DESIGN OF FUZZY CONTROLLER OF INDUCTION MOTOR FOR ELECTRIC VEHICLE APPLICATION

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ABSTRACT

Variable speed drives are growing, varying and consuming energy at the same time. From this response, the vehicle's explicit capabilities as well as its contribution to the system performance of the driver/vehicle combination are obtained. Two different controllers, a conventional controllers and artificial intelligence for an electric vehicle (EV) are developed in this project to control the vehicle, namely a PI controller and a Fuzzy Logic Controller (FLC). Artificial intelligent has found high application in most nonlinear systems same as motors drive. On top of that artificial intelligent techniques can use as controller for any system without requirement to system mathematical model. Thus the performances of the aforesaid two controllers have been studied extensively in this project. For achieving an improved response, parameters of both the PID and FLC have been tuned and their performances have been compared. Further, the effect of major components power consumption response is also presented. To validate the above two control performances, a nonlinear simulation model of an EV is developed and is used in the simulation studies. Both the controllers track the desired directional signal efficiently. Both PI and Fuzzy controllers provide competitive performances. Although with the assumption of all parameters of the vehicle available PID controller exhibits slightly better dynamic performance but in the real-world scenario the fuzzy controller is preferred due to its robustness i.e. it does not depend on the parameters of the vehicle.

ABSTRACT

Kelajuan yang semakin bertambah, yang berbeza-beza dan memakan tenaga pada masa yang sama. Dari jawapan ini, keupayaan jelas kenderaan serta sumbangannya kepada prestasi sistem daripada kombinasi pemandu / kenderaan diperolehi. Dua pengawal yang berbeza, pengawal konvensional dan kecerdasan buatan untuk kenderaan elektrik (EV) disediakan dalam kertas ini untuk mengawal kenderaan itu , iaitu pengawal PI dan Pengawal Logik Fuzzy (FLC). Buatan pintar telah mendapati permohonan yang tinggi dalam kebanyakan sistem tak linear sama seperti motor memandu. Selain itu, teknik buatan pintar boleh digunakan sebagai pengawal untuk semua system tanpa memerlukan system model matematik. Oleh itu, persembahan yang dinyatakan di atas dua pengawal telah dikaji secara meluas dalam kertas ini. Untuk mencapai tindak balas yang lebih baik , parameter kedua-dua PID dan FLC telah ditala dan persembahan mereka telah dibandingkan . Selanjutnya, kesan utama sambutan penggunaan kuasa komponen juga dibentangkan. Untuk mengesahkan di atas dua persembahan kawalan , satu model simulasi tak lelurus EV satu dibangunkan dan digunakan dalam kajian simulasi . Kedua-dua pengawal menjejak isyarat arah yang dikehendaki dengan cekap . Kedua-dua PI dan pengawal Fuzzy memberikan persembahan yang kompetitif. Walaupun dengan andaian semua parameter bagi kenderaan yang ada pameran pengawal PID lebih baik sedikit dinamik prestasi tetapi dalam senario dunia sebenar pengawal kabur lebih disukai kerana keberkesanannya iaitu ia tidak bergantung kepada parameter kenderaan.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF PROJECT

An electric car is an automobile propelled by one or more electric motor powered by batteries or another energy storage device. It has become more popular lately due to growing concern over problems associated with environment pollution caused by fuelled vehicle emission and increasing in oil price worldwide. On the other hand, electric vehicle also benefits in term of cleaner vehicle technologies that helps everyone breathe easier, cut down greenhouse gas emissions and reduce our dependence on oil (wevaonline.net, retrieved on 10 Jun 2013).

The major components of an electric vehicle system are the electric motor, controller, power supply, charger and drive train [1]. Figure 1 shows the basic components in an electric vehicle. It begins with the electric motor to drive the vehicle. The electric motor gets its power from a controller but the controller gets its power from an array of rechargeable batteries. There are many types of batteries and depends on the batteries, the distance an electric vehicle can goes is vary. The distance is also depends on the controller used in the electric vehicle. Controller is the heart of an electric vehicle and the key for the realization of a high performance electric vehicle with an optimal balance of maximum speed, acceleration performance and travelling range per charge [2]. Therefore, the controller that should be designed is not only for the performance of the vehicle but also for the energy management of the batteries on the vehicle.

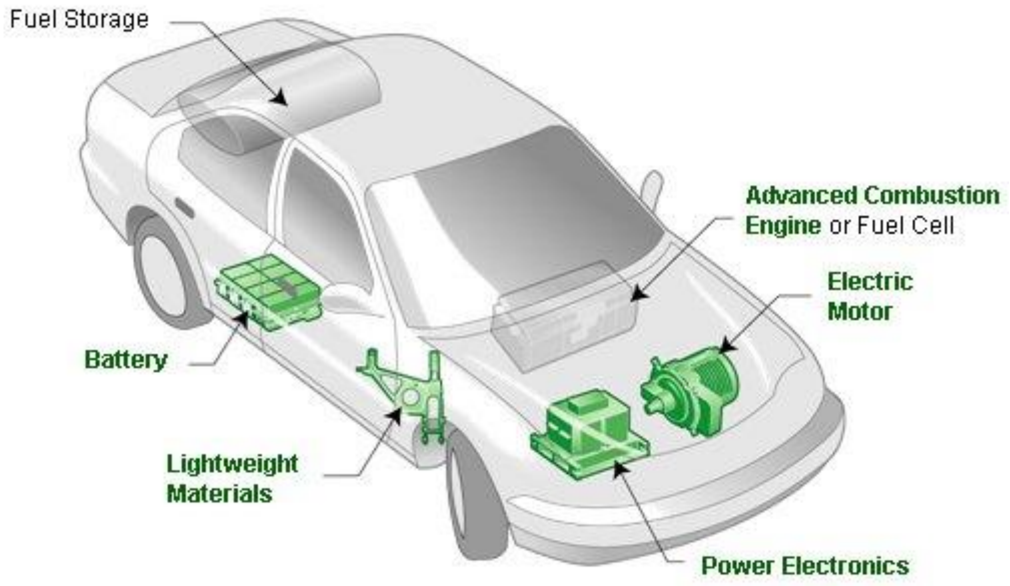

Figure 1.1: Basic components in electric vehicle

Conventional controller such as Proportional Integral (PI), Proportional Derivative (PD) or Proportional Integral Derivative (PID) offers very efficient solution, robust and reliable control. The only problem associated with use of conventional PI, PD and PID controllers in speed control of induction motor is the complexity in design arising due to the non-linearity of induction motor dynamics and also due to other components in electric vehicle. The conventional controllers have to linearize the non-linear systems in order to calculate the parameters [3]. The usual method of computation of mathematical model of the induction motor is difficult, due to the non-linearity of motor dynamics. Whenever a variation in system or ambient parameter arises, the system's behaviour becomes non-pleasing. The conventional controllers designed to provide high performance increase the design complexity along with the cost. To obtain a perfect non-linear model is almost impossible and hence the values of the parameters that are obtained from it are thereby approximate. The conventional control methods possess the following difficulties:

1. Dependence on the exactness of the mathematical model of the system that usually is unknown [5, 6].

2. Expected performance not being met due to the load disturbance [7], motor saturation [7, 6] and thermal deviation [6].
3. Adopting the right coefficients for acceptable results [8].

From the above, it can be concluded that in order to implement conventional controller, it is necessary to have knowledge of the system's model and all parameter that is needed to be controlled. Due to complex operation condition of electric vehicle, intelligent controller is used to increase efficiency and deal with complex operation modes [9, 10]. There are many artificial intelligence controllers that are widely used and they are:

1. Fuzzy Logic Controller (FLC)
2. Fuzzy-Neural Network (FNN)
3. Neuro Network (NN)
4. Genetic Algorithm (GA)

Fuzzy Logic Controller is being used in most complicated application nowadays since many recent and future applications are based on non-linear model. Thus, to overcome the complexities of conventional controllers, fuzzy control has been implemented in many motor applications [11]. In term of performance, FLC have faster and smoother response than conventional systems. Fuzzy control has emerged as one of the fruitful areas of research especially in industrial processes as it does not rely on conventional methods that lack of quantitative data. Fuzzy logic provides interference structure that enables appropriate human reasoning capabilities. Fuzzy logic controller has the capability to control nonlinear, uncertain systems even in case where no mathematical model is available for the control system. So with these characteristics, combine with robust conventional controller, PI Fuzzy will result a better solution in controlling an electric vehicle. A good control strategy and controller design will develops multiple characteristics such as fast rise time, minimum overshoot and minimum steady state error. In other words, a good performance is achieved.

So far, there is no evidence suggested universal agreement in regard to which motor or machine should be used in electric vehicle [12]. Motors like DC motor, Brushless DC motor (BLDC), Permanent Magnet Synchronous Motor (PMSM), Induction Motor etc have been put into operation. But the most commonly used in this application is induction motor. Some research even concludes that induction machine provides better overall performances compared to other machines [13]. Induction motors have many advantages compared to DC motor in many aspects such as size, efficiency, life span and maintainability. Other advantages that induction motor are simple construction and control, robustness, high reliability and low cost but the main advantage is that induction motor do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors [14]. Low cost and ease of manufacturing have made induction motor a good choice for electric vehicles.

1.2 PROBLEM STATEMENT

Different from Internal Combustion Engine (ICE) that gets supply from oil, an Electric Vehicle (EV) gets supply from a battery. Battery has it issue in terms of:

- Driving range
- Recharge time
- Battery cost
- Size & weight

The brain that decides power consumed by the vehicle is the controller and many electric vehicle manufacturers is still using conventional controller. Although conventional controller used in electric vehicle nowadays is already robust and reliable [15, 16], but in the same time it consume a lot of energy to operate it. When a lot of energy was consumed, the distance an electric vehicle can achieved is limited, more time needed to recharge. People tend to find other alternatives of battery but this will option to bigger size & weight and cost more. So to solve this problem, an artificial intelligence controller is introduced that is Fuzzy controller to make the controller more energy efficient thus resulted for more distance to be driven.

1.3 AIM AND OBJECTIVES OF THE RESEARCH

The development of model and control strategy of fuzzy controller of Induction Motor for electric vehicle application is the aim of this project. To achieve this aim, the objectives of this research are formulated as follows:

1. To develop a controller based on artificial intelligence by using existing model of induction motor.
2. To compare the performance of the conventional controller and newly developed controller in terms of response and power consumption.

1.4 SCOPE OF RESEARCH

The research will be focused on the induction motor for electric vehicle application. The controller will be based on artificial intelligence technique especially fuzzy logic controller. The performance of the controller will be evaluated on motor energy efficiency. The simulation study has been carried out on Matlab/Simulink platform.

1.5 THESIS OUTLINE

This thesis contained five chapters. Chapter 2 gives a detailed overview on basic components of electric vehicle such as the principle and basic knowledge of the electric motor used in this project that is the induction motor. In this topic also will explain surface idea on Fuzzy Logic Controller, FLC regarding how it works and the component needed. The previous successful work done by other people related to this subject is also explained.

Chapter 3 presents the methodology used in order to make this project successful. This is also included on more detailed explanations on fuzzy logic design, features and functioning.

Chapter 4 presents the simulation result along with discussions on speed control of induction motor drives. The power consumption for the electric vehicle is also discussed and presented.

Chapter 5 presents the conclusion and recommendations for future enhancements.

1.6 PROJECT PLANNING

1.6.1 Gantt Chart

Figure 1.2 shows the Gantt chart of overall project with estimated time to finish the whole project takes around 12 months.

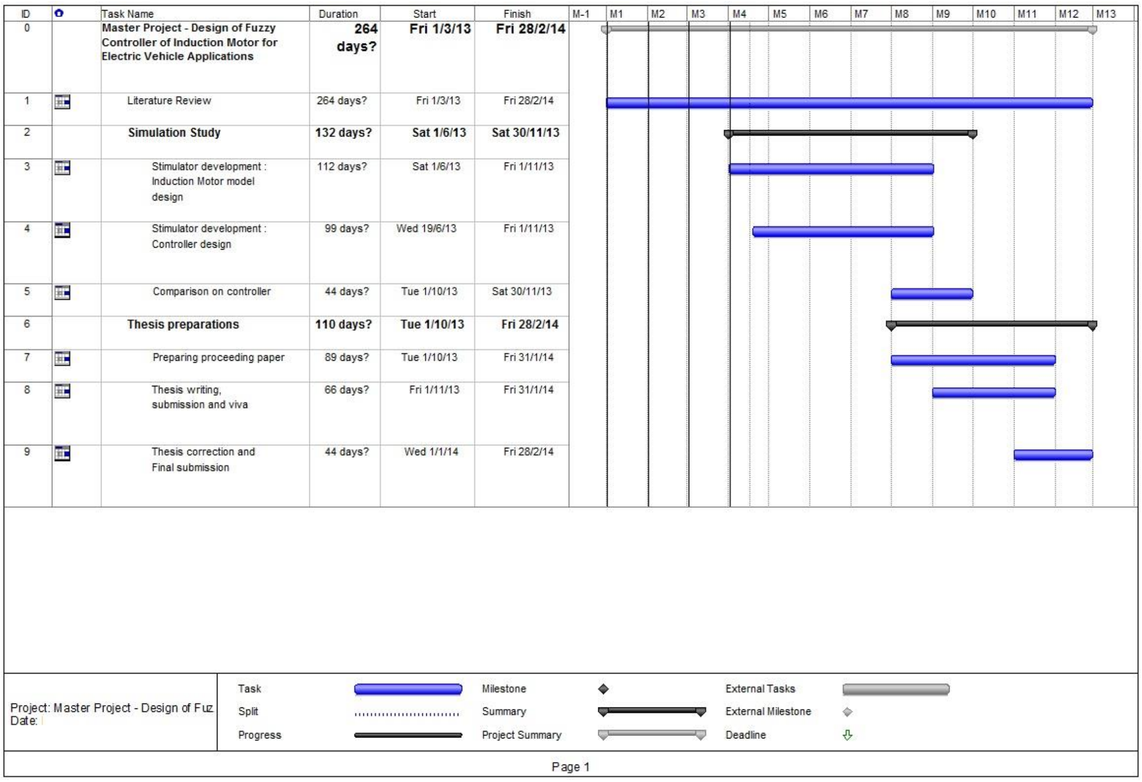

Figure 1.2: Project Gantt Chart

CHAPTER 2

A BRIEF REVIEW ON PREVIOUS RESEARCH

2.1 INTRODUCTION

M. King Hubbert created and first used the models behind peak oil in 1956 to accurately predict that United States oil production would peak between 1965 and 1971 [17]. His logistic model, now called Hubbert peak theory as shown in figure 2.1, and its variants have been used to describe and predict the peak and decline of production from regions, and countries [18] and have also proved useful in other limited-resource production-domains. According to the Hubbert model, the production rate of a limited resource will follow a roughly symmetrical logistic distribution curve based on the limits of exploitability and market pressures. In other words, oil production and drilling would suffocate in the near future. Over this concern, electric vehicle was introduced to overcome this problem. As time goes by, a lot of improvement has been introduced. Two main components to achieve these goals are the electric motor and the controller. In this paper, the proposed electric motor is the induction motor.

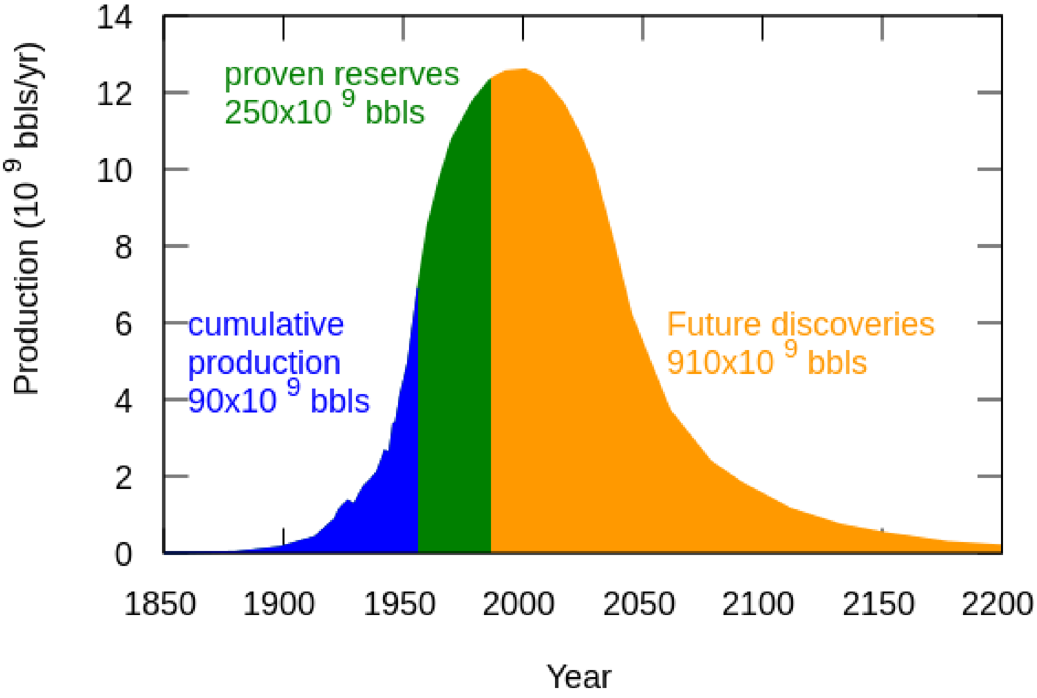

Figure 2.1: Hubbert peak oil plot, (photo courtesy of M. King Hubbert 1956)

2.2 INDUCTION MOTOR

2.2.1 Construction and Operation

Like any other electric motor, a three phase induction motor also have two main parts namely stator and rotor. The stator of an induction motor is a stationary part of induction motor. It is made up of number of stampings, which are slotted to receive the windings. The three phase windings are placed on the slots of laminated core and these windings are electrically spaced 120 degrees apart as shown in figure 2.2. These windings are connected as either star or delta depending upon the requirement. The leads are taken out usually three in number, brought out to the terminal box mounted on the motor frame. The insulation between the windings is generally varnish or oxide coated.

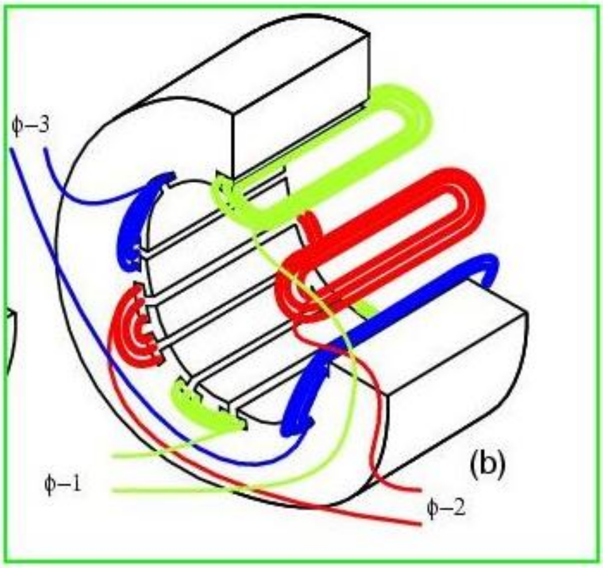

Figure 2.2: Stator construction of Induction Motor

As for rotor, it is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft. The rotors are further classified as squirrel cage rotor and wound rotor or phase wound rotor. Squirrel cage rotor is a cylindrical in shape and has slots on its periphery. The rotor conducting bars are usually not parallel to the shafts but are purposely given slight skew. The squirrel cage rotor consists of aluminum, brass or copper bars. These aluminum or copper bars are called rotor conductors and are placed in the slots on the periphery of the rotor. The rotor conductors are permanently shorted by the copper or aluminum rings called the end rings. In order to provide mechanical strength these rotor conductor are braced to the end ring and hence form a complete closed circuit resembling like a cage and hence got its name as ‘squirrel cage induction motor”. Figure 2.3 shows the construction of squirrel cage rotor. While wound rotor is wound for the same number of poles as that of stator but it has less number of slots and has less turns per phase of a heavier conductor. The rotor also carries star or delta winding similar to that of stator winding. The rotor consists of numbers of slots and rotor winding are placed inside these slots. The three end terminals are connected together to form star connection. As its name indicates three phase slip ring induction motor consists of slip rings connected on same shaft as that of rotor. Figure 2.4 shows the construction of wound rotor.

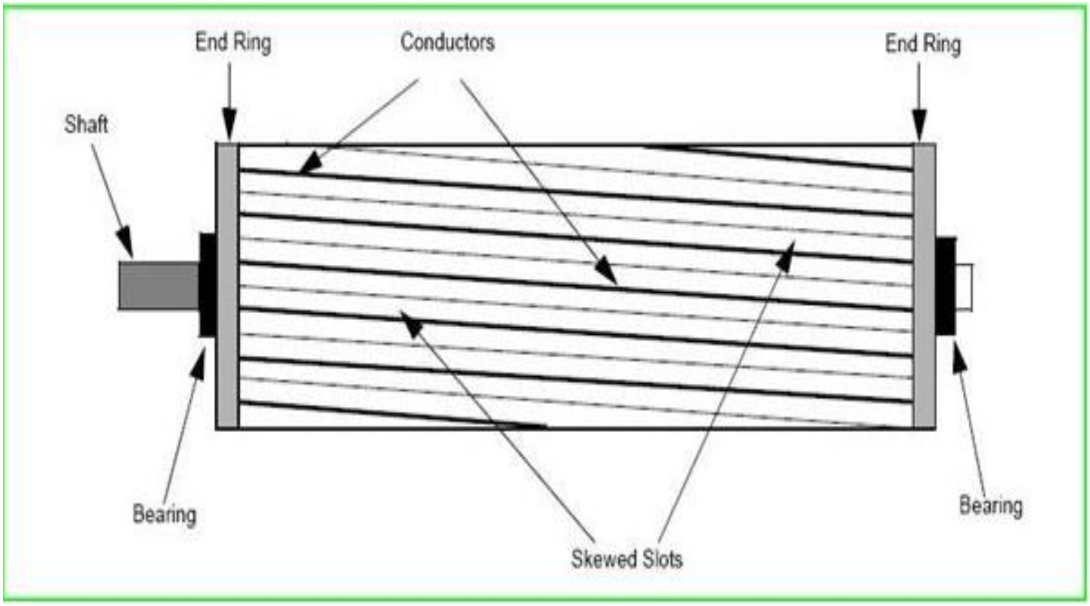

Figure 2.3: Squirrel Cage Rotor constructions, (photo courtesy of www.tpub.com retrieved on 29 Nov 2013)

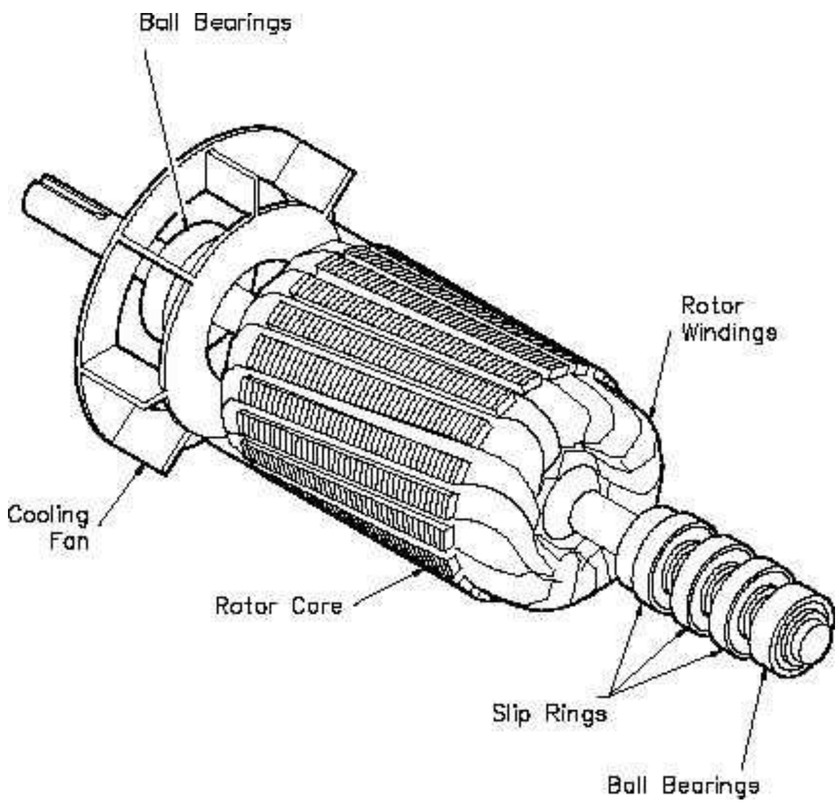

Figure 2.4: Wound Rotor constructions, (photo courtesy of www.tpub.com retrieved on 29 Nov 2013)

The reason for having skewed rotor is as follow [4]:

1. It helps in reduction of magnetic hum, thus keeping the motor quiet,
2. It also helps to avoid ‘Cogging’, i.e. locking tendency of the rotor. The tendency of rotor teeth remaining under the stator teeth due to the direct attraction between the two,
3. Increase in effective ratio of transformation between stator and rotor.

2.2.2 Principle of Rotating Magnetic Field

When a three phase voltage is applied to the stator winding, a rotating magnetic field is created. It is called a rotating field since its poles do not remain in a fixed position on the stator but go on shifting their positions surrounding the stator. It is also called synchronous because at steady state the speed of the rotor is the same as the speed of the rotating magnetic field in the stator. This field passes through the air-gap and cuts the stationary rotor conductors. Owing to the relative speed between the rotating flux and the static rotor, electromotive forces are induced in the rotor conductors. For the reason that the rotor circuit is short-circuited, currents start flowing in the rotor conductors. These currents interact with the rotating magnetic field created by the stator. As a result, mechanical force acts on the rotor conductors. A torque, produced as a result of this force, tends to move the rotor in the same direction as the rotating field. This is justified by Lenz’s law, according to which the direction of rotor currents will be such that they have a tendency to oppose the cause producing them. Now, the relative speed between the rotating field and the standstill rotor conductors is the cause generating the rotor currents. Thus to reduce this speed, the rotor starts running in the same direction as that of stator field and tries to catch it. Clearly, the rotor speed is always less than the stator field speed.

2.2.3 Applications of Induction Motor in Electric Vehicle

The use of induction motors has increased tremendously since the day of its invention. They are being used as actuators in various industrial processes, robotics, house appliances (generally single phase) and other similar applications. The reason for its day by day increasing popularity can be primarily attributed to its robust construction, simplicity in design and cost effectiveness [19-21]. Induction motors are seen as more rugged electric vehicle application compared to permanent magnet motors which are vulnerable to possible degradation or demagnetization of the magnets due to over-temperature or accidental over-current at power levels over 5kW [22]. Though induction motors have few advantageous characteristics, they also possess nonlinear and time-varying dynamic interactions [23-27], using conventional PI controller, it is very difficult and complex to design a high performance induction motor drive system. The fuzzy logic control (FLC) is attractive approach, which can accommodate motor parametric variations and difficulty in obtaining an accurate mathematical model of induction motor due to rotor parametric and load time constant variations.

2.3 CONTROLLER

There are two main parts in a control system and that is model based and non-model based. Motion control, adaptive structure control and signal processing control are the example of model based control where mathematical model is a must. While non-model based like artificial intelligence does not require the knowledge of the exact mathematical model. In this chapter fuzzy logic controller which one of the artificial intelligence is discusses. Block diagram of Fuzzy logic Controller along with the membership functions, Inference engine and various defuzzification techniques are presented. Fuzzy set theory and operations are also discussed in detail. Below is a few journals that proves Fuzzy logic controller performs better than conventional controllers.

1. Abdullah I. Al-Odienat et al (2008) in the “The Advantages of PID Fuzzy Controllers over the Conventional Types” studied the advantages of fuzzy logic controller over the PID controllers. The voltage raising type-pulse controller is considered. Fuzzy controllers used for the control of boost converter are investigated and proved that fuzzy logic provides fast response times with virtually no overshoot.

2. Ashutosh Mishra (2012) in “Fuzzy Logic Controller for Speed Control of An Induction Motor (IM) using Indirect Vector Control Method” developed and implemented an intelligent controller for speed control of an induction motor (IM) using indirect vector control method. The comparative performance of Fuzzy Logic control technique has been presented and analysed. The present approach avoids the use of flux and speed sensor which increases the installation cost and mechanical robustness. The fuzzy logic controller is found to be useful techniques to obtain a high performance speed control.

3. Mohammed Shoeb Mohiuddin, Mahboob Alam (2013) in “Performance analysis of Fuzzy logic based speed control of DC motor” states that self-tuning FLC has better performance in both transient and steady state response and also has better dynamic response curve, shorter response time, small overshoot, small steady state error, high steady precision compared to the conventional PID controller.

One of the reasons for the popularity of Fuzzy Logic Controllers is its logical resemblance to a human operator. It operates on the foundations of a knowledge base which in turn rely upon the various if then rules, similar to a human operator. Unlike other control strategies, this is simpler as there is no complex mathematical knowledge required. The FLC requires only a qualitative knowledge of the system thereby making the controller not only easy to use, but also easy to design. The basic concepts of PI controllers along with the transfer functions and the block diagram are also being discussed in this chapter.

2.3.1 Introduction to Fuzzy Logic Controller

Fuzzy logic, first introduced by Lotfi A. Zadeh in 1965, embodies human-like thinking into a control system. A fuzzy controller employs a mode of approximate reasoning resembling the decision making route of humans, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions stipulated by membership functions. The conventional Boolean logic has been

extended to deal with the concept of partial truth – truth values which exist between “completely true" and "completely false", and what we shall be referring to as *fuzzy logic.* This is achieved through the concept of degree of membership. The essence of fuzzy logic rests on a set of linguistic if-then rules, like a human operator. It has met a growing interest in many motor control applications due to its nonlinearity handling features and independence of plant modelling. Moreover, the fuzzy logic concepts play a vital role in developing controllers for the plant since it isn’t needy of the much complicated hardware and all it necessitates are only some set of rules.
The advantages provided by a FLC are listed below [30]:

- It is simple to design
- It provides a hint of human intelligence to the controller.
- It is cost effective.
- No mathematical modelling of the system is required.
- Linguistic variables are used instead of numerical ones.
- Non-linearity of the system can be handled easily.

These advantages allow fuzzy controllers can be used in systems where description of the process and identification of the process parameters with precision is highly difficult. Hence it provides a fuzzy characteristic to the control mechanism.

The design of a Fuzzy Logic Controller requires the choice of Membership Functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs. To achieve finer control, the membership functions near the zero regions should be made narrow. A wider membership function away from the zero regions provides faster response to the system. Hence, the membership functions should be adjusted accordingly. After the appropriate membership functions are chosen, a rule base should be created. It consists of a number of Fuzzy If-Then rules that completely define the behaviour of the system. These rules very much resemble the human thought process, thereby providing artificial intelligence to the system.

2.3.2 Application Areas of Fuzzy Logic Controllers

The fuzzy logic controllers are basically put to use when [30]:

1. The system is highly non-linear thereby making the mathematical modelling of the systems very arduous.
2. The analytical form of the system is not provided, instead a linguistic form is provided.
3. The precise identification of the system parameters.
4. The system behaviour has a vague characteristic under precisely defined conditions.
5. The conditions themselves are vague.

2.3.3 Components of FLC

The inputs to a Fuzzy Logic Controller are the processed with the help of linguistic variables which in turn are defined with the aid of membership functions. The membership functions are chosen in such a manner that they cover the whole of the universe of discourse. To avoid any discontinuity with respect to minor changes in the inputs, the adjacent fuzzy sets must overlap each other. Because of a small time constant in Fuzzy Logic Controllers, this criterion is very important in the design of the same.

There are basically three essential segments in Fuzzy Logic Controller and the structure is shown as figure 2.5 [30]:

1. Fuzzification block of Fuzzifier
2. Inference System
3. Defuzzification block of Defuzzifier

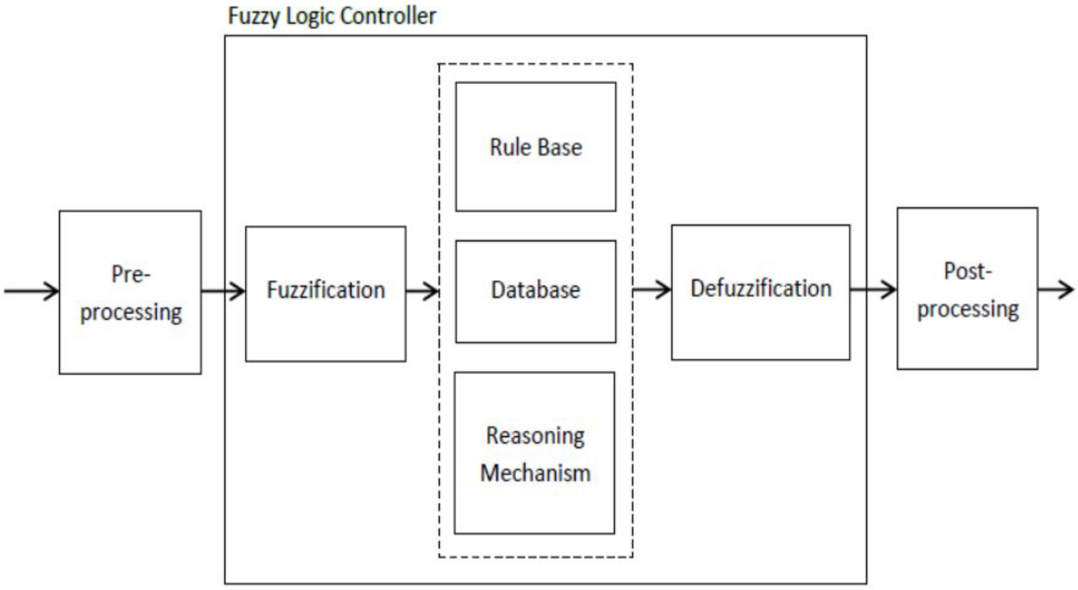

Figure 2.5 Fuzzy Logic Controller Structure, (photo courtesy of El-Saady et al, 1994)

1. Fuzzification

The first step towards designing a Fuzzy Logic Controller is choosing appropriate inputs which will be fed to the same. These input variables should be such that, they represent the dynamical system completely. Then the function of the Fuzzifier comes into picture. As discussed before, instead of using numerical variables, fuzzy logic uses linguistic variables for processing information. But since the inputs to the FLC are in the form of numerical variables (or in other words, crisp sets), they need to be converted into linguistic variables. This function of converting these crisp sets into fuzzy sets (linguistic variables) is performed by the Fuzzifier. The fuzzification technique involves outlining the membership functions for the inputs. These membership functions should cover the whole universe of discourse and each one represents a fuzzy set or a linguistic variable. The crisp inputs are thus transformed into fuzzy sets. Triangular MF, Trapezoidal MF, Bell MF, Generalized Bell MF or Sigmoidal MF can be used. Even a hybrid of any of the above Membership Functions can be used for fuzzification.

2. Inference System

The inference system of a Fuzzy Logic Controller consists of the following three paradigms:

1. Rule Base: - It consists of a number of If-Then rules. The If side of the rule is called the antecedent and the Then side is called the consequence. These rules are very much similar to the human thought process and the computer uses the linguistic variables, derived after fuzzification for execution of the rules. They very simple to understand and write and hence the programming for the fuzzy logic controller becomes very simple. The control strategy is stored in more or less the normal language.
2. Database: - It consists of the all the defined membership functions that are to be used by the rules.
3. Reasoning Mechanism: - It performs the inference procedure on the rules and the data given to provide a reasonable output. It is basically the codes of the software which are process the rules and the all the knowledge based on a particular situation. It exercises a human brain type of attribute to methodically carry out the inference steps for processing the information.

3. Defuzzification

A defuzzifier performs the exact opposite function of a fuzzifier. It transforms the fuzzy variables (which are obtained as output after processing of the inputs) to crisp sets. The defuzzifier is necessary because in the real world the crisp values can only be taken as inputs to the other systems. Even though the fuzzy sets resemble the human thought process, their functionality is limited only to the above processes. A defuzzifier is generally required only when the Mamdani Fuzzy Model is used for designing a controller. There are other types of architectures that can be used are:

- Tagaki-Sugeno Fuzzy Model
- Tsukamoto Fuzzy Model

Mamdani model is preferred here because it follows the Compositional Rule of Inference strictly in its fuzzy reasoning mechanism. Unlike the Mamdani model, the outputs are defined with the help of a specific function for the other two models (first order polynomial in the input variables) and hence the output is crisp instead of fuzzy. This is counterintuitive since a fuzzy model should be able to propagate the fuzziness from inputs to outputs in an appropriate manner.

2.3.4 Designing Fuzzy Logic Controller

Any membership function completely characterizes the fuzzy set that it belongs to. A convenient and succinct way to define an MF is to express it as a mathematical function. In order to define fuzzy membership function, designers choose many different shapes based on their preference and know how. Different classes of parameterized membership functions commonly used are:

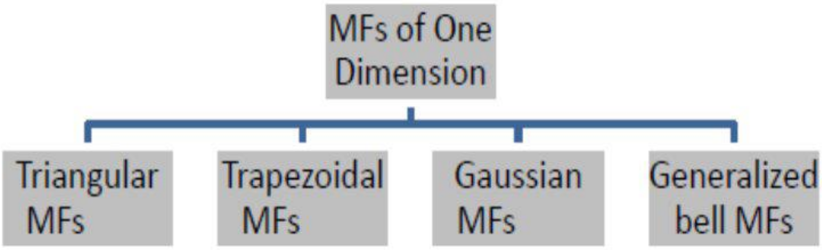

Figure 2.6: Classes of Membership Functions

Among the alternatives just mentioned, the most popularly used MFs in real-time implementations are triangular and trapezoidal because of the fact that these are easy to represent the designer's idea and require low computation time.

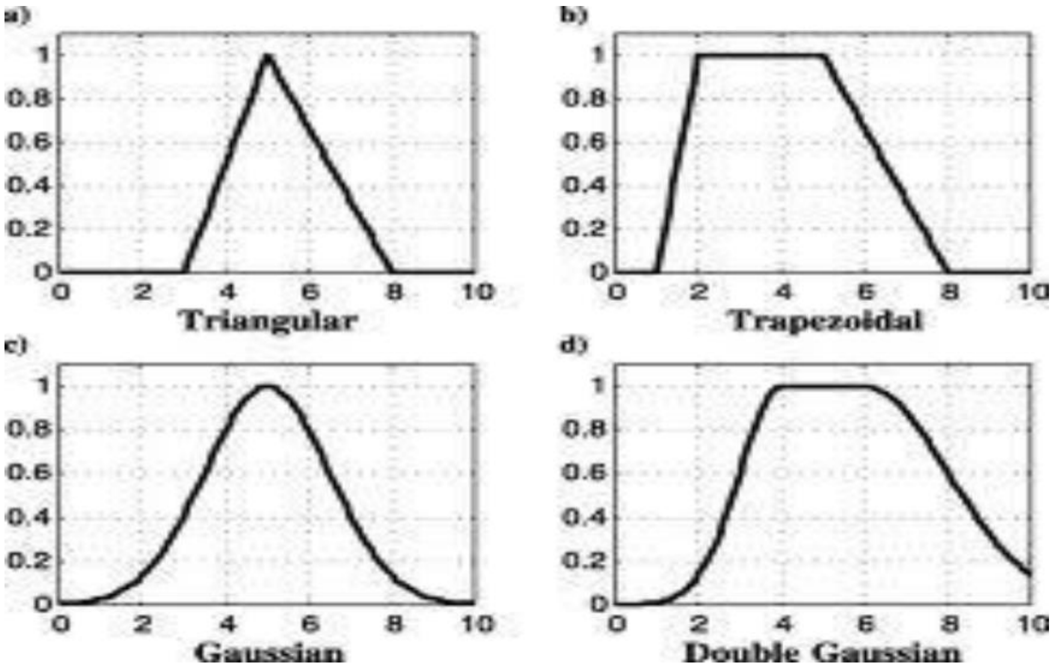

Figure 2.7: Examples of four classes on MF parameter, (photo courtesy of El-Saady et al, 1994)

Figure 2.7 shows the classes of MFs parameter with a single input. MFs of higher dimensions can be defined similarly as per increase in the number of inputs.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the methodology to achieve the result of this project is presented. Step by step designing is summarized in a flow chart. In this project, existing model for electric vehicle will be used. The model was submitted to mathwork by Patrice Brunelle in 2011 but was originally developed by Olivier Tremblay, Souleman Njoya Motapon, Louis-A. Dessaint from Ecole de Technologie Superieure, Montreal. In this model, the existing electric motor used was Permanent Magnet Synchronous Motor (PMSM) with conventional controller to power up the electric vehicle. Further research of reaction on induction motor and fuzzy logic controller will be done in this project to compare the outcome in term of the performances and efficiency and explained the result in the next chapter. Figure 3.1 shows the model that will be used in this project. This FCV is propelled by one electric motor powered by a fuel cell and a battery.

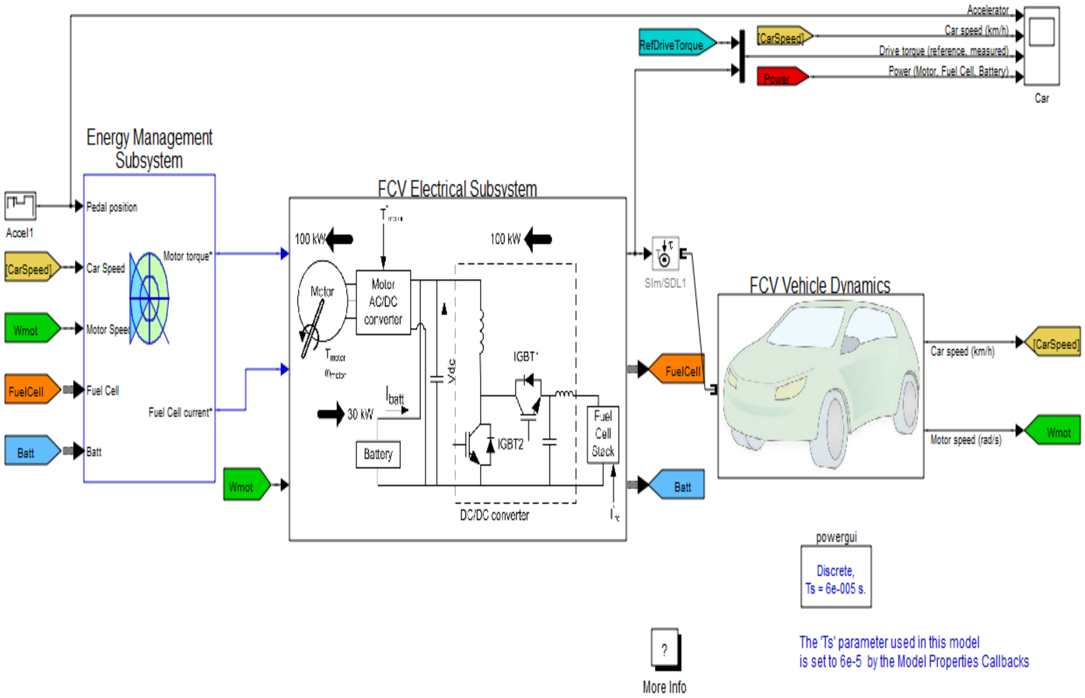

Figure 3.1: Electric vehicle Simulink model, adapted from Olivier Tremblay, Souleman Njoya Motapon, Louis-A. (2011), Fuel Cell Vehicle (FCV) Power Train model

The FCV Electrical Subsystem is composed of four parts: The electrical motor, the battery, the fuel cell and the DC/DC converter.

- The electrical motor is a 288 Vdc, 100 kW interior Permanent Magnet Synchronous Machine (PMSM) with the associated drive (based on AC6 blocks of the SimPowerSystems Electric Drives library). This motor has 8 pole and the magnets are buried (salient rotor's type). A flux weakening vector control is used to achieve a maximum motor speed of 12 500 rpm.
- The battery is a 13.9 Ah, 288 Vdc, 25 kW Lithium-Ion battery.
- The fuel cell is a 400 cells, 288 Vdc, 100 kW Proton Exchange Membrane (PEM) fuel cell stack.
- The DC/DC converter (buck type) is current-regulated.

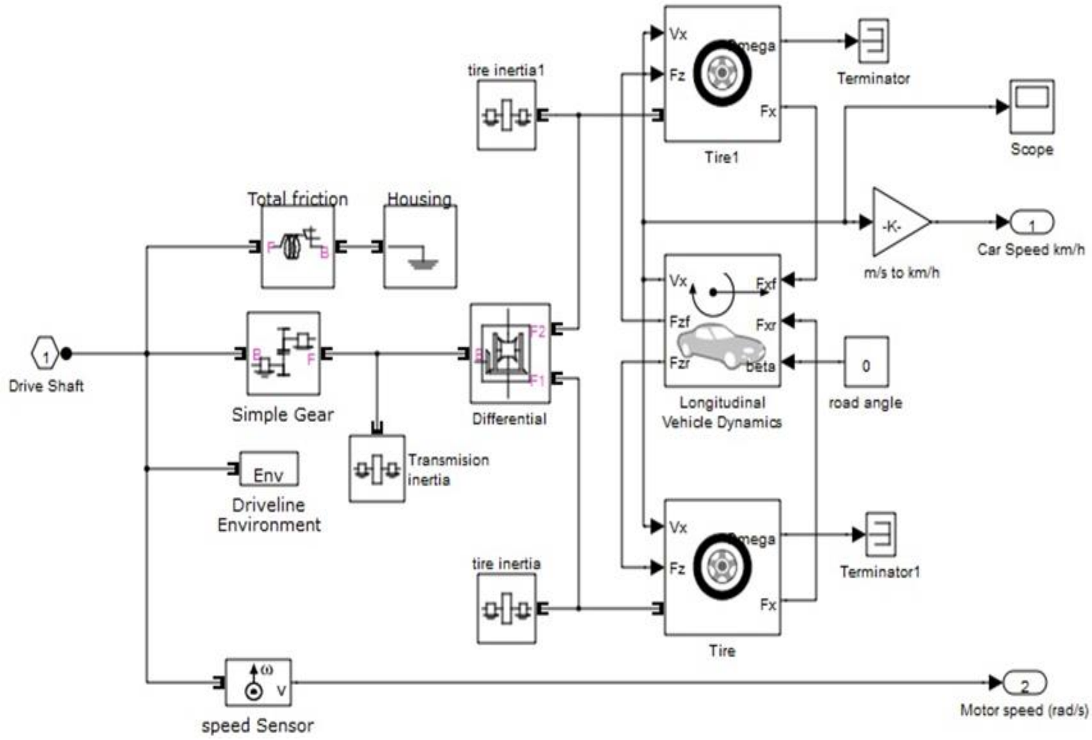

Figure 3.2: FCV Vehicle Dynamics Subsystem, adapted from Olivier Tremblay, Souleman Njoya Motapon, Louis-A. (2011), Fuel Cell Vehicle (FCV) Power Train model

Figure 3.2 shows the FCV Vehicle Dynamics Subsystem that models all the mechanical parts of the vehicle:

- The single reduction gear reduces the motor's speed to increase the torque.
- The differential splits the input torque into two equal torques.
- The tires dynamics represent the force applied to the ground.
- The vehicle dynamics represent the motion influence on the overall system.
- The viscous friction models all the losses of the mechanical system.

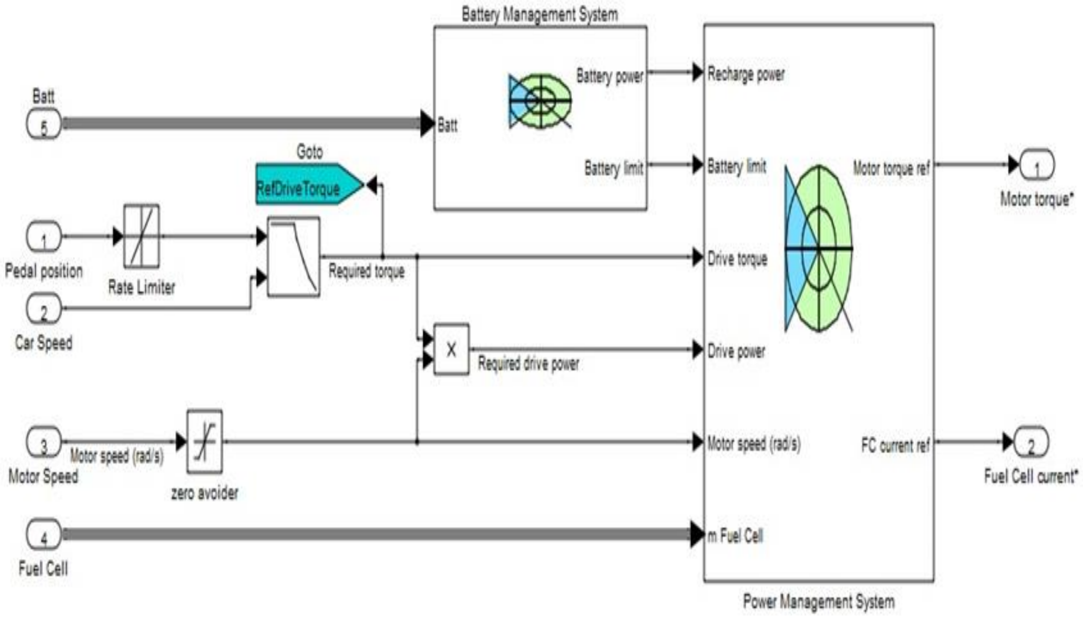

Figure 3.3: Energy Management Subsystem (EMS), adapted from Olivier Tremblay, Souleman Njoya Motapon, Louis-A. (2011), Fuel Cell Vehicle (FCV) Power Train model

The Energy Management Subsystem (EMS) as shown in figure 3.3 determines the reference signals for the electric motor drives, the fuel cell system and the DC/DC converter in order to distribute accurately the power from the two electrical sources. These signals are calculated using mainly the position of the accelerator, which is between -100% and 100%, and the measured FCV speed. Note that a negative accelerator position represents a positive brake position. The Battery management system maintains the State-Of-Charge (SOC) between 40 and 80%. Also, it prevents against voltage collapse by controlling the power required from the battery. The Power Management System controls the reference power of the electrical motor by splitting the power demand as a function of the available power of the battery and the fuel cell. This power is controlled by the DC/DC converter current.

3.2 FLOW CHART

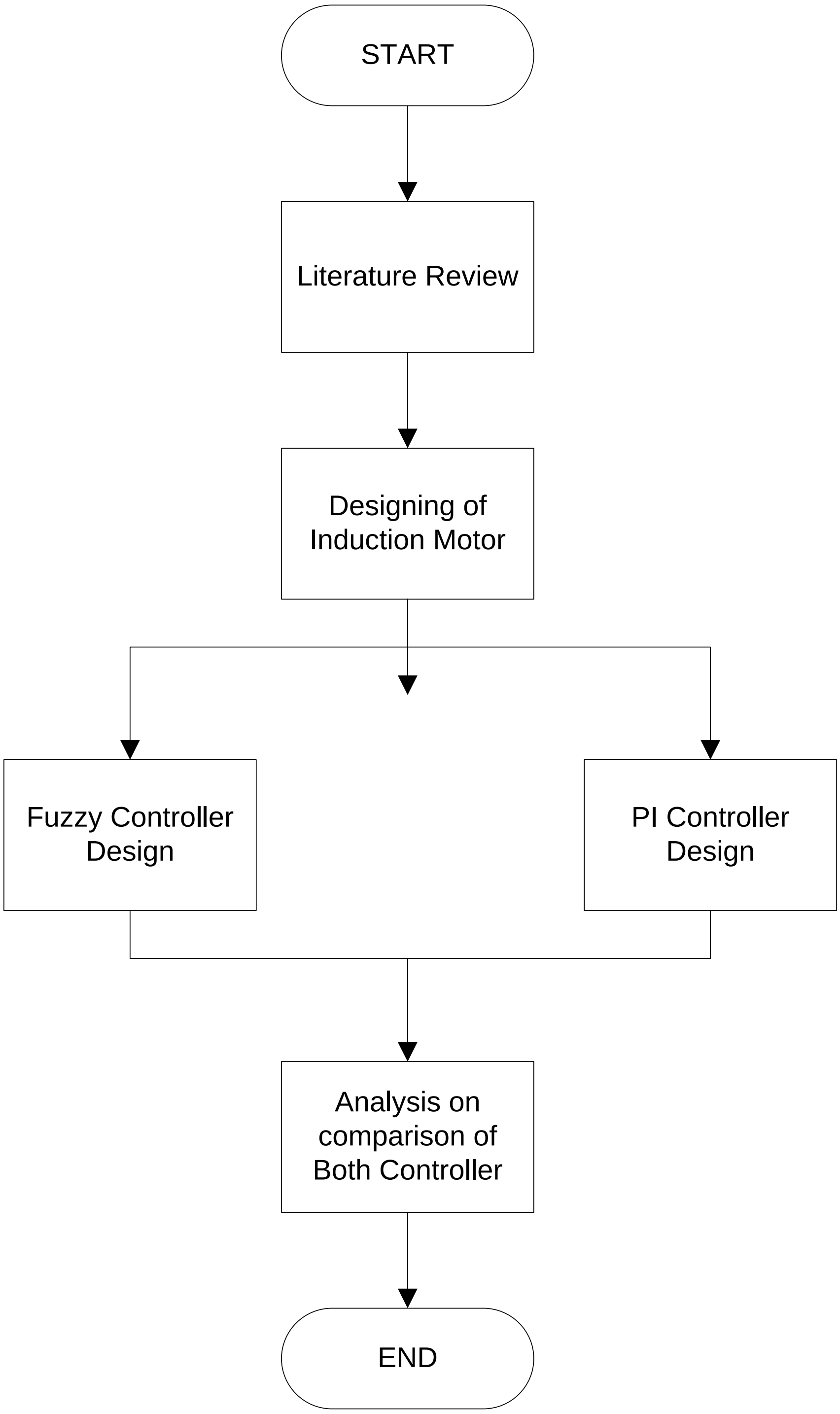

Figure 3.4: Flowchart process of the project

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