ELECTRIC VEHICLES – EEE4016

PROJECT REPORT

Modelling of Velocity and Torque control model for a synchronous reluctance motor

by

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ACKNOWLEDGEMENT

We would like to express our special thanks of gratitude to our teacher Mrs. Razia Sultana who gave us the opportunity to do this project on "Modelling of Velocity and Torque control model for a synchronous reluctance motor", which also helped us in doing a lot of Research and we came to know about so many new things. Secondly, I would also like to thank my parents and friends who helped me a lot in completing this project within the limited time frame that too in the current pandemic situation.

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1. Introduction

1.1 Objective –

The project proposes a novel approach to control the velocity and torque of a Synchronous Reluctance Motor for supporting Electric Vehicle applications.

1.2 Motivation –

The growing requirement for an abundant and clean source of energy has prompted an expanding interest in transportation electrification. Albeit a lot of the improvements has been in regions such has power electronics, control and energy storage frameworks, there is a developing interest for new and progressed traction motors to meet the necessary performance indinces of an electric powertrain at an anticipated and lower cost. For an ideal electric vehicle, need of an ideal traction motor emerges, which have the accompanying characteristics:[1] High Efficiency over a wide range of velocity (especially for regenerative braking), high torque and power density, high torque at low velocity for starting, acceleration, and hill climbing; high power at high velocity for cruising, wide constant power velocity range (CPSR), fast dynamic response, operation in demanding conditions as frequent start/stop, operation in harsh environmental conditions such as dust, water, cold and hot temperatures; Intermittent overload capability (twice the rated power); low frequency service and maintenance, ruggedness and robustness, fault tolerance and safety, comfort (proper acoustics) and low cost.

Several types of EMs have been introduced and investigated in terms of their suitability for traction applications. In the majority of recent applications, synchronous PM machines such as brushless DC machines (BLDCM), surface mounted permanent magnet synchronous machines (SM-PMSM), and interior permanent magnet synchronous machines (IPMSM) in both axial and radial flux magnetic configurations have been used. PM machines have advantages that make them the preferred candidate for electrified transportation. However, available permanent magnet resources are limited and their price is increasing or at best is unpredictable.

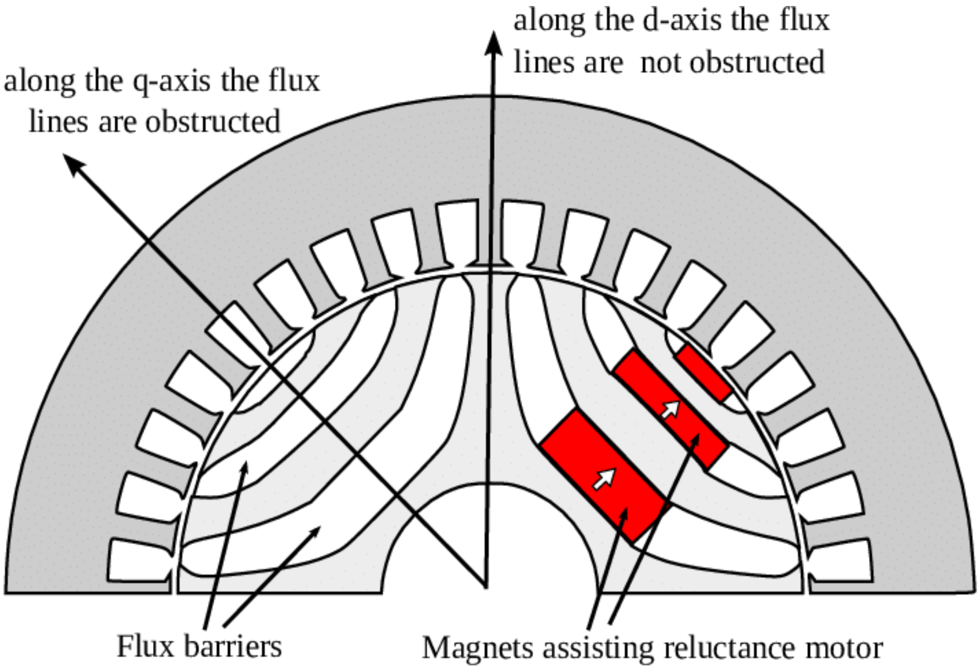


Figure 1- Construction of a Synchronous Reluctance Motor (Syn-RM)

1.3 Background

Owing to their robust structure and low cost, SRMs are considered as strong candidates for e-bike and e-scooter powertrains. Moreover, their simple rotor geometry makes them suitable for top velocity low-cost applications like vacuum cleaners and air blowers, and thanks to their ability to work in harsh environments, SRMs are used for starting and secondary electric power generation in more-electric aircraft engines. A future economically and ecologically sustainable solution may dwell REE-free motors.

Innovators have now introduced two such motors which are aimed toward providing very high efficiency, high power density and freedom from the complications surrounding REE materials. These motors are the synchronous reluctance motor (Syn-RM) and therefore the permanent-magnet-assisted synchronous reluctance motor (Syn-RM2), which uses ferrite magnets. Syn-RMs perform better than conventional IMs. they will be designed for high-efficiency performance or to provide a far better power density for a smaller footprint than an equivalent IM. they have less maintenance, have a reduced inertia and are extremely reliable.

The lower operating temperature of a Syn-RM has multiple benefits including longer insulation life, and longer bearing greasing intervals or lifetime (bearing failure may be a major explanation for motor outage). Syn-RM hardware is just like that of its equivalent IMs. Only the rotor is different. This simplifies spare-part provision and maintenance. It also means replacing an existing IM with a Syn-RM is straightforward.

1.4 Project Description and Goals –

The project deals with two models; current- velocity controlled and current-torque control. A high-voltage battery feeds the Syn-RM through a controlled three-phase converter. An ideal angular velocity source provides the load. The Control subsystem uses an open loop approach to control torque and closed loop approach to control the current. At each sample instant, the torque or velocity request is converted to relevant current references using the maximum torque per Ampere strategy. The current control is PI-based. The simulation uses torque step in both the motor and generator mode. We aim to vary multiple parameters namely:
Nominal DC Battery voltage, No. of pole pairs, Switching Frequency and the type of switch being used and check the respective max torque value and rotor torque for these parameters and experimentally arrive at a model that could be implemented in real time.

2. Working Principle

Before we move further, we'd like to research a number of the parameters getting used in our project. They are –

Maximum torque [N*m]- the first use of torque is to form the car accelerate, and therefore the number usually quoted is that the maximum torque of the ICE at the crankshaft – and that is usually above the quantity at the wheels. Torque is additionally important when vehicles get heavier and bigger .

Stator inductance [H]- Stator inductance estimation for static magnet motors using the PWM excitation. An adaptive observer is employed to calculate the inductance parameters from the present measured. The proposed method does not use external injection, instead it relies on the PWM excitation used for normal motor drive control.

Stator resistance [Ohm]- The stator and rotor resistance are calculated employing a mathematical model and therefore the motor velocity is estimated by use of a wavelet network, then the temperature is obtained consistent with the principle that the metal resistance depends on its temperature.

Number of pole pairs - Simply defined, a pole may be a north or south magnetic flux of force that's generated by a static magnet or current passing through a coil of wire. For stepper motors, however, this definition doesn't necessarily translate to an easy definition of pole count. Different manufacturers use different names to ask their poles and various stepper-motor types have varying kinds and numbers of poles. The formula is:

$n = 60 \times f / p$

where,

n = synchronous velocity

f = supply frequency

p = pairs of poles per phase.

The actual running velocity is that the synchronous velocity minus the slip velocity.

For a 50 Hz three phase supply:

2 poles or 1 pair of poles = 3,000 R.P.M.

4 poles or 2 pairs of poles = 1,500 R.P.M.

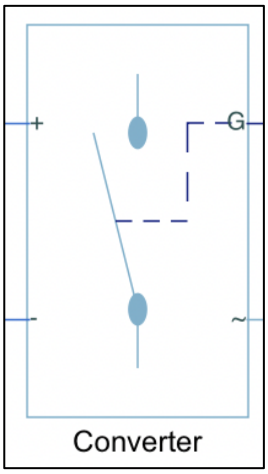
6 poles or 3 pairs of poles = 1,000 R.P.M.

3. COMPONENTS USED

A] Main Block

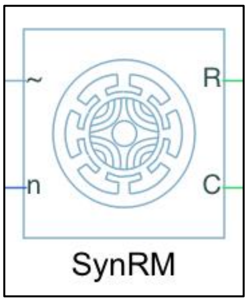
i)Converter-

This block represents a 6-pulse 3-phase controlled converter consisting of three bridge arms each with two switching devices. Select between these switching devices: IGBT, MOSFET , GTO, Ideal Semiconductor Switch, Thyristor, or Averaged Switch.



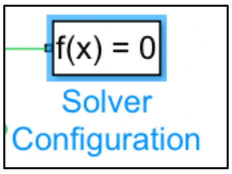
ii)Synchronous RM-

The Synchronous RM block represents a synchronous reluctance machine with sinusoidal flux distribution.



iii)Solver configuration-

Defines solver settings that are to be used for simulation.



iv)HV battery-

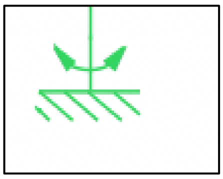
A battery is represented by the High Voltage battery block. The block mimics the battery as a series internal resistance and a constant voltage source if the Battery charge capacity parameter is set to infinite. The battery is modelled as a series internal resistance plus a charge-dependent voltage source as shown below if the Battery charge capacity parameter is set to Finite:

V = Vnom*SOC/(1-beta*(1-SOC))

where SOC is the state of charge and Vnom is the nominal voltage. Coefficient beta is calculated to satisfy a user-defined data point [AH1,V1].

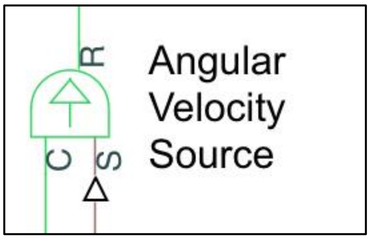
v) Mechanical rotational reference-

A mechanical rotating reference point, such as a frame or a ground, is represented by this block. It's for connecting mechanical rotational ports to the frame that are rigidly attached (ground).



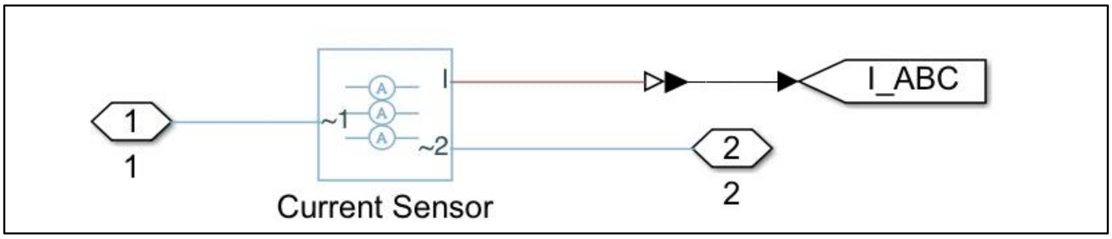
vi)Angular velocity source

Defines solver settings to use for simulation.



B] Current sensing block

The block is a three-phase current sensor in its ideal form. It outputs a three-element PS vector after measuring current flowing between two three-phase electrical nodes.

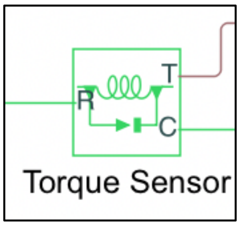


C] Torque sensing block

i)Torque sensor-

The block depicts an ideal torque sensor, which is a device that translates a variable passing through it into a control signal proportional to torque with a predetermined coefficient of proportionality. The sensor is ideal since it ignores inertia, friction, delays, energy consumption, and other factors.

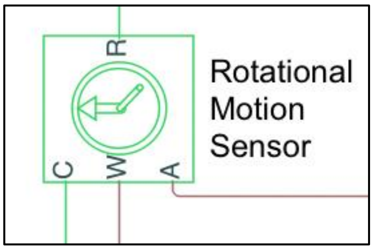
R and C are mechanical rotational conserving ports that link the sensor to the line that is being monitored for torque. The measurement result is output through Connection T, which is a physical signal port. The positive direction of the sensor is from port R to port C.



ii)Rotational motion sensor

The block depicts an ideal mechanical rotational motion sensor, which translates an across variable recorded between two mechanical rotational nodes into a control signal proportional to angular velocity or angle. The sensor is perfect since it ignores inertia, friction, delays, energy consumption, and other factors.

W and A are physical signal output ports for velocity and angular displacement, respectively. Connections R and C are mechanical rotational conserving ports, and connections W and A are physical signal output ports for velocity and angular displacement, respectively.



D] Gate Drive

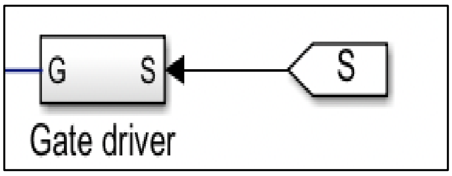
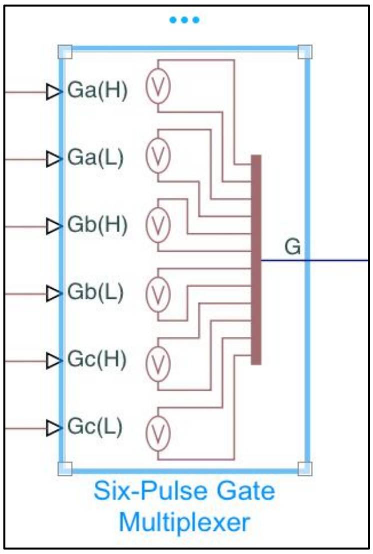


Fig. gate drive in the main system

i) Six-pulse gate multiplexer-

The connections necessary to control a three-phase converter are multiplexed into a single vector G by this block. Use this block in conjunction with the Converter block in the Semiconductors sub-library.



4. PID CONTROL ALGORITHM

The acronym PID stands for proportional integral derivative, and it's a simple device used in industrial applications to manage various process variables such as pressure, flow, temperature, and velocity. An impact loop feedback device is used to manage all of the method variables Kp, Ki, and Kd in this controller. The proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times the integral of the error plus the derivative gain (Kd) times the derivative of the error equals the control signal from the controller to the plant.

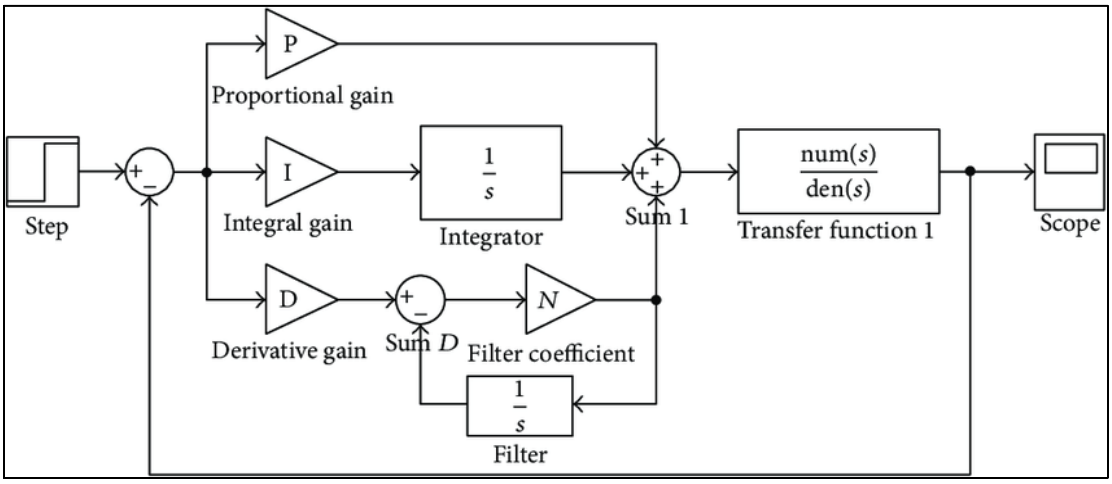


Figure 2- PID Control block diagram

5. MATLAB Code for Machine Parameters

```
%% Machine Parameters
Tmax=205;
p=5;    % No. of poles
Ld=0.05;
Lq =0.004;
L0 =0.0051;
Rs =0.33;
%% High Voltage System Parameters
Vnom=600; %nominal voltage
Cdc=0.001;
V1=550;
```

```
%% Control Parameters
Ts=5e-6;    % fundamental sample time
fsw=600;   % switching frequency
Tsi=1e-4;
Kp_id=50; % PID Control parameters
Ki_id=1000;
Kp_iq=10;
Ki_iq=500;
```

6. Design Approach and Details

A high-voltage battery feeds the Syn-RM through a controlled three-phase converter. a perfect angular velocity source provides the load. The Control subsystem uses an open-loop approach to regulate the torque and a closed-loop approach to regulate the present. The torque/velocity request is translated to relevant current references utilising the maximum torque per Ampere technique at each sample instant. The current control is based on PI. In both the motor and generator modes, torque steps are used in the simulation.

a] Velocity Control –

•An increase in the nominal voltage brings about very small changes in the rotor velocity, and hardly affects it. As we can see, the velocity value shows a constant increase as we increase the Nominal voltage, suggesting that operation at higher voltage for the system would need a greater velocity value.

•Pole pair on the other hand shows a drastic decrease, suggesting that decrease in pole pairs reduces the max velocity output.

•Frequency change showed an uneventful trend as it dropped suddenly by 105% when we reduced the frequency.

•The best response of the system was shown with an IGBT switch, and a huge rotor velocity reduction was seen when we used a MOSFET. The system doesn’t work when we use GTO/ Thyristor in our converter.

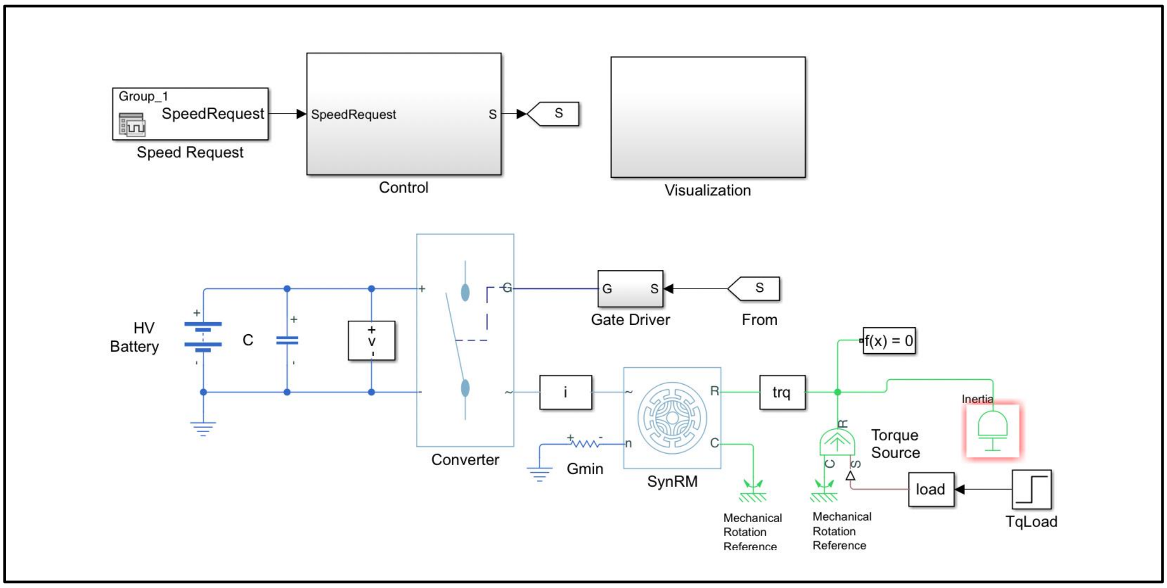


Figure 3- Simulation diagram for velocity control

Nominal voltage	Rotor Speed
600	998.7
700	1017
800	1017
900	1013
1000	1040

Pole pairs	Speed
P = 2	998.7
P = 3	661.7
P = 4	519.3
P = 5	427.4

Switching Freq	Speed
1000	998.7
900	447.7
800	441.9
700	452.3
600	447.2

Switch	Speed
IGBT	998.7
GTO	-
Ideal	435.1
MOSFET	435.1
Thyristor	-

Figure 4- Velocity variation for different parameters

b] Torque Control -

Direct torque control (DTC) is a newer control method for PWM inverter-fed induction motor (IM) drives. It enables precise and fast adjustment of the IM flux and torque without the use of complicated control algorithms. Furthermore, it just requires knowledge of the stator resistance in principle. The maximum torque decreases as the battery's nominal voltage is increased. When there are three pole pairs with a value of 49.51, the maximum torque peak is reached. Higher torque is obtained as the frequency is reduced, however this causes stability concerns, therefore a balance must be maintained. Using a perfect semi-conductor switch, as opposed to velocity control, produces a far higher torque value.

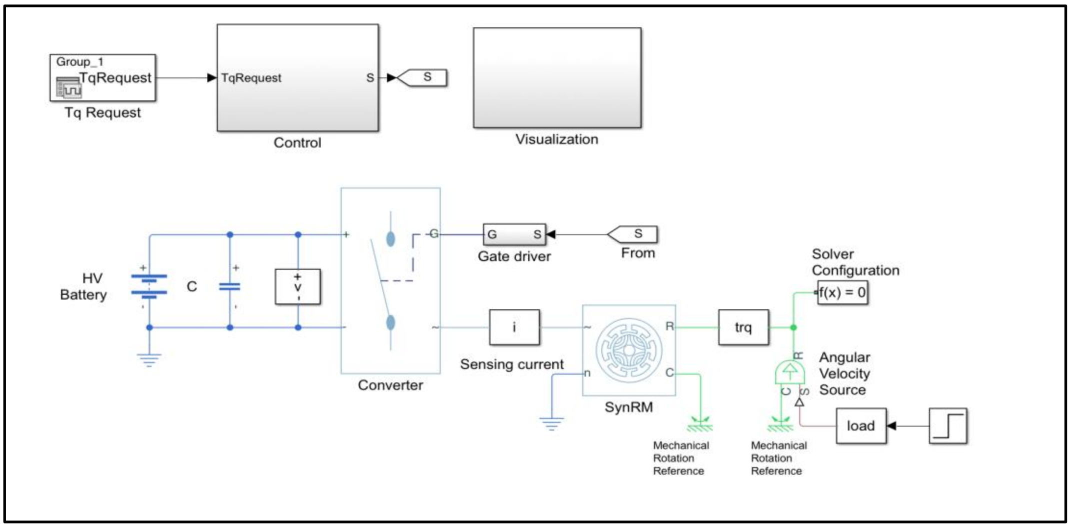


Figure 5- Simulation diagram for Torque control

Nominal voltage	Torque
600	46.23
700	45.93
800	45.05
900	44.74
1000	44.38

Pole pairs	Torque
P = 2	46.23
P = 3	49.51
P = 4	44.76
P = 5	45.58

Switching Freq	Torque
1000	46.23
900	52.16
800	53.1
700	53.4
600	62.08

Switch	Torque
IGBT	46.23
GTO	-
Ideal	58.7
MOSFET	58.7
Thyristor	-

Figure 6.Torque variation for different parameters

7. System Modification and optimization

a) For velocity control

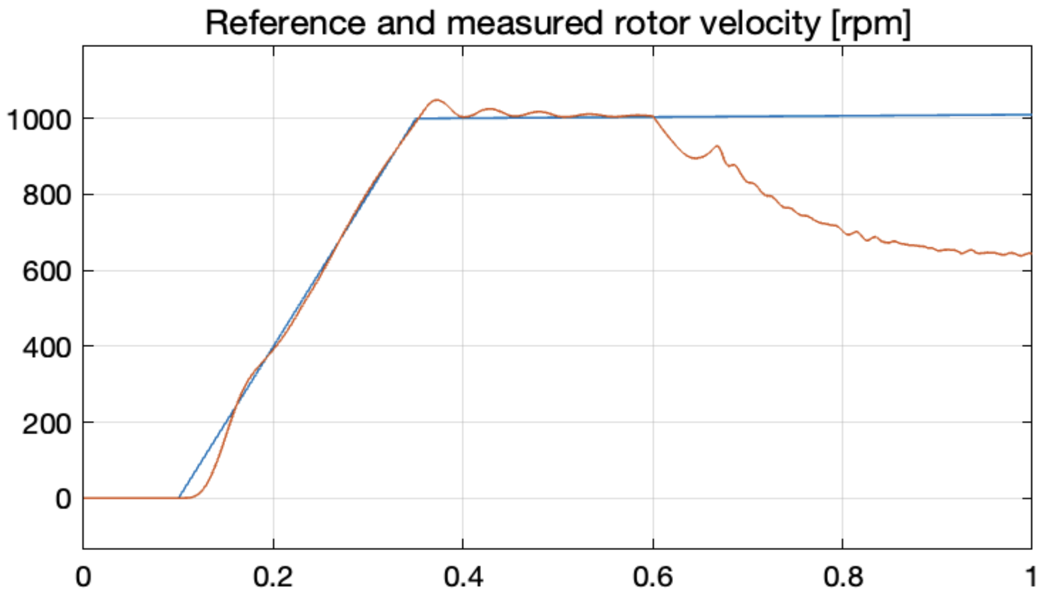
Parameter	Earlier Model	New Model
Nominal Voltage	600	800
Frequency	1000	5000
Pole Pairs	2	3
Switch Used	IGBT	IGBT

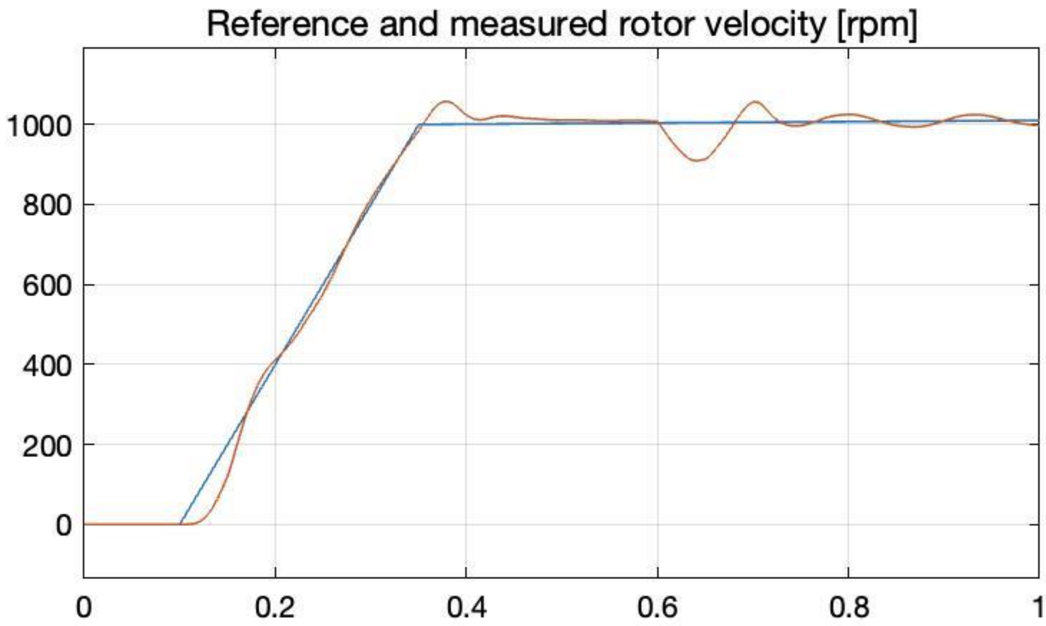
b) For torque control

Parameter	Earlier Model	New Model
Nominal Voltage	600	800
Frequency	1000	5000
Pole Pairs	2	3
Switch Used	IGBT	IGBT

8. Output Graphs

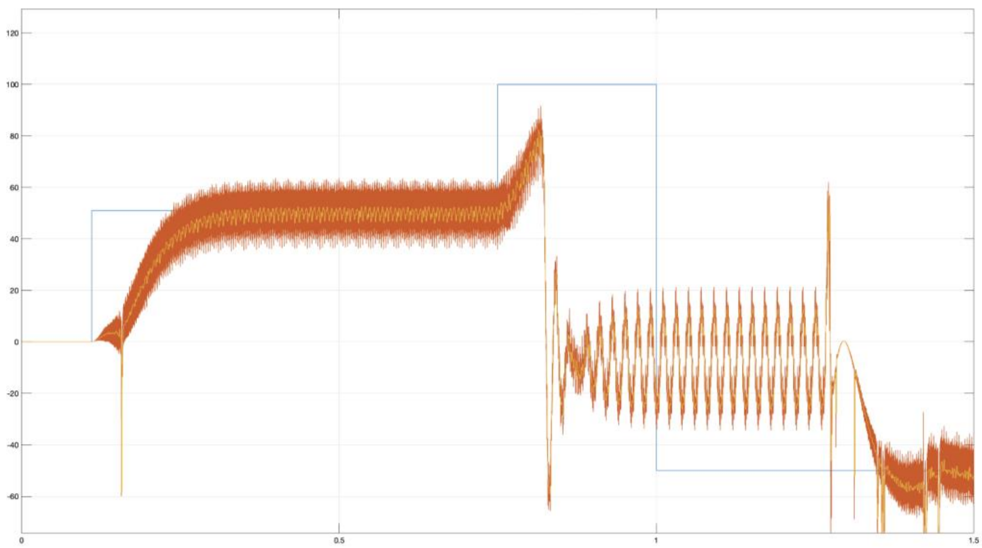
a) Velocity Control-

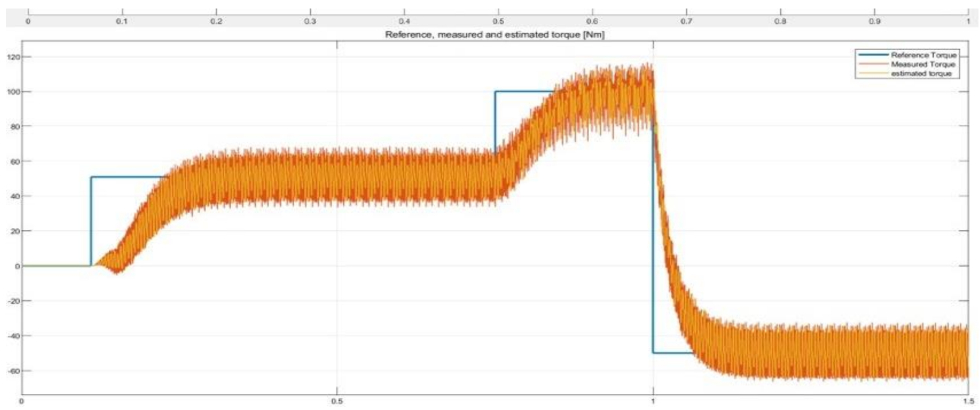




b) Torque control-

Reference measurement of estimated torque [Nm]





9. CONCLUSION

We have obtained two separate models for our Syn-RM control with two separate parameters that can be tested in real time to get to desirable outcomes. We also came across certain observations such as in velocity control, Rotor velocity is directly proportional to the pole pairs being used and when the frequency was switched below 1000 Hz, it showed a large drop and for torque control, increasing the nominal voltage results in reduction of peak torque value and the highest value is obtained when we use 3 pole pairs. An Ideal switch functions better in torque control as IGBT's are desired due to their high voltage capacity, low ON resistance and fasting switching frequency and none of them are that important in torque control. Ideally, the models for torque control and for velocity control can't be implemented in the same machine (same construction) since both have best output for different values of p.

10. References

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