PERFORMANCE ANALYSIS OF A COMPLETE EV POWERTRAIN USING A CONTROLLER AND MATLAB SIMULINK

PROJECT REPORT

submitted by

ABHISHEK MOHAN (Reg. No : **MAC18EE005**)
ADWAITH S (Reg. No : **MAC18EE007**)
ALFIA SUBAIR (Reg. No : **MAC18EE016**)
ANTO JOSE (Reg. No : **MAC18EE022**)

to

the APJ Abdul Kalam Technological University
in partial fulfillment of the requirements for the award of the Degree

of

Bachelor of Technology
in
Electrical and Electronics Engineering

Department of Electrical and Electronics Engineering

Mar Athanasius College of Engineering
Kothamangalam, Kerala, India 686 666

JUNE 2022

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
MAR ATHANASIUS COLLEGE OF ENGINEERING
KOTHAMANGALAM

CERTIFICATE

This is to certify that the report entitled **Performance Analysis of a Complete EV Powertrain using a Controller and MATLAB Simulink** submitted by **Mr.Abhishek Mohan** (**MAC18EE005**) **Mr.Adwaith S** (**MAC18EE007**) **Ms.Alfia Subair** (**Reg.No.MAC18EE016**) **Mr.Anto Jose** (**MAC18EE022**) to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in Electrical and Electronics Engineering is a bonafide record of the project carried out by her under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

Prof. Ninu Joy	Prof. Beena M Varghese
Project Coordinator & Guide	Head of the Dept.
24/6/22	24/06/22
Internal Examiner(s)	External Examiner(s)

01-06-2022

ACKNOWLEDGEMENT

It is a great pleasure to acknowledge all those who have assisted and supported us for successfully completing our project.

First of all, we thank God Almighty for his blessings as it is only through his grace that we were able to complete our project successfully.

We take this opportunity to extend our sincere thanks to Project Guide and Faculty Advisor Prof. Ninu Joy, Assistant Professor, Department of Electrical & Electronics Engineering for her constant support and immense contribution for the success of the project.

We are also grateful to Prof. Beena M Varghese, Head of Electrical & Electronics Engineering Department, for the valuable guidance as well as timely advice which helped us a lot during the preparation of the project.

We are deeply indebted to Dr. Mathew K, Principal, Mar Athanasius College of Engineering for his encouragement and support.

We whole - heartedly thank all our classmates, for their valuable suggestions and for the spirit of healthy competition that existed between us.

ABSTRACT

Electric Vehicle is anticipated to have a massive market soon in our country. This accounts for having a better performance of the vehicle. Hence estimating the performance and behavior of the electric vehicle components reduces testing time and cost and makes it more efficient. The development of an Electric Vehicle powertrain and the control algorithm of the motor is intended. The specifications and parameters of a commercially available electric vehicle were analyzed and its powertrain dimensions were decided as the benchmark parameters. A complete model of the dimensioned powertrain and its control algorithm will be simulated in the Simulink environment and analyzed. The control algorithm for the motor will be uploaded onto a commercially available motor controller and the performance, and efficiency of the algorithm will be analyzed on a virtual motor and vehicle model using the processor in loop feature (PIL) of MATLAB Simulink. Real-time speed control of a motor using the control algorithm and Hardware in Loop test (HIL) using MATLAB will also be implemented. The objective is to compare the performance of the designed powertrain and its control algorithm with that of existing benchmarks. The system gives various performance parameters of the electric motor and the battery pack by taking the drive cycle as the input.

TABLE OF CONTENTS

Contents | Page No.

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Adoption of electric cars especially in developing nations of Asia-Pacific is showing a healthy increase over the past few Years. Leading automobile manufacturers in India has recently jumped into the development and production of electric vehicles. The project focuses on the development of the powertrain of an electric vehicle through analytical calculations and with technical specifications of an already existing EV as a benchmark.The EV can be designed in MATLAB/Simulink environment based on analytical calculation thereby giving intuitive performance results of the implemented vehicle model.The results will be summarized in forms of various tables and plots.The vehicle will be simulated for various velocity inputs and standard drive cycles. Each block of an electric powertrain will be modeled based on its underlying principles and parameters and recuperation function of an electric vehicle will also be implemented to estimate battery SoC at the end of a drive cycle simulation.

A control algorithm requires an efficient controller for its implementation. A processor-in-the-loop (PIL) simulation cross-compiles generated source code, and then downloads and runs object code on your target hardware.It provides a framework to verify the actual controller code on a dedicated microcontroller that interacts with a simulation in the software environment. The test is done by having a target hardware in series with a virtual plant of the inverter and motor model of a power plant running in a matlab environment.

Hardware in Loop testing is a technique where real signals from a controller are connected to a test system that simulates reality, tricking the controller into thinking it is in the assembled product. In accordance with the feasibility of the project the control algorithm will be modified for the small scale implementation of speed control of electric motors by suitable parameter changes.

The project focuses on the development of an electric vehicle powertrain in matlab and simulink environments through analytical calculations and also a novel study of various tests done in automotive development stages.

Hardware in Loop testing is a technique where real signals from a controller are connected to a test system that simulates reality, tricking the controller into thinking it is in the assembled product. In accordance with the feasibility of the project the control algorithm will be modified for the small scale implementation of speed control of electric motors by suitable parameter changes.

The project focuses on the development of an electric vehicle powertrain in matlab and simulink environments through analytical calculations and also a novel study of various tests done in automotive development stages.

CHAPTER 2

LITERATURE REVIEW

Jose Jacob et.al[1] The Permanent Magnet Synchronous Motor is controlled using Field Oriented control algorithm and space vector pulse width modulation. The implementation of these techniques is discussed and its working principle is described. Application of these algorithms to a multilevel inverter to control a PMSM motor and development of the same in a MATLAB/simulink environment is also discussed.

J. Mina et.al[5] Processor-in-the-loop (PIL) is a test technique that allows designers to evaluate a controller, running in a dedicated processor, of a plant which runs in an offline simulation platform. By the other side, Hardware-in-the-Loop (HIL) is an approach to test a plant or controller running in a digital platform which interacts with the real controller or plant. The use of these techniques in the automotive industry is of great value as it provides insights into control algorithm efficiency. The pre-requisites and implementation of these tests are discussed.

Carlos Miguel-Espinar et.al [2] An enhanced Flux Weakening (FW) control scheme for Permanent Magnet Synchronous Motors (PMSMs), focused on electric vehicle applications. The dq-axis current references are calculated from the proposed algorithm by using a polar coordinate system. Another fundamental merit of the proposed scheme is its capacity to work in all the dq-plane throughout the Maximum Torque per Ampere (MTPA) strategy. Simulations and experimental results on a Permanent Magnet Synchronous Motor (PMSM) is verified for its effectiveness on the proposed method.

CHAPTER 3

MODELLING OF SIMULATION

3.1 INTRODUCTION

The drivetrain of an electric vehicle is made up of various subsystems. The modelling of each block is done in simulink environment by careful study of various inputs and outputs of each block, their underlying principle and how they interact with each other.

3.1 shows the basic block diagram of the ev powertrain based on which the simulation is build upon.

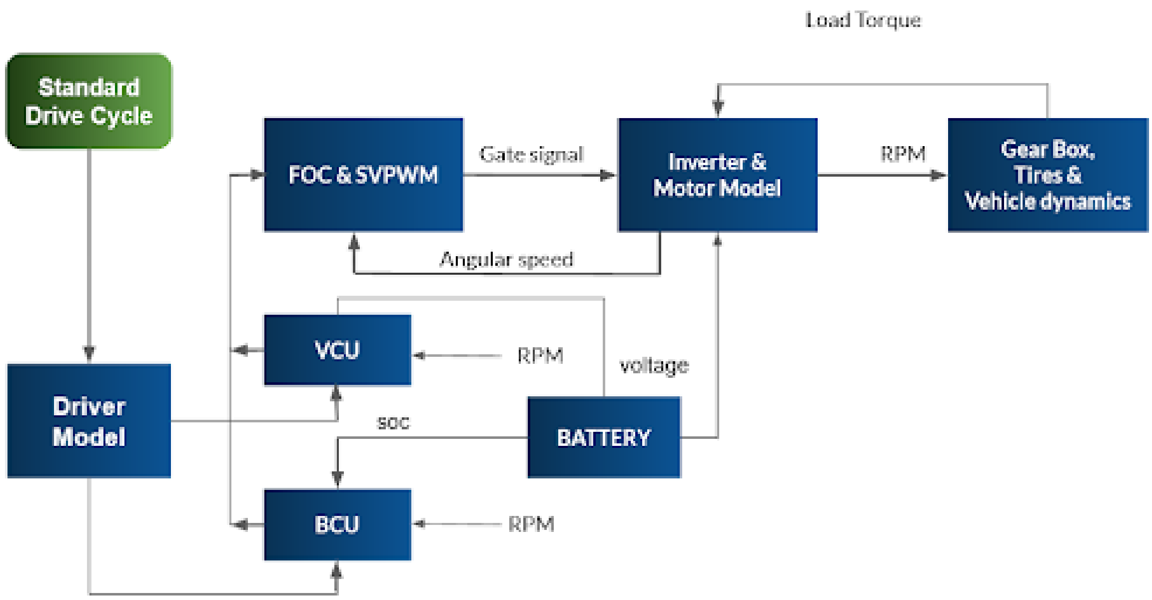

Figure 3.1: Blocks to be simulated in MATLAB environment

3.2 PRELIMINARY CALCULATIONS AND MOTOR PARAMETER ESTIMATION

Consider the total weight of the vehicle to be 1505 kg. Let Tyre radius be 0.33 m , which implies wheel circumference to be 2.073m. Assume a top speed of 120kmph and acceleration of 0-100 kmph in 13.5 seconds.

Drag resistance

$$\text{At top speed, } F_a = 0.5{*}\rho{*}C_d{*}A{*}v^2 = 0.5{*}1.225{*}0.29{*}2.89{*}33.332 = 570.373N \quad (3.1)$$

$$\text{At 100 kmph, } F'_a = 0.5 * \rho * C_d * A * v^2 = 0.5 * 0.29 * 2.89 * 27.772 = 396.092\ N \quad (3.2)$$

Rolling resistance

$$\text{At top speed, } F_r = C_r * m * g = 0.018 * 1505 * 9.18 = 248.68\ N \quad (3.3)$$

Gradient resistance

$$F_g = m * g * sin(\alpha) = 1505 * 9.18 * sin(0.327) = 4447.37\ N \quad (3.4)$$

Acceleration resistance

Force for Acceleration from 0-100 kmph in 13.5 sec in straight road,

$$F_acc = m * dvdt = 1505 * 27.7778 * 13.5 = 3096.707819\ N \quad (3.5)$$

Consider an average acceleration of 1.15 ms^2 when the vehicle is ascending its maximum gradable slope of 35%

$$F''_{acc} = m * a = 1505 * 1.15 = 1730.75\ N \quad (3.6)$$

Tractive Force in level plane at 100 kmph =

$$F'_a + F_r + F_{acc} = 396.0927855 + 248.6862 + 3096.707819 = 3741.486804\ N \quad (3.7)$$

Reqd. Tractive Force while ascending =

$$F_a + F_r + F_g + F''_{acc} = 570.3736111 + 248.6862 + 248.6862 + 1730.75\ N \quad (3.8)$$

Tractive Torque at 100 kmph = $Tractiveforce * Tyreradius$
= $3741.486804 * 0.33 = 1234.69\ Nm$

Maximum Tractive Torque = $Maximum\,required\,tractive\,force * Tyre\,radius$
$= 6997.185 * 0.33 = 2309.071308 Nm$

Wheel R.P.M at Top Speed =

$$\frac{Top\,speed\,in\,m/s * 60}{2 * \pi * r} = \frac{33.33 * 60}{2 * \pi * 0.33} = 964.57\,RPM \tag{3.9}$$

Let the peak motor Torque be 280 Nm. Gear Ratio Required is MTT/Peak torque = 2309.071 38 / 280 = 8.246. Consider a gear ratio of 8.25:1. Motor R.P.M at Top Speed = Wheel RPM at top speed * Gear ratio = 964.57 * 8.25 = 7957.747 RP. Minimum required Peak Speed of the motor for top speed = 7957.747 RPM

Let it be 8000 RPM. At 100kmph, Peak Power Required at wheel=

$$\frac{2 * \pi * N * T}{60} = \frac{2 * \pi * 803.8128439 * 1234.690645}{60} = 103930.189\,W = 103.93\,kW \tag{3.10}$$

Let the transmission efficiency be 95% = 0.95 Motor output Power Required = Peak Power required at wheel/transmission efficiency= 103.930189/0.95 = 109.400199.
Let it be 110 KW. Base RPM =

$$\frac{Power * 60 * 1000}{2 * \pi * peak\,motor\,Torque} = 3751.509373\,RPM. \tag{3.11}$$

3.3 MODELLING OF DRIVETRAIN SIMULATION

3.3.1 VCU & BCU

The VCU and BCU based on accelerator and brake pedal inputs generate reference id and iq values.The inputs from driver model is fed into the VCU and BCU ,based on which the Id and Iq reference selector choses its action.MTPA and field weakening is engaged in the design of VCU and BCU.

The Maximum Torque Per Ampere (MTPA) computes the Id & Iq reference currents for both Velocity Control Unit and Brake Control Unit using the reference torque.For the Brake Control Unit,there is a brake logic block which splits between Regenerative Braking and Mechanical Braking.Only regenerative Braking needs the value of Id and Iq reference as mechanical braking is not provided by the motor..The Id and Iq values come from both VCU and BCU .Inorder to select that ,we have an Id Iq reference selector block. VCU gets the accelerator command input from driver model (0 to 1) which is a torque demand for the MTPA/FW block inside it and MTPA/FW block outputs desired Id and Iq values. Similarly BCU also gets brake input from driver model.

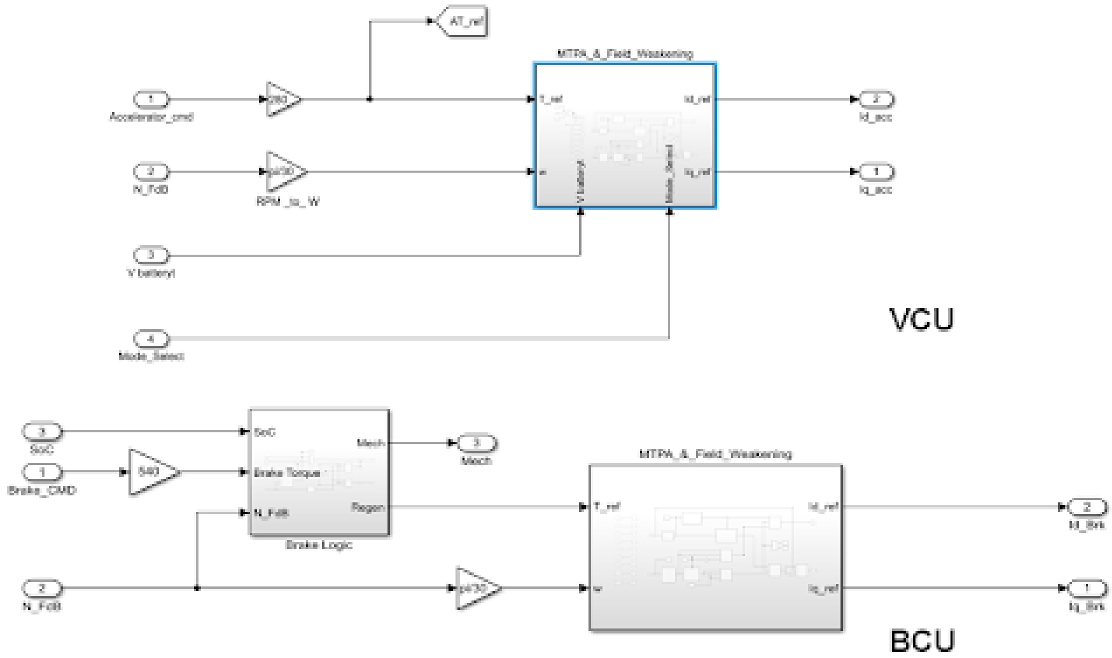

Figure 3.2: Velocity Control Unit and Brake Control Unit

The logic splits the input brake torque into required torque for Regenerative braking and required torque for Mechanical braking based on motor RPM and battery SOC.

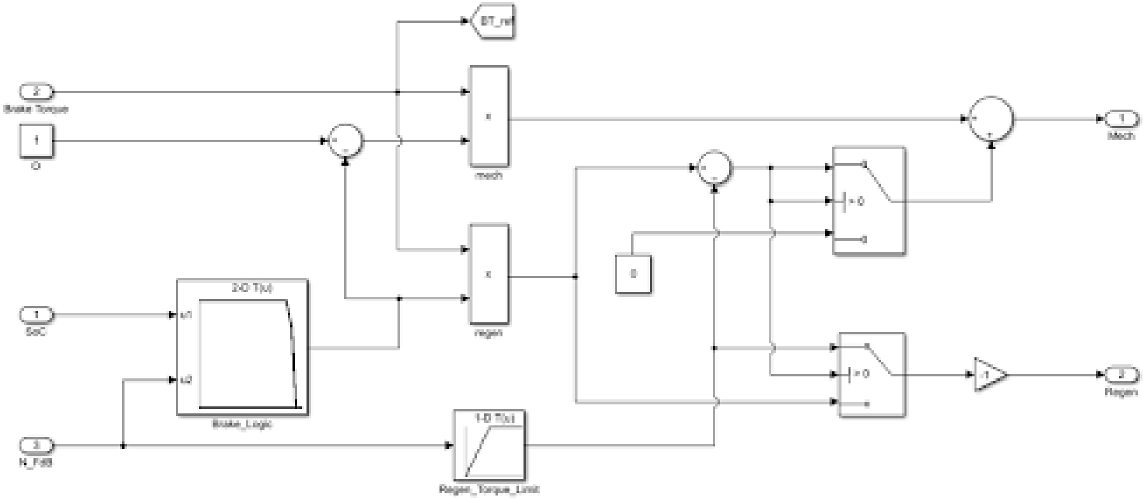

Figure 3.3: Brake Logic

3.3.2 FOC & SVPWM

Field Oriented Control (FOC) is one of the methods used to control a PMSM'ss speed and torque. FOC greatly reduces the ripples from the system response and helps in smoother operation of motor. Field oriented control (also known as vector control) is a technique used to generate a 3-phase sinusoidal modulation which then can be controlled in frequency and amplitude. Calculations are used to transform the three-phase signals into two phases that are easier to control and implement in the motor control circuit. Field weakening can also be employed in the motor to make the motor run at speed higher than nominal speed.As the angle between stator magnetic field and rotor magnetic field increases ,torque is produced. Sensorless control eliminates the position sensors .For the simulation of the powertrain position sensoring happens with the position .But for HIL part here ,we are not using position sensors. The inputs to the current controller are Id reference, Iq reference , Rotor angle and Stator current. Output will be the gate signal to Voltage Source Inverter.

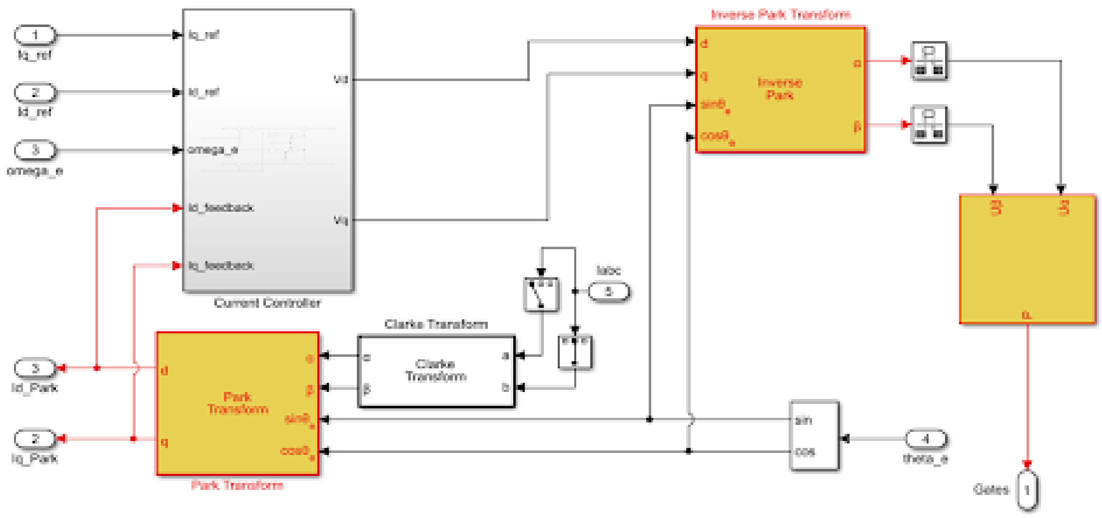

Figure 3.4: Field Oriented Control

Space vector pulse width modulation (SVPWM) is a technique used in the final step of field oriented control (FOC) to determine the pulse-width modulated signals for the inverter switches in order to generate the desired 3-phase voltages to the motor. The Clarke transform converts the time domain components of a three-phase system (in abc frame) to two components in an orthogonal stationary frame. The Park transform converts the two components in the $\alpha\beta$ frame to an orthogonal rotating reference frame (dq).

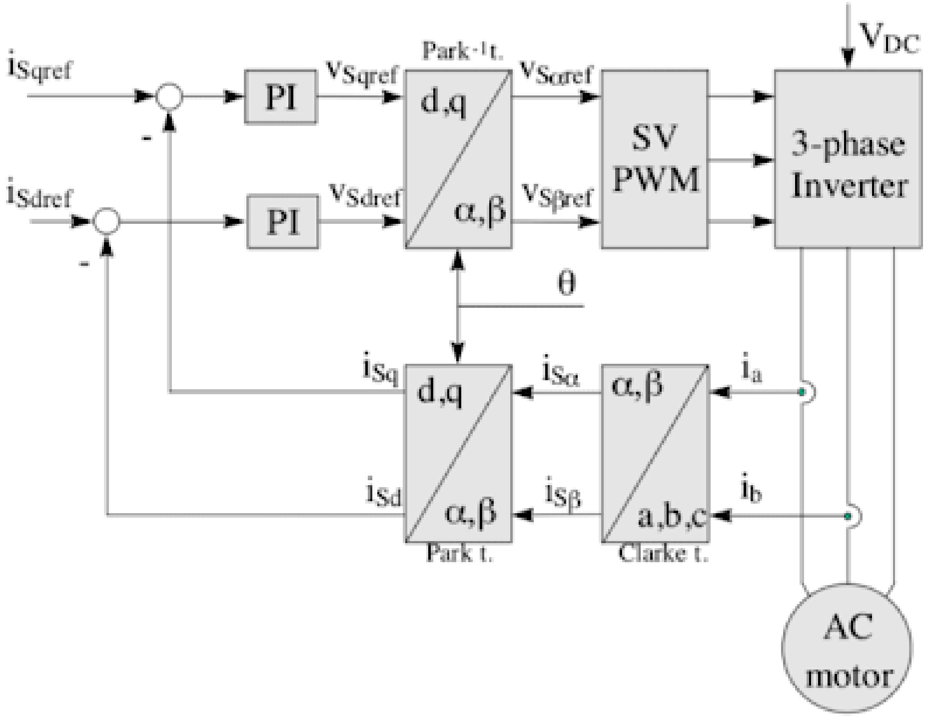

Figure 3.5: Control with Space Vector Pulse Width Modulation

3.3.3 Inverter & Motor model

To model the inverter and motor of the drive train available blocks in simulink are used. A universal bridge of IGBT is used as the inverter, the battery terminals are connected to the available ports and a port for receiving the gate pulses from the SVPWM generator is also available. A three-phase two-Level VSI has been considered for the power delivery to motor.

To model the motor, an available PMSM motor block is used and its parameters are modified as below with values obtained from secondary research.

Parameter	**Symbol**	**Value**
No. of Pole Pairs	P	4
Stator Resistance per phase	R_s	3.3
Direct Axis Inductance	I_d	415
Quadrature Axis Inductance	I_q	375
Rotor Inertia	J	$0.018Kgm^2$
Permanent Magnet Flux	σ_m	0.018

Table 3.1: PMSM Parameters

The three phase current from inverter is given as input to the motor and the rotor position , rotor speed and electromagnetic torque are taken as feedback for the control strategy.

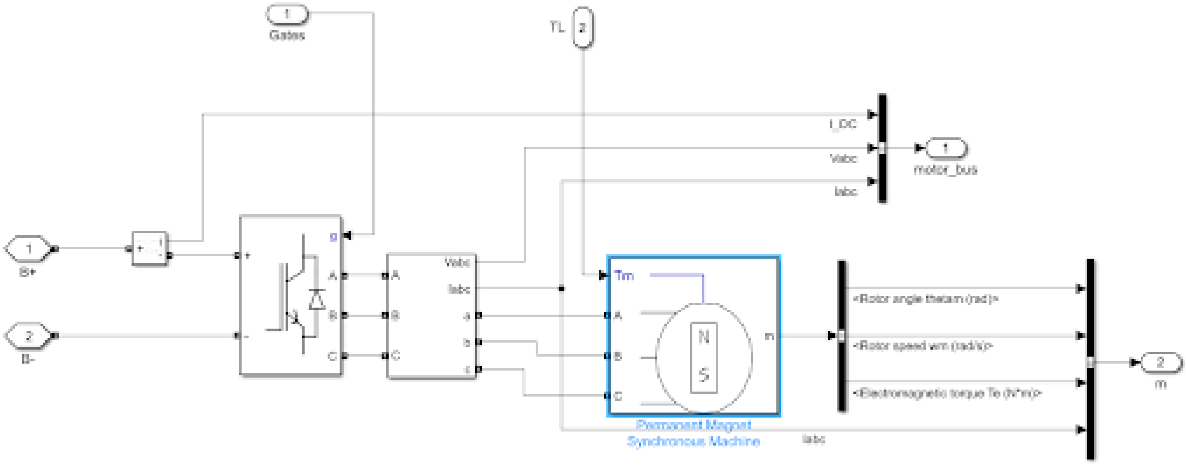

Figure 3.6: Inverter and Motor Model

3.3.4 Gearbox, Tyres & Vehicle Dynamics

3.3.4.1 Vehicle Dynamics

The vehicle body is modelled using the vehicle dynamic equations.The forces acting on a vehicle are modelled using Simulink blocks. The various forces are:

Aerodynamic Drag

One of the primary forces acting on a vehicle is aerodynamic drag, which is the oppositional force imparted on the vehicle by the air that it collides with as it moves forward. As the vehicle speed increase, the aerodynamic drag force opposes the vehicle motion as the air as is forced to flow around the moving vehicle. It can be calculated as the product of the aerodynamic drag coefficient C_d the front area of the vehicle A, the air density and the square of the vehicle speed v, divided by 2. The drag force can be calculated using equation

$$F_a = 0.5 * \rho * C_d * A * v^2 \tag{3.12}$$

It is hence important to note that the aerodynamic drag in independent of vehicle mass but has a strong dependence on the vehicle speed. At sea level, ρ is 1.225. Secondly, the coefficient of drag is typically about 0.25 to 0.35 for a modern car. We have used 0.29 as coefficient of drag.

Rolling Resistance

In addition to overcoming air resistance, the vehicle needs to overcome rolling resistance, which is a loss generated by the wheels in contact with the road surface. While there are many things that can contribute to rolling resistance, the primary component of it is hysteresis: as the wheel rolls along the road, the wheel (and to a lesser extent, the road surface) is constantly being deformed, which causes a loss of energy in the form of heat.The equation for rolling resistance is

$$F_r = C_r * m * g * cos(\alpha) \tag{3.13}$$

In the case of a road with an inclination angle, the normal force becomes the weight m*g multiplied by the cosine of the road angle. It is important to note that the rolling resistance force is independent of the vehicle speed, and it is always opposite the driving direction. The coefficient C_r should be low so as to keep the frictional losses low. For modern cars, it's typically around 0.01 to 0.02. We have used C_r as 0.018.

Gradient Force

The third force that acts on a vehicle is the gradient force, and it occurs when the vehicle is driving on an uphill or a downhill road. The gradient force is due to the longitudinal component of gravitational force, namely mg where alpha is the inclination angle of the road. As seen earlier, the cosine component of the gravity contributes to the normal force and the corresponding rolling resistance force. The gradient force and the angle alpha are negative when driving downhill, and positive when driving uphill. The equation for grading resistance is

$$F_g = m * g * sin(\alpha) \tag{3.14}$$

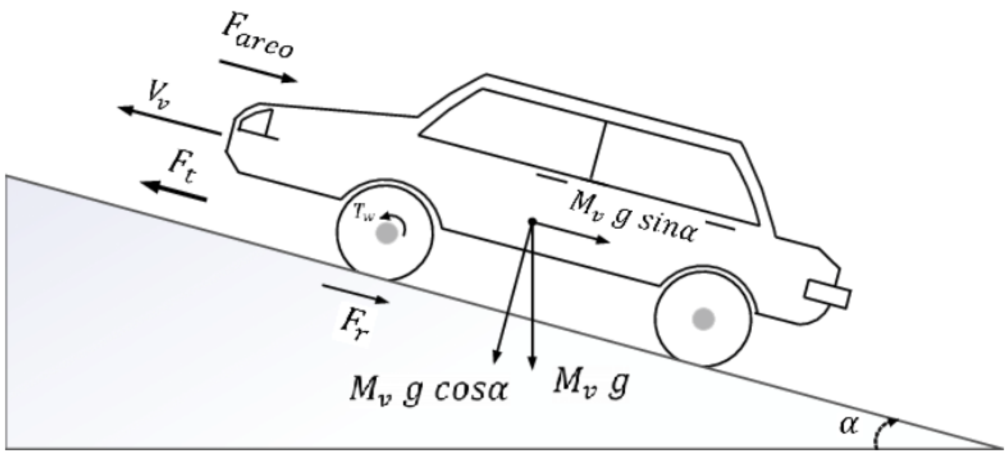

Figure 3.7: Dynamic forces acting on a vehicle in motion

Linear Acceleration

If the vehicle is traveling at constant velocity, the three forces described above are sufficient to form a basic model of the vehicle's behavior. But much of the time a vehicle is also accelerating as well as decelerating. The linear acceleration of a vehicle along the road is defined by the equation

$$F_{acc} = m * \frac{dv}{dt} \tag{3.15}$$

The total tractive effort required to move the vehicle is simply the sum of all of the forces we have discussed.

$$\text{Total Tractive Force Required} = F_a + F_r + F_g + F_{acc} \tag{3.16}$$

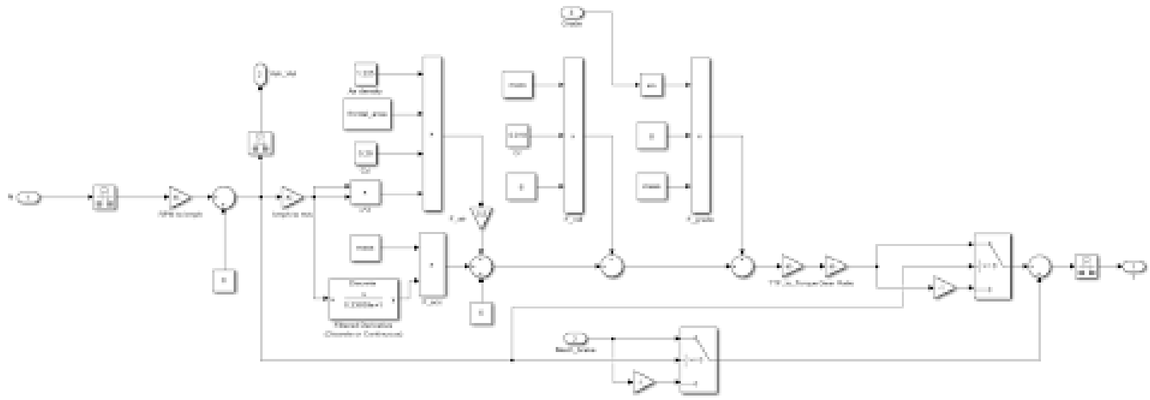

Figure 3.8: Vehicle Body

3.3.4.2 Gearbox & Tyres

The transmission refers to the transfer of the power from one part to another part. The transmission in an Electric vehicle refers to transfer of electric power from a motor to wheels through gearbox and shaft. The main objective of the transmission is to provide the driver more than the enough torque to the wheels from the motor. The torque should be enough in such a way that the car should move faster against road load resistance. Power P = $2 * \pi * N * T/60$

Where, N is the speed in RPM, T is the motor torque in Nm, P is the power in KW. The gear ratio used is 8.25:1. The tyres used are of size 215/60 R16 95H.

Parameter	Value
Total Gross Weight	1505 Kg
Top Speed	120 Kmph
Gradeability	34% or $\alpha = 18.77$
Acceleration	0-100 Kmph in 13.5 s
Rolling Radius	0.33m

Table 3.2: Vehicle Dimensions

3.3.5 Battery

The equivalent circuit model for a single Li-ion cell is shown in fig 3.9 The battery pack used in the vehicle has a total of 125 cells connected in series. The open circuit voltage, ohmic resistance are multiplied by the total number of cells and the storage capacitance was divided by the number of cells as were connected in series. The diffusivity capacitance was divided by the total number of cells and the diffusivity resistance was multiplied by total number of cells, resulting in same time constant as that of cells.

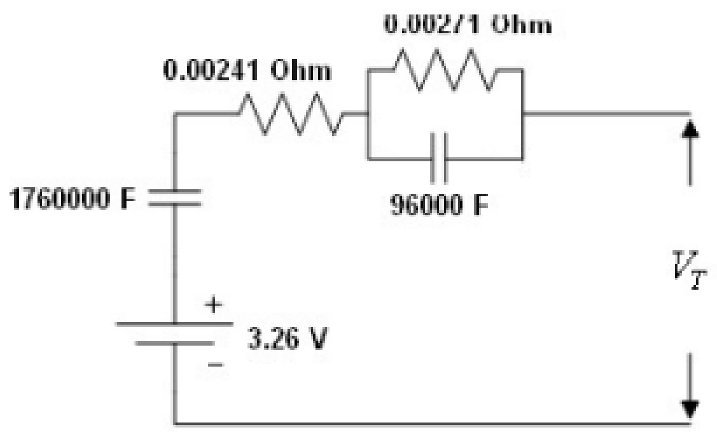

Figure 3.9: Equivalent circuit of Li-ion cell

The SOC of the battery pack is calculated from the initial state of charge (SOCinitial) and the battery current (icalc) using the integral equations where,

SOC(n) = SOC at the nth instant of time (%)
SOC(n-1) = SOC at the n-1th instant of time (%)
i(t) =instantaneous current drawn from the battery (A)
Qt = Ah capacity of the battery pack (Ah)
v(t) = instantaneous voltage of the battery (V)

Initial SOC is given as input and real-time SOC is obtained along with used battery power and regenerative power and a DC link Capacitor of 3000µF is provided to reduce voltage ripple to 5

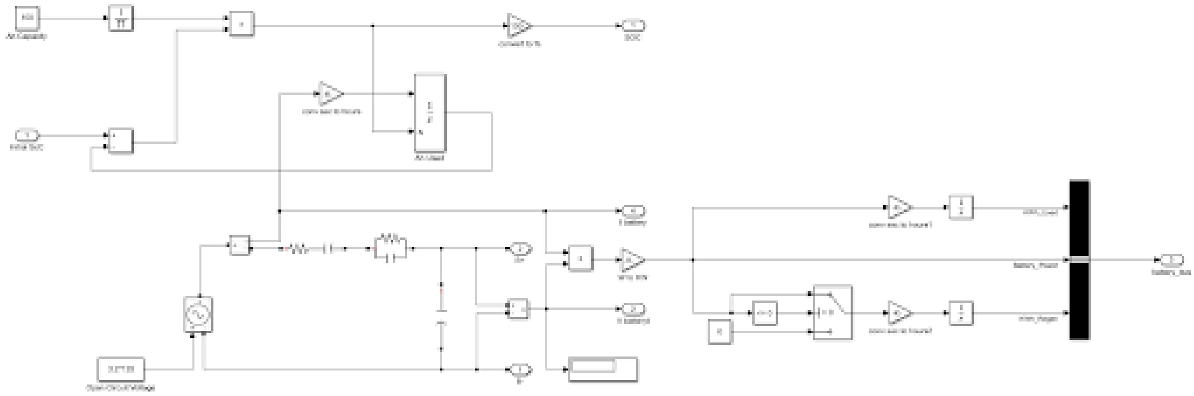

Figure 3.10: Modelled circuit of Battery pack

A 4kW load to comprise for headlights,brake light,vehicle horn, infotainment and air conditioning systems is also modelled as shown below:

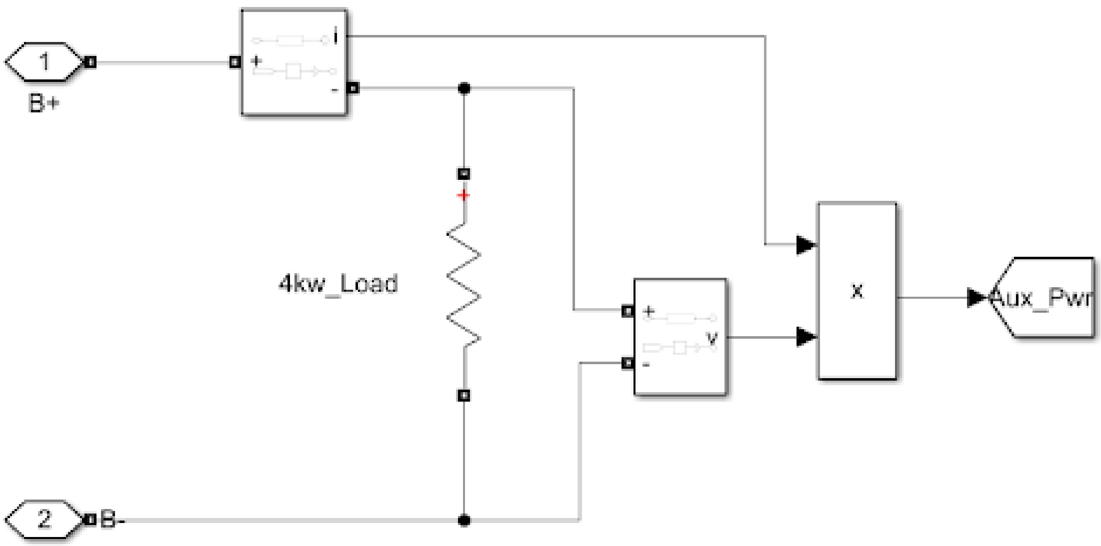

Figure 3.11: Modelled circuit of Auxiliary load

3.4 INTERPRETATION OF DRIVETRAIN SIMULATION

3.4.1 PIL testing

3.4.1.1 Introduction

Processor-in-the-loop (PIL) is a test technique that allows designers to evaluate a controller, running in a dedicated processor, of a plant which runs in an offline simulation platform. PIL is a test process where compiled code that describes a controller runs in an external DSP, FPGA, common processor or microprocessor, and the plant model runs on an offline simulator, both subsystems, controller and plant, are linked by a communication protocol or data exchange port as shown in 3.12

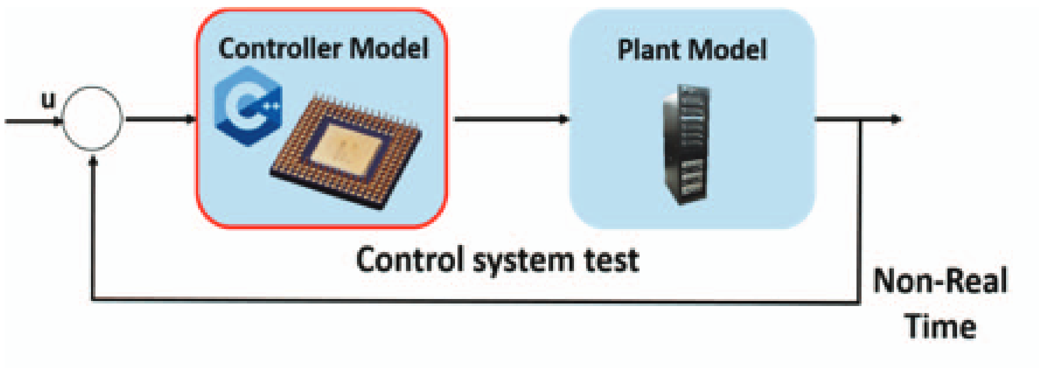

Figure 3.12: Processor-in-loop

Although PIL is typically used to evaluate a controller; nevertheless, it can be useful to test parts of a complex system, where such parts can be embedded in the digital platform (DSP, FPGA, etc.) and the rest of the system can run on the offline simulator.The important thing with PIL is that it allows debugging either the controller or the subsystem under test in order to correct possible errors about its performance.

3.4.1.2 PIL Testing Procedure

PIL is carried out in co-simulation between Simulink-MatLab and the micro-controller. The procedure to implement PIL is as follows:

1. Select the subsystems which will run in the offline simulation platform (Simulink-MatLab); and the subsystem which will run in the micro-controller.

2. Build the subsystem to be offline simulated using Simulink blocks.

3. Build the subsystem to be embedded in the micro-controllerusing functional blocks.

4. Choose a set up for the target hardware : STM32F401RE Nucleo Board.

5. Select a communication mean between Simulink and the FPGA.

6. Download the compiled model of the subsystem to be embedded in the micro-controller and run the PIL simulation.

7. Observe and record the results.

3.4.1.3 PIL Test Implementation

The whole simulation under testing is build in matlab simulink environment. The test is done inorder to validate the control algorithm in the target microcontroller (STM32F401RE Nucleo Board). As the first step, The subsystem block to be run in the hardware is used to build its PIL subsystem using matlab functionalities as shown in 3.13 and 3.14

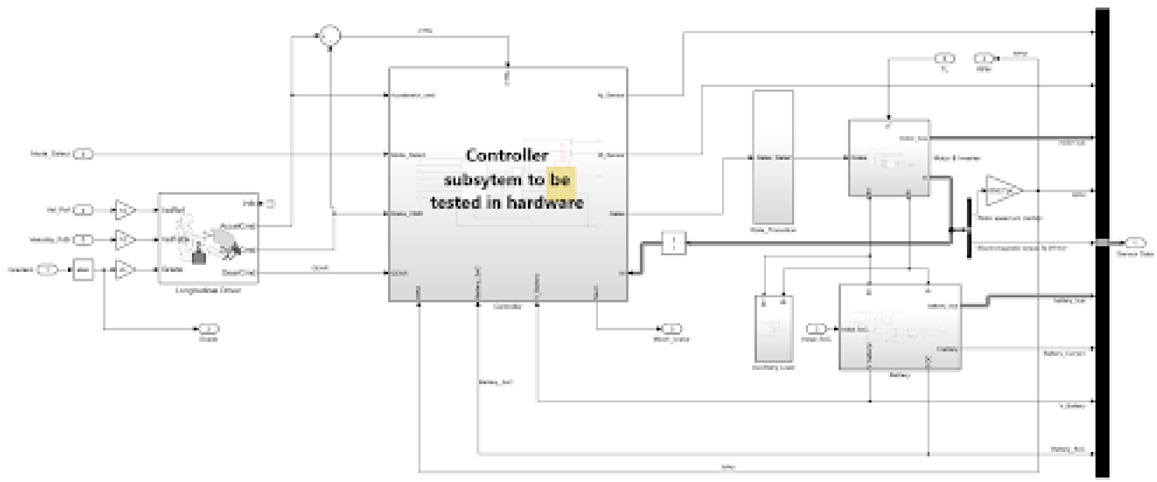

Figure 3.13: Controller subsystem to generate PIL block.

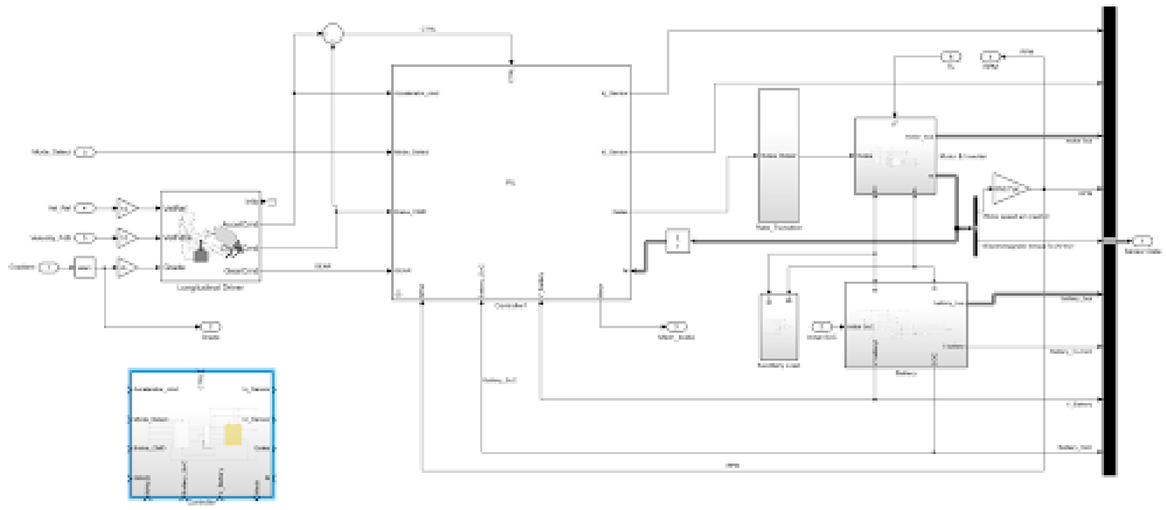

Figure 3.14: Controller subsystem replaced with its PIL Block.

After successful generation of PIL block and linking it to the remaining simulation, the hardware is implemented (The development board is interfaced with the PC) and the simulation is run. The code for the controller is generated in this process and is embedded and run in the harwdare.

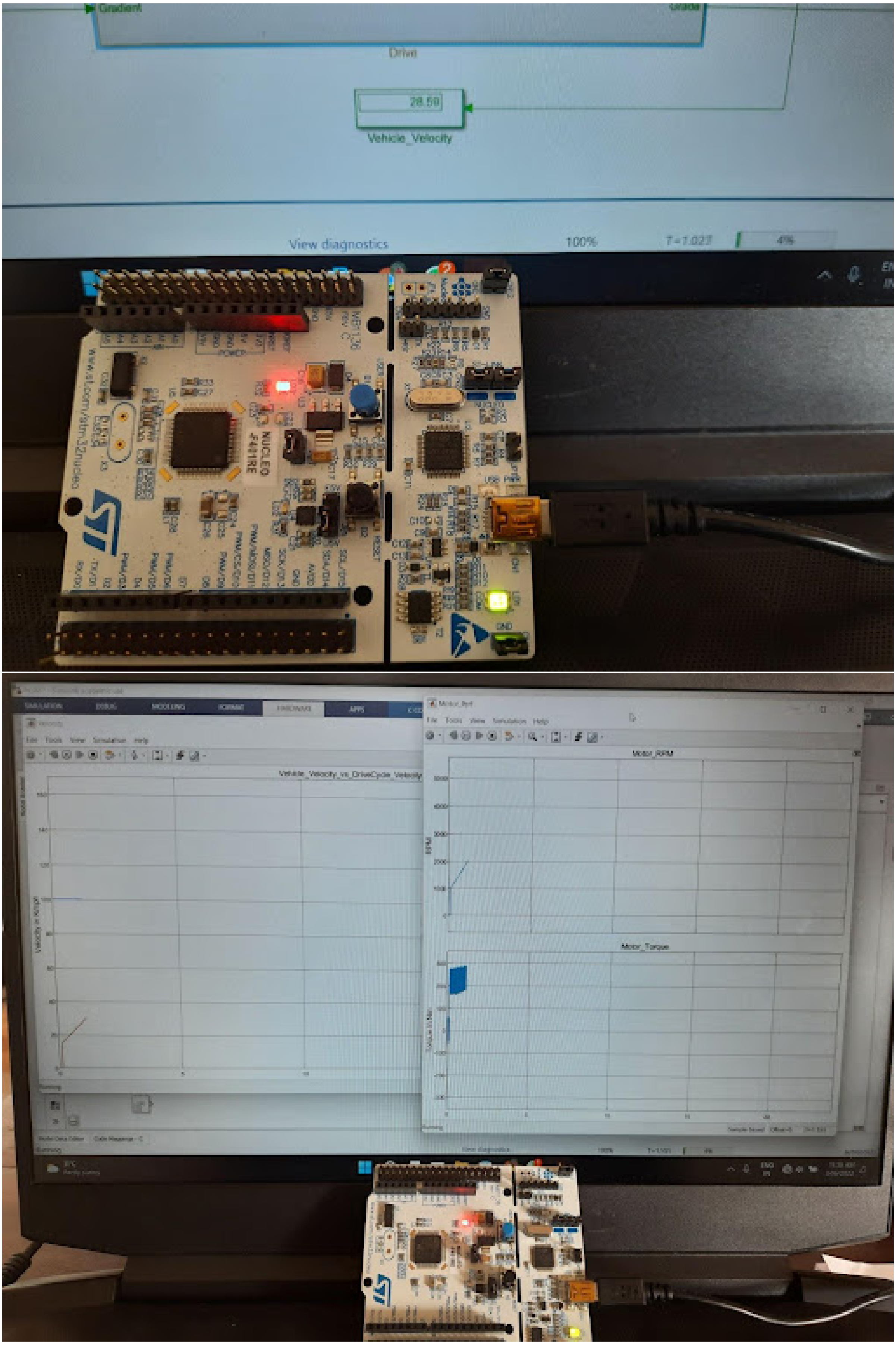

Figure 3.15: Micro-Controller interfaced to the PC

The vehicle velocity and motor rpm are visualized through the scopes and the error when run in a target hardware is analyzed.

3.4.2 HIL Testing

3.4.2.1 Introduction

HIL Testing is a method of testing where real signals from a controller are connected to a test system that simulates reality, tricking the controller into thinking it is in the assembled product. Test and design iteration take place as though the real-world system is being used.An HIL test replaces the engine with a simulation comprising hardware and software that interacts with real I/O as though the physical engine were present. Because updates can be made in software, you can quickly incorporate ECU or engine software changes, test a wide breadth of relevant scenarios, and expand test coverage as needed to fearlessly and comprehensively test without risk to a physical, costly system.For HIL testing to be of value, the quality of the simulation software is of utmost importance. Simulation software must be paired with hardware that not only accounts for system specifications such as connector type and I/O but also allows for fault insertion and the ability to test real-world scenarios.

Hardware-in-the-loop (HIL) simulation is a technique for validating your control algorithm, running on an intended target controller, by creating a virtual real-time environment that represents your physical system to control. HIL helps to test the behavior of your control algorithms without physical prototypes.

HIL simulation is widely used in the automotive, aerospace and defense, and industrial automation and machinery industries to test embedded designs. HIL is also being adopted in medical devices, communications, semiconductors, and other industries.

3.4.2.2 HIL Testing Procedure

1. Select the subsystem that has to be run in the real time simulation platform.(Here LAUNCHXL-F28069M).
2. Create the mathematical model of the subsystem chosen in MATLAB.
3. Choose a set up for the target hardware in MATLAB.
4. Select and configure the communication channels between the Launchpad and the physical subsystems.
5. Deploy the code from MATLAB to the microcontroller board.

6. Download the compiled model of the subsystem to be embedded in the Launchpad and run the HIL simulation.

7. Observe and record the results.

3.4.2.3 HIL Test Implementation

The Motor, Development Board and motor driver are connected along with power supply to the PC as shown in .3.16 The driver module is mounted over the development board.The motor is interfaced to the driver and the development board to the PC.

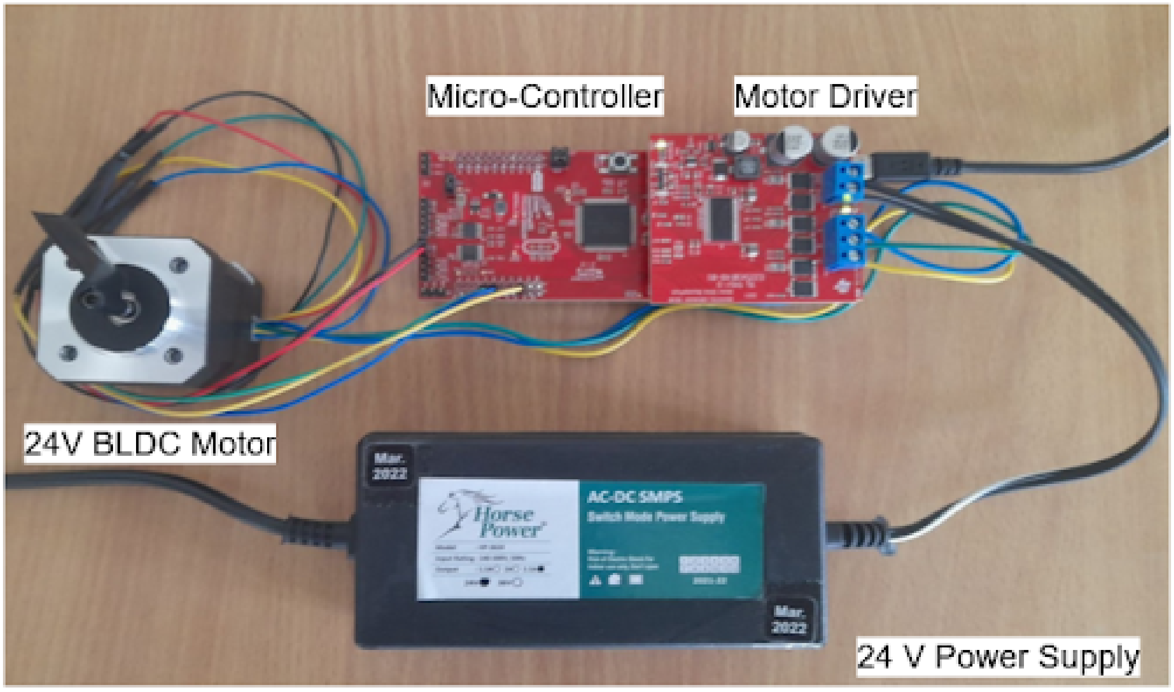

Figure 3.16: HIL Test Setup

The motor parameters are determined using the functionalities available in MATLAB.The FOC control algorithm for the motor is modified and the following HIL simulation environment is developed in MATLAB environment as shown in 3.17

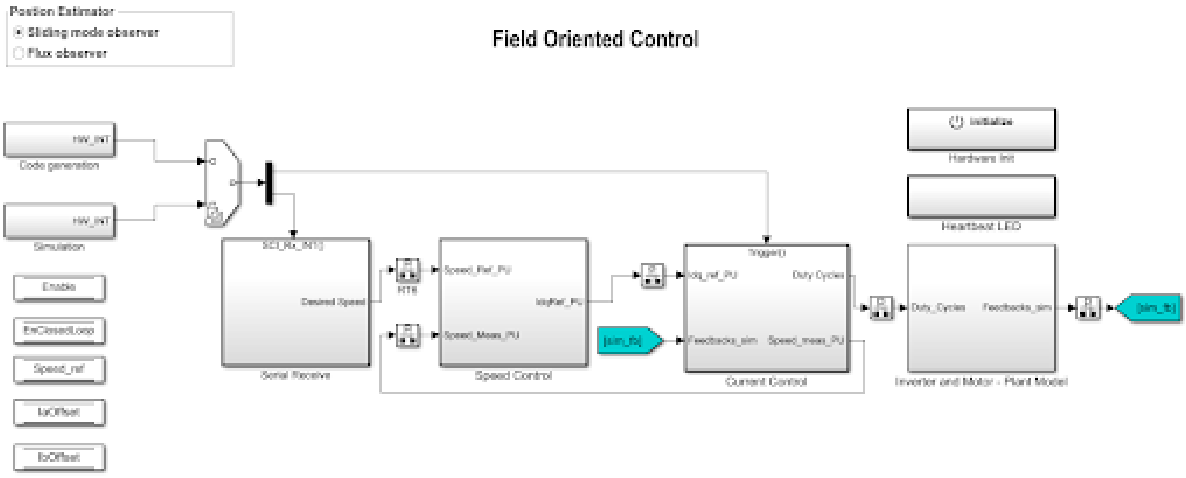

Figure 3.17: FOC algorithm developed in Matlab environment for HIL test

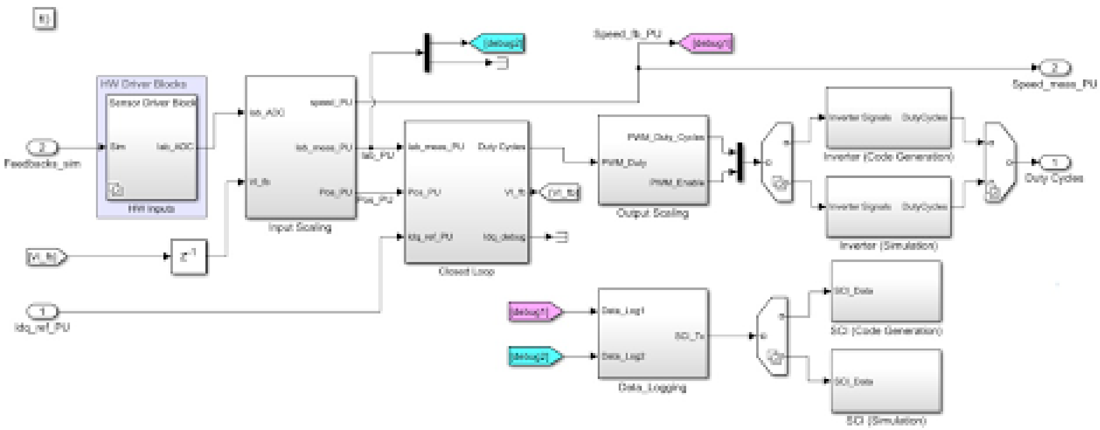

Figure 3.18: Current controller block

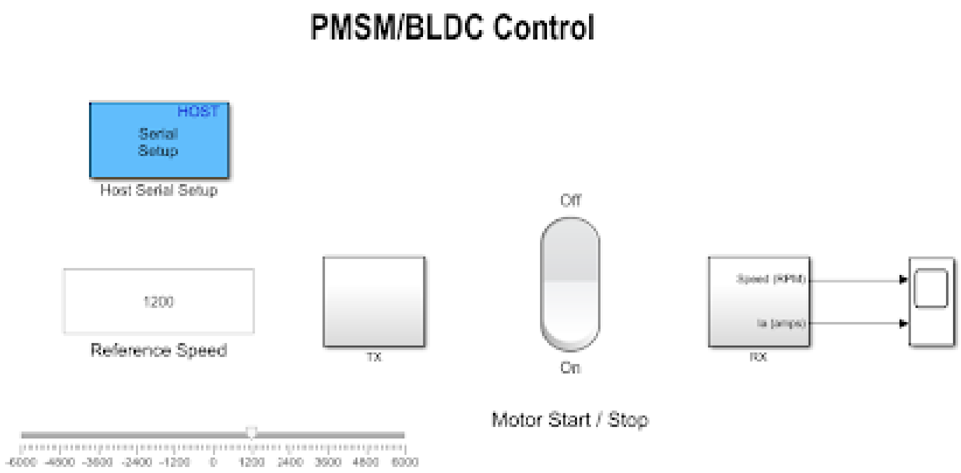

Figure 3.19: Matlab interface to provide reference speed or drive cycle.

After succesful interfacing of hardware to the PC. The code for FOC control is generated and deployed.The control of motor speed in realtime is then visualised.

CHAPTER 4

RESULTS

[Introduction]INTRODUCTION The powertrain model has been tested in native simulink, PIL and in HIL simulations. The model has been observed to follow the drivecycle minute error and has achieved as well as overcame the target benchmark performance.

4.1 SIMULATION RESULTS

Analysing the simulation results ,we can find that the vehicle velocity chases the input WLTP Drive cycle with a minimal error of 0.33% as shown in .4.1. The range of the vehicle is thereby calculated and found to be 175 km approximately, which aligns with the present day electric vehicle range.

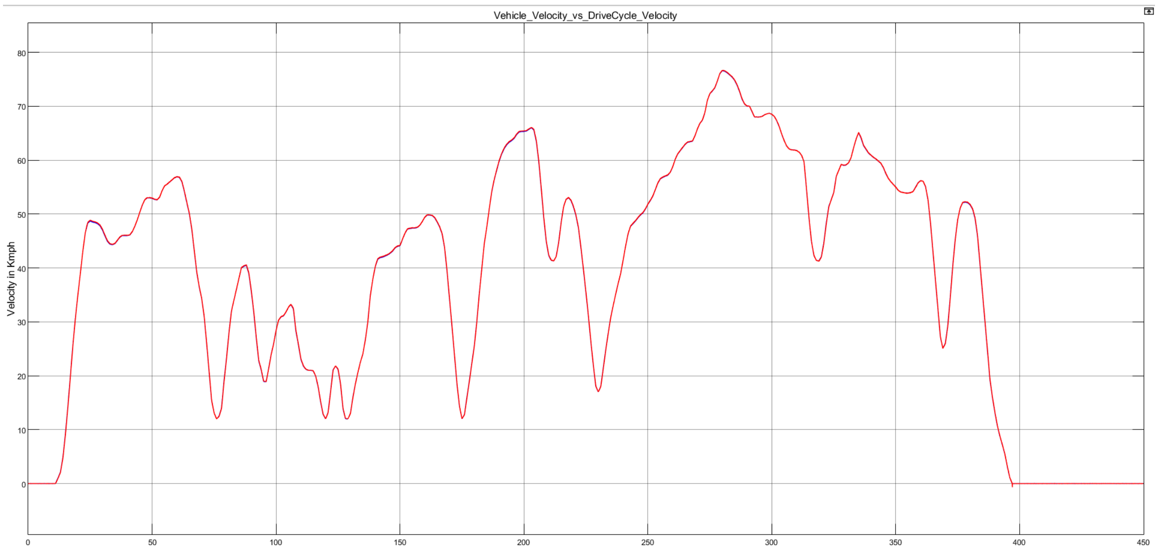

Figure 4.1: Drive Cycle Result for WLTP Medium Phase

WLTP drive cycle distance = 23.262 km
SoC Consumption = 90% -76.98% =13.02% per drive cycle
Vehicle Range = 178.66 km.
So,Approximate Vehicle Range =175 km.

The simulation results are compared with the benchmarks and is found to have achieved the set targets as shown in table 4.1.

Parameter	**Target in Drive Mode**	**Achieved**	**Target in Sports Mode**	**Achieved**
Acceleration from 0 to 100 Kmph	16.4s	13s	9.3s	9s
Top Speed	120 Kmph	120 Kmph	120 Kmph	170 Kmph
Over Taking from 20 to 80 Kmph	8.33s	6s	5.11s	5s
Maximum Gradeability	34%	35%	34%	46%
Braking Distance from 100 to 0 Kmph	41.66m	41.66m	42.6m	41.66m

Table 4.1: Simulation Performance

4.2 PIL RESULTS

The normal simulation is considered as baseline benchmark and the PIL simulation is compared with it to analyse any deviation or error. Both vehicle velocity and motor rpm are considered for this test.

RPM (Run 1: m_02 (SIL/PIL))

	BASELINE	COMPARE TO
Name	RPM (Run 1: m_02 (SIL/PIL))	RPM (Run 2: m_02)
Result	✓	--
Max Difference	0.000	--
Line		
Override Global Tolerance	no	no
Absolute Tolerance	0	0
Relative Tolerance	0.00%	0.00%
Time Tolerance	0	0
Units		
Data Type	double	double
Sample Time	3.57143e-05	3.57143e-05
Run	Run 1: m_02 (SIL/PIL)	Run 2: m_02
Align By	Path	Path
Model	m_02	m_02
Block Name	Gain	Gain
Block Path	m_02/Drive/Gain	m_02/Drive/Gain
Port	1	1
Dimensions	[1]	[1]
Channel		
Interp Method	zoh	zoh
Sync Method	union	union
Time Series Root		
Time Source		
Data Source		

Figure 4.2: Motor rpm compared in normal simulation and PIL simulation

The PIL test concludes that the target hardware chosen is suitable for running the control algorithm and the control strategy works as expected. The analyses shows zero error between the desired and actual values of respective parameters which implies that the algorithm works in realtime in a controller without any delay or problem that may accompany.

4.3 HIL RESULTS

Speed of the motor is controlled using the control algorithm.The 4.4 shows the acceleration of motor when we increase the speed using the slider in the Matlab environment; the deceleration of motor is shown in 4.5 The variation of phase current is also shown in both cases of acceleration and deceleration.

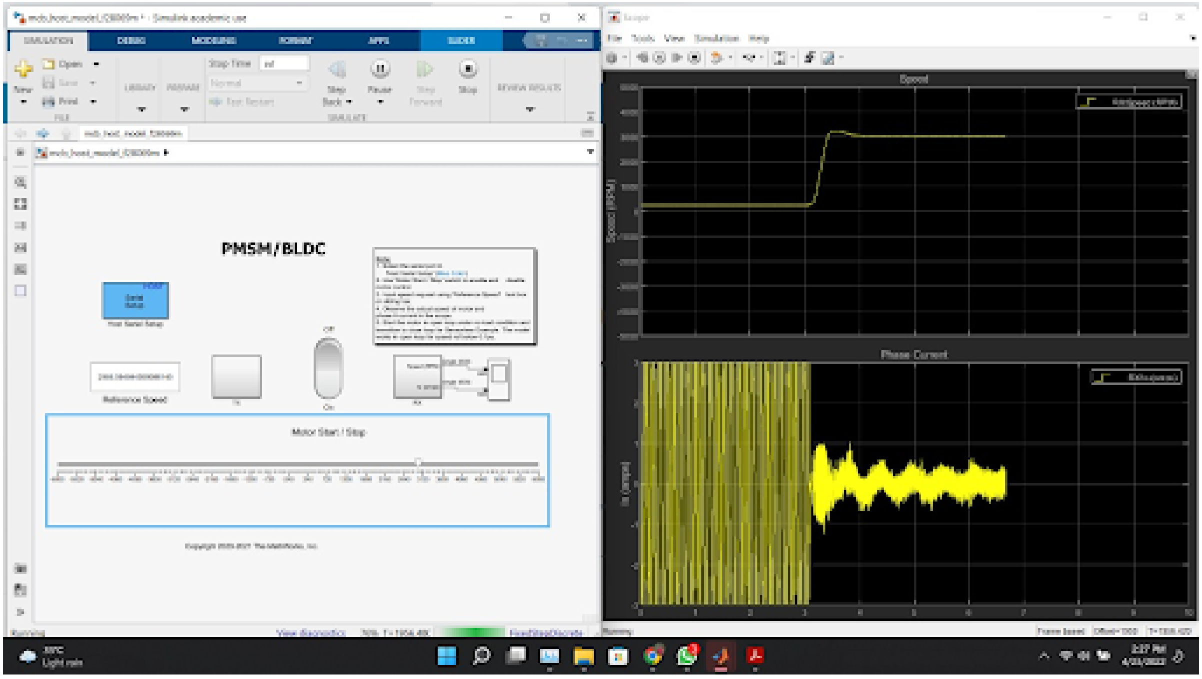

Figure 4.3: Acceleration of Motor

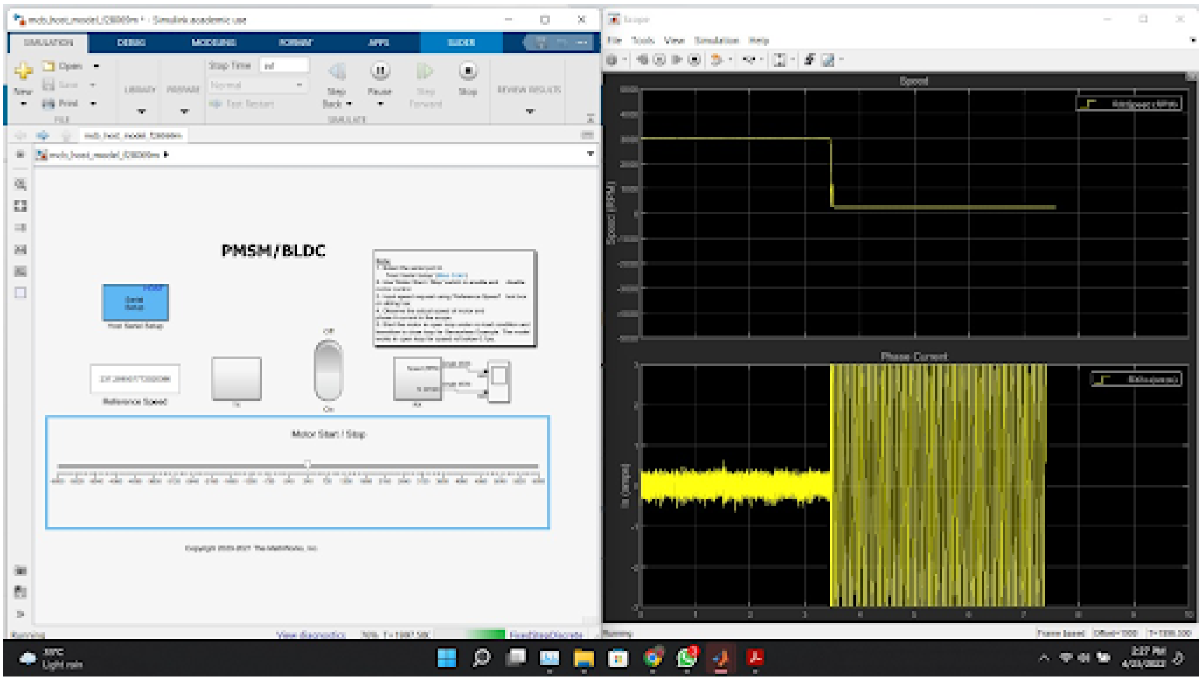

Figure 4.4: Deceleration of Motor

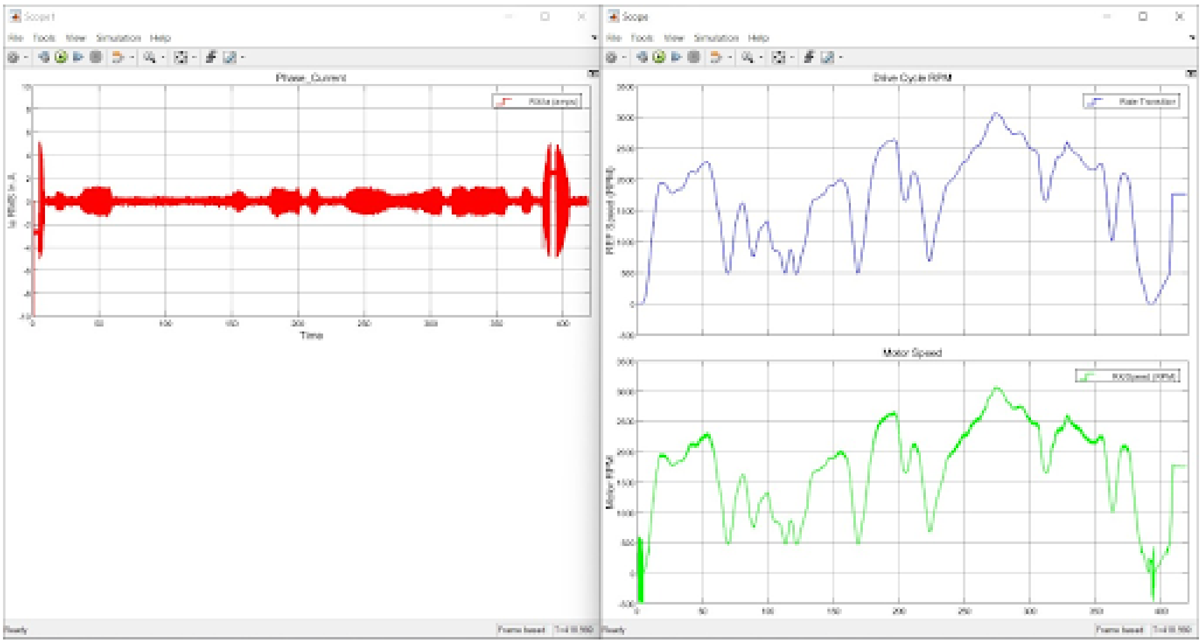

Figure 4.5: Drive-cycle test run

CHAPTER 5

CONCLUSION

Electric vehicles will replace conventional vehicles in the near future. The field marks good progress in research over the past years. Newer control strategies, e-machines and automotive tests are conceptualized and experimented. Currently Permanent Magnet Synchronous Motor and Field Oriented Control are of wide usage in the electric vehicle industry for its high efficiency. Designing a power train by considering the parameters of components and control strategy in a simulink environment has shown results and gave insights into the range of a vehicle, which is of prime importance. The speed and torque tracking of the vehicle to the input drive cycle has shown that the control algorithm works efficiently with a minimal error of 0.03% between the demanded speed and vehicle velocity. Novel tests such as Processor in loop test gave insights into the realtime working of the control strategy in a target hardware implying that the algorithm works with no delay or issues that could occur in the selected hardware under test. A widely used automotive test to check for control strategy accuracy is Hardware in Loop test. The successful study and implementation of real time Motor Speed control using the hardware interfaced with the Matlab environment showed the efficiency of the control algorithm devised.

REFERENCES

[1] Jose Jacob ,Chitra A, "Field Oriented Control of Space Vector Modulated Multi-level Inverter fed PMSM Drive," ***ELSEVIER***, 2017

[2] Carlos Miguel-Espinar ,Daniel Heredero-Peris ,Gabriel Gross, "Maximum Torque per Voltage Flux -Weakening strategy with speed limiter for PMSM drives," ***IEEE Transactions On Industrial Electronics***, 2020

[3] Wei Wang, Zhixiang Lu, Wei Hua, "A Hybrid Dual Mode Control for Permanent Magnet Synchronous motor Drives", ***IEEE Access***, 2020

[4] Ram N. Hajare ,Archana G Thosar , "Modelling and Simulation of Permanent Magnet Synchronous Motor using MATLAB" , ***International Journal of Electrical Engineering***, 2014

[5] Carlos Miguel-Espinar, Daniel Heredero-Peris, "Maximum Torque per Voltage Flux-Weakening strategy with speed limiter for PMSM drives," ***IEEE Transactions On Industrial Electronics*** , 2020