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Experimental Validation of Electric Vehicle Traction System Using RST Controller

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Abstract

Our work focussed on three parts, The first was a general definitions of the electric vehicles with its types HEV,PEV And we talked about the most important manufacturers of EV's , We mention the power supply , the various engines and the converters used in an EV's , the second part was a mathematical modulation of the traction system followed by the RST controller model , the third part was an experimental validation of the speed of EV using RST controller , we achieved it by using the Arduino Mega simulated by Matlab/Simulink real-time environment.
Key words: Electric Vehicle;HEV;PEV;traction system;Arduino;RST Controller; Matlab/Simulink;Real-time Environment

Dedication

we dedicate this work to

our parents,

our brothers and sisters,

our professors,

and our friends,

Acknowledgment

We would like to express my sincere gratitude to our advisor Dr. Okba Kraa for the continuous support of our study in all those years, for his patience, motivation, enthusiasm, and immense knowledge. he guided us through our studies.

we also would like to thank our thesis examiners: Dr. mohammedi Messaoud and Dr. Derradji belloum Karima for their insightful comments and corrections. Also, we thank our friends for all the supports all the prayers that help us to reach the level who we are now ,Thanks.

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Introduction

EVs first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. Modern internal combustion engines have been the dominant propulsion method for motor vehicles for almost 100 years, but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types. Electric vehicle technology is the happy marriage of mechanical,chemical and electrical/automatics laws wish operate in perfect harmony , our work covers multidisciplinary aspects of EV's.

The outline of this work is structured in three main chapters, organized as follows:

Chapter 1: In this chapter we introduced a general definitions of the electric vehicles with its types Hybrid EV (series,parallel and mixed) and Pure EV And we talked about the most important manufacturers of EV's such us Tesla, General Motors and Nissan , We mention the power supply that the EV's need , the various engines whether it is DC or AC and the converters used in an EV's.

Chapter 2: We made this chapter a full mathematical modeling of the EV traction system part by part from the used power supply the lead-acid battery , we modeled the DC motor and the different chopper converters .
Also we chose The RST discrete-time controller and made it clear from mathematical purpose.

Chapter 3: We made an experimental validation of the speed of EV using RST controller achieved it by using the Arduino Mega with observing the behavior under changing of reference and introducing disturbance . we made an effective change on controller variables to see the effectiveness on the response speed , stability and precision .

Chapter 1

Fundamentals of Electric Vehicles

1.1 Introduction

Recently the development of the new generation vehicle, which is more efficient and less air polluting is accomplished actively. This vehicle's generation development can be divided to two kinds, one is the EV and the other one is the Hybrid Electric Vehicle (HEV). Nowadays, EVs are particularly well suited to urban applications and commuter-town cars. To use EVs as a practical solution, it is necessary to have technical feasibility and commercial viability that meets the user's needs and affordability. The EV must first be safe, reliable and cost effective with good performance and effective travel range, with consistency of the battery system being the key to determine the usefulness as vehicle.[11] In this chapter, general description of EV's power-train and drive-train system , we mention the most important manufacturers of EV's, we introducing the configuration of EV's and the difference between them finally we made a study on ETU (Electric Traction Units) with clarifying all their properties .

1.2 Electrical Vehicle History

Electric vehicles paved their way into public use as early as the middle of the 19th century,even before the introduction of gasoline-powered vehicles. In the year 1900, 4200 automobiles were sold ,out of which 40% were steam powered, 38% were electric powered, and 22% were gasoline powered.However, the invention of the starter motor, improvements in mass production technology of gas-powered vehicles, and inconvenience in battery charging led to the disappearance of the EV in the early 1900s. However, environmental issues and the unpleasant dependence on oil led to the resurgence of interest in EVs in the 1960s. Growth in the enabling technologies added to environmental and economic concerns over the next several decades, increasing the demand for investing in research and development for EVs. Interest and research in EVs soared in the 1990s, with the major automobile manufacturers embarking on plans for introducing their own electric or hybrid electric vehicles. The trend increases today, with EVs serving as zero-emission vehicles, and hybrid electric vehicles already filling infor ultra low-emission vehicles.[**ElecH**]

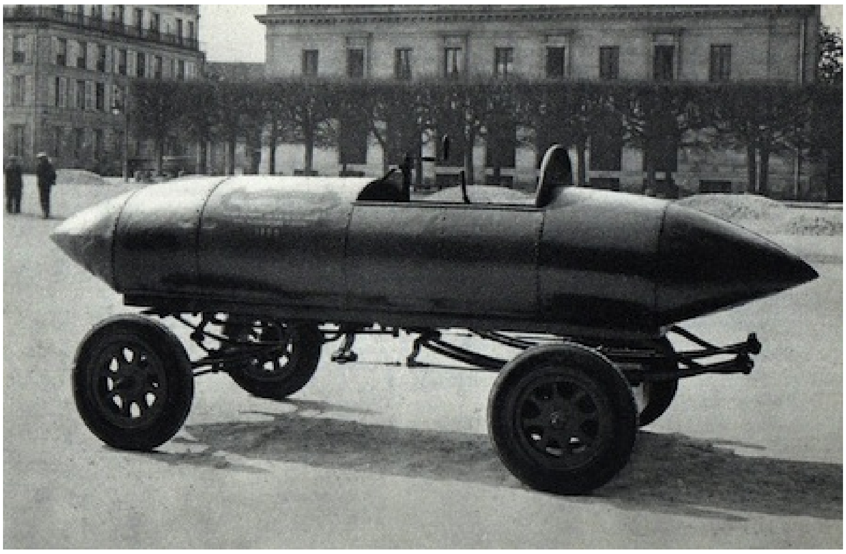


Figure 1.1: La Jamais contente in 1899 [18]

1.3 Architecture of an Electric Vehicle

An EV is an electromechanical system made up of an electrical part that includes an electrical source, a DC-DC converter (or DC-AC) and the electric motor this part is called the powerchain of EV, then it comes the set of mechanical transmission elements called the mechanical transmission chain.

1.3.1 The Electric Vehicle Powertrain

Set of organs through which the flow of energy passes, and which provide a vehicle with its capacity for movement.

1.3.1.1 The Drive Train

Part of the traction system ensuring the mechanical transmission of movement. It is made up of the wheels, the differential, the transmission or gearbox and an engine converting the energy coming out of the on-board generator into mechanical energy.

1.3.1.2 On-board Energy Generator

Part of the traction system ensuring storage and an adaptation system (converter / or transformer).

1.3.1.3 Energy Converter

system that changes the nature of energy (engine, radiator, etc.).

1.3.1.4 Energy Transformer

System that conserves the nature of the energy but changes its type (gearbox, DC / AC electric converter).

1.3.1.5 Energy Typing

Characterizes the parameters of a similar energy (for electricity: voltage, current, frequency).

1.3.1.6 Nature of Energy

Characterizes the different forms that energy can take (mechanical, electrical, chemical, hydraulic, radiant or nuclear, ...).

1.3.1.7 Differential

is a mechanical system whose function is to distribute a rotational speed by distribution of the kinematic force, adaptively, immediately and automatically, to the needs of a mechanical assembly.

1.3.1.8 Gear

is a mechanical system made up of two toothed wheels used to transmit the rotational movement. These two cogwheels are in contact with each other and transmit power through obstacles. When there are more than two cogwheels, we speak of a gear train.

1.3.1.9 Reducer

is a gear system with a transmission ratio of less than 1, to increase the torque of the rotating motor.

1.3.2 Electric Vehicles manufacturers

There are currently about forty different electric vehicles available, from about twenty different electric car manufacturers. These include BEV's (battery electric vehicle) which are 100% electric, and PHEV's (Plug-in electric hybrid vehicles) which have a battery and an electric motor, but also have an internal combustion engine. PHEVs drive on electric sometimes, and gasoline or diesel once the battery is depleted.

How to Assess Electric Car manufacturers The Models? One metric to consider is which electric car companies are making the top selling vehicles, and what are the world's most popular electric cars? The three companies selling the most electric cars in the US are Tesla, General Motors and Nissan. These three automakers account for more than 60% of all electric cars sold in the US through September in 2018. The top electric cars from these companies are:[21]

1-Tesla

2-Chevrolet

3-Nissan

4-BMW

(a) Tesla Model x

(b) Nissan LEAF

(c) Chevrolet Volt

Figure 1.2: Electric Vehicle [21]

1.4 Main configurations of EVs

Depending on the type of energy on board the electric vehicle, there are two main families of the latter, namely, the hybrid vehicle and the pure electric vehicle. In what follows we present the main characteristics of each of these two families.

1.4.1 Hybrid EV

A Hybrid Electric Vehicle (HEV) is a vehicle that uses two or more sources of power. The two sources are electricity from batteries and mechanical power from an internal combustion engine. This combination offers very low emissions of vehicles with the power and range of gasoline vehicles. Many configurations are possible for HEVs as series fig1.3 , parallel HEVs fig1.4 and The dual mode (series-parallel) fig1.5 [11].

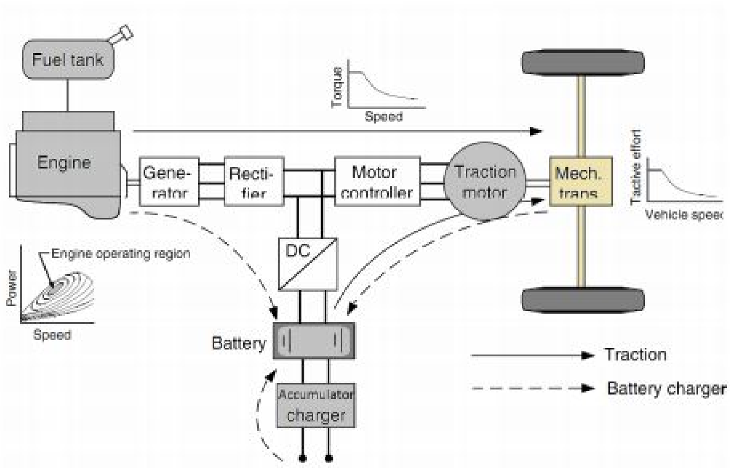


Figure 1.3: Series hybrid vehicle [11]

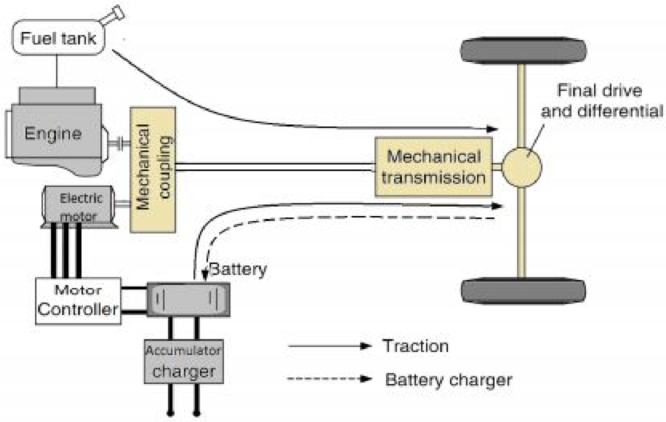


Figure 1.4: Parallel hybrid vehicle [11]

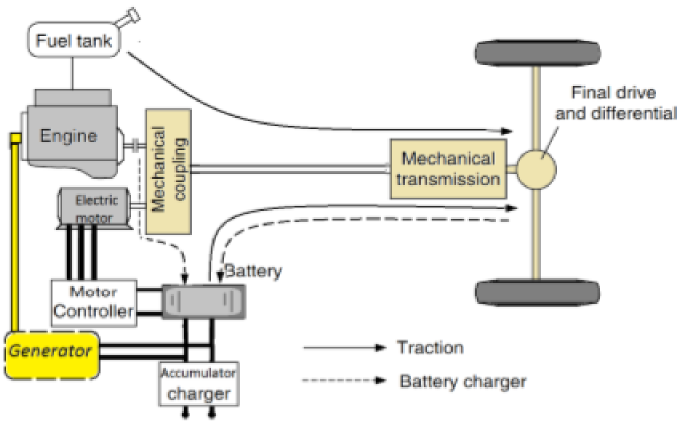


Figure 1.5: The dual mode hybrid vehicle [11]

1.4.2 Pure EV

Pure electric vehicle is a type of EV that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion (e.g. hydrogen fuel cell, internal combustion engine, etc.). fig1.6

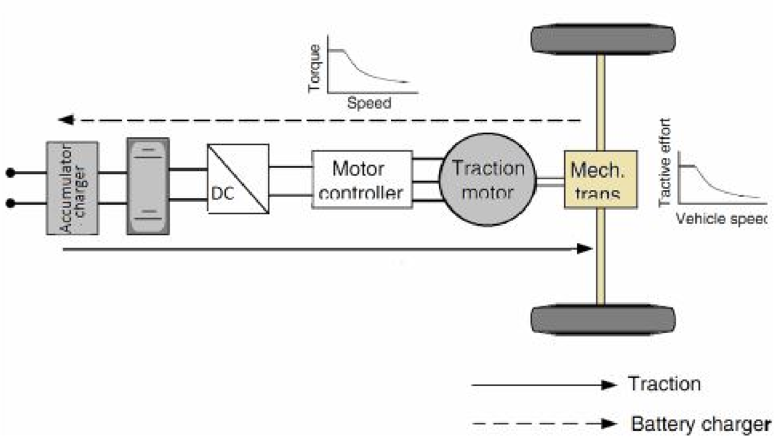


Figure 1.6: Pure electric vehicle [11]

Configuration	Advantage	Disadvantages
Series Hybrid	-Autonomous -Zero emission mode operation -Battery largely undersized -Power comparable to the vehicle	-the importance of the Series motor system -high mass -high cost
Parallel Hybrid	-Autonomous and efficient -Zero emission rate in electric mode -Less polluting	-Large size of the motorization system -High mass -High cost
Dual Mode Hybrid	-High autonomy -The most sold -Comparable to ICE Vehicles -Less polluting	-Complexity of energy management -Complexity of arrang between its components -High cost and mass
Pure EV	-Zero mission -Silent -Easy use and driving	-Travel range obstacle -Oriented only for urban -High cost

Table 1.1: Advantages and disadvantages of the various architectures presented

1.4.3 Difference

In EVs, the electric motor is the propulsion unit, while in hybrid electric vehicles (HEVs), the electric motor and the ICE together in a series or parallel combinations provide the propulsion power. In an EV or an HEV, the electric traction motor converts electrical energy from the energy storage unit to mechanical energy that drives the wheels of the vehicle.[11]

1.5 Electric traction units

Before starting the description of the motors, electronic converters and batteries , we give a few elements to appreciate the value of the use of electric traction in propulsion systems. first , the mechanical torque of the electric motor results from the action of a magnetic induction flux on an electric current. In a motor, the flux imposes the dimensions of the magnetic medium (iron) and the current imposes the section of the wires (generally copper) which constitute the windings. the dimensions of an electric motor depend to a large extent on the characteristics of the torque that one wants to obtain.[3]

The power of an engine is equal to the product of the torque times the rotational speed, so that for a given power the size of the motor is smaller then its rotational speed is .

In a DC motor, the speed of rotation is limited :
- Mechanically, by the risk of unwinding of the coils and the blades of the collector.
- Electrically, by switching the current between the connector blades.

In practice, the electric motors used in the propulsion of road vehicles have unit powers of less than 50-60 kW and their supply voltage remains mostly below 200 Vdc. Under these conditions, it is possible to manufacture direct current motors which rotate at 5000 rpm. AC motors, due to the absence of a commutator, can achieve higher rotational speeds than DC motors. For the powers involved in conventional road vehicles, 10,000 rpm is a perfectly feasible speed. Therefore, the specific power of an AC motor is higher than that of a DC motor. Whatever its nature (direct current or alternating current), the electric motor has a number of advantages :[3]
1- It can provide torque at all speeds, especially when stationary. This property allows the elimination of the clutch in the torque transmission chain, with appropriate control of the supply voltage in the case of a DC motor, or by the inverter in the case of an AC motor.
2- It can withstand short loads, and provide significant over torques of the order of 2 to 4 times the nominal torque during the starting period.
3- It can be reversible.

1.5.1 The Electric motors

There is a close relationship between increasing engine performance and achieving high performance electric vehicles in operation. There are three main categories of motors (direct current, asynchronous and synchronous). When it comes to the choice of motorization technology, the reference solution has long been direct current motorisation.[20]

Either in its version with series excitation, a robust solution which intrinsically has a traction characteristic (Volta), or more recently, in its version with separate excitation controlled by chopper (Express). But the evolution of power electronics and materials such as permanent magnets is now leading to a move towards more efficient solutions such as synchronous or asynchronous motors.

1.5.1.1 Direct Current Motors

Among the different types of DC motors (series motor, separately excited motor, permanent magnet motor), it is mainly the separately excited motor that is used. It is the most economical and reliable solution thanks to its chopper-type armature converter with two switches and a lower power inductor chopper. But this technology has the following drawbacks :[3][9][5]
- the difficulty of cooling the rotating armature, which limits the possibilities of obtaining a high mass torque.
- the rotational speed of the armature is limited by its constitution.
- the wear of brushes requiring periodic maintenance to remove conductive dust that adversely affects the isolation of the collector.
- the construction cost is high because the machine is complex: collector, winding of the armature.

1.5.1.2 Asynchronous motors

The asynchronous motor is robust, fairly inexpensive and easily industrialized. It has a fairly high power to weight, which leads to good efficiency for the driveline. The Asynchronous motors is the most suitable candidate to power hybrid electric vehicles (HEV).[12]

However, the main difficulty remains its piloting. As the excitation is induced by stator currents, separate control of torque and flux is difficult to do. The control of the asynchronous machine by vector control is managed by a microprocessor. However, the increased performance of the computers and the extensive integration of this control have resulted in a reliable solution at a reasonable cost.[3]

1.5.1.3 Synchronous motors

In this category, we find several kinds of configurations, the most frequent :
The permanent magnet synchronous motor (PMSM) seems in more than one way a suitable solution for its technical performance and in particular its compactness and efficiency. The excitement in this case is created by the permanent magnets. There are several kinds of permanent magnet synchronous machines, the total torque of which is the sum of a hybrid, a relaxation torque and a reluctant torque :
- the magnets on the surface: the reluctant torque is zero, the rotor showing no protrusion. This machine is non-salient poles or smooth poles.[6]
- buried magnets.
- flux concentration magnets.

The advantages of these machines are the high values of the torque, mass and power, mass ratios as well as their good efficiency.
However, the price of magnets is high. the defluxing operation in the constant power operating zone is difficult (complex machine control, risk of demagnetization, additional electrical losses due to increased stator current).[3][9][5][6]

1.5.1.4 Switched Reluctance motor

The rotor of this type of motor contains neither magnets nor excitation windings. Torque is created only through the reluctance effect. The stator is similar to that of most AC machines. The rotor is constructed so that the ratio between the inductance in the direct axis and the quadrature axis (Ld / Lq) is as large as possible. The constant power speed operating range is directly related to this ratio. The same is true for the power factor (the higher this ratio, the greater the power factor). Obtaining a high ratio (Ld / Lq) induces constraints at the manufacturing level, which have a negative impact on the cost. The disadvantages for this type of machine are summarized in the delicacy of the manufacture due to the need for a high salience ratio, the low power factor and the complexity of the control electronics requiring a position sensor. The main advantages of these machines are the possibility of high speed operation (thanks to the passivity of the rotor) and the relatively high efficiency compared to the asynchronous machine.[3][9][5][6]

	DCM	ASM	PMSM	SRM
maximum efficiency	Well	Fair	Very good	medium
medium efficiency	medium	Well	Very good	Well
Maximum speed	Fair	Well	Well	Well
Electronic of power cost	Very good	Fair	medium	Well
Motor cost	Fair	Well	medium	Very good
Torque-speed space	medium	medium	Very good	Well

Table 1.2: Comparison of electric motor technologies

We can then conclude that for a purely electric vehicle application, the permanent magnet solution is preferred for many reasons:
- efficiency in the area of use of the electric vehicle, compactness and mass.
On the other hand, for versatile use (alternator-starter, hybrid and pure electric) and when the cost criterion becomes the determining parameter, the choice of the Switched reluctance machine seems relevant compared to synchronous and asynchronous solutions because of the more low cost of manufacturing the machine and low cost of producing power electronics.[3][9][5][6]

1.5.2 The Electric converters

The use of an electric power train in autonomous road vehicles implies the presence on board of a source of electrical energy which may be:
- an accumulator battery of suitable capacity for the desired range of the vehicle in the case of an pure electric vehicle.
- a lower capacity accumulator battery, associated with a thermoelectric unit (combination of a heat engine and an alternator) or with a fuel cell in the case of a hybrid electric vehicle.

In most electric vehicles, we are faced with the compatibility of DC and AC power sources and within the same category with compatibilities between the voltages of sources and receivers. This compatibility problem implies the presence of electronic converters whose role is to remove operating incompatibilities.

As a result, we can find:
- converters of alternating current to direct current (AC-DC), called rectifiers.
- converters of direct current into direct current of deferred voltage (DC-DC) called choppers.
- converters of direct current to alternating current (DC-AC) called inverters.

The purpose of this section is not to give an exhaustive description of each of these types of organs but to explain the most utilizable converter.

1.5.2.1 Choppers (DC-DC)

A chopper is a current converter which makes it possible to obtain from a DC voltage source of substantially constant value, voltages and currents that are controlled, adjustable, different from the input values and adapted to the needs necessary for the 'supply of various receivers (motors, batteries, etc.).

In an electric vehicle, choppers have two main uses:
- they are essential in the power supply of propulsion motors when these are direct current motors.
- they are necessary to adapt the voltage of the main battery to that of the electronic auxiliaries used (sensors, regulators, etc.).

Indeed, one cannot envisage the sudden connection of a direct current motor to a fixed voltage energy source (accumulator battery for example) for the following reasons:
- no adjustment of the engine torque or of the engine speed would be possible.
- the transient regime when the motor is directly powered on would be destructive both from an electrical point of view (overcurrent) and mechanically (over torque).

The use of a chopper makes it possible to maintain the motor current at the desired value while ensuring the progressive adjustment without noticeable loss of the voltage of the engine. It also makes it possible to adjust the torque and the speed of the engine and therefore of the vehicle in traction but also in electric braking.

1.5.3 EV Power supply

1.5.3.1 Electrochemical battery

Electrochemical batteries, more commonly referred to as batteries, are electrochemical devices that convert electrical energy into potential chemical energy during charging, and convert chemical energy into electric energy during discharging .[15] Many different battery types exist, e.g., lead-acid, nickel-metal hydride, lithium ion, etc. However, today the lithium ion is the preferred choice for the EV applications due to its relatively high specific energy and power .[16] While the term "battery" is often used, the basic electrochemical unit being referred to is the "Battery cell". A battery consists of one or more of these cells, connected in series or parallel, or both, depending on the desired output voltage and capacity. The battery cell consists of three major components as shown in Fig 1.7 [17]

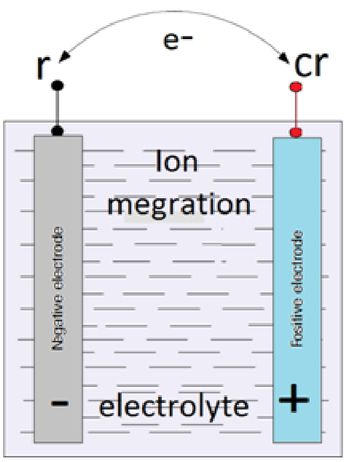


Figure 1.7: An electrochemical battery cell

1.The anode or negative electrode, the reducing or fuel electrode, which gives up electrons to the external circuit and is oxidized during the electrochemical reaction.

2.The cathode or positive electrode, the oxidizing electrode, which accepts electrons from the external circuit and it is reduced during the electrochemical reaction.

3.The electrolyte, the ionic conductor, which provides the medium for transfer of charge, as ions, inside the cell between the anode and cathode. The electrolyte is typically a liquid, such as water or other solvents, with dissolved salts, acids, or alkalis to impart ionic conductivity. Some batteries use solid electrolytes, which are ionic conductors at the operating temperature of the cell.[17]

There are many different battery types, the most popular types is :

1 - Lead–acid battery

2 - The Nickel based battery :

- The Nickel Cadmium (NiCd) battery.
- The Nickel-Metal Hydride (NiMH) battery.

3 - The Lithium based battery :

-The Lithium Polymer battery.

-Lithium-Ion (Li-Ion) Battery.

1.5.3.2 Fuel Cell

- What is fuel cell :

A fuel cell is an electrochemical device that combines hydrogen fuel with oxygen to produce electricity, heat and water. The fuel cell is similar to a battery in that an electrochemical reaction occurs as long as fuel is available. Hydrogen is stored in a pressurized container and oxygen is taken from the air. Because of the absence of combustion, there are no harmful emissions, and the only by-product is pure water.[8]

Fundamentally, a fuel cell is electrolysis in reverse, using two electrodes separated by an electrolyte. The anode (negative electrode) receives hydrogen and the cathode (positive electrode) collects oxygen. A catalyst at the anode separates hydrogen into positively charged hydrogen ions and electrons. The hydrogen is ionized and migrates across the electrolyte to the cathode compartment, where it combines with oxygen. A single fuel cell produces 0.6–0.8V under load. To obtain higher voltages, several cells are connected in series. Fig 1.8 [8]

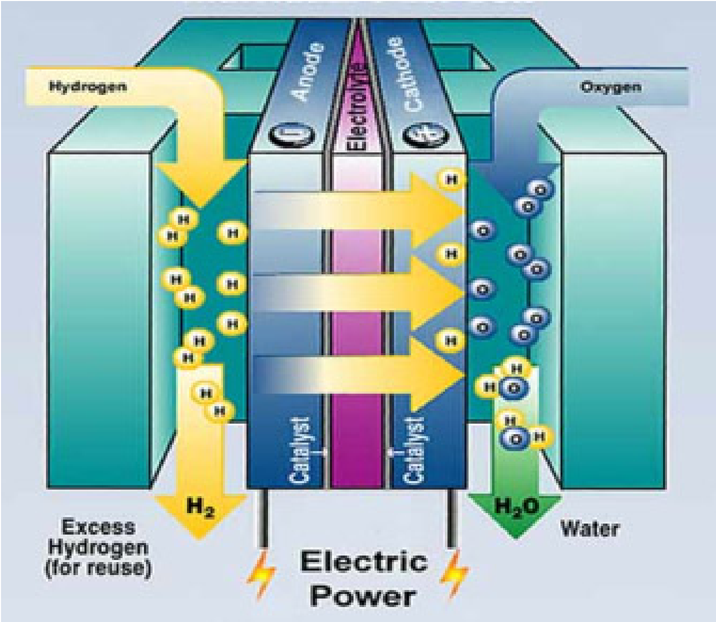


Figure 1.8: Concept of a fuel cell[8]

Here are the most common fuel cell concepts.
- Proton Exchange Membrane Fuel Cell(PEMFC)
- Alkaline Fuel Cell (AFC)
- Solid Oxide Fuel Cell (SOFC)
- Direct Methanol Fuel Cell (DMFC)
- Phosphoric Acid Fuel Cell (MCFC)
- Molten Carbonate Fuel Cell (PAFC)

1.5.3.3 Hybrid Power Source

Batteries often constitute the energy storage system in electric vehicles (EV), where they are subject to time-varying current demands, including acceleration and regenerative braking. Many efforts are being made to improve the performance of batteries for this application because the high cost, limited energy density, and short cycle lifetime of current battery technology hinders the viability of the EV.
One popular method is the addition of ultracapacitors (UC) as an auxiliary energy storage (AES) system to supply a portion of the power during high discharging or charging currents. Active control of the load fraction supplied from the AES provides superior performance over a passive parallel combination of the battery and UC . Active control is usually accomplished with a dc-to-dc converter between the battery and the UC bank.[2]

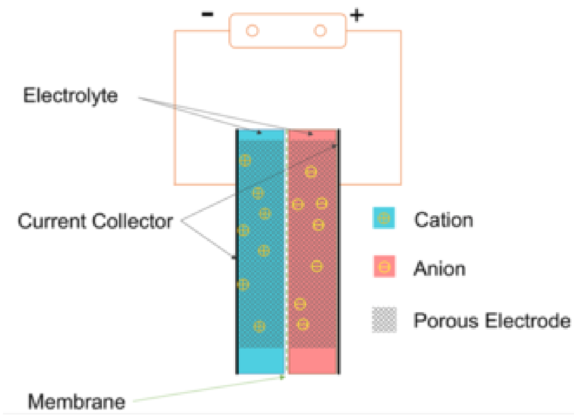


Figure 1.9: Schematic illustration of a supercapacitor[19]

1.6 Conclusion

The main aim of this chapter was study and a comprehensive definition of an electric vehicle from all historical, economic and scientific aspects and we took off the cover on the components of the traction system and also see the difference between them , it mean , if you read this part, you can get at least a comprehensive overview of what electric vehicle is .

And for an in-depth study we made a full mathematical modelling to each part we talked about previously in the next chapter .

Chapter 2

Electric Vehicle Modeling

2.1 Introduction

In order to achieve the first goal of this work , we have to do full mathematical modeling of the various parts used in traction system , And this is what was in this chapter , which is a mathematical modeling of the used power supply lead-acid battery meets the needs of the DC motor that we used which in turn we reviewed a model for it .

Also, to change speed , the given tension to the DC motor from the battery had to be changed from his constant form to a variable form with DC/DC chopper converter that why we also introduce mathematical modeling of the different chopper buck/boost/buck-boost.

Finely , the important part in the closed loop control system is the controller which is in our work the RST controller, we illustrated the z-transform which is the tools that we can used in the discrete-time and we made a Design of it .

2.2 Mathematical Model of the lead-acid battery

In systems, where the low power load is present, the power supply battery may often be treated as an ideal or real voltage source. In such cases, the mathematical model constitutes a circuit diagram which comprises an ideal voltage source or a voltage source with serially connected resistor that represents the internal resistance of the battery. However, while considering the dynamic systems, in which load is distributed unevenly and which are fastchanging, a more accurate model that takes into consideration the behaviour of the battery and the parasitic and thermal phenomena taking place in it must be used. One of the more accurate mathematical models used to analyse the battery performance is the electric circuit consisting of the voltage source Em and the pairs of capacitors and resistors joined in parallel R_n C_n . The electric charge losses caused by the self-discharge of the battery are represented by the occurrence of the P-N branch, through which the parasitic current I_p flows. Depending on the expected model accuracy, the appropriate number of pairs of RC dynamic branches must be selected. The number as such also depends on the dynamics of changes in the load of the analysed battery. The electric diagram of the discussed n-order model of a single cell of the lead-acid battery is presented in figure 2.1 (with the n-number of the connected RC branches) .[4]

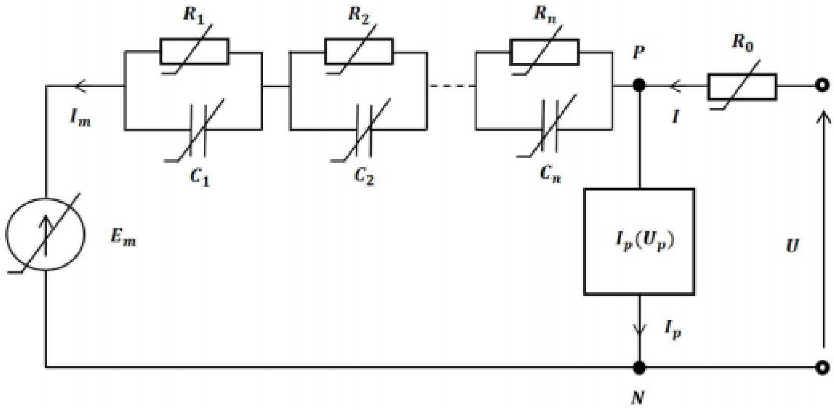


Figure 2.1: Electric diagram of the lead-acid battery cell[4]

The value of the majority of parameters of the cell's equivalent circuit depends, above all, on the battery state of charge SOC, the load and the electrolyte temperature T_e . The parameters, which affect the operational properties of the battery are described in detail in publications, and their values for the second-order model can be determined from following equations:[4]

$$E_m = E_m0 - K_e(1 - SOC)(273.15 + T_e) \tag{2.1}$$

$$SOC = 1 - \frac{Q_e}{C(0,T)} \tag{2.2}$$

$$R_0 = R_{00}(1 + A_0(1 - SOC)) \tag{2.3}$$

$$R_1 = -R_{10}ln(DOC) \tag{2.4}$$

$$C_1 = \frac{\tau_1}{R_1} \tag{2.5}$$

$$R_2 = R_{20}\frac{\exp A_{21}(1 - SOC)}{1 + \exp \frac{A_{22}I_m}{I_n}} \tag{2.6}$$

where: E_m electromotive force of the cell,E_{m0} open-circuit voltage of fully charged battery at 0°C, SOC battery state of charge, T_e electrolyte temperature, Qe electric charge drawn from the battery (described by formula), $C(0,T)$ unloaded battery capacity at T, R_0, R_1, R_2 main branch resistances, K_E, R_{00}, R_{10}, R_{20},A_0, A_{21}, A_{22} constants depended on battery parameters, DOC battery depth of charge, τ_1 time constant of the dynamic branch, I_m current flowing in the main branch, I_n rated battery current. The charge drawn from a single cell and the battery energy capacity are given by equations (2.7-2.8)

$$Q_e(t) = \int_0^t -I_m(t)dt \tag{2.7}$$

$$C(I,T) = \frac{K_c C_0^*(1 + \frac{T_e}{-T_f})^\epsilon}{1 + (K_c - 1)(\frac{I}{I_n})^\delta} \tag{2.8}$$

where: K_C, δ,ϵ constants set on the basis of the manufacturer's data, C_0^* battery capacity at 0°C, T_f electrolyte freezing temperature, I battery load current.[4]

The electrochemical reactions are described by the following reactions.[13]

$$\mathrm{PbO_2} + 2\,\mathrm{H_2SO_4} + \mathrm{Pb} \xrightarrow{\text{discharge}} \xleftarrow{\text{charge}} 2\,\mathrm{PbSO_4} + 2\,\mathrm{H_2O} \tag{2.9}$$

2.3 Mathematics Model of DC Motor

The modeling of DC motor can be represented by: [7]

$$\Phi \propto i_f \tag{2.10}$$

$$\Phi = K_f i_f \tag{2.11}$$

Where:

$$T \propto \Phi i_a \tag{2.12}$$

$$T = K_T i_a \tag{2.13}$$

The generated back E.M.F:

$$E_b \propto \Phi\omega \tag{2.14}$$

$$E_b = K_b\omega \tag{2.15}$$

$$E_b = K_b\frac{d\theta}{dt} \tag{2.16}$$

By applying Kirchhoff Law:

$$V_a = R_a i_a + L_a\frac{di_a}{dt} + E_b \tag{2.17}$$

And

$$T = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} \tag{2.18}$$

Where load torque

$$T = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + T_L \tag{2.19}$$

Taking Laplace transform:

$$T(s) = Ki_a(s) \tag{2.20}$$

$$E_b(s) = Ks\theta(s) \tag{2.21}$$

$$V(s) = i_a(s)(R_a + sL_a) + E_b \tag{2.22}$$

$$V(s) - E_b = i_a(s)(R_a + sL_a) \tag{2.23}$$

$$T(s) = (Js + B)s\theta(s) \tag{2.24}$$

or

$$T(s) = (Js + B)\omega(s) \tag{2.25}$$

$$T(s) = Ki_aI(s) \tag{2.26}$$

The transfer function of DC motor given by:

$$\frac{\omega(s)}{V(s)} = \frac{K_t}{(R_a + sL_a)(Js + B) + K_bK_t} \tag{2.27}$$

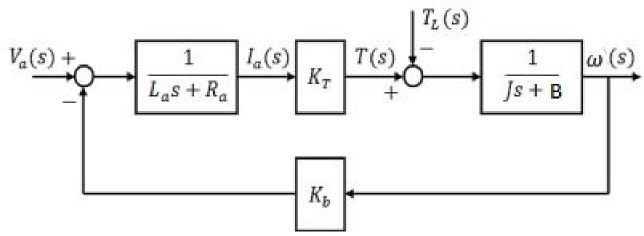


Figure 2.2: Block diagram of DC motor armature control

2.4 Mathematics Model of Choppers

2.4.1 Buck Converter Modeling

The buck converter with ideal switching devices will be considered here which is operating with the switching period of T and duty cycle D. fig 2.3[10]

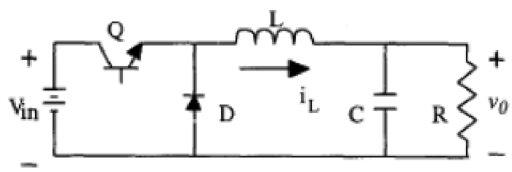


Figure 2.3: DC-DC Buck Converter[10]

The state equations corresponding to the converter in continuous conduction mode (CCM) can be easily understood by applying Kirchhoff's voltage law on the loop containing the inductor and Kirchhoff's current law on the node with the capacitor branch connected to it. When the ideal switch is ON, the dynamics of the inductor current $i_L(t)$ and the capacitor voltage $v_C(t)$ are given by: [10]

$$\begin{gathered} \begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in} - v_0) \end{cases} \\ \begin{cases} \dfrac{dv_0}{dt} = \dfrac{1}{C}(i_L - \dfrac{v_0}{R}) \end{cases} \\ 0 < t < DT, Q : ON \end{gathered} \tag{2.28}$$

and when the switch is OFF are presented by

$$\begin{gathered} \begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(-v_0) \end{cases} \\ \begin{cases} \dfrac{dv_0}{dt} = \dfrac{1}{C}(i_L - \dfrac{v_0}{R}) \end{cases} \\ DT < t < T, Q : OFF \end{gathered} \tag{2.29}$$

2.4.2 Boost Converter Modeling

The boost converter of Fig 2.4 with a switching period of T and a duty cycle of D is given. Again, assuming continuous conduction mode of operation, the state space equations when the main switch is ON are shown by :[10]

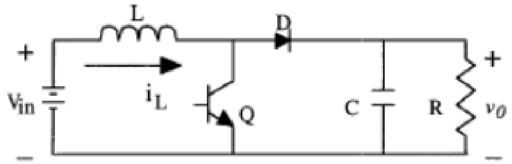


Figure 2.4: DC-DC Boost Converter[10]

$$
\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in}) \end{cases}
\begin{cases} \dfrac{dv_0}{dt} = \dfrac{1}{C}(-\dfrac{v_0}{R}) \end{cases}
0 < t < DT, Q : ON \tag{2.30}
$$

and when the switch is OFF

$$
\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in} - v_0) \end{cases}
\begin{cases} \dfrac{dv_0}{dt} = \dfrac{1}{C}(i_L - \dfrac{v_0}{R}) \end{cases}
DT < t < T, Q : OFF \tag{2.31}
$$

2.4.3 Buck-Boost Converter Modeling

In Fig DC-DC Boost Converter a DC-DC buck-boost converter is shown. The switching period is T and the duty cycle is D. Assuming continuous conduction mode of operation, when the switch is ON, the state space equations are given by,[10]

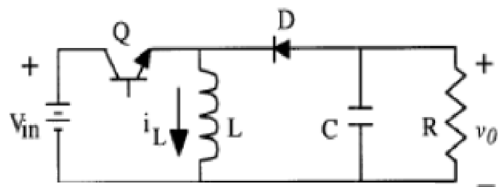


Figure 2.5: DC-DC Buck-Boost Converter[10]

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in}) \end{cases}$$
$$\begin{cases} \dfrac{dv_0}{dt} = \dfrac{1}{C}(-\dfrac{v_0}{R}) \end{cases} \tag{2.32}$$
$$0 < t < DT, Q : ON$$

and when the switch is OFF

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(v_0) \end{cases}$$
$$\begin{cases} \dfrac{dv_0}{dt} = \dfrac{1}{C}(-i_L - \dfrac{v_0}{R}) \end{cases} \tag{2.33}$$
$$DT < t < T, Q : OFF$$

2.5 RST Controller

The modern electric vehicle performance depends very much on automation systems applied. The conventional control methods have been found not so adequate and many control problems have come up due to imprecise input output relation and unknown external disturbances. Many new controllers such as fuzzy logic controller (FLC) have been suggested in near past to address such problems . Various control techniques such as well known Proportional-Integral-Derivative (PID) controller , state feedback controller (SFC) such as Pole Placement Technique (PPT) , and Linear Quadratic Regulator (LQR) Controller are designed by authors for electric vehicle application . The RST discrete-time controller provides a robust control for reference tracking and disturbance rejection, once the discrete model of the plan is known and the desired closed loop polynomial is chosen.[14]

2.5.1 Discrete Time Integrals and Derivatives

- Discrete Time Integrals

$$\int_0^k y(t)dt = y(k) \approx y(k-1) + \frac{f(k) + f(k-1)}{2} * T_s \tag{2.34}$$

- Discrete Time Derivatives

$$y(k) \approx \frac{f(k) - f(k-1)}{T_s} \tag{2.35}$$

2.5.2 z-Transform

$$X[z] = \mathcal{Z}x[k] = \sum_{k=0}^{\inf} x[k]z^{-k} \tag{2.36}$$

$$z = A \exp j\theta \tag{2.37}$$

Time shifting property:

$$\mathcal{Z}x[k-n] = z^{-n}X[z] \tag{2.38}$$

Where $\mathcal{Z}x[k] = X[z]$

2.5.3 RST Controller Design

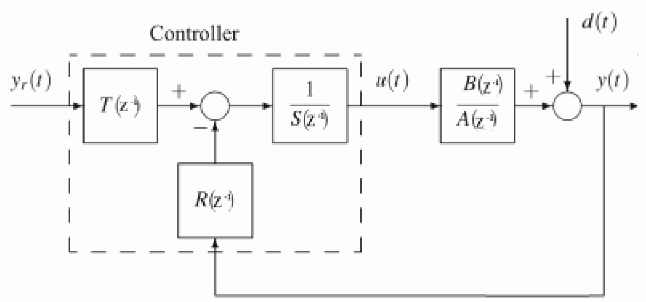


Figure 2.6: Structure of RST controller[14]

A plan controlled by a digital RST regulator is composed by the scheme illustrated in Fig 2.6. A(z) and B(z) are the system polynomials; R(z), S(z) and T(z) controller polynomials their degree ns, nr et nt respectively. They have the form:[14]

$$\begin{aligned} R(z^{-1}) &= r_0 + r_1 z^{-1} + 1...r_{nr} z^{nr} \\ S(z^{-1}) &= s_0 + s_1 z^{-1} + 1...s_{ns} z^{ns} \\ T(z^{-1}) &= t_0 + t_1 z^{-1} + 1...r_{nt} z^{nt} \end{aligned} \tag{2.39}$$

The existence of RST controllers depends on the constraints on polynomial degrees The control design consists in determining the R, S and T polynomials of digital regulator that ensures desired performance for the closed-loop system using the controller specified by the equation (2.39)[14]

$$G_{cl}(z^{-1}) = \frac{T(z^{-1})B(z^{-1})}{A(z^{-1})S(z^{-1}) + B(z^{-1})R(z^{-1})} = \frac{P(1)B(z^{-1})}{B(1)P(z^{-1})} \tag{2.40}$$

in which $B(z^{-1})$ contains the plant zeros that will remain unchanged . $P(z^{-1})$ defines the desired closed loop poles and the term $\frac{P(1)}{B(1)}$ is introduced in order to ensure a unit gain between the reference and the output in steady state .Since $S(1) = 0$ which implies $P(1) = B(1)R(1)$. Then $T(z^{-1})$ will be a gain equal to the sum of the coefficient of $R(z^{-1})$. The only difference from RST controller is that now $T(z^{-1}) = R(1)$ instead of $R(z^{-1})$, there by preserving the unitary gain of the closed loop system in steady state without however introducing the effect of the zeros of $R(z^{-1})$.The coefficients of$R(z^{-1})$ and $S(z^{-1})$ will be calculated in the same way as for the PI controller by specifying the polynomial $P(z^{-1})$ such that: [14]

$$P(z^{-1}) = A(z^{-1})S(z^{-1}) + B(z^{-1})R(z^{-1}) \tag{2.41}$$

2.5.4 Discrete TF of PID

$$\frac{U[z]}{E[z]} = K_p + K_i \frac{T_s}{2} \frac{z+1}{z-1} + K_d \frac{z-1}{zT_s} \tag{2.42}$$

$$\frac{U[z]}{E[z]} = \frac{K_p(z^2 - z) + K_i \frac{T_s}{2}(z^2 + z) + \frac{K_d}{T_s}(z^2 - 2z + 1)}{z^2 - z} \tag{2.43}$$

$$\frac{U[z]}{E[z]} = \frac{(K_p + K_i \frac{T_s}{2} + \frac{K_d}{T_s})z^2 + (-K_p + K_i \frac{T_s}{2} - \frac{2K_d}{T_s})z + \frac{K_d}{T_s}}{z^2 - z} \tag{2.44}$$

$$U[z] = z^{-1}U[z] + aE[z] + bz^{-1}E[z] + cz^{-2}E[z] \tag{2.45}$$

$$u[k] = u[k-1] + ae[k] + be[k-1] + ce[k-2] \tag{2.46}$$

$$a = (K_p + K_i \frac{T_s}{2} + \frac{K_d}{T_s}) \tag{2.47}$$

$$b = (-K_p + K_i \frac{T_s}{2} - \frac{2K_d}{T_s}) \tag{2.48}$$

$$c = \frac{K_d}{T_s} \tag{2.49}$$

2.6 Conclusion

We used a model that takes into consideration the behaviour of the battery and the parasitic and thermal phenomena because it is any change in the energy output it may cause real change in the response of system .

Also we made the most commonly DC motor model with all the relation of torques and EMF that he took from the power supply and her relationship with the speed ω that we need to change .

We used the buck converter because we need the control the EMF coming from the battery and made it variable to maintain the desired speed reference .

The RST controller provides a robust control for reference tracking and disturbance rejection , we define his relationship in discrete-time domain and we extracted the three variable we need to change the controller behavior to the system .

Chapter 3

Experimental Validation

3.1 Introduction

To understand the behavior of the speed response under a closed loop we need to see the response system to a specific input and comparing the result with other input to see what the changing do to his behavior , the changing it can be on the reference or the controller variables , that what this chapter is all about .We change the reference speed and we change the values of the resistive torque also the variables of the RST a,b and c ,to see the speed, stability and precision .We used arduino MEGA as a microcontroller to implement the control system and achieve a speed control closed loop .

3.1.1 General Experimental Circuit

We will present a diagram of Circuit with each elements .We use Arduino Mega 2560 based on the ATmega2560 ,Bühler DC Motor 24V/3A with high-quality electric drive technology , a lead-acid battery 24v , Darlington transistors TIP121, the devices are manufactured in planar technology with layout and monolithic Darlington configuration with high gain performance coupled with very low saturation voltage.

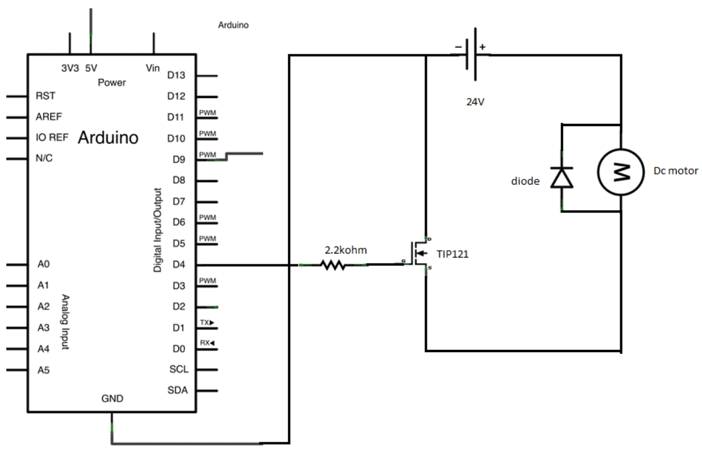


Figure 3.1: A Diagram of the Experimental Circuit

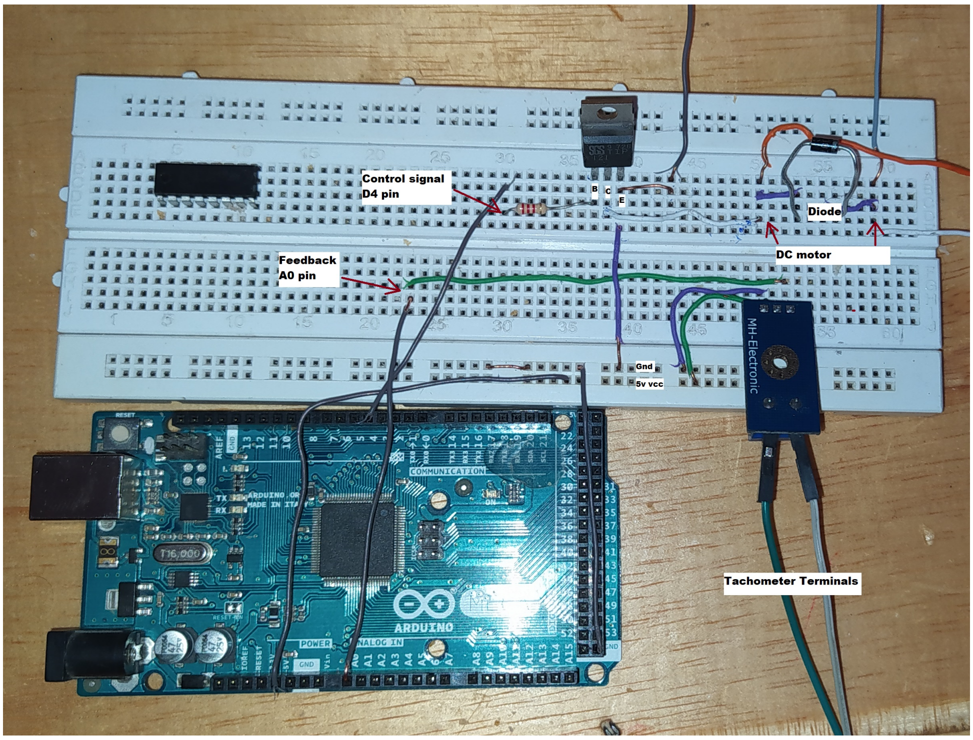


Figure 3.2: The Practical Circuit

3.1.2 Tests

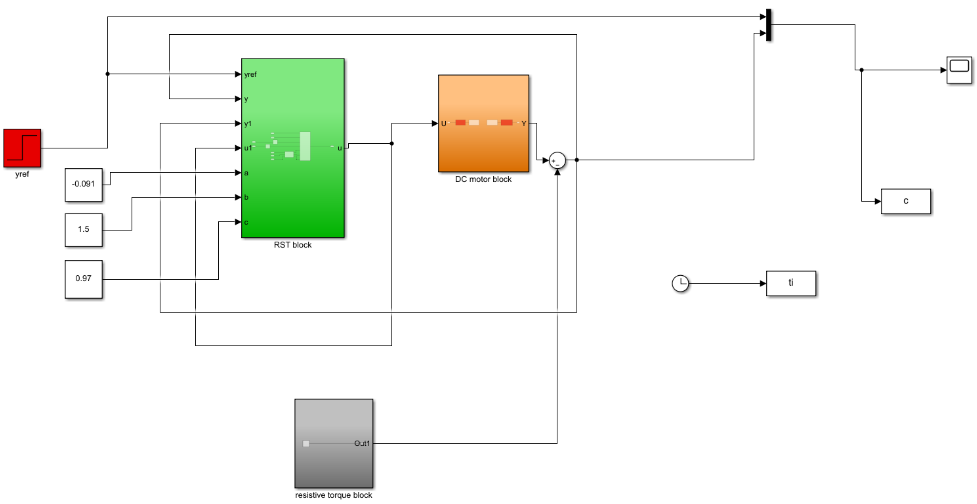


Figure 3.3: Simulink Block

identification :
After determining the response of the system, we move on to the determination of the transfer function G (s) . see Appendix A

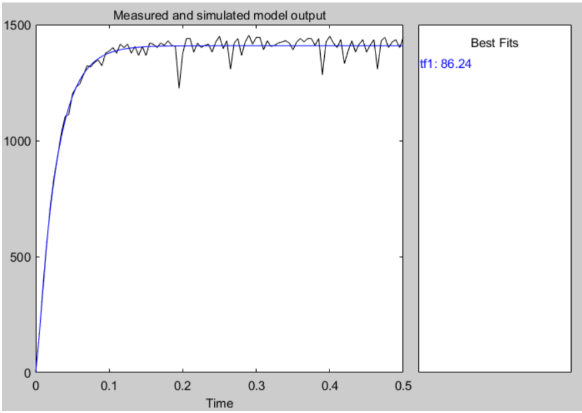
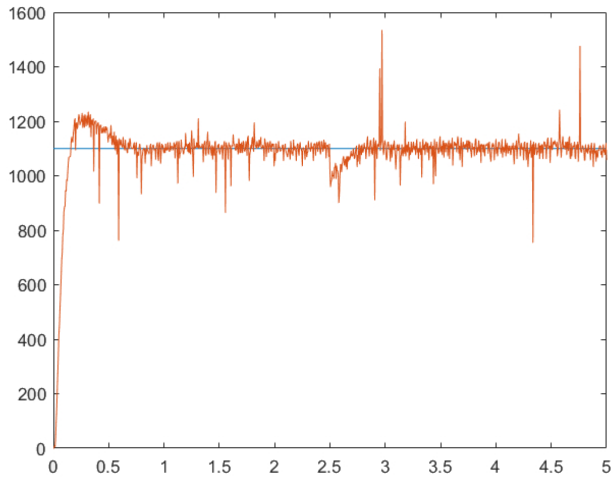
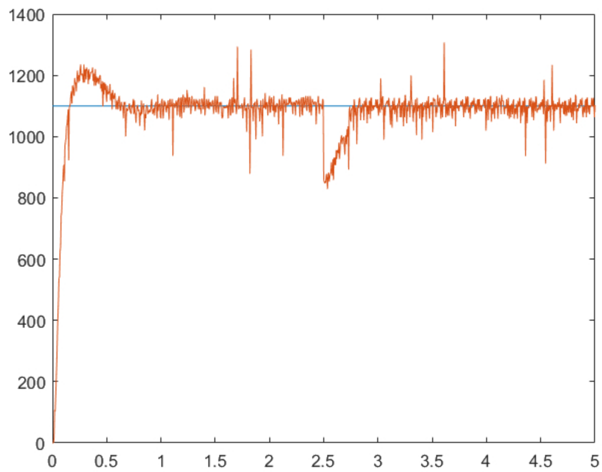


Figure 3.4: Curve fitting approximation

Speed tests :



(a) 1100 Rpm , Tr=0.193Nm

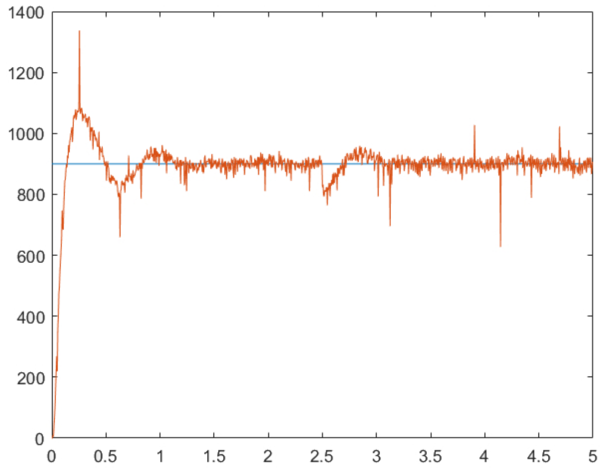


(b) 1100 Rpm , Tr=0.4825Nm

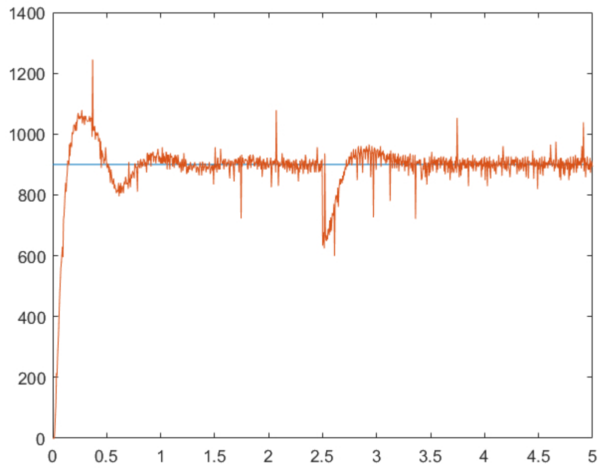
Figure 3.5: 1100 Rpm , Tr=changing

We carried out experiments at different speeds with presence of a different resistive torque , And variable values of RST controller, We extracted the results presented above.

Notes and commentary : We set (1100 Rpm) as a speed reference with a resistive torque of (0.193/0.4825 Nm) applied in (2.5 s) .We can see :**Rise time** 0.23s with peak oscillation amplitude of 100 rpm shifted away from the reference.**Peak time** 0.37s. **The response system** reach the stabilisation to the reference after 0.75s.in (2.5s) we noticed that the response return to follow the reference on a (0.5s) delay . We can said that this response is slightly acceptable .



(a) 900 Rpm , Tr=0.193Nm

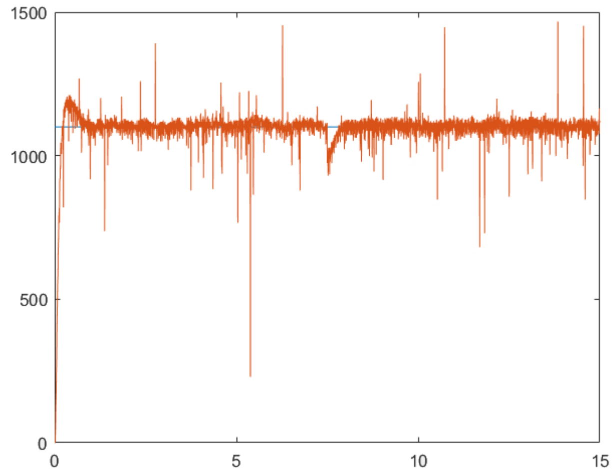


(b) 900 Rpm , Tr=0.4825Nm

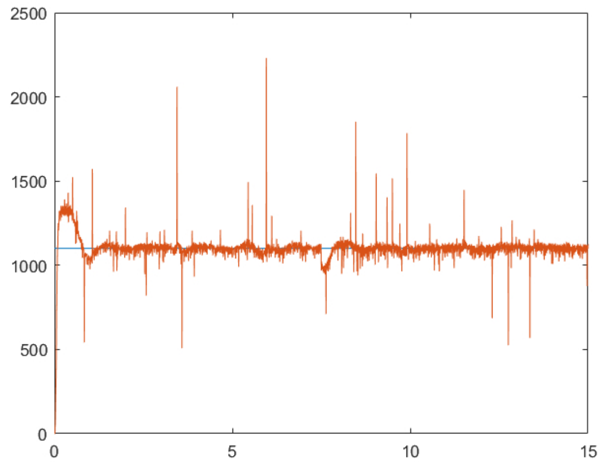
Figure 3.6: 900 Rpm , Tr=changing

Notes and commentary : We set (900 Rpm) as a speed reference with a resistive torque of (0.193/0.4825 Nm) applied in (2.5 s) .We can see :**Rise time** 0.13s with peak oscillation amplitude of 190 rpm shifted away from the reference.**Peak time** 0.25s.**The response system** reach the stabilisation to the reference after 1s. in (2.5s) we noticed that the response return to follow the reference on a (1.4s) delay.We can said that this response is slightly more oscillated than the previous due the decreasing of speed .

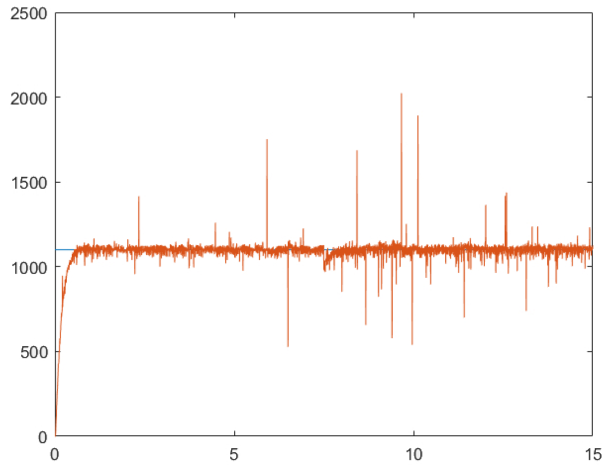
- Tests of the RST controller parameters:



(a) a=-0.091



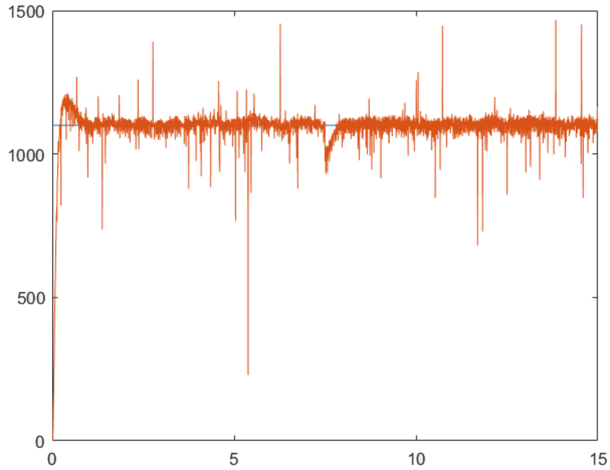
(b) a=1.8



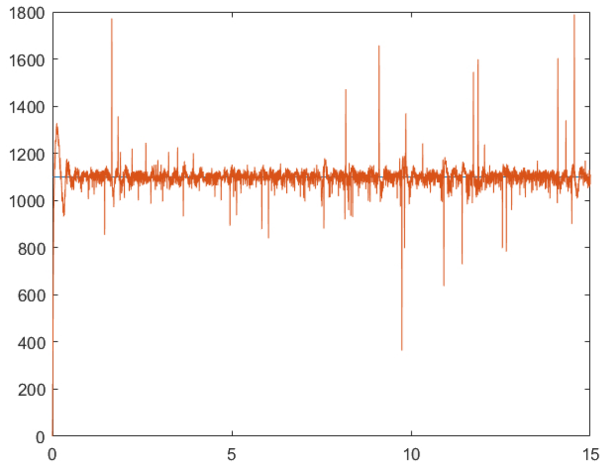
(c) a=-2

Figure 3.7: a=changing b=1.5 c=0.91

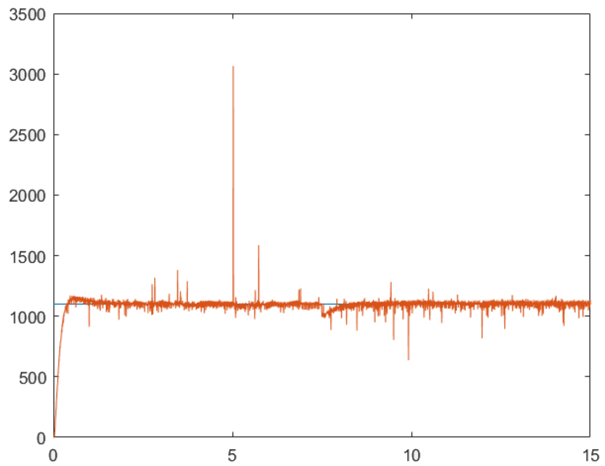
Notes and commentary : We changing the (a) parameter and we see its behavior on peak,rise and response time .if we decreased (a) value the oscillation is completely disappearing with slightly increasing in Rise time.if we increased (a) value , we see more oscillation but we can notice that the rise and the peak time is decreasing .



(a) b=1.5



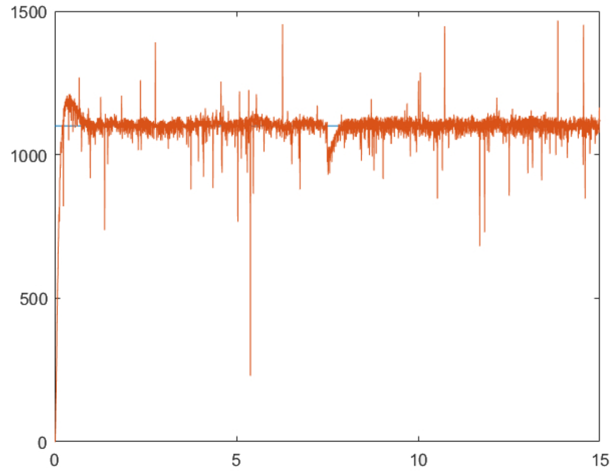
(b) b=0.1



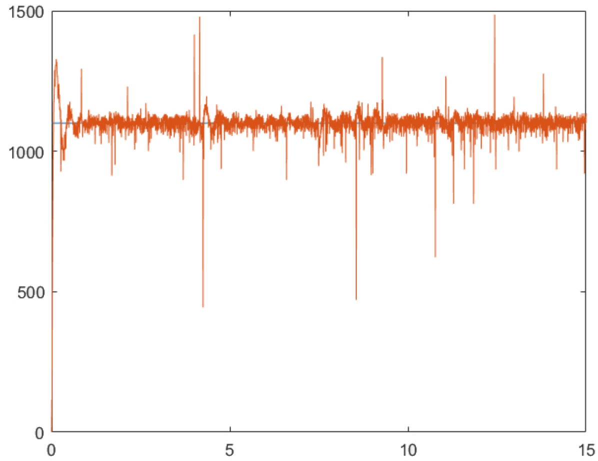
(c) b=3

Figure 3.8: a=-0.091 b=changing c=0.91

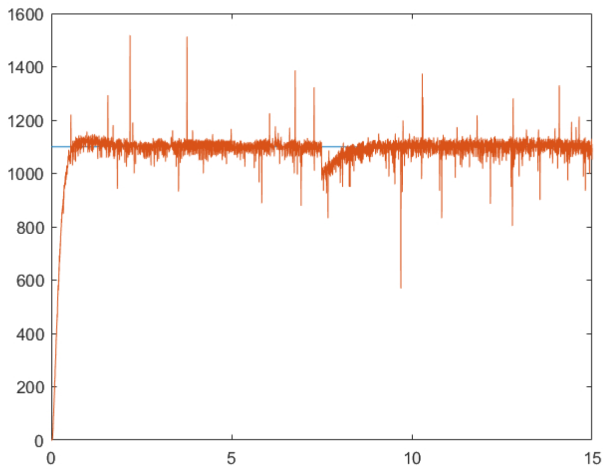
Notes and commentary : We changing the (b) parameter and we see its behavior on peak,rise and response time .if we decreased (b) value the oscillation is decreasing with slightly increasing in Rise and Peak time .if we increased (b) value , we see more oscillation but we can notice that the rise and the peak time is hugely decreasing .



(a) c=0.91



(b) c=0.3



(c) c=0.97

Figure 3.9: a=-0.091 b=1.5 c=changing

Notes and commentary : We changing the (c) parameter and we see its behavior on peak,rise and response time .if we decreased (c) value the oscillation is decreasing with slightly increasing in Rise and Peak time .if we increased (c) value , we see more oscillation but we can notice that the rise and the peak time is hugely decreasing .the only difference we noticed from changing (b) that the peak of the first oscillation is slightly small .

3.2 Conclusion

It's impossible to reach to an ideal response combine the speed and the precision but we can reach a perfect response with an experiments and decided what we favor for our uses . this is a key thing in the control system domain .

we found out that for this system the best RST controller values (a=-0.091 b=1.5 c=0.91), this values insure a fast and precision with no oscillated speed response.

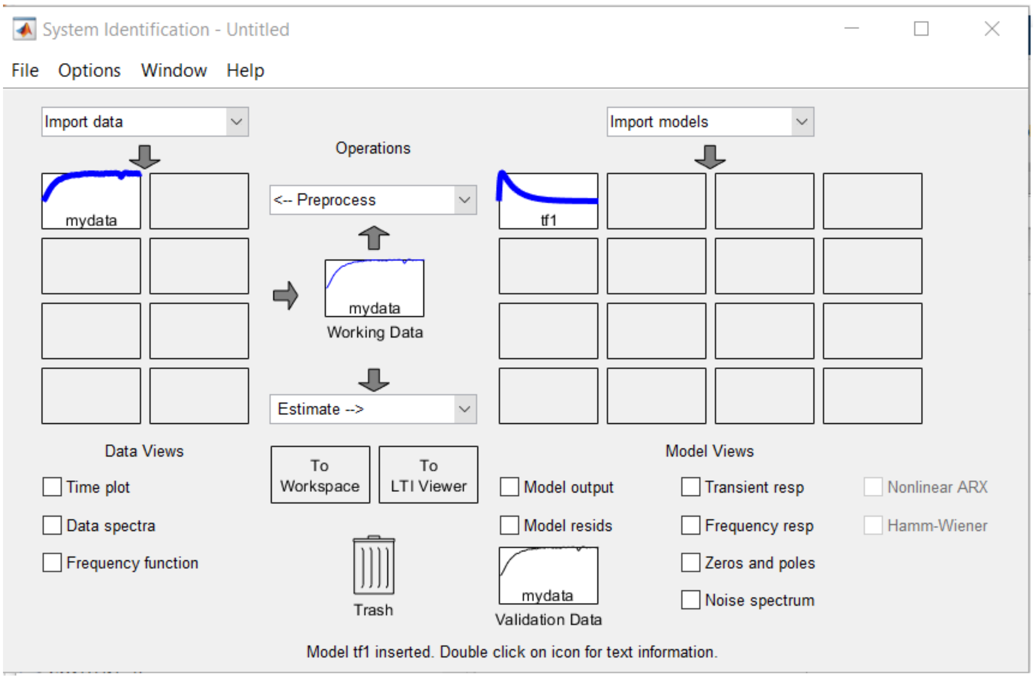
Chapter 4

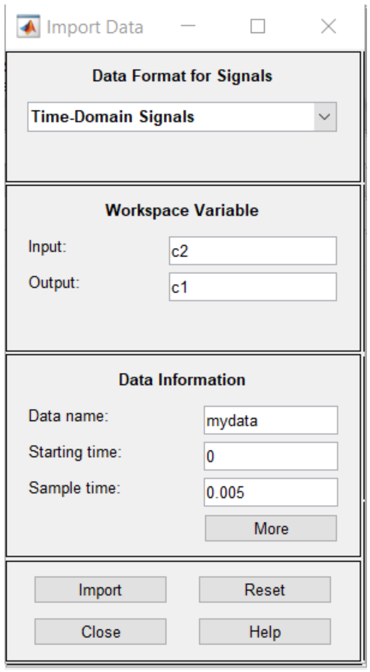
Conclusion

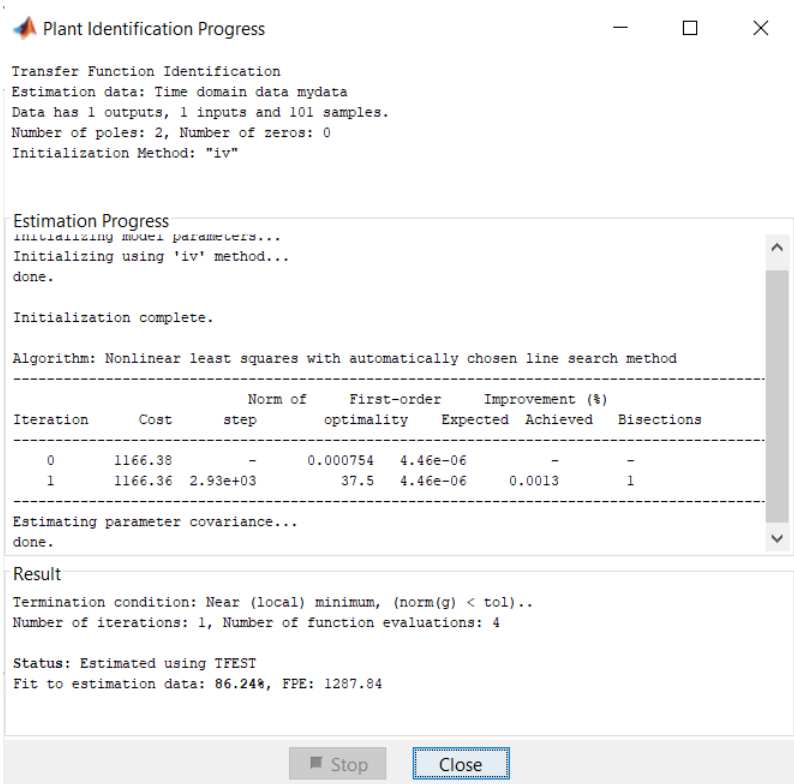
Through this work, the control of the EV's traction system have been presented . The kinematic and energy description of the EV power and drive trains are considered as first step to understand and model the EV system. The similarities and comparison between different pure and hybrid EV architectures and their drive-trains were discussed. Also, we study the used supply sources in the EV's. we introduce a mathematical modeling of the EV traction system part by part from the used power supply the lead-acid battery , we modeled the DC motor and the different chopper converters . Also we chose The RST discrete-time controller and made it clear from mathematical purpose. the main goal was to make a reduced scale of EV and control her speed with RST controller based on ARDUINO Mega microcontroller and the real-time matlab/simulink interfacing , we reached our goal by presenting an experimental validation of electric vehicle traction system with several cases of speed response system and we showed the behavior of each parameter and we made a conclusion that "**it's impossible to reach to an ideal response combine the speed and the precision but we can reach a perfect response with an experiments and decided what we favor for our uses** "

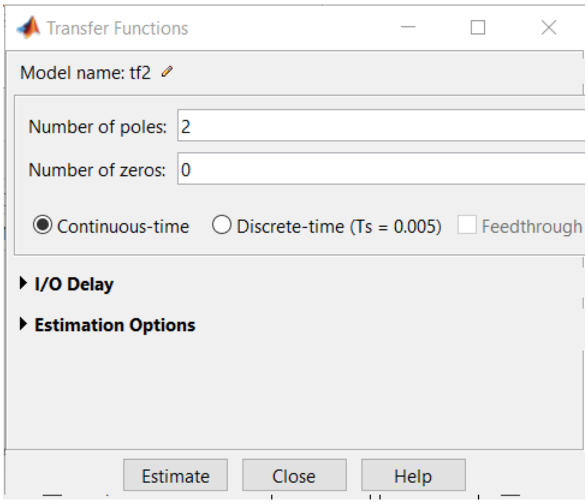
Appendix A

Identification blocks




Import Data
Data Format for Signals
Time-Domain Signals
Workspace Variable
Input:
c2
Output:
c1
Data Information
Data name:
mydata
Starting time:
0
Sample time:
0.005
More
Import
Reset
Close
Help


Plant Identification Progress
Transfer Function Identification
Estimation data: Time domain data mydata
Data has 1 outputs, 1 inputs and 101 samples.
Number of poles: 2, Number of zeros: 0
Initialization Method: "iv"
Estimation Progress
Initializing using 'iv' method...
done.
Initialization complete.
Algorithm: Nonlinear least squares with automatically chosen line search method
Iteration Cost Norm of step First-order optimality Improvement (%) Expected Achieved Bisections
0 1166.38 - 0.000754 4.46e-06 - -
1 1166.36 2.93e+03 37.5 4.46e-06 0.0013 1
Estimating parameter covariance...
done.
Result
Termination condition: Near (local) minimum, (norm(g) < tol)..
Number of iterations: 1, Number of function evaluations: 4
Status: Estimated using TFEST
Fit to estimation data: 86.24%, FPE: 1287.84
Stop
Close


Transfer Functions
Model name: tf2
Number of poles: 2
Number of zeros: 0
Continuous-time
Discrete-time (Ts = 0.005)
Feedthrough
I/O Delay
Estimation Options
Estimate
Close
Help

Appendix B

Arduino MEGA

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 . It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. see figure B.1

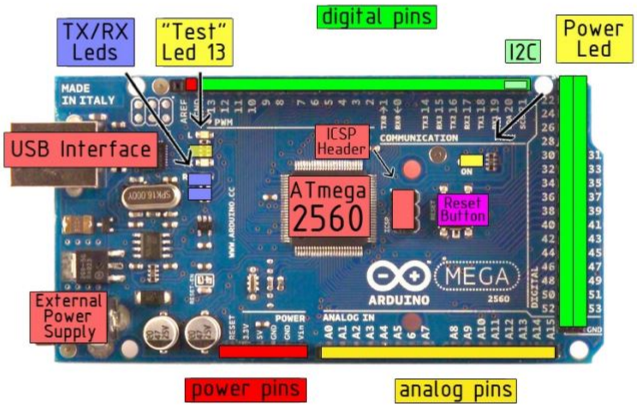


Figure B.1: Arduino MEGA 2560

Appendix C

Project parts

DC Motor
buhler DC motor is powered by a 24V with 3A nominal current .

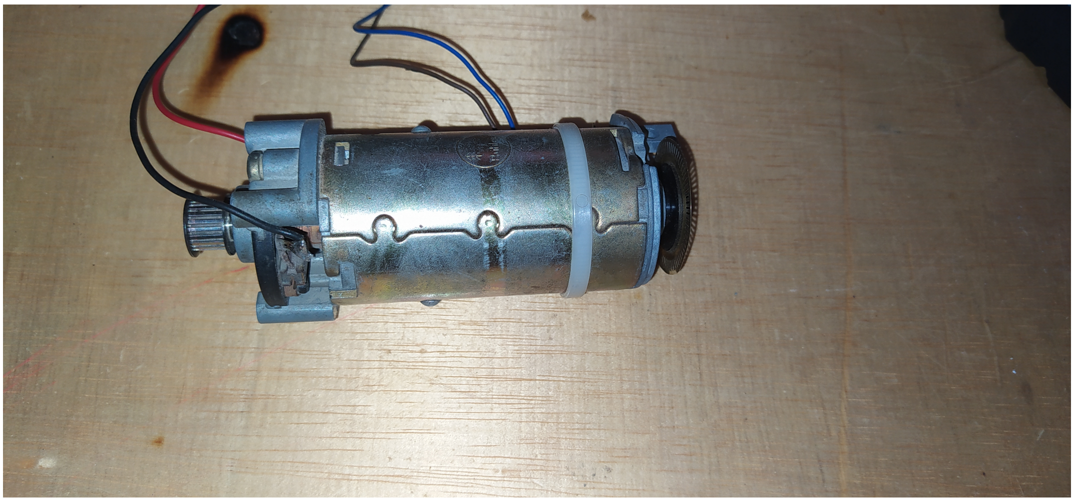


Figure C.1: DC Motor

Transistor TIP121
It is a Darlington NPN transistor which can amplify the current up to 5A with its amplification gain at least $\beta = 1000$ according to the data sheet, it has three legs: Base, Collector, Emitter.[1]

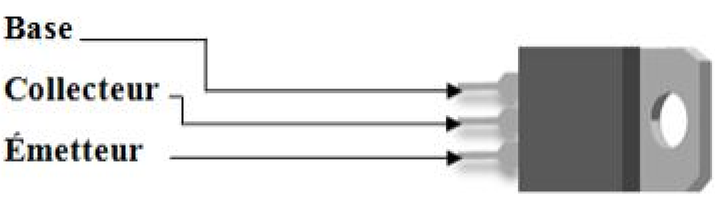


Figure C.2: Transistor TIP121

Lead-acid Battery

Figure C.3: Lead acid Battery

Bibliography

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