Regenerative Braking in an Electric Vehicle

Efficiency, Stability and Controls.

Under the Guidance of:

Professor Karl Izsak

Submitted by:

Mohammad Taha Siddiqui

11012463

SRH Hochschule Heidelberg

Table of Contents

Abstract

Regenerative braking is not by itself sufficient as the sole means of safely bringing a vehicle to a standstill, or slowing it as required, so it must be used in conjunction with another braking system such as friction -based braking.

The regenerative braking effect drops off at lower speeds, and cannot bring a vehicle to a complete halt reasonably quickly with current technology, although some cars can bring the vehicle to a complete stop on even surfaces when the driver knows the vehicle's regenerative braking distance. This is referred to as One Pedal Driving.

Current regenerative brakes do not immobilize a stationary vehicle; physical locking is required, for example to prevent vehicles from rolling down hills.

Many road vehicles with regenerative braking do not have driver motors on all wheels (as in a two-wheeled drive car); regenerative braking is normally only applicable to wheels with motors. For safety, the ability to brake all wheels is required.

The regenerative braking effect available is limited, and mechanical braking is still necessary for substantial speed reductions, to bring a vehicle to a stop, or to hold a vehicle at a standstill.

Regenerative and friction braking must both be used, creating the need to control them to produce the required total braking. The GM EV-1 was the first commercial car to do this. In 1997 and 1998 engineers Abraham Farag and Loren Majersik were issued two patents for this *brake-by-wire* technology. [7]

Introduction

The brake system in a traditional combustion engine is based on hydraulic braking technology. However, this technology has various downsides - mainly a large waste of energy. [8] A moving car has an immense amount of kinetic energy. When the driver steps on the brakes, there is a lot of energy conversion going on. The kinetic energy of the car turns into heat energy as the car slows down. Because cars are so heavy, large amounts of heat energy is produced. Since the produced heat energy is not captured in a hydraulic braking system, there is a large amount of wasted energy that could be used for other vehicle related tasks. On top of this, the heat causes the brakes of the car to wear down and become weaker and weaker.[10]

The use of regenerative braking systems in electric vehicles has been able to overcome many of the disadvantages of the traditional hydraulics braking system. In urban settings, regenerative braking recycles about half of the total brake energy. There are various other positives about the technology. [9] In fact, the benefits are becoming more and more beneficial to society that cars like the one in Fig. 1 are becoming more and more popular on the road

Regenerative braking is an energy recovery mechanism that slows down a moving vehicle or object by converting its kinetic energy into a form that can be either used immediately or stored until needed. In this mechanism, the electric traction Motor uses the vehicle's momentum to recover energy that would otherwise be lost to the brake discs as heat. This contrasts with conventional braking systems, where the excess kinetic energy is converted to unwanted and wasted heat due to friction in the brakes, or with dynamic brakes, where the energy is recovered by using electric motors as generators but is immediately dissipated as heat in resistors. In addition to improving the overall efficiency of the vehicle, regeneration can significantly extend the life of the braking system as the mechanical parts will not wear out very quickly.

In this paper, we will be looking at the efficiency, stability controls and general controls of an electric vehicle with regenerative braking in place. We will also be looking at a simulation model of such a car in a MATLAB/Simulink environment to calculate the efficiency and stability data by varying other physical factors of the car like dimension, wheel radius etc that need to be considered in such an electric vehicle.

The Simscape Library is extensively used to build this simulation model. Most blocks present in this paper are from the Simscape Library available on MATLAB/Simulink 2020a trial version (student version).

1. Stability and Control

1.1 Introduction

In a series regenerative braking system, regenerative braking is generally used to the maximum extent prior to the introduction of friction braking. During the regenerative braking phase, this generally means that the front to rear braking distribution will be less than ideal since it is often only possible to apply braking torque to a single axle. This can have significant implications for vehicle handling and stability during cornering, particularly if the axle concerned is the rear axle. The first part of this paper considers the impact on vehicle stability of applying regenerative braking through the rear axle of a sports utility vehicle. It is shown that, on low mu surfaces in particular, a moderately sized electric motor has the capability to significantly compromise vehicle stability during cornering. The second part of the paper then considers how this issue may be resolved. Various solutions are considered and it is shown that redistributing the regenerative braking torque using active driveline devices allows vehicle stability to be protected whilst maintaining maximum energy recovery

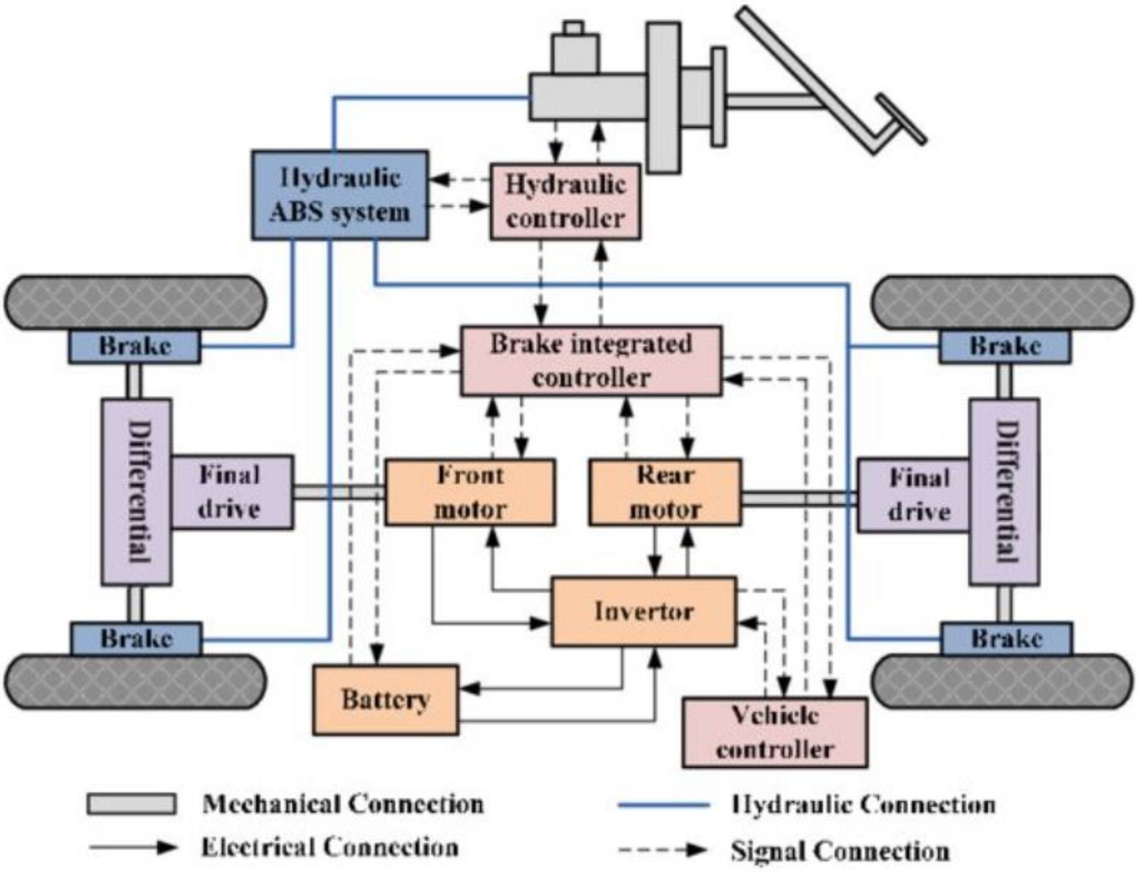


Fig. 1 The RBS Configuration of an FWD Electric Vehicle [1]

1.2 Battery Electric Vehicles (BEVs)

Figure 2 depicts a schematic of a battery-powered electric vehicle (BEV). BEVs use one or more electric motors for propulsion and batteries to store electricity. The batteries store energy to power all of the electrical systems in the car. The batteries can recharge from grid electricity at recharging stations, house outlets, non-grid sources such as solar panels, or by using onboard recuperative energy systems. BEVs can potentially emit zero greenhouse gases and air pollutants; however, the type of electricity generation (solar, wind, coal, etc.) determines the well-to-wheel emission. Nevertheless, even if the electricity that charges the batteries comes from a CO2 emitting source such as a coal-powered plant, the amount of CO2 emitted from a BEV is about one-half to one-third less than what a gasoline-powered vehicle emits.

Additionally, electric vehicles have a “tank-to-wheels” efficiency that is three times greater than that of a gasoline vehicle.

In addition to the environmental benefits, there are other advantages of using electric vehicles compared to conventional ICE vehicles. Electric vehicles can deliver at least 75% energy efficiency, while internal combustion engines can be as low as 15% [1]. Also, it is more cost-effective to maintain an electric vehicle because there are less mechanical or emission control components. For example, BEVs do not have a muffler, catalytic converter, tailpipe, and gas tank. Likewise, the clutch assembly and the transmission system are usually replaced with the electric motor drive system to control the torque of the motor. The main components of the drive system of an electric vehicle are an accelerator pedal, an electric motor drive/ controller, batteries, and traction electric motors.

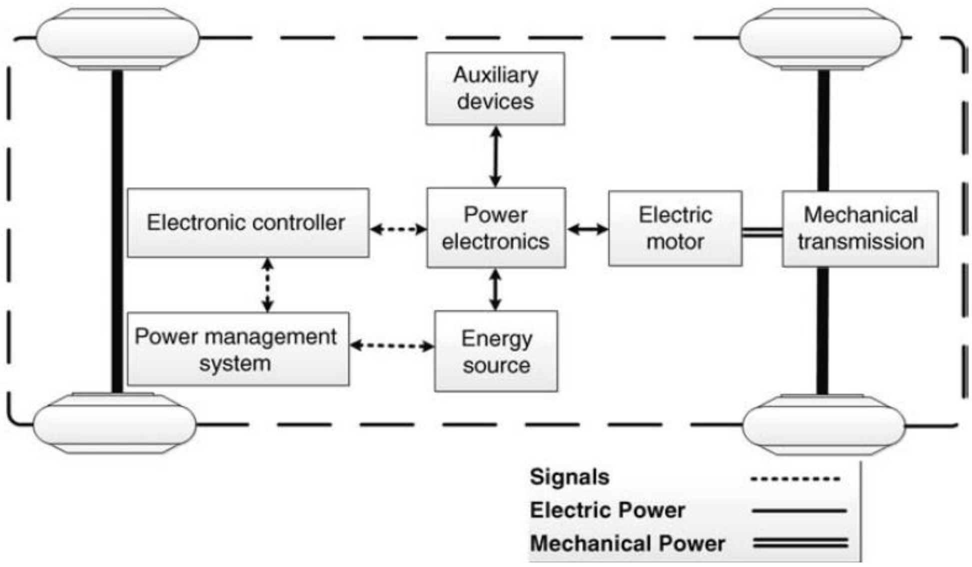


Fig. 2 Schematic of a BEV Powertrain [2]

1.3 Electric Traction Motors

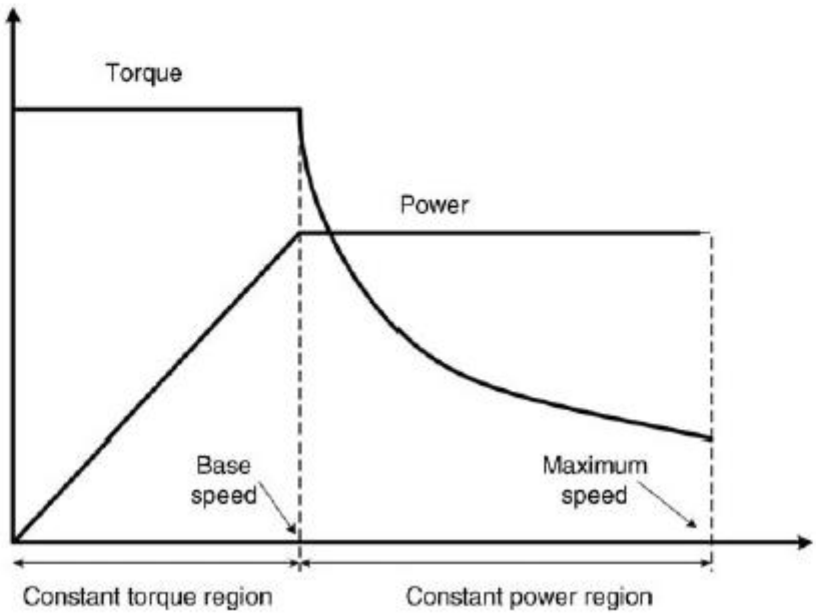
Electric motors convert the electrical energy from energy sources into mechanical energy in order to provide the required traction force for the vehicle motion. The electric motors of a BEV must satisfy a wide range of driving requirements, such as frequent starting and stopping, high rate of acceleration/deceleration, low-torque high-speed cruising, high-torque low-speed hill climbing, and moving the vehicle from a standstill. The type, size, weight, and performance of an electric motor in a BEV depend on the overall powertrain specifications. These specifications include single or multiple-motor configuration, fixed or variable transmission, and whether the motor is geared or gearless. However, the primary requirements and specifications associated with the proper selection of electric motors for a BEV are as follows:

- to provide sufficient maximum torque, typically four or five times that of the rated torque for
- temporary acceleration and hill-climbing;
- to provide high efficiency over wide speed and torque ranges for the reduction of total
- vehicle weight and the extension of driving range;

- to provide high controllability, high steady-state accuracy, and good dynamic performance;

- to provide sufficient robustness against high temperature, bad weather, and frequent
- vibration;

- to provide high efficiency for regenerative braking.



Graph 1. Traction Motor Characteristics [3]

1.4 DC Motors

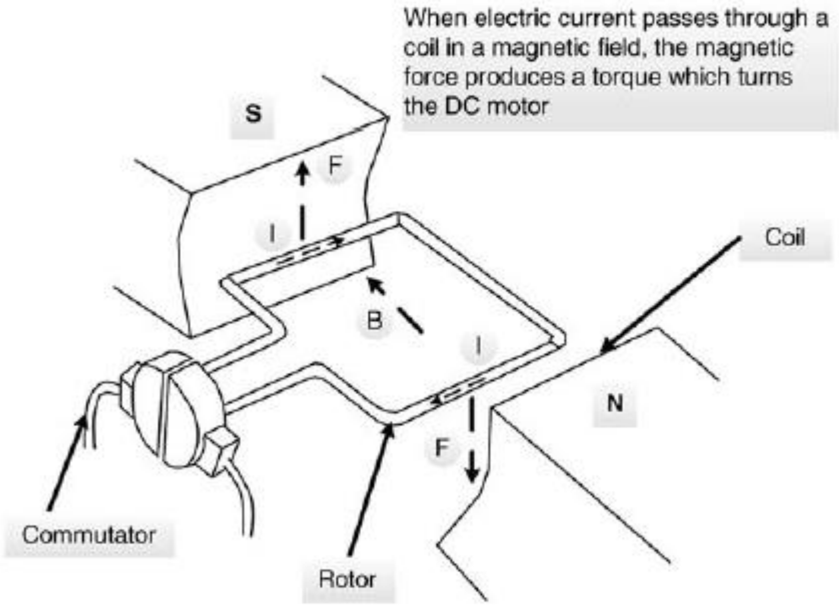


Fig 3. Schematic of a brushed DC Motor [4]

Typically, DC motors have a set of coils (field), a rotor (armature), a commutator, and an optional brush. In DC motors, the set of coils generates magnetic forces that provide the torque. The rotor is mounted on bearings and turns inside a magnetic field.

The commutator acts like a switch to supply voltage to a revolving armature from the stationary brush assembly and makes the rotor turn, thereby providing the mechanical power. Brushes make contact with the commutator to make the connections. DC motors provide the sufficient traction requirement because of their torque-speed characteristics. Also, they have a simple speed control system which lowers the cost of the DC motor/controller combination. The best use of these motors is for short bursts of acceleration.

However, they suffer from being heavy, low efficiency, low reliability, and high maintenance. This is because the brush contact results in wear and tear, which requires periodic brush replacement. The DC motor/controller system is still popular today because it keeps the cost down on some electric vehicles.

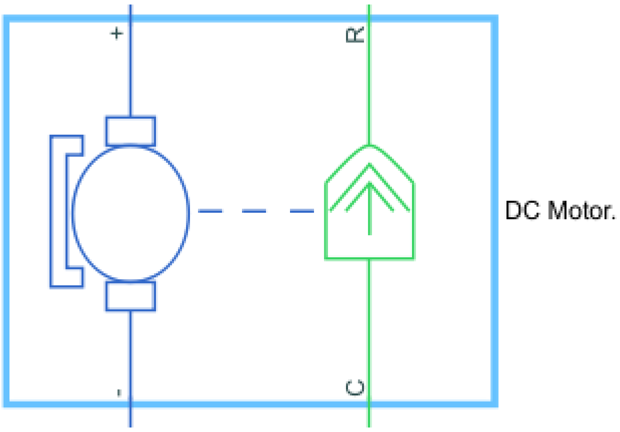


Fig 4. Typical DC Motor used for simulation in the Simulink Model

This block represents the electrical and torque characteristics of a DC motor.

The block assumes that no electromagnetic energy is lost, and hence the back-emf and torque constants have the same numerical value when in SI units. Motor parameters can either be specified directly, or derived from no-load speed and stall torque. If no information is available on armature inductance, this parameter can be set to some small non-zero value.

When a positive current flows from the electrical + to - ports, a positive torque acts from the mechanical C to R ports. Motor torque direction can be changed by altering the sign of the back-emf or torque constants.

No load Speed: 800rpm

Rated Speed: 500 rpm

Rated DC Supply Voltage: 300 V

Rotor inertia: 0.01 g.cm^2

The connections include the positive and negative of the electrical shaft going to the H-Bridge, about which we will discuss later in this paper.

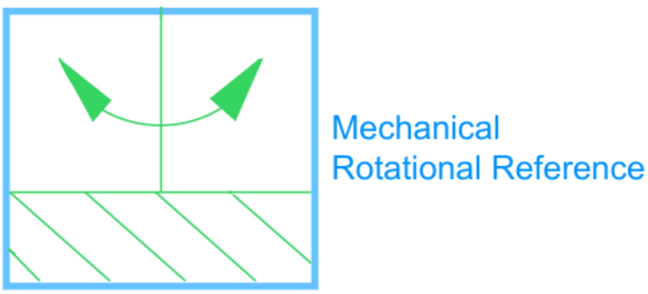


Fig 5. Mechanical Rotational Reference (Casing).

The mechanical part is coupled with a Casing at the negative end which works as a mechanical rotational reference. This part remains steady and the rotor will rotate with reference to it.

2 Working of the Simulink Model

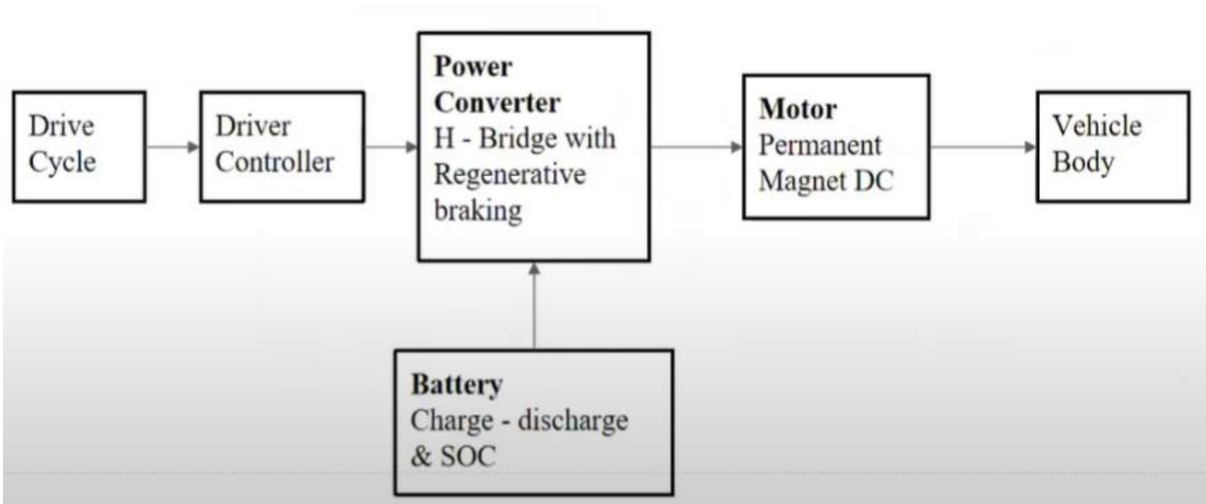


Fig. 6 Block Diagram of the Simulink model

The model consists of six blocks out of which, five have been implemented in Simulink. The running blocks include :

- Drive Cycle
- Driver Controller
- Power Converter
- Motor
- Vehicle Body
- Battery

The calculation of efficiency using the state of charge meter could not be implemented.

We can calculate the actual speed of the vehicle and over a period of time and compare it with the drive cycle simulations.

Also, The State of Charge can be observed to take down the effects of regenerative braking by the addition of an SOC block to the battery of this model.

3 Complete Simulink Model Schematics

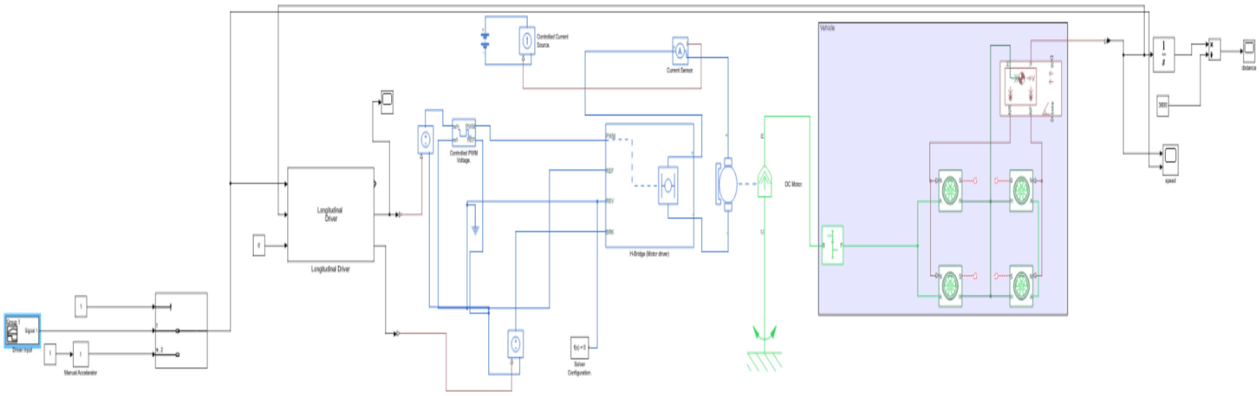


Fig 7. Simulink Model of a vehicle with regenerative braking

The figure given above shows the simulation model constructed to show the working of a vehicle with regenerative braking. The different parts of this simulation model will be discussed below.

3.1 Vehicle Body

Represents a two-axle vehicle body in longitudinal motion. The block accounts for body mass, aerodynamic drag, road incline, and weight distribution between axles due to acceleration and road profile. The vehicle can have the same or a different number of wheels on each axle. Optionally include pitch and suspension dynamics or additional variable mass and inertia. The vehicle does not move vertically relative to the ground.

Connection H is the mechanical translational conserving port associated with the horizontal motion of the vehicle body. The resulting traction motion developed by tires should be connected to this port. Connections V, NF, and NR are physical signal output ports for vehicle velocity and front and rear normal wheel forces, respectively. Wheel forces are considered positive if acting downwards. Connections W and beta are physical signal input ports corresponding to headwind speed and road inclination angle, respectively. If variable mass is modelled, the physical signal input ports CG and M are exposed. CG accepts a two- element vector representing the x and y distance offsets from vehicle CG to additional load mass CG. M represents the additional mass. If both variable mass and pitch dynamics are included, the physical signal port J accepts the inertia of the additional mass about its own CG.

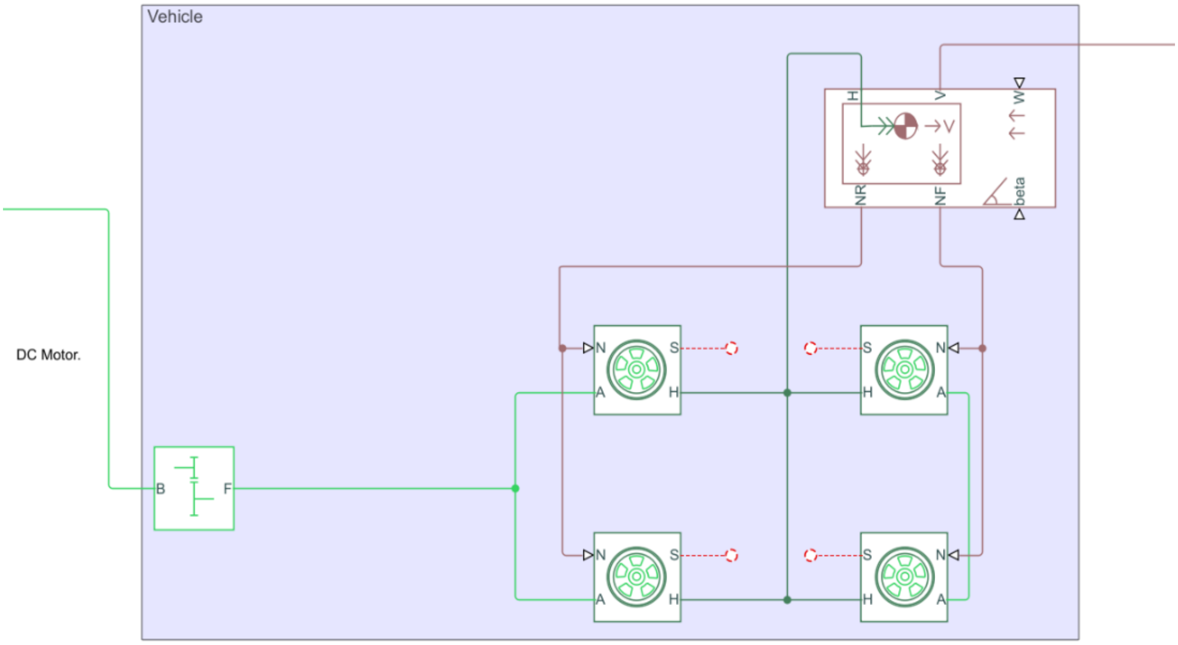
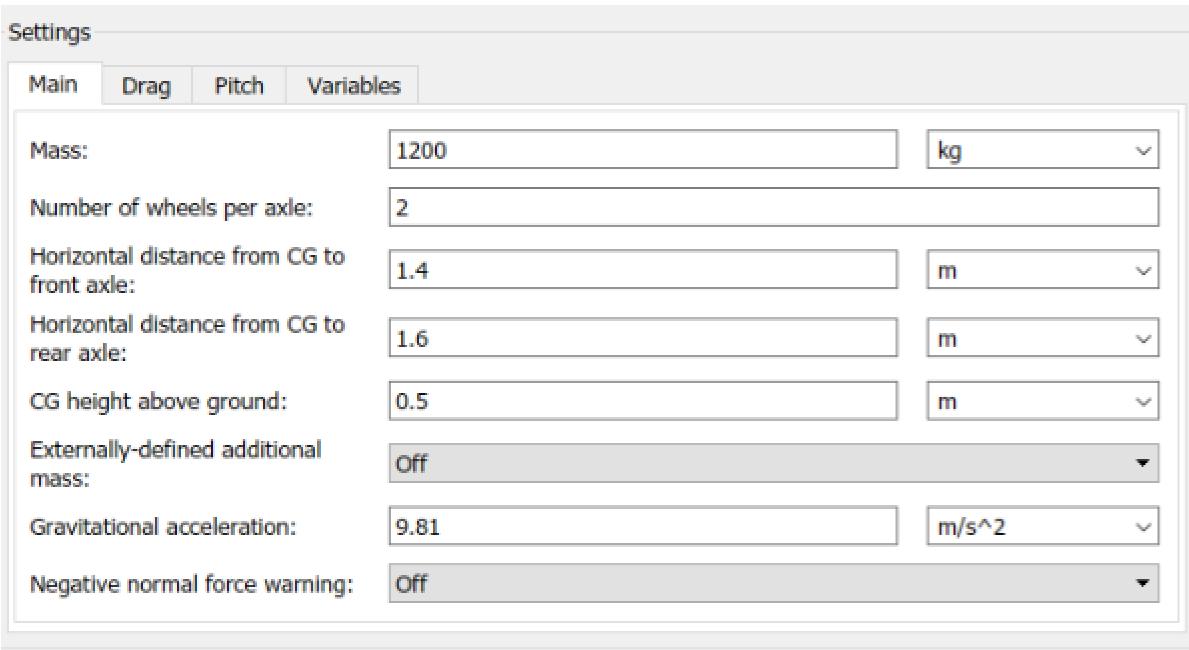


Fig 8. Snippet of the vehicle body in the Simulink Model

The vehicle body is given real time parameters neglecting the inclination angle of the vehicle as well as the air drag. Other variables like the surface slip and inertia have also been ignored in this simulation. The input parameters are as follows:



Settings

Main | Drag | Pitch | Variables

Mass:	1200	kg
Number of wheels per axle:	2	
Horizontal distance from CG to front axle:	1.4	m
Horizontal distance from CG to rear axle:	1.6	m
CG height above ground:	0.5	m
Externally-defined additional mass:	Off	
Gravitational acceleration:	9.81	m/s^2
Negative normal force warning:	Off	

Table 1. Vehicle body input parameters

3.2 Tire (Magic Formula)

It represents the longitudinal behavior of a highway tire characterized by the tire Magic Formula. The block is built from Tire-Road Interaction (Magic Formula) and Simscape Foundation Library Wheel and Axle blocks. Optionally, the effects of tire inertia, stiffness, and damping can be included.

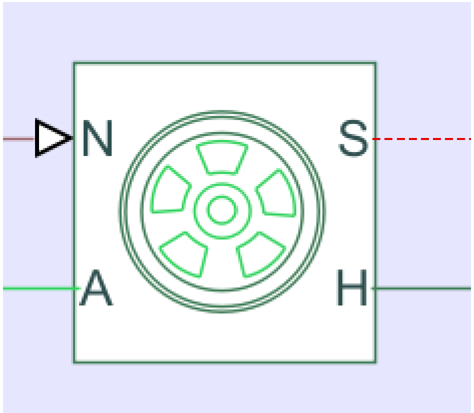


Fig 9. Tire from Simscape Foundation Library Wheel and Axle Block

Connection A is the mechanical rotational conserving port for the wheel axle. Connection H is the mechanical translational conserving port for the wheel hub through which the thrust developed by the tire is applied to the vehicle. Connection N is a physical signal input port that applies the normal force acting on the tire. The force is considered positive if it acts downwards. Connection S is a physical signal output port that reports the tire slip. Optionally expose physical signal port M by setting Parameterize by to Physical signal Magic Formula coefficients. Physical signal port M accepts a four element vector corresponding to the B, C, D, and E Magic Formula coefficients.

The radius of the tire is taken to be 0.3 metres in this simulation and the Rated vertical load is 3000N with the longitudinal force being 3500 N at the rated load.

3.3 H-Bridge (Motor Driver)

This block represents an H-bridge motor drive. The block can be driven by the Controlled PWM Voltage block in PWM or Averaged mode. In PWM mode, the motor is powered if the PWM port voltage is above the Enable threshold voltage. In Averaged mode, the PWM port voltage divided by the PWM signal amplitude parameter defines the ratio of the on-time to the PWM period. Using this ratio and assumptions about the load, the block applies an average voltage to the load that achieves the correct average load current. The Simulation mode parameter value must be the same for the Controlled PWM Voltage and H-Bridge blocks.

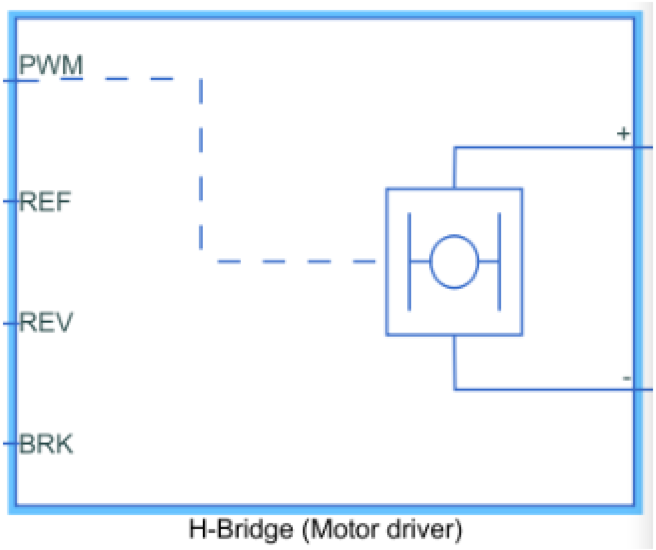


Fig 10. Motor Driver

If the REV port voltage is greater than the Reverse threshold voltage, then the output voltage polarity is reversed. If the BRK port voltage is greater than the Braking threshold voltage, then the output terminals are short circuited via one bridge arm in series with the parallel combination of a second bridge arm and a freewheeling diode. Voltages at ports PWM, REV and BRK are defined relative to the REF port.

If exposing the power supply connections, the block only supports PWM mode. The input threshold values are predefined to the following values.

Settings

Simulation Mode & Load Assumptions | Input Thresholds | Bridge Parameters

Enable threshold voltage:	2.5	V
PWM signal amplitude:	5.0	V
Reverse threshold voltage:	2.5	V
Braking threshold voltage:	2.5	V

Table 2. Input Threshold Voltages of Motor Driver

The output voltage is set to 300 Volts in the simulation. It is kept the same as the supply voltage from the battery.

3.4 Controlled PWM Voltage

This block creates a Pulse-Width Modulated (PWM) voltage across the PWM and REF ports. The output voltage is zero when the pulse is low, and is equal to the Output voltage amplitude parameter when high. Duty cycle is set by the input value.

At time zero, the pulse is initialized as high unless the duty cycle is set to zero or the Pulse delay time is greater than zero.

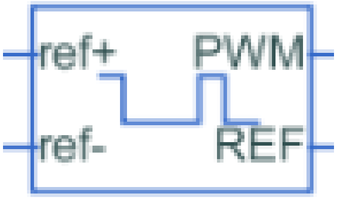


Fig 11. Controlled PWM Voltage Block from Simscape Library

The Simulation mode can be set to PWM or Averaged. In PWM mode, the output is a PWM signal. In Averaged mode, the output is constant with value equal to the averaged PWM signal.

The PWM frequency is set to 1000 Hz for this simulation on average mode as it takes a longer simulation time on the PWM mode.

3.5 Longitudinal Driver

A parametric longitudinal speed tracking controller for generating normalized acceleration and braking commands based on reference and feedback velocities.

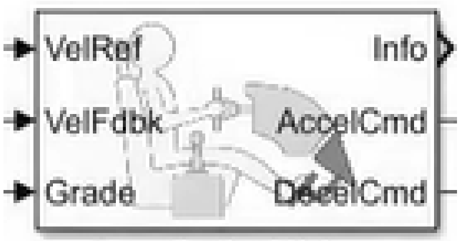


Fig 12. Longitudinal Driver Block from the Simscape Library [5]

We can use the external actions to input signals that can disable, hold, or override the closed-loop commands determined by the block. The block uses this priority for the input commands: disable, hold, override.

Here the reference speed is give to VelRef and the actual speed to VelFdbk. The longitudinal Driver will compare these velocities and decide which command to give to the voltage source.

It primarily performs the following logical functions:

- If VelRef > VelFdbk, The driver will accelerate.
- If VelRef < VelFdbk, The driver will press the brake.

The Control type is PI with the following Gain values:

- Proportional Gain Kp: 10
- Integral Gain Ki: 5

Working PI Equation:

$$y = K_{ff_v} nom\, v_{ref} + K_{p} e_{ref_v} nom + \text{Integral of } (K_{i} e_{ref_v} nom + K_{aw} e_{out}) dt + K_{g}\theta$$

4 Efficiency of the Electric Vehicle

An electric vehicle is controlled to conform its operation to that of a conventional internal-combustion-engine powered vehicle. In some embodiments, the charging of the batteries by the auxiliary source of electricity and from dynamic braking is ramped in magnitude when the batteries lie in a state of charge between partial charge and full charge, with the magnitude of the charging being related to the relative state of charge of the battery. The deficiency between traction motor demand and the energy available from the auxiliary electrical source is provided from the batteries in an amount which depends upon the state of the batteries, so that the full amount of the deficiency is provided when the batteries are near full charge, and little or no energy is provided by the batteries when they are near a discharged condition. At charge states of the batteries between near-full-charge and near-full-discharge, the batteries supply an amount of energy which depends monotonically upon the charge state. Charging of the batteries from the auxiliary source is reduced during dynamic braking when the batteries are near full charge. Control of the amount of energy returned during dynamic braking may be performed by control of the transducing efficiency of the traction motor operated as a generator.

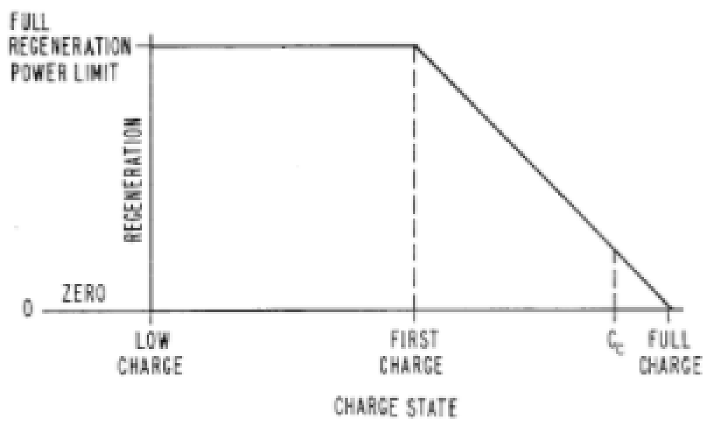


Fig. 13. State of Charge (SOC) Working Principle [6]

4.1 Efficiency Control and Tracking in an Electric Vehicle

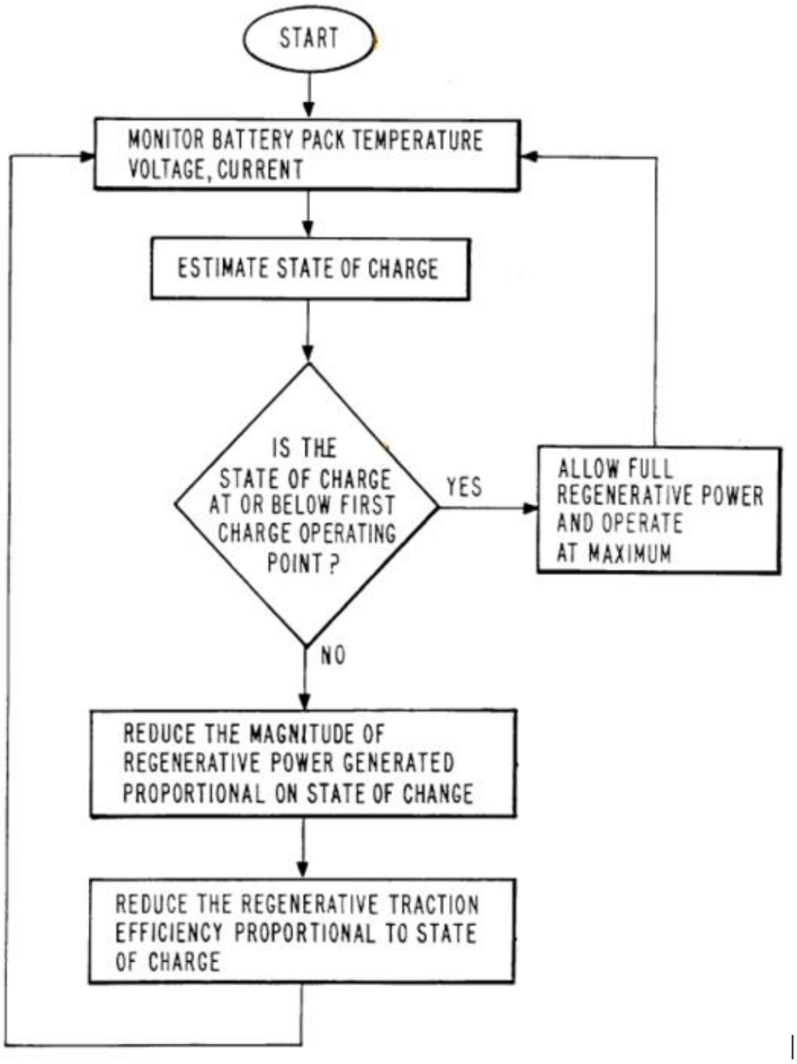


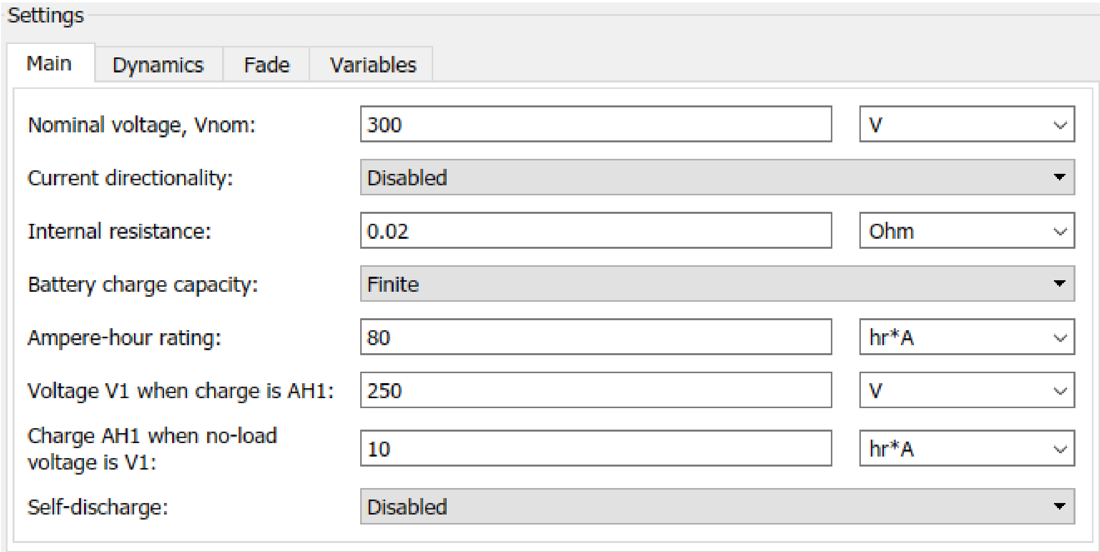
Fig14. State of Charge Working Flowchart

4.2 Battery

In our simulation model, a 330V battery is connected to a controlled current source. If we select Infinite for the Battery charge capacity parameter, the block models the battery as a series internal resistance and a constant voltage source. If you select Finite for the Battery charge capacity parameter, the block models the battery as a series internal resistance plus a charge-dependent voltage source defined by:

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

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].



Settings

Main | Dynamics | Fade | Variables

Nominal voltage, Vnom:	300	V
Current directionality:	Disabled	
Internal resistance:	0.02	Ohm
Battery charge capacity:	Finite	
Ampere-hour rating:	80	hr*A
Voltage V1 when charge is AH1:	250	V
Charge AH1 when no-load voltage is V1:	10	hr*A
Self-discharge:	Disabled	

Table 3. Battery parameters used in the simulation model.

The State of Charge could not be implemented in the Simulink model and the correct battery percentage of a running vehicle could not be calculated.

4.3 Calculation of SOC

The SOC of the battery refers to the ratio of the current remaining battery capacity to the available capacity under certain conditions (temperature, charge and discharge ratio, etc.), and its mathematical expression is shown in Equation .

SOC = Qc/Q × 100%= 100% − Qe/Q .

However, different scholars hold different views on this issue. The difficulty lies in the understanding of the numerator and the equation’s denominator, and the denominator of this Equation is the battery capacity. The definition of the battery capacity known here is not consistent. The rated capacity, factory capacity, cycle capacity, or current battery actual capacity is usually used as the denominator of this equation. In the theoretical analysis, the most used capacity is rated capacity as a classic definition of the denominator of the equation. This method regards the rated capacity as a fixed value, and the SOC is obtained by subtracting the amount of charge or discharged from the rated capacity. At present, most electric vehicles define SOC from the perspective of electric charge quantity, so in this equation, Qc is the residual power of the battery at the moment of calculation, and its unit is A·h; Q is the total capacity of the battery, and its unit is A·h. Qe is the battery charge. In fact, the battery usually varies with many factors, and this equation needs to be modified. The Equation more commonly used is:

SOC(t) = SOC(t0) – Integral of (limits t - t0) ηI/Cn dτ

In this equation, SOC(t) is the nominal capacity of the battery, and its unit is A·h. η is the coulomb efficiency, also called the discharged efficiency, which refers to the ratio of the discharge capacity of a battery to the charge capacity in one loop($\eta = Q/Qn$). The entered charge is often unable to convert all the active substances into electricity, because there is a certain loss, such as the battery occurred irreversible side reactions. Therefore, the value of η is usually less than 100%. In fact, the current lithium-ion batteries have a coulomb efficiency of 99.9% or more. Its value can be obtained by the Peukert equation, combining the measured residual charge and discharge current of the two batteries. However, in practice, it is difficult to measure the coulomb efficiency, which is extremely susceptible to the influence of charge and discharge current, temperature, battery aging degree and internal resistance of the battery. When talking about SOC, another parameter to consider is the state of health (SOH). SOH can well reflect the aging degree of battery. SOH is affected by various kinds of factors. During the use of battery assembly vehicle, due to the influence of temperature, ventilation condition, self-discharge degree, electrolyte concentration and other differences of the batteries in the battery pack, the inconsistencies of battery voltage, internal resistance, capacity and other parameters will be increased to some extent, which will affect the value of SOH. [7]

The relationship between the two is as follows.

$$SOC(t) = SOH(t) - DOD(t).$$

In this third equation , SOH(t) is the state of charge. When the battery is a new one, we consider SOH as 100%. DOD(t) (depth of discharge) represents the percentage of discharge of the battery and the rated capacity of the battery. DOD is considered when the discharge of the battery exceeds at least 80% of its rated capacity.

5 Limitations

Due to the maximum recharging rate of the circuit and the capacity of battery, the braking force from an electromagnetic type RBS is always limited. Therefore, a traditional friction brake system is required to convert the excess energy from the vehicle. The friction brake can also prevent the loss of braking ability in the case of RBS failure.

RBS can only be installed on driving wheels since a drive train is required for energy recovery. The waste heat is not significantly reduced unless the vehicle is an all-wheel drive model.

Adding a RBS to a vehicle means to increase the curb weight of it. Although RBS can improve fuel economy under start-and-stop driving conditions, it may have negative effect on fuel consumption during highway cruising.

The design of RBS involves varieties of sensors and logic control units to adjust the operation of RBS. The reliability concern of these electrical parts should not be neglected.

6 Conclusion

The simulation model gives an account of the speed and distance comparison of the Drive cycle and the vehicle and allows us to understand the slight deviation at the points of acute acceleration and braking.

The simulation results cannot be shown due to the unavailability of the licences for the blocksets containing the Longitudinal Driver Block, namely, Powertrain Blockset, Vehicle Dynamics Blockset and Automated Driving System Toolbox.

However, on running the model with the abovementioned Blocksets, this simulation model should run perfectly and provide the following results:

The general observations suggest that the actual velocity of the vehicle does not match the duty cycle during high acceleration and the desired value is not attained and the vehicle velocity is slightly less than the duty cycle.

On the other hand, due to inertia of the car and other factors, the actual speed of the car does not match the duty cycle during acute braking of the vehicle and it takes a longer time to reach the desired minimum speed value while braking the vehicle.

The state of charge decreases during the running cycle as the battery in constantly being drained but little hikes can be observed in the charge state while the vehicle is braking, charging the battery and slightly increasing the state of charge of the battery.

7 References

- Four-Wheel Electric Braking System Configuration With New Braking Torque Distribution Strategy for Improving Energy Recovery Efficiency January 2019 IEEE Transactions on Intelligent Transportation Systems PP(99):1-17 Wenfei Li, Haiping Du [1]
- Electric and Hybrid Vehicles [Technologies, Modeling and Control: A mechatonic approach] Amir Khajepour, Saber Fallah, Azesta Gooderzi 2014. [2] [3][4]
- Mathworks website: de.mathworks.com/help/vdynblks/ref/longitudinaldriver.html [5]
- Electronic Stability Control for Electric Vehicle with Four In-wheel Motors. Bo-Chiuan Chen, Chia-Cheng Kuo June 2014. International Journal of Automotive Technology 15(4):573-580
- An optimal torque distribution control strategy for four-independent wheel drive electric vehicles Bin Lia , Avesta Goodarzia , Amir Khajepoura∗, Shih-ken Chenb and Baktiar Litkouhib
- Experimental Evaluation and Prediction Algorithm Suggestion for Determining SOC of Lithium Polymer Battery in a Parallel Hybrid Electric Vehicle. Insu Cho 1, Jongwon Bae 1, Junha Park 1 and Jinwook Lee 2,
- Improving power grid transient stability by plug-in electric vehicles. Andrej Gajduk, Mirko Todorovski, Juergen Kurths and Ljupco Kocarev
- **https://patents.google.com/patent/US5941328A/en**
- Hu, X.; Zou, C.; Zhang, C.; Li, Y. Technological developments in batteries: A survey of principal roles, types, and management needs. IEEE Power Energy Mag. 2017, 15, 20–31.
- Zhang, C.; Wang, L.Y.; Li, X.; Chen, W.; Yin, G.G.; Jiang, J. Robust and adaptive estimation of state of charge for lithium-ion batteries. IEEE Trans. Ind. Electron. 2015, 62, 4948–4957.
- Hu, X.; Li, S.E.; Yang, Y. Advanced machine learning approach for lithium-ion battery state estimation in electric vehicles. IEEE Trans. Transp. Electrif. 2015, 2, 140–149. [CrossRef]
- Xiong, R.; Zhang, Y.; He, H.; Zhou, X.; Pecht, M.G. A double-scale, particle-filtering, energy state prediction algorithm for lithium-ion batteries. IEEE Trans. Ind. Electron. 2017, 65, 1526–1538. [CrossRef]
- Yang, R.; Xiong, R.; He, H.; Mu, H.; Wang, C. A novel method on estimating the degradation and state of charge of lithium-ion batteries used for electrical vehicles. Appl. Energy 2017, 207, 336–345.
- Castano, S.; Serrano-Jimenez, D.; Sanz, J. BMS influence on Li-ion packs characterization and modeling. In Proceedings of the 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, 7–10 June 2016.
- en.wikipedia.org/wiki/Regenerative_brake [7]
- https://electrek.co/2018/04/24/regenerative-braking-how-it-works/
- M. K. Yoong, *et al.*, "Studies of Regenerative Braking in Electric Vehicle", IEEE 5686984, 20 Nov 10.[8]
- L. Li *et al.*, "Analysis of Downshift's Improvement to Energy Efficiency of an Electric Vehicle During Regenerative Braking," Appl. Energy **176**, 125 (2016).[9]
- N. D. Lakshmi *et al.*, "Energy Efficient Electric Vehicle Using Regenerative Braking System," International Journal of Advance Research, Ideas and Innovations in Technology **3**, 155 (2017).[10
- Regenerative Braking Juan Leis-Pretto November 8, 2017 Submitted as coursework for PH240, Stanford University, Fall 2017