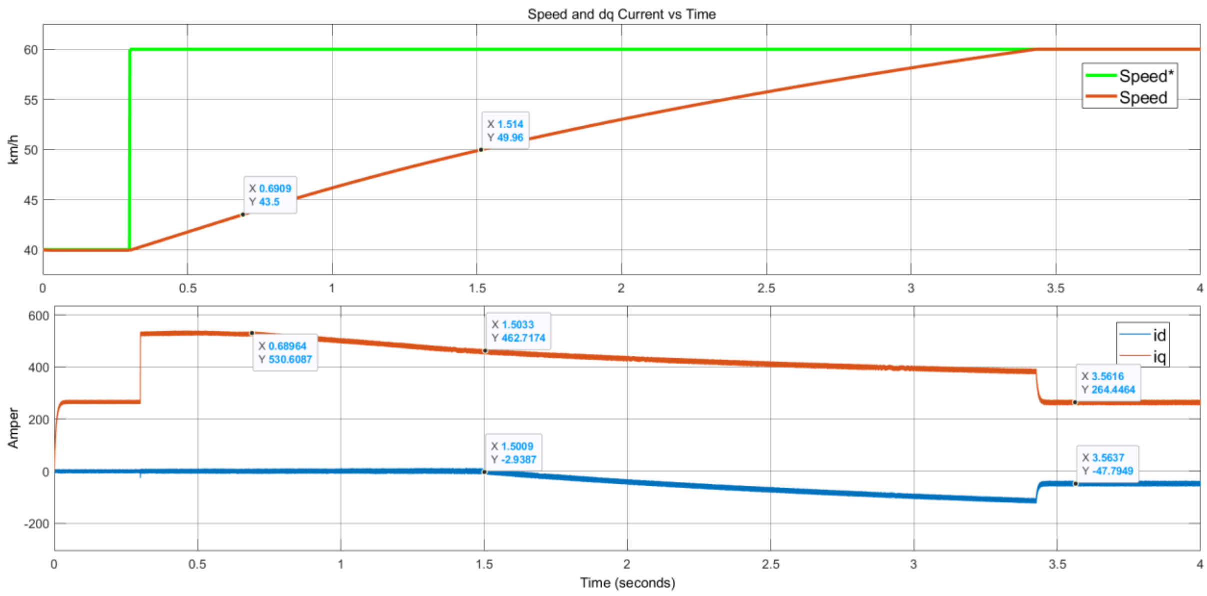

Figure 13 Speed and dq current waveforms for the step change of 40km/h to 60km/h at the half of the rated torque.

The following explanations are solely explained what we have learned with different approach. This approach does not consider the power conservation of the machine. The calculation of i_d^* is the same as above solution. However, determination of $i_{q-limit}$ is done with just consideration of phase voltage limit. Therefore, the negative id current start to be applied at 47.469km/h as seen in Figure 15. Also, Figure 15 shows that the required id and i_q current for initial and final conditions are the same as the theoretically calculated values.

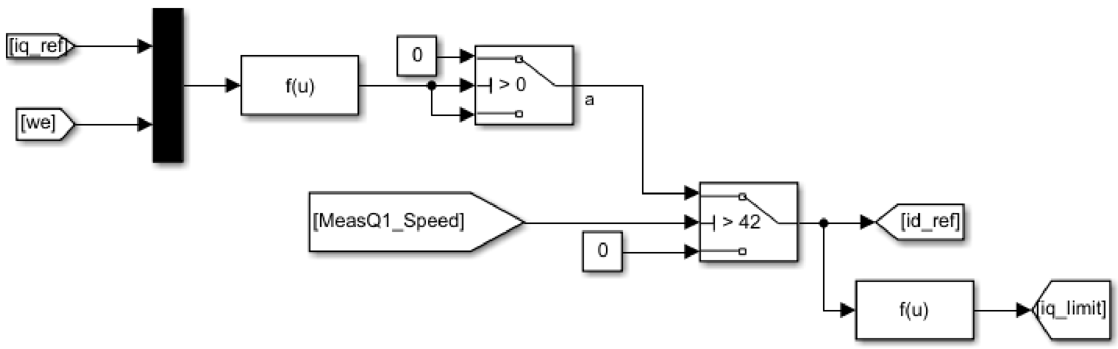

Figure 14 Simulink blocks for closed-loop control of speed transition from 40km/h to 60km/h with field-weakening. Power conservation is not taken account.

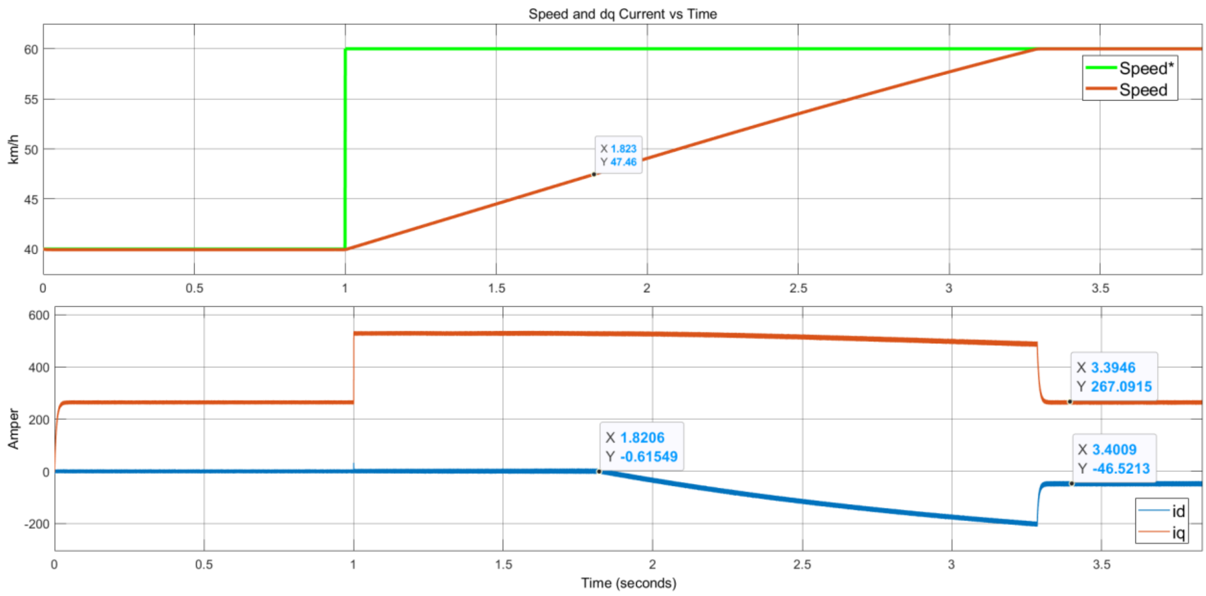

Figure 15 Speed and dq current waveforms for the step change of 40km/h to 60km/h at the half of the rated torque. Power conservation is not taken account.

In addition, in this approach, we can calculate the base speed of the PMSM theoretically from the calculation of voltage on MTPA. The base speed equation in d-q coordinates is written as follows:

$$w_{e-base} = \frac{V_s}{\sqrt{\lambda_{PM}^2 + \left(L_s * i_q\right)^2}}$$

Another situation is that in case of MTPA there is only current on the q axis. The current value on the d axis is zero.

$$i_s = i_q = 530\ A\ (peak)$$

So:

$$w_{e-base} = \frac{210}{\sqrt{0.11^2 + (165 * 10^{-6} * 530)^2}}$$

$$w_{e-base} = 1494.387\ rad/s$$

The base speed we found above is electrical. A pole pair is required to find the mechanical base speed. The mechanical base speed is found by the equation given below:

$$w_{base} = \frac{w_{e-base}}{pole\ pair}$$

$$w_{base} = \frac{1494.387}{4}$$

$$w_{base} = 373.597\ \ rad/s$$

There is a gearbox in the system, with a ratio of 8.5. With the help of the following formula, the mechanical shaft speed which is referred to as the vehicle speed is found.

$$\frac{w_{base}}{w_{vehicle}} = 8.5$$

$$w_{vehicle} = \frac{373.597}{8.5}$$

$$w_{vehicle} = 43.953\ rad/s$$

In the project definition, vehicle speed is expected in km/h. Therefore, we must first multiply the velocity we found in rad/s by the radius. Then we have to multiply by 3600/1000.

$$V_{vehicle} = w_{base} * r * \frac{3600}{1000}$$

$$V_{vehicle} = 43.953 \ * 0.3 * \frac{3600}{1000}$$

$$V_{vehicle} = 47.469\ km/h$$

When we look at the experimental and theoretical the vehicle speed results in km/h, it is clearly seen that the values are matched.

4. Part C: Component Selection

1.

Selected IGBT module can be seen in Figure 16. This module includes array of two IGBTs and two anti-parallel diodes.

Figure 16 Selected IGBT array module. MG06300D-BN4MM, Littelfuse Inc.

Table 1 shows the significant parameters of IGBT module which are considered during selection. The most important parameters are the ratings of the IGBT, and they are selected with sufficient safety margin. The minimum of voltage rating is considered as the DC-link voltage. The required current rating is taken as RMS of the IGBT current. In fact, mean value of the current can also be used but it would be bad estimation because of dynamic resistance behavior between Vce and Ic. As collector current increases, the saturation voltage increases.

The switching loss of the devices are approximately zero according to the simulation. However, the ideality cannot be preserved in practical implementation so that the switching energy of IGBT and diode is also considered as a significant parameter to succeed thermal management. On the other hand, the integrated diode has also effect on selection.

Table 1 Significant parameters of selected IGBT module.

Parameters	Values	Description
V_{CE} – Breakdown Voltage	600V	Rating of the device
I_C – Collector Current	400A (25°C) – 300A(70°C)	Rating of the device
$V_{CE,SAT}$ – Saturation Voltage	1.45V (300A, V_{GE} = 15V, 25°C)	Conduction loss of IGBT
E_{ON} – ON Switching Energy	2mJ – (25°C, 300V, 300A)	Switching loss of IGBT
E_{OFF} – OFF Switching Energy	9mJ – (25°C, 300V, 300A)	Switching loss of IGBT
R_{thJC} – Junc-to-Case Thermal (IGBT)	0.16K/W	Thermal management of IGBT
V_{FD} – Diode Forward Voltage	1.55V (300A, 25°C)	Conduction loss of diode
E_{rec} – Recovery loss	6.2mJ (300A, 300V, 125°C)	Recovery (switching) loss of diode
R_{thJC} – Junc-to-Case Thermal (Diode)	0.32K/W	Thermal management of diode

2.

The loss calculation in the drive system can be separated as motor loss and inverter loss. Motor loss includes copper losses, core losses and mechanical losses. On the other hand, inverter loss includes switching losses and conduction losses of switching devices. The core losses and mechanical losses are ignored.

The phase current is equal to $530A_{PEAK}$ and phase currents has sinusoidal shape. Phase voltage is calculated below for the base speed and the rated torque.

$$P_{copper} = 3\, I^2 R_s = 3\left(\frac{530}{\sqrt{2}}\right)^2 0.016 = 6.74kW$$

The IGBTs share the phase current half by half. While above IGBTs takes upper part of the sinusoidal, below IGBTs takes bottom side of the sinusoidal. Conduction losses can be calculated from the saturation voltage and mean of the IGBT current, which is the simplest approach for calculation of conduction loss of switching device. The loss calculation of from mean current and saturation voltage may results in discrepancy due to dynamic resistance behavior of the relation between Vce and Ic. The conduction loss of IGBTs is calculated below. Safety margin

$$P_{cond,IGBT} = 6\, I_{mean}(1.5)V_{CE,SAT} = 6x132.5Ax(1.5)x1.45V = 1.73kW$$

The switching losses are calculated based on carrier frequency, which is 10kHz. The calculation is done based Eon and Eoff. The switching loss calculation is shown in the below equation. The switching energies are also taken with consideration of safety margin.

$$P_{SW,IGBT} = 6\left(E_{on} + E_{off}\right)f_{sw} = 6x(15mJ)x10kHz = 0.9kW$$

The diode has also conduction and switching losses. The loss calculations for diode can be seen in the following equations. The mean value of the current is taken from the simulation.

$$P_{cond,DIODE} = 6\, I_{mean}(1.5)V_{FD} = 6x35Ax(1.5)x1.5V = 0.47kW$$

$$P_{SW,DIODE} = 6\,(E_{rec})f_{sw} = 6x(6.2mJ)x10kHz = 0.37kW$$

Total loss of the inverter and motor is 10.21kW and efficiency is %92.16. The thermal management with selected modules could not be so hard because they have more volume than the discrete IGBTs. However, the integrated diode and IGBT in a single package can be problem. The usage of heatsink could be necessary for discrete IGBTs and modules with integrated diode. Moreover, the forced cooling system should be used because the power dissipations is very high.

3.

Three half-bridge driver is used to turn on and off the IGBTs. The controller determines when the gates will be turned on and off. Hence, the only function of driver is supplying a current when the controller makes the intput logic high. The selected driver is PM8834TR.

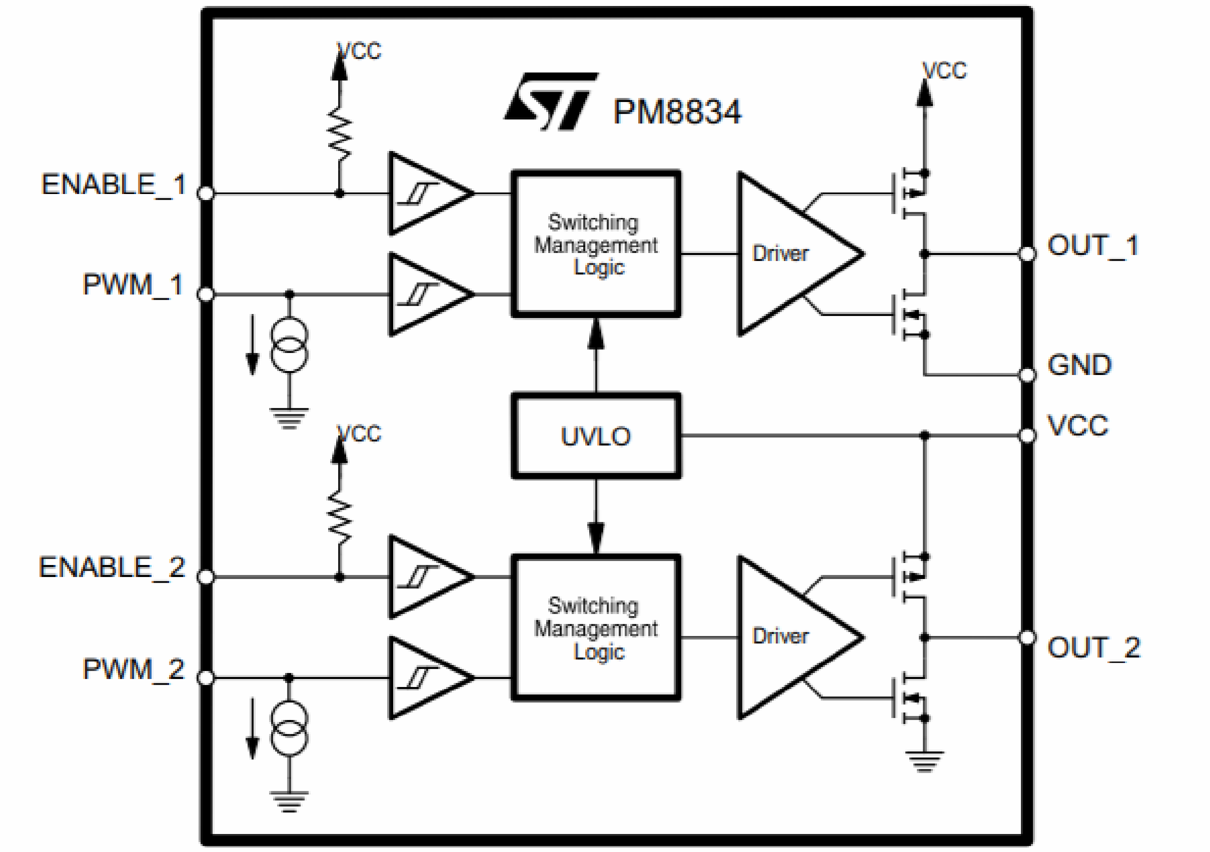

Figure 17 Block diagram of PM8834TR

The most significant parameters for the driver selection are the output voltage and output current. The desired voltage level is 15V to turn on IGBT, which provides the IGBT with less Vce,sat. Driver can supply 4A current, which affects the turn on and off time of IGBT. If the supply current becomes high, the gate capacitance can be charged fast. Therefore, the supply voltage and current of the driver are the most important parameters for the selection.

Current is calculated based on gate charge and turn on time. If we want to turn on the IGBT in 2 seconds, the supply current should be 1.6A since the gate charge is 3.2 uC.

5. Conclusion

To conclude, we have investigated the speed control mechanisms for an SM-PMSM in this project. With the help of MATLAB/Simulink, we have created a variable frequency drive system for the SM-PMSM. For the control of the field and speed of an SM-PMSM, we have used cascaded speed and current controllers by using dq currents. We have computed the essential and significant parameters for the variable frequency drive system. The base speed and maximum applied electrical frequency of the supplied SM-PMSM. Then, for the motor drive system's Voltage Source Inverter (VSI), we have chosen a suitable switching frequency. In the constructed motor driving system, we have used the Sinusoidal PWM (Sine-PWM) method. The performance of the proposed motor drive system using the Sine-PWM method has been observed for different cases. The speed, voltage, current, and torque waveforms of the SM-PMSM have been observed during the transition from 35 km/h to 40 km/h. The reaction of the motor drive system to a change in load torque has been investigated. Also, the response of the drive system to the speed has been observed for the speed reversal case. The response time and overshoot have been improved for both cases by changing the proportional and integrator coefficients. Here, it has been observed how much the parameters of the controller affect the response of the system. Furthermore, a method has been presented for running the motor at 60 km/h without exceeding the rated currents while the vehicle is driving at 40 km/h with half the rated torque (assume a constant load torque and inertia of the load). To succeed in this operation, we have suggested that the motor should operate field-weakening region. So, initial, and final d-q axis current values have been calculated theoretically. Also, we have created a loop with the help of Simulink block to apply this method. Thanks to this loop, the necessary d and q currents are given to the system. As a result of our observations, we have seen that the initial and final d and q currents in the loop we implemented on Simulink are the same as the values we calculated theoretically. We also observed that the proposed method works very well.

Selection of IGBT is done based on required maximum ratings and thermal management. The more expensive IGBT is selected to satisfy thermal management. Half-bridge driver which satisfies output voltage and current values is selected. Th

6. Part D: About the Project

Berkay UZUN: 35 Hours

Yunus ÇAY: 34 Hours