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Energy management in the embedded system

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بسم الله الرحمن الرحيم

﴿ رَبَّنَا لاَ تُؤَاخِذْنَا إِن نَّسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلاَ تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِن قَبْلِنَا رَبَّنَا وَلاَ تُحَمِّلْنَا مَا لاَ طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا وَارْحَمْنَا أَنتَ مَوْلاَنَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ﴾ **سورة البقرة : الآية286 .**

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DEDICATION

I dedicate this brief piece to:

To my incredibly loving parents, who helped me with my education.

To my wonderful family and my loving sisters.

all of my pals.

To everyone I love and who loves me

To you.

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List of Abbreviations

Abbreviation	Definition
CC	Constant-Current
CV	Constant-Voltage
Ch	Charge
EKF	Extended Kalman Filters
Li - ion	Lithium-ion
LA	Lead Acid
Li - $ion\ POL$	Lithium-ion Polymer
Li	Lithium
$NiCd$	Nickel-Cadmium
$n\ m$	Overpotential model
SOC	State-of-Charge
EMS	Energy Management System
HEV	Hybrid Electric Vehicle
$HEV\ s$	Hybrid Electric Vehicles
EV	Electric Vehicle
$EV\ s$	Electric Vehicles
DC	Direct Current
CC - CV	Constant-Current-Constant-Voltage
h	hours
AC	Alternative Current
R	Resistance
C	Capacitance
$BATT$	Battery
$SOC\ s$	State-of-Charge-Systems
$SOCest$	State-of-Charge Estimed

$SOCbat$	State-of-Charge battery
$SOC0$	Initial State-of-Charge

List of Symbols

mbol	Definition	Unite
EMF	Electro-Motive Force	[V]
E_{0q}	Amount of the energy	[J]
E_{Iq}	Non-linear part of the amount of the energy	[J]
E_{eq+}	Equilibrium potential of the positive electrode	[V]
E_{eq-}	Equilibrium potential of the negative electrode	[V]
E_{0+}	Standard redox potential of the positive electrode	[V]
E_{0-}	Standard redox potential of the negative electrode	[V]
E_0	Parameter for the SOC-EMF	[V]
F	Faraday Constant	[C/mol]
f	Frequency	[Hz]
$Is\ max$	Constant maximum current	[A]
$Is\ min$	Predefined minimum current	[A]
IM	Uncertainties from Maccor current measurement	[A]
IS	Standby current	[A]
Id	Measured discharge current	[A]
Q_{max}	Battery maximum capacity	[Ah]
Qd	Discharge battery capacity	[Ah]
$Q_{max}{}^{+}$	Maximum capacity of the positive electrode	[1]
$Q_{max}{}^{-}$	Maximum capacity of the negative electrode	[1]
Q_{ch}	Amount of charge flowing into the battery during the charge state	[Ah]
SOC	State-of-Charge	[%]
$SOC\ (EMF)$	SOC calculated based on the EMF voltage	[%]

$SOC\ (vp)$	SOC Calculated based on the predicted voltage	[%]
$SOC\ e$	SOC error	[%]
$SOCend$	SOC indicated at the end	[%]
$SOCin$	SOC in the initial state	[%]
$SOC\ ch$	SOC in the charge state	[%]
t	Time	[s]
T	Temperature	[°C]
$T\ ref$	Reference temperature	[°C]
$Vbat$	Battery terminal voltage	[V]
V	Battery voltage	[V]
Vd	Battery voltage after discharging	[V]
Vch	Battery voltage after charging	[V]
VM	Uncertainties from Maccor voltage measurement	[V]
$V0$	Battery voltage at t=1min	[V]
$V\ ocf$	Fully stabilized Open-Circuit-Voltage	[V]
$Vsmax$	Maximum charge voltage in CV	[V]
$V\ off$	Voltage offset	[V]
γ	Rate-determing variable	-
δ	Parameter in the voltage prediction model	-
Γ	Constant for voltage prediction	-
ϕ	Phase angle	[rad]
τ	Voltage relaxation time	[s]
τq	Time constant associated with the increase in overpotential in almost empty battery	[s]
τd	"Diffusion" time constant	[s]

General Introduction

General Introduction

In today's society, high importance is being placed on the stress levels that technology puts on the environment. This factor has pushed automobile technology to an eco-friendlier solution which is electric vehicles (EV) [1]. When compared to petroleum-based vehicles using the internal combustion engine (ICE), EVs have a significantly less footprint depending on their fuel source [2].

The aim of this work is to studied the energy management of an embedded system while, it consists in controlling the energy flows of the different sources constituting the system. It makes it possible to satisfy the power demands of the load and increase the service life of the system while respecting various operating constraints such as the limited power of the sources, the states of charge of the storage elements, etc. For an "Electric Vehicle" application, we present in this work the energy management of an autonomous hybrid system composed of lead acid batteries used as the main source, super capacitors considered as an auxiliary source.

This thesis is divided into three chapters, in the first chapter, gives a state of the art on the energy management system, which is composed with: Electrical vehicle architectural and some State of the art in the energy management system. The second chapter presents the Energy Management System Modeling. The third chapter is devoted to the simulation results and discussion of the rule based energy management strategy.

Chapter I

State of the art in the energy management system

I.1. Introduction

In this first chapter, an overview and a brief history of the electric vehicle will be given, then its operating principle as well as its different architectures and constituent elements will be detailed, In addition to describes the state of the art in the field of Ultracapacitors (a.k.a. Super Capacitors), particularly as utilized at the present time in electric and hybrid vehicles.

I.2. State of Art on EV

I.2.1.History of electric vehicles

Joint advances in energy accumulators such as batteries and electric motor as drive systemsalong with the predominance of the electromagnetic induction since 1831 have led to significant advances electric mobility technology. Two researchers stand out in this context:

Alessandro Volta ("Battery Back") for inventing the battery's forerunner in 1800, and Michael Faraday for creating the homopolar motor in 1821. In the 1830s, non-rechargeable batteries were used in the first electric cars [3]. Rechargeable lead-acid batteries, which are currently the most popular type of batteries, were created in 1859 by Mr. Gaston Plante and are notably popular in storage and automotive applications. The performance of the aforementioned battery type was then improved by Aphonse Camille Faure, resulting in its commercialisation on vehicle boards in 1881 [4]. In 1882, Mr. Trouvé developed the first lead-acid battery-powered electric vehicle in France. In the meantime, other lead-acid battery-powered electric vehicles made their debut in the United States and the United Kingdom. Although steam mobility existed at the time, particularly in public transportation, the electric vehicle quickly established itself as an ideal choice for urban traffic because it produces no noise and pollutes the environment.

In the early 1900s, Thomas Edison, intrigued by the potential of electric vehicles, developed the nickel-iron battery, which had a storage capacity 40 % greater than the lead battery but a much higher cost of production. To conclude, the nineteenth century is mainly characterized by important findings in battery technology such as the development of nickel-zinc and zincair batteries [5].

a. First cycle of electric vehicles (1837-1912)

At the beginning of the twentieth century, many researchers thought that electric and conventional vehicles could coexist together and each vehicle type will find its own customers.

However, researchers' prediction was not correct and electric vehicles commercialization has decreased significantly during this period for the following reasons:

- The removal of the crank used in combustion powered vehicles as a result of electric starter invention in 1912 [4].
- In 1920, the highways in the United States interconnected several cities and this required vehicles with large autonomy capable of traveling long distances [5].
- Success of commercialization of petrol vehicles. According to [6], the number of electric power cars in 1912 in the United States reached 30 000 units and the amount of petrol cars was already thirty times larger.
- Oil discoveries in Texas have reduced gasoline prices, making it an attractive fuel for the transportation sector [7].
- The impressive progress of distillation techniques along with the low cost of petroleum products contributed together in the expansion of the automobile industry's technological development toward gasoline-powered vehicles [8].

The performance of the first generation of electric vehicles in terms of speed and autonomy is shown in Figure I.1. As can be observed, the maximum speed is 35 km/h, and the maximum vehicle autonomy is somewhere about 65 km. It is important to note that at the same time, combustion engine vehicles' autonomy was 3 times greater for both autonomy and speed [9]. According to the aforementioned source, gasoline automobiles cost between $1,000 and $2,000 and had an operating cost of $0.01 per mile. On the other hand, the price of an electric vehicle at the time ranged from $1,250.00 to $3,500, with an operating cost of $0.03 per mile..

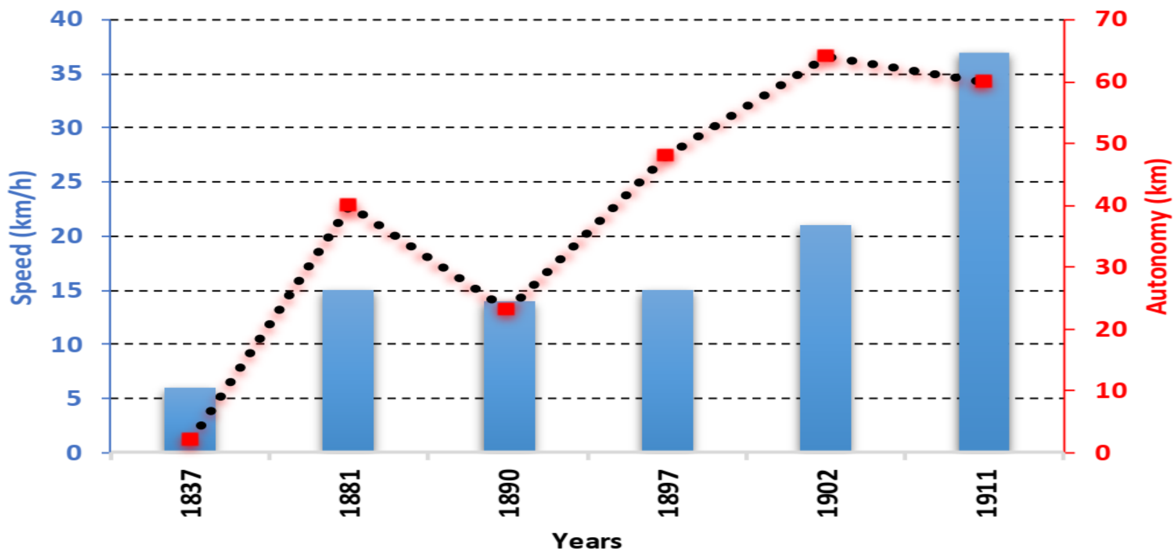


Figure I.1: Autonomy and speed ratings for first generation of electric vehicles [10].

b. Second generation of electric vehicles (1912-1973)

Following many oil field finds, conventional vehicles fueled by diesel and gasoline have gained popularity and have proven to be preferable to electric vehicles in terms of speed, autonomy, and running costs. Oil costs rose as a result of the First World War in 1914, which has rekindled hope for the future of electric automobiles. The technological advancements made during this time period in favor of electric vehicles also contributed to this enthusiasm [11]. For instance, storage space and battery life were both increased by 35%. Despite the technical and commercial efforts spent to impose electric vehicle dominance in the vehicle market, the number of electric vehicles fell from 10% in 1913 to only 3% in 1925 according to [12] because of its limited autonomy and reduced comfort.

Moreover, the long charging time of vehicle batteries has reduced its large scale commercialization.

Figure I.2 shows the performance of the second generation of electric vehicles in terms of maximum speed and autonomy. At first look, it could be noticed that the vehicle speed and autonomy are significantly improved compared to the first generation of electric vehicles.

According to [13], researchers' interests during this period were oriented toward the elaboration of vehicles with minimum energy consumption and less CO_2 emissions as issues about CO_2 usage were raised and laws discussing fuel emissions restrictions began to be adopted.

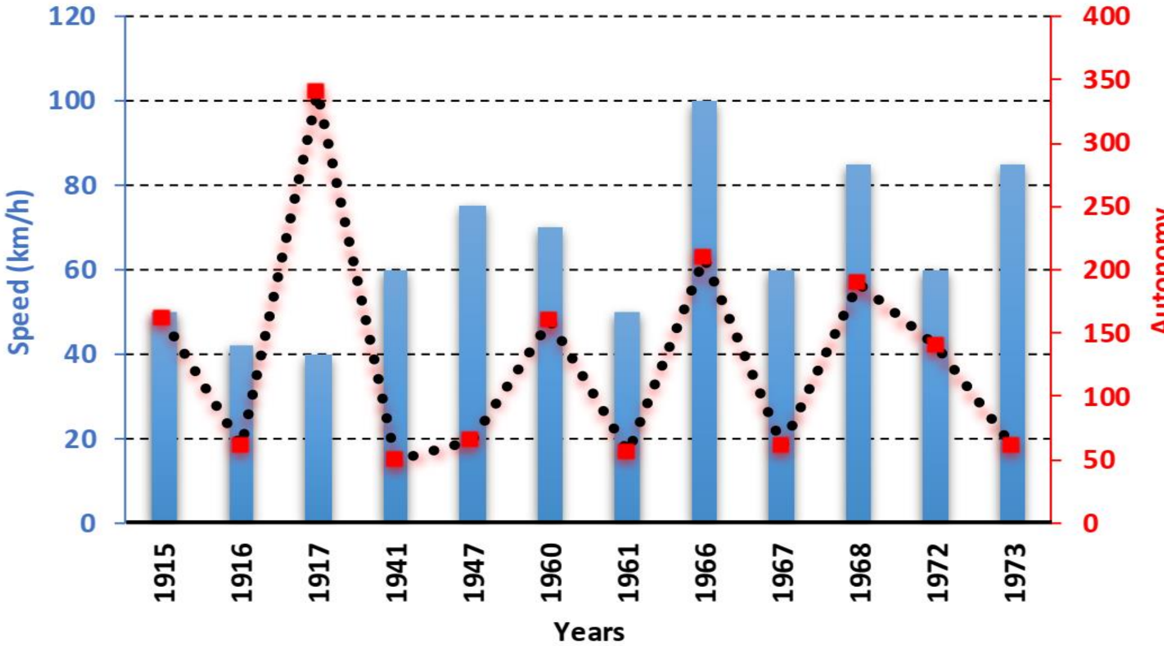


Figure I.2: Autonomy and speed ratings for second generation of electric vehicles[10].

c. Third generation of electric vehicles (1973-1996)

Demand for electric vehicles grew rapidly until the late 1980s, when the issue of urban air pollution became more widely discussed [14]. The oil crisis caused by OPEC (Organization of Petroleum Exporting Countries) in 1973 had opened up new opportunities for electric vehicles.

The countries which depend significantly on oil coming mainly from Arab region reconsidered their policies and have adopted some regulations and strategies to reduce oil dependence.

One suggestion for lessening reliance on oil was for their transportation sectors to be massively, gradually, and continuously electrified. Numerous cutting-edge automobiles were introduced to the market throughout the 1980s and 1990s, such the Ford Ranger EV, Toyota RAV4-EV, and General Motors EV-1. To assess the commercial viability of these vehicles, substantial study on battery costs and lifespan was carried out [15]. Even if electric cars were more energy-efficient than traditional ones, their benefits were negligible when oil prices were at their lowest levels [16].

Figure I.3 highlights the performance of the third cycle of electric vehicles in terms of maximum speed and autonomy. Despite the different barriers preventing the large scale commercialization of electrified vehicle, one could notice easily from figure I.3 that significant enhancement in terms of speed and autonomy have been made compared to the first and second generations of electric vehicles shown respectively in figures I.2 and I.1.

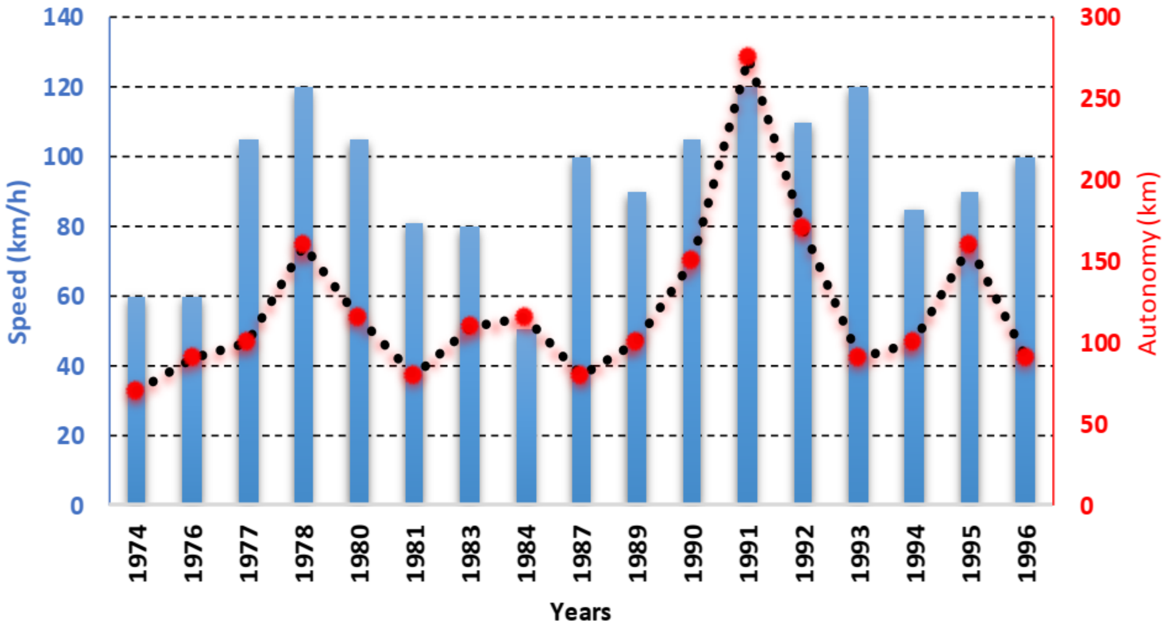


Figure I.3: Autonomy and speed ratings of the third generation of electric vehicles[10].

d. Fourth generation of electric vehicles (1996-2012)

Hybrid electric vehicles and plug-in hybrid vehicles became popular during this time as potential solutions to problems including energy security, pollution, and dependence on fossil fuels. The first significant development during this time period occurred in 1997 with the introduction of the four-door cars "Toyota prius" and "Insight" in the Japanese and American markets, respectively [17]. In the North American market, 1.9 million HEVs (Hybrid Electric Vehicles), 60.0 thousand PHEVs (Plug-in Hybrid Electric Vehicles), and BEVs (Battery Electric Vehicles) have been sold since the introduction of the Toyota Prius in 1997 [18]. This commercialization success can be attributed in large part to the encouragement of the U.S. government to manufacturers and consumers of hybrid and electric vehicles. Worldwide, over the last decade, many HEVs, PHEVs and BEVs have been sold, totaling more than 2.5 million vehicles. In early 2011, the penetration of these technologies in the market is of 2% in the U.S. and 9% were sold in Japan [19]. With the new developments in batteries, electric vehicles now have their storage capacity between 20 and 60 kWh, allowing its interconnection with the electric distribution network through the consumption of energy.

Furthermore, in the very near future, this will provide energy according to the needs of network functionality through the Vehicle Connected to grid technology (V2G). Figure 1.6 depicts the performance of the fourth generation of electric vehicles in terms of maximum speed and autonomy. One can deduce from figure I.4 that important improvements in terms of speed and autonomy have been made compared to the three first generations.

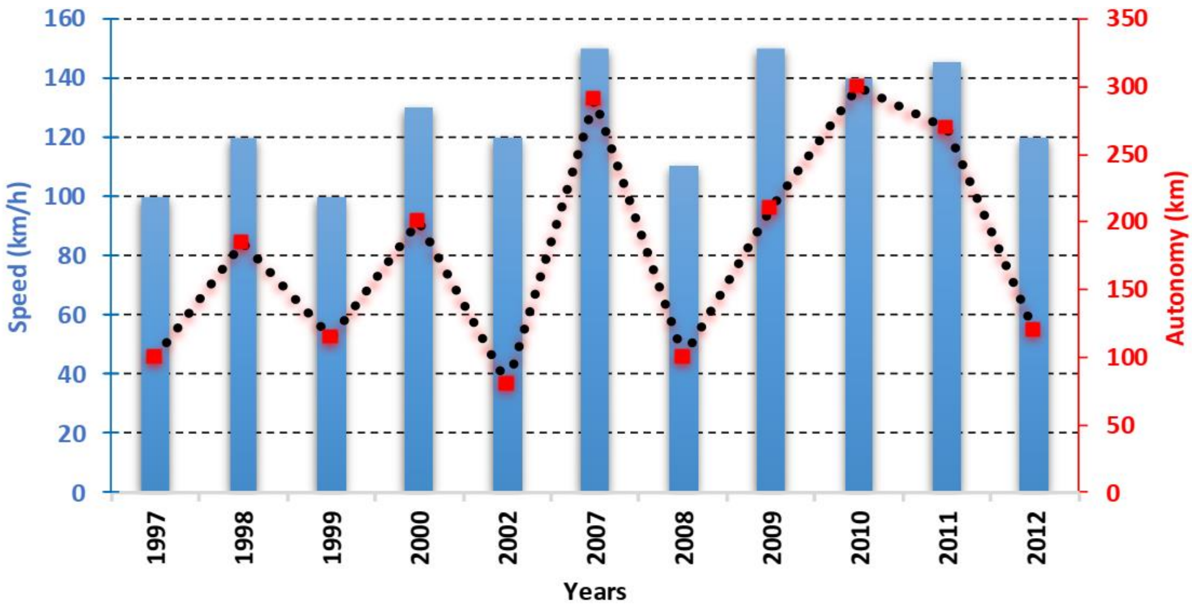


Figure I.4: Autonomy and speed ratings of the fourth generation of electric vehicles[10].

I.2.2. 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 should electric car makers be evaluated? Which electric car manufacturers are producing the best-selling models, and which models are the most in demand globally, are two metrics to take into account. Tesla, General Motors, and Nissan are the three manufacturers that sell the most electric vehicles in the US. More than 60% of all electric cars sold in the US through September of 2018 were produced by these three automakers. The top electric vehicles made by these manufacturers include [20]:

1. Tesla
2. Chevrolet
3. Nissan
4. BMW

(a) Tesla Model x ***(b) Nissan LEAF (c)*** ***Chevrolet Volt***

Figure I.5: Electric Vehicle [20]

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.). figure I.6

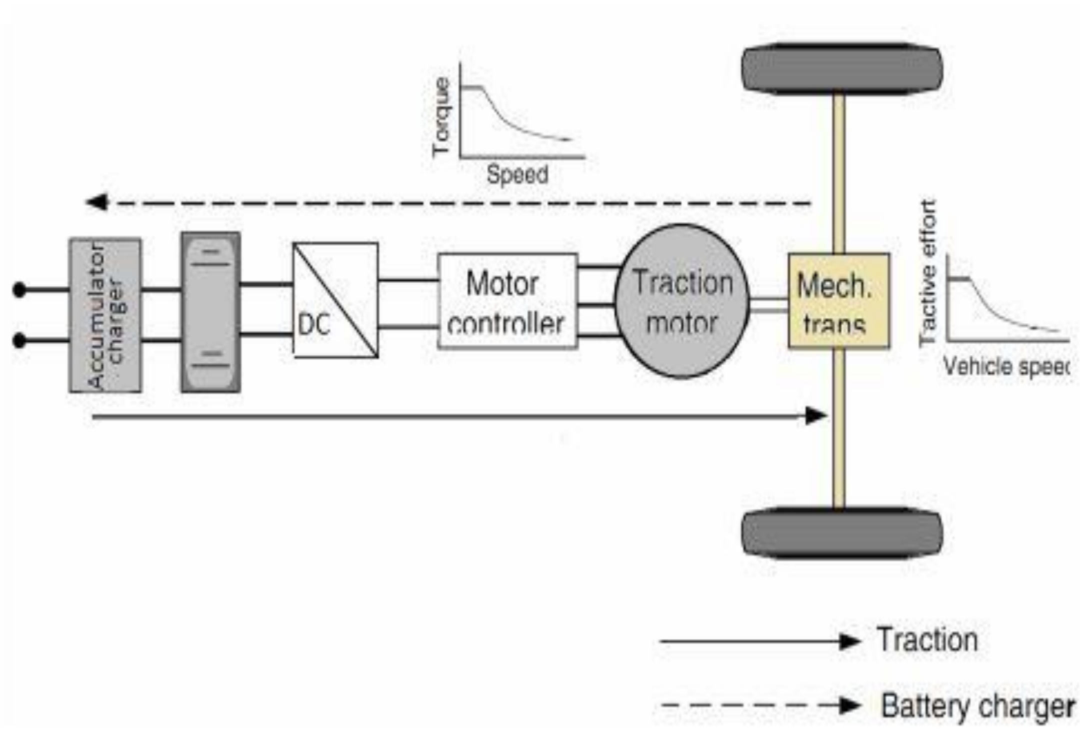


Figure I.6: Pure electric vehicle [21]

I.3.State of the art in the energy management system

The distribution of power among the various hybrid system components is defined by energy management. In order to maximize the complementarity between these two energy sources, numerous studies have helped define how to manage energy between batteries and supercapacitors.

These strategies may be based on three concepts [22,23] (see Figure. I.8).

1. Rule-based strategies: these are defined beforehand based on knowledge or understanding of the specifics of the system's components. Although these techniques are straightforward to use, they may not always result in the greatest potential outcome.
2. Deterministic optimization-based strategies: these strategies force the system to adapt so as to minimize (or maximize) the performance criterion. This idea is the foundation for several optimization approaches, including optimum control, dynamic programming, and linear programming. There are two possible groups: both real-time and offline optimization.
3. Strategies based on stochastic optimization methods such as the learning machine: The learning machine offers the ability to learn in order to achieve an objective (maximization / minimization of a criterion) without being explicitly programmed with cycles training.

I.3.1. Rule-based strategies

Only a few management rules—fuzzy rules, neural networks, and deterministic rules—can be mentioned for hybrid sources in the automotive industry.

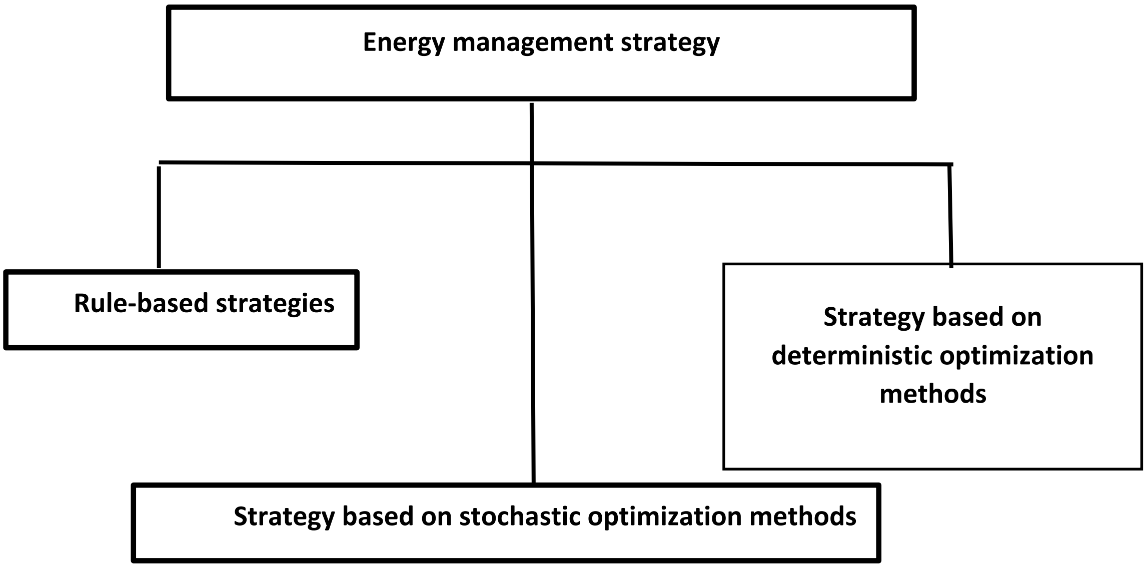


Figure I.7: Existing energy management strategies[7].

A. Fuzzy rules

The fuzzy rules are very practical in cases where the analytical modeling of the system is complex. Fuzzy Logic Controllers (FLCs) are the most widely used because of their independence from the mathematical model of the system to be controlled.

Fuzzy logic has been used by researchers like Gao, Caux, and Erdinc to study fuel cell hybrid systems [24,25]. Eren [26] combined the management of the fuel cell's internal dynamics into a method to energy management based on fuzzy logic. Due to the strategy's reliance on a particular level of expertise, the use of fuzzy rules has a detrimental effect. This implies that a few firm assumptions that rely on the designer's understanding of the issue must be made [23,27].

B. Neural networks

Neural network models are computer simulations of human cognitive processes (memory and reasoning). The literature has some studies that employ neural networks' approach to energy management. Ates [28] presented an adaptive linear neural network (ADALINE) method-based supervisory controller to specify the power output of a fuel cell system in a hybrid car.

Although Askarzadeh [29] and Prokhorov [30] also employed the same kind of neural network, there were more options when fuzzy logic was added. The drawback of this strategy is that it requires a sizable experimental database to construct the knowledge process and that there is no evidence of stability [22,23,25].

C. Deterministic rules

Deterministic rules define the power sharing techniques between the energy sources of the hybrid system. In this context, we shall cite various techniques used in multi-source vehicles.

Strategy for « All or Nothing »

These are on/off thermostat strategies. Their principle is to distribute the power flows between the two sources in such a way as to ensure that each source operates around its best overall performance. Power sharing is done by assigning an active (On) or deactivated (Off) state to each power source (all or nothing switching). As shown in Figure I.8, it is either the battery that takes the entire required profile or the supercapacitors that delivers the required power with a sudden switch between the two states [3].

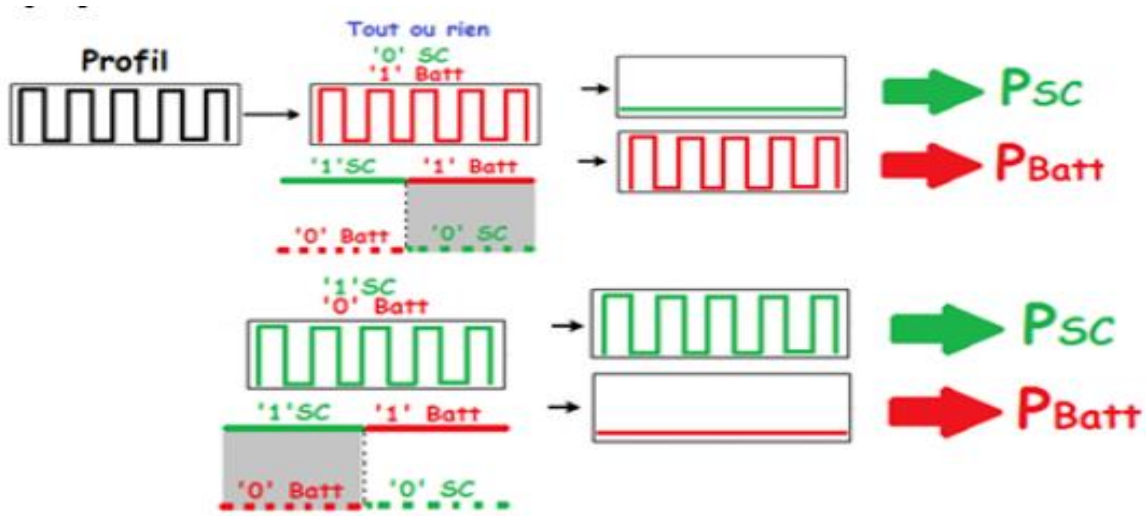


Figure I.8: Principle of the "All or Nothing" management strategy
Where: Pbatt: power of the battery, Psc: power of the supercapacitor, SC: supercapacitor, Batt: battery[30].

The "smooth transition" between storage systems is an improved version of this strategy. As shown in Figure I.9, switching between the supercapacitors and the battery takes place at a linear transition stage in order to avoid additional current requirements during sudden switching [30].

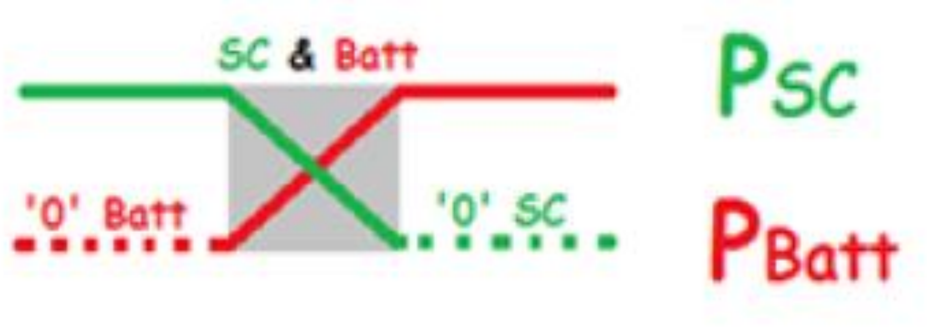


Figure I.9: Principle of the "smoothed transition" management strategy[30].

- **Strategy for « Power saturation »**

This method is based on restricting the battery's power across the complete needed power profile. The battery's power threshold is established in advance. As a result, the supercapacitors handle the discrepancy between the profile's power and the set threshold (see Figure I.10) [23,31]. By using this technique, it is feasible to keep current variations within a specific range of power. The peculiarities and characteristics of the storage systems being employed are typically taken into account when determining the power threshold.

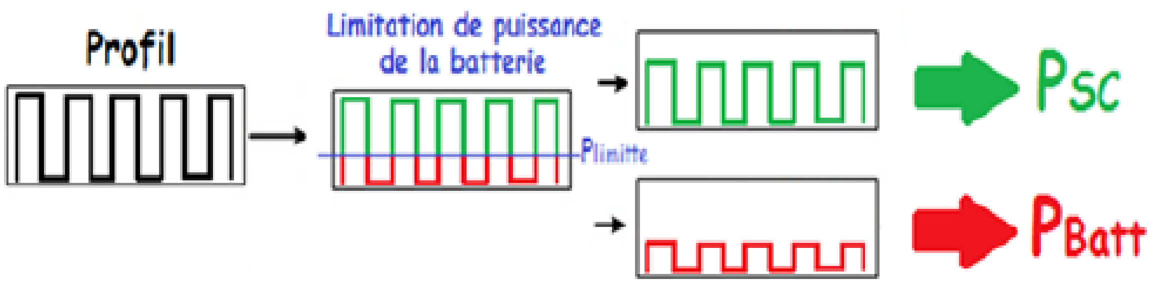


Figure I.10: Principle of the "power saturation" management strategy[30].

- **Strategy for « Adaptive power saturation »**

The above-mentioned plan has been developed into this strategy. The idea behind flow distribution is the same. However, it provides additional flexibility because the battery side power limit fluctuates according to the energy stored in the supercapacitors. This method provides additional latitude for manipulating power flows, improving performance [23].

- **Strategy for "Frequency sharing"**

The high/low frequency decomposition of the requested profile serves as the foundation for the power frequency sharing method. (see Figure I.11). It enables the utilization of the innate qualities of the employed storage sources. With this form of sharing, the batteries are given the low-frequency components while the supercapacitors handle the power peaks. [32].

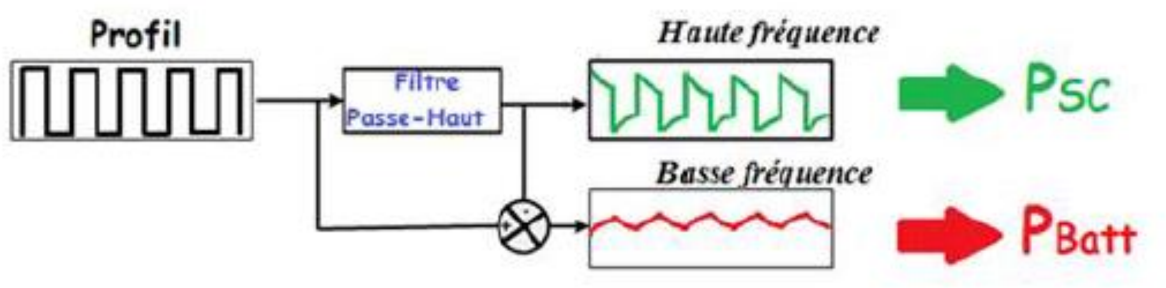


Figure I.11: Principle of the "frequency sharing" management strategy[30].

Table I.1 evaluates the different rule-based strategies presented in terms of ease of implementation and performance.

Table. I.1. Comparison of deterministic rule-based strategies[26].

strategies	simplicity of implementation	performances
all or nothing	+ + +	-
power saturation	+ -	+ - -
adaptive power saturation	+ -	+ +
frequency sharing	-	+ + +

+ advantage - disadvantage

I.3.2. Strategy based on deterministic optimization methods

These optimization techniques seek to achieve the best possible control over the power flows in a multi-source system. Depending on the resolution techniques, these optimization solutions are categorized differently. Both offline and online (real time) kinds of resolution are defined in this context.

A. Offline optimization strategy

Strategies for offline optimization demand an understanding of the driving cycle. The target objectives are used to calculate the best power distribution, which is then carried out in advance. This makes it impossible to use this kind of optimization method in real-time systems. However, the following situations call for various kinds of offline optimization:

- ✓ to use it as a reference for the evaluation of other real-time strategies [33];
- ✓ Aid for the dimensioning of multi-source systems [34],
- ✓ Adjusting other rule-based management strategies upstream [35].

In order to determine the best way to distribute power in a hybrid storage system that combines a battery and a supercapacitor with a "objective" function, numerous researchers have reportedly used dynamic programming approaches to address optimization challenges. according to cutting down the battery's RMS current [36,37].

B. Online optimization strategy

In contrast to offline optimization techniques, online control strategies achieve optimum distribution of power flows in real time. This method does not require prior knowledge of the driving profile. The challenge of the success of this approach therefore concerns two key points:

- on the one hand, the time of calculation that must be limited in order to make the solution workable in real time;
- on the other hand, it is necessary to decouple the optimal solution from the knowledge of driving conditions in order to make the implementation possible.

Therefore, it is feasible to choose the optimal option regardless of the vehicle's driving circumstances. The issue of energy management in multi-source systems has been addressed using a number of real-time optimization strategies, including predictive control and optimum control based on equivalent consumption minimization (ECMS) [38].

Predictive control

The "Model-Predictive control" MPC-type of predictive control relies on projections of the vehicle's upcoming driving circumstances. The system's predetermined template is used for this [39]. The MPC command can now be positioned in relation to rule-based techniques thanks to a comparison research. This study's findings support the notion that the rule-based approach is more effective than the MPC command in terms of convergence speed and solution efficiency.

This predictive control is quite efficient in systems with multiple inputs and outputs [40].

Optimal control

The "Maximum Pontriaguine Principle" (PMP)-based optimal control strategy is an offline approach to problem solving. This strategy has been modified for real-time application, though. By employing the "Equivalent Consumption Minimization" (ECMS) method, for instance, the versions of the strategies emerging from the PMP offer an instantaneous optimal allocation of power flows in a multi-source system [38,41]. This latter approach's fundamental tenet is to reduce the weighted sum of powers [42]. Several works on multi-source vehicles have utilized the ECMS [43]. By incorporating the control loop, the - control technique enables adjusting the parameter defining the resolution method [22].

I.3.3. Strategy based on stochastic optimization methods (Machine Learning)

Artificial intelligence (AI) has a subfield known as machine learning (ML). It alludes to systemic adjustments that are adaptive [44]. Adaptive adjustments are those that make it possible for the system to carry out the same duties in the future, or tasks for the same population, more effectively. It is a branch of computer science that uses data observation and experience to train algorithms to carry out "intelligent" tasks. To put it more specifically, this approach teaches how to improve future performance in light of seen or experienced past performance [45]. For example, apps from popular websites such as "Amazon" "Facebook" and "Google" use machine learning. For example, the recommendation for movies in the “Netflix” app is based on one of these methods. Machine learning intersects with physics, statistics, theoretical computer science, and so on. It is widely used to solve problems related to optical character recognition, face detection, spoken language comprehension, weather forecasting and robotics [46].

The algorithms used to manage the energy of battery-based storage devices have also shown the effectiveness of the methods (ML). M. Triki [47] employed the dynamic power management algorithm "Dynamic Power Management" at work to prolong a mobile phone's battery life. This control method (ML) can optimize power flow distribution in automotive applications while learning how to make the best choices in the present based on past driving patterns [48,49]. Work as it were [50] demonstrates that a hybrid vehicle's fuel consumption can be decreased with the use of machine learning. It has been demonstrated in earlier studies that a control strategy based on this algorithm (ML) provides a compromise between the ease of real-time implementation, the computation time, and the solution's optimality [51].

I.3.4. Summary of management strategies

A. Evaluation of deterministic optimization strategies

Optimization-based solutions enable convergence towards a clearly defined goal in order to address the issue of energy management in a hybrid source [40]. On decreasing (or maximizing) the performance criterion, they are based. Even the most effective online resolution algorithms require lengthy processing periods, making the real-time deployment of these solutions a substantial challenge [24,41]. Additionally, the most optimal approaches call for prior knowledge of the power profile [52,22].

B. Evaluation of strategies based on deterministic rules

Deterministic rule-based management techniques have the benefit of being easy to develop, making them suitable for use with real-time computers. Furthermore, these techniques don't need to know the direction the vehicle will take beforehand [30]. However, how well these strategies work depends on the expertise of the person who establishes the rules and uses the multi-source system's inherent potential. The effectiveness of the solution may be impacted by a significant change in the driving circumstances under which the system has been configured [32].

C. Hybridization of strategies

Hybridization of strategies is another alternative to multi-source energy management. Hybridization of strategies enables the use of the strengths of each type of strategy (Table I.2).

Table. I.2. Evaluation of the different strategies[40].

strategies	real-time implementation	optimal solution	calculation time	A prior knowledge of driving conditions
Strategy based on deterministic optimization methods	+ -	+	- +	-
Rule-based strategies	+	-	+	+
Strategy based on stochastic optimization methods	+ -	+ -	+ -	+

+ advantage - disadvantage

Hybrid techniques, which combine optimization strategies with rule-based strategies, are being used more frequently. Through the use of offline optimization findings, some works have added more intelligence to the deterministic rules that are already in place. [53,40,43].

In these approaches, the definition of rule-based strategies is based on the results of offline optimization algorithms. For instance, A.L. Allègre [54] has developed a rule-based strategy with a coefficient that characterizes the distribution of power between two sources. This coefficient is then generated by an offline resolution that minimizes losses in the primary storage source (battery). In the work of J.P.F. Trovão [55,56], an offline “particle swarm optimization” (PSO) algorithm based on power saturation was used to limit the search interval for the optimal solution. Hybridization (rule-based and optimization-based strategies) improves the degree of solution optimization of rule-based approaches. At the same time, optimization approaches see their computation time reduced due to the predefined application of the rules.

I.4.Conclusion

This chapter gives an overview of the State of Art on EV and State of the art in the energy management system.

Where we see after this study by comparison with batteries, ultracapacitors offer the advantages of very short charge/discharge time, virtually unlimited cycle life, zero maintenance requirements, and operability over a very wide range of temperatures.

Ultracapacitors, however, still lag behind batteries in the aspect of energy density. Current research efforts to close that so-called “energy gap”, which will allow ultracapacitors to be competitive with batteries, are described.

That we will choose the battery of a Lead acide to study in the next chapters because it is the easiest and most effective according to the approved references in this study.These type of batteries were originally used in early electric vehicles such as General Motor's EV1, and also used in conventional vehicles.

Chapter II

Energy Management System Model

II.1. Introduction

Energy management in hybrid vehicles consists in deciding the amount of power delivered at each instant by the energy sources present in the vehicle while meeting several constraints. In this chapter, the role and main features of the energy management controller are introduced, and the problem of designing such a controller is formalized using optimal control theory.

II.2. Presentation of the architecture chosen

The architecture chosen for the electric vehicle is topology A (presented at the end of the first chapter). It is an electric vehicle with two energy sources (the battery and the supercapacitor), their respective two power converters (Buck-boost) and the group powertrain.

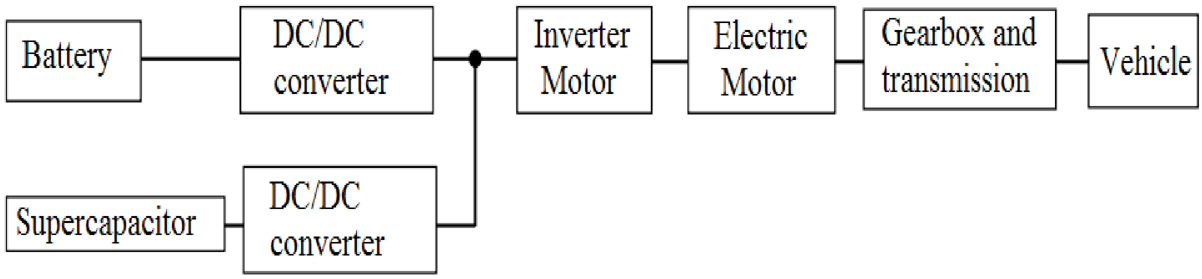


Figure II.1 Architecture of the chosen vehicle[14].

The architecture presented in Figure II.1 gives us the most degrees of freedom it ensures also a stable voltage on the DC bus. The variation in the voltage of the DC bus is due to a Load variation according to the rolling cycle.

II.3. EV Power supply

II.3.1. Electrochemical battery

When charged, electrochemical batteries, often known as batteries, transform electrical energy into potential chemical energy; when discharged, they transform chemical energy back into electric energy [34]. There are many distinct kinds of batteries, including lead-acid, nickel-metal hydride, lithium-ion, and others. However, due to its very high specific energy and power, lithium ion is currently the preferred option for EV applications.[33].

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. II.2 [32]:

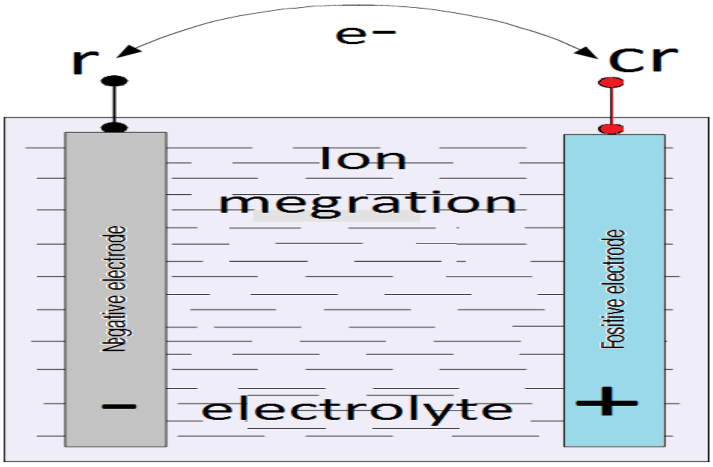


Figure II.2 An electrochemical battery cell [32].

- The electrolyte, the ionic conductor, which provides the medium for transfer of charge, as ions, inside the cell between the anode and cathode.
- 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.
- The cathode or positive electrode, the oxidizing electrode, which accepts electrons from the external circuit and is reduced during the electrochemical reaction The electrolyte is often a liquid having dissolved salts, acids, or alkalis to provide ionic conductivity, such as water or other solvents. Solid electrolytes, which are ionic conductors at the working temperature of the cell, are used in some batteries [32].

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

❖ **Lead-acid battery:** This technology offers high-speed performance, moderate low and high temperature performance, easy indication of state of charge and good charge retention for intermittent charging applications. There are few disadvantages like: low energy density and long charging time, heavy and it needs careful maintenance [31].

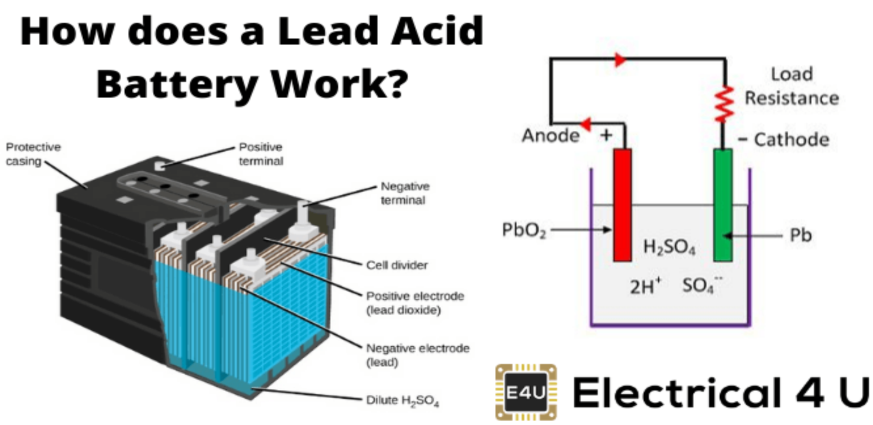


Figure II.3 Lead-acid battery[31].

- **Nickel-cadmium (NiCd) battery**: It was used in the beginning of space exploration. It has a long cycle life, good low temperature, and can be fully discharged without damage. As disadvantages, it is expensive, as cadmium is very toxic, the use of these batteries in EVs is therefore prohibited.

Figure II.4: Nickel-cadmium (NiCd) battery[31].

- **Nickel-metal hydride (NiMH) battery:** These cells have a higher capacity than nickel-cadmium cells, fast recharging capability, long life and long shelf life. The disadvantages of this technology are that it has low charging and discharging efficiency, high cost, poor cold weather performance.

Figure II.5:Nickel-metal hydride (NiMH) battery[32].

- **Sodium-nickel chloride battery:** Some advantages of these batteries are their relatively high energy density of 90-120 Wh/kg, as well as their insensitivity to ambient temperature. However, the main disadvantage of these batteries is that they need to be recharged when not in use so they are also inefficient as they consume power even when not in use.

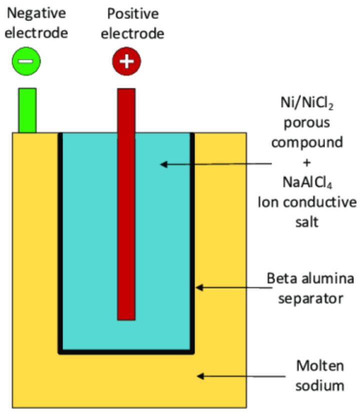


Figure II.6: Sodium-nickel chloride battery[32].

- **Lithium-Ion (Li-ion) battery:** Li-ion batteries are characterized by their energy density, which allows the vehicle to have a longer electric range; however, they generally do not have the specific power to deliver or accept large power spikes. They are used mainly in the latest electric vehicles nowadays.

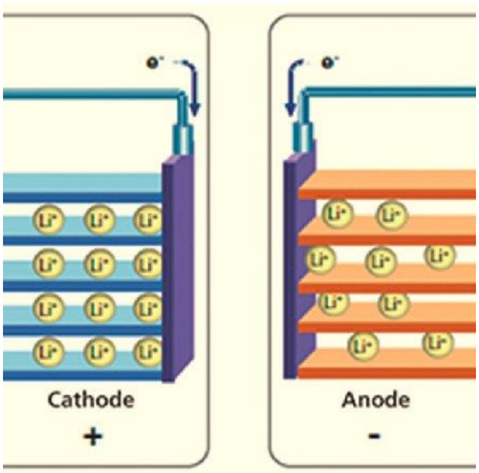


Figure II.7: Lithium-Ion (Li-ion) battery[32].

II.3.2. Accumulators

They store energy by transforming chemical energy. The accumulators consist of two electrochemical couples composed of two electrodes, immersed in an electrolyte. As soon as oxidation or reduction reactions occur which exchange electrons, the ions generated circulate in the electrolyte. To have a large stored energy, it is necessary, on the one hand, a large number of exchanged electrons, a reaction associating, a very oxidizing element and a very reducing element and on the other hand, it is necessary a perfect reversibility of the electrochemical processes, as well as low mass or low molar volume materials [32].

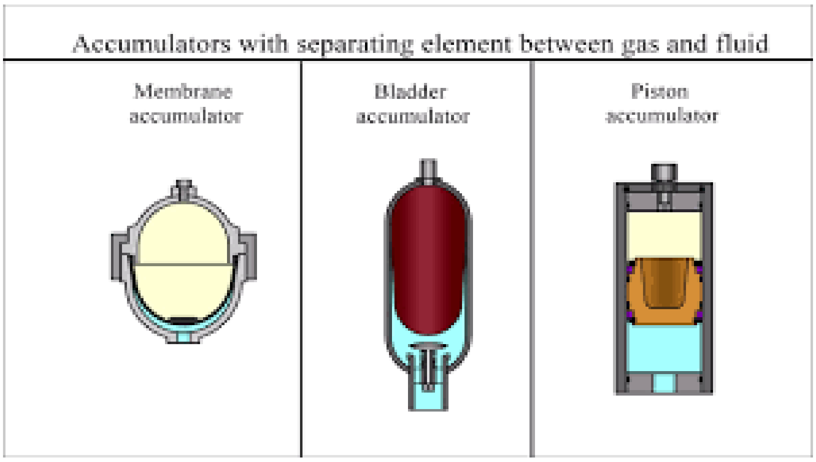


Figure II.8: Accumulators[4]

II.3.3. Super capacitor

They store electrical energy in electrostatic form. The general operating principle of super capacitors is based on the formation of a double electrochemical layer at the interface of an electrolyte and a polarizable electrode with a large specific surface. The application of a potential difference across the terminals of the device leads to the ionic storage of charges at the two electrode-electrolyte interfaces which behave like two capacitors in series.

Super-capacitors are characterized by a specific energy 10 to 20 times lower than that of accumulators, but their specific power can be up to 10 times higher than that of lead batteries for example.

The batteries most used in electric vehicles are those made up of accumulators, for example lead-acid batteries, which have never left the scene for more than a century, and Nickel/Cadmium accumulators and lithium-ion batteries or li-ion which are more recent, with a much higher energy density than that of lead/acid batteries, and Nickel/Metal Hydride accumulators which can store twice as much energy as lead batteries and 35% of more than Nickel/Cadmium for equal weight.

Many studies propose the use of super capacitors in electric vehicles. The use of super-capacitors essentially makes it possible to operate the battery at a nominal operating rate and therefore to increase its lifespan.[5].

The use of super capacitors in the automotive sector particularly meets the following needs:

- Starting and stresses at low temperature.
- Acceleration assistance and energy recovery.
- Supply of auxiliary organs

Figure II.9: Examples of compact supercapacitor[36].

II.4. System modeling

II.4.1.Battery model

Any battery is a set of elements or electrochemical cells capable of storing electrical energy in chemical form, then partially restoring it afterwards, thanks to the reversibility of the reactions involved. These reactions consist of oxidations and reductions at the electrodes, where current flows as ions in the electrolyte and as electrons in the circuit connected to the battery.fig. (II.10) [57].

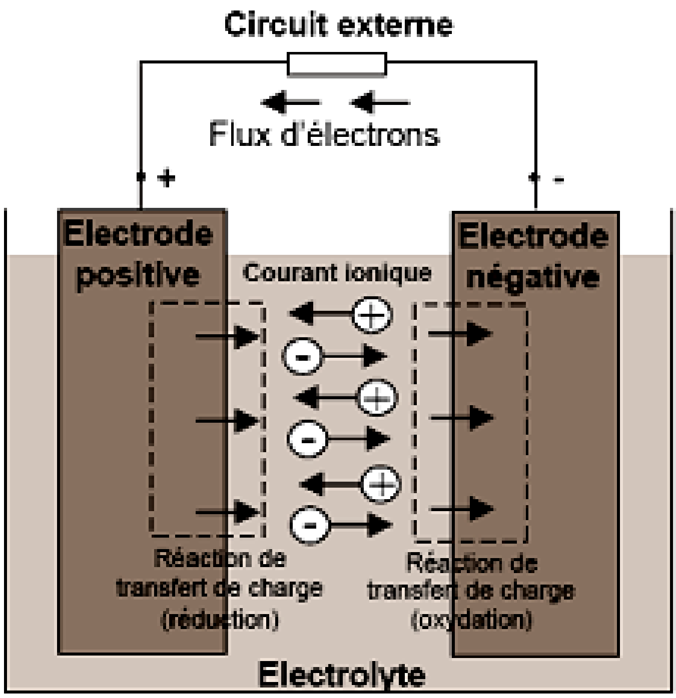


Figure II.10: Basic electrochemical cell[36].

Currently, the most widely used technology for photovoltaic applications is lead (Pb) technology [58]. It is still the most competitive and best mastered technology. Here we present the model of this accumulator.

The battery model adopted is the one used to predict the autonomy of the elevator system, i.e. to allow at each moment to estimate the remaining energy (state of charge SOC_{bat} depth of discharge DoD) in the battery [59]. The hoisi model is, therefore, an equivalent electric model (fig. II.11) composed of a voltage source in series with a resistor (internal resistance) [60], [58].

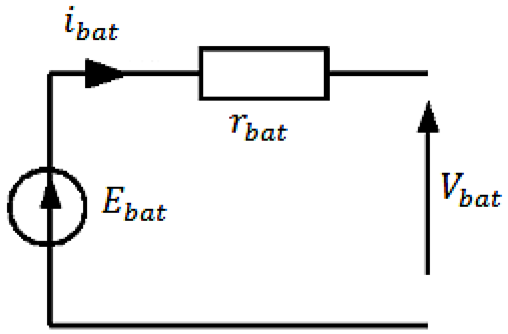


Figure II.11: Simple electric equivalent model of a battery[58].

II.4.1.1. Electric equation of charge and discharge

The voltage under load is deduced directly from the no-load voltage and the drop of tension due to internal resistance series [61]:

$$V_{bat} = E_{bat} - r_{bat}.i_{bat} \tag{II.1}$$

The no-load voltage E_{bat} is roughly inversely proportional to the battery's level of charge [62]. Equation (II.2) provides a reliable representation of the electrical equation by treating the DoD variable as a parameter that changes between 0 and 1, depending on whether the battery is completely charged or discharged [62].

$$E_{bat} = n(2.15 - DoD.(2.15 - 2.00)) \tag{II.2}$$

$$DoD = 1 - SOC_{bat} \tag{II.3}$$

II.4.1.2.State of charge equation

The state of charge of the battery is an estimated parameter while the battery is traversed by an electric current. The E_{bat} is given as the ratio between the current available capacity and the total actual capacity available at the time before utilization [63].

$$SOC_{bat} = \frac{C_{actuelle}}{C_{totale}} = SOC_{bint} + \frac{100}{C_N}\int i(t)dt \quad (II.4)$$

II.4.2. Supercapacitor model

Supercapacitors are a novel form of energy storage that outperforms traditional capacitors in terms of specific energy storage and outperforms electrochemical accumulators in terms of specific power.

Ironically referred to as electrochemical capacitors, double-layer electric supercapacitors really function similarly to traditional electrostatic capacitors. Typically, said metal electrodes are made up of two metal electrodes spaced apart by a dielectric. By applying a potential difference between these two electrodes, the energy is stored as an induced electric charge close to the electrode-dielectric interface. Capacitance, also referred to as capacitance, is a measure of a device's capacity to store energy and is defined as the ratio of the stored load to the applied voltage. Written are the fundamental relations for a linear capacitance. [64]:

$$C_1 = \frac{Q}{V_1}\epsilon\frac{A}{d} \quad (II.5)$$

$$w = \frac{1}{2}C_1V_1^2 \quad (II.6)$$

Thus, the objective is to establish a sufficiently accurate and accessible knowledge model of energy storage by supercapacitors. The equivalent model of a supercapacitor element is a capacitor C_{sc} in series with a resistor (R_{sc}) [65] (fig. II.12). Resistance describes the ohmic losses of the component while capacitance refers to the behavior of the supercapacitor during charging and discharging [66].

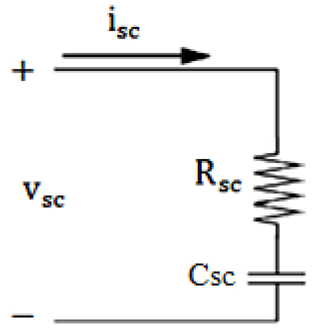


Figure II.12* : *Model of a Supercapacitor[66].

II.4.2.1. Electric equation of charge and discharge

To analyze the circuit of the previous model, it is assumed that the current of the supercapacitor i_{sc} is positive during the discharge phase and it is negative during the charging phase. The terminal voltage of super capacitors can be presented by [67]:

$$V_{sc} = Vc_{sc} + R_{sc}.i_{sc} \qquad \text{(II.7)}$$

II.4.2.2. State of charge equation

The state of charge, called SOC_{SC}, characterizes the amount of energy present in supercapacitors. It is worth 100% when fully charged and 0% when charged to their minimum value. Equation (II.8) presents the model adopted in this work [67].

$$SOC_{sc} = \frac{V_{SC}^2}{V_{SCmax}^2} \qquad \text{(II.8)}$$

II.4.3. Average model of the battery bidirectional converter

In the case of the Hasher used for charging/discharging batteries, the electric current must be reversible. Thus, to achieve the energy transfer in both directions, a booster chopper and a devolting chopper were associated as shown in Figure (II.13) [68].

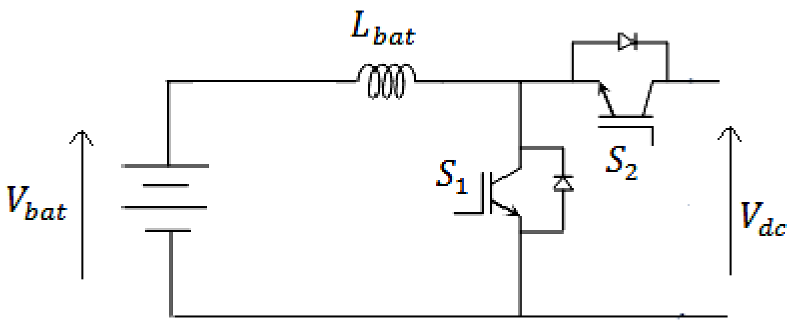


Figure II.13** : **Converter associated with batteries[68].

a. Operating sequences and equations of state:

The reversible battery current converter also uses the average concept. In the latter, continuous models of the entire system will be used to test the control methods. When IGBTs are closed, a wire represents their switching phase, but when they are open, there is no connection. Thus, the cutting period (T_{pwm}) is split into two [69], [70].

- **First conduction sequence t ∈ [0 ; α_{bat}.T_{PWM}]**

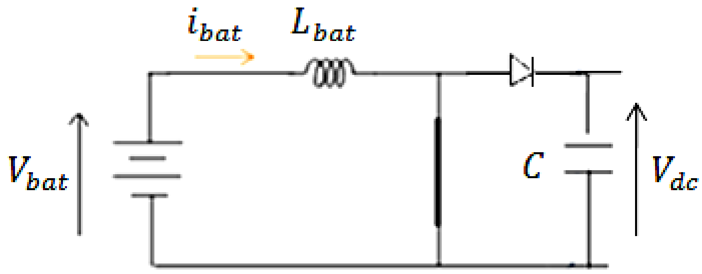


***Figure II.14**: The schematic diagram of the first conduction sequence [70].*

The dynamic equation of the current of the coil is written [70]:

$$V_{bat} = L_{bat}\frac{di_{bat}}{dt} \tag{II.9}$$

- **Second conduction sequence t ∈ [α_{bat}.T_{PWM} ; T_{PWM}]**

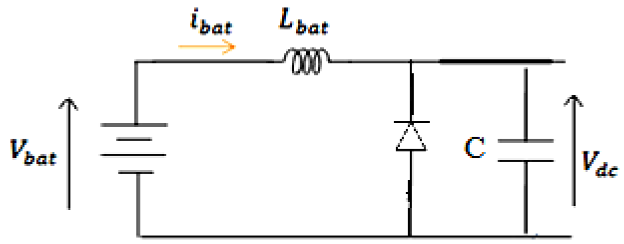


***Figure II.15**: The schematic diagram of the second conduction sequence [70].*

The dynamic relationship between battery voltage and bus is given by [70]:

$$V_{bat} = L_{bat}\frac{di_{bat}}{dt} + V_{dc} \tag{II.10}$$

The time mean of these two equations thus gives an average model of this converter[70]:

$$L_{bat}\frac{di_{bat}}{dt} = V_{bat} - (1 - \alpha_{bat})V_{dc} \tag{II.11}$$

The model of equation (II.11) reproduces the behavior of the battery under charging (i_{bat}<0) and discharging (i_{bat}>0).

<u>Note:</u> The bidirectional converter of the supercapacitor is modeled analogous to that of the battery[70]:

$$L_{sc}\frac{di_{sc}}{dt} = V_{sc} - (1-\alpha_{sc})V_{dc} \quad \text{(II.12)}$$

II.5. Energy Management System

II.5.1. Solving the energy management problem

The electrical vehicle under study, as we saw in the first chapter, is made up of two reversible converters (Buck-boost converters) and two electrical sources (batteries and supercapacitors). This topology includes an EMS, or energy management system, which stands for energy management system. In order to increase efficiency, the Buck-boost converter between the battery and the DC bus must provide a constant DC bus voltage. (Figure II.16).

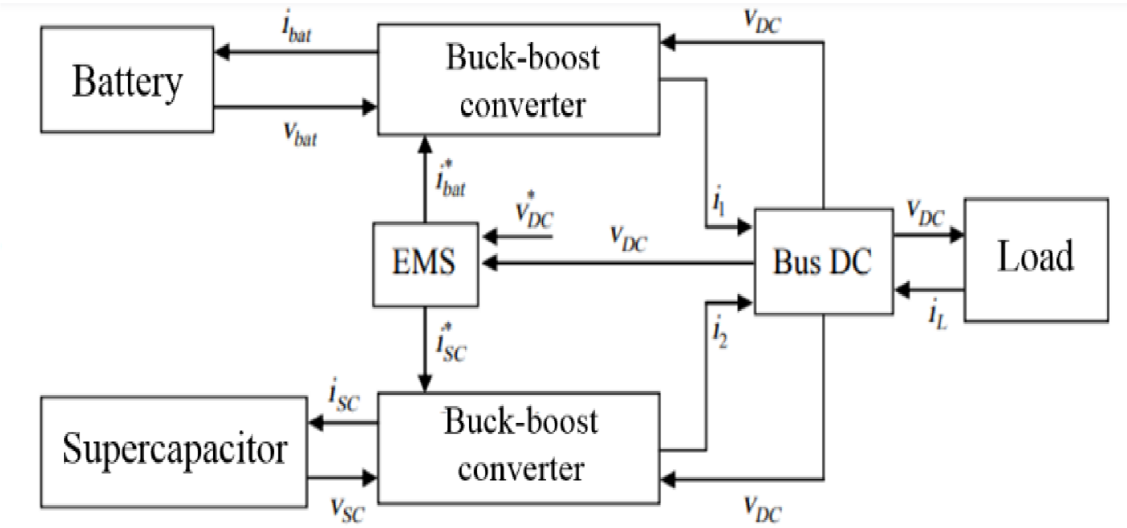


Figure II.16: The architecture of the studied electric vehicle [72]

It should be kept in mind that the system's optimal energy management is intended to reduce variations in the current the battery supplies to the load during the driving cycle (speed/time). This system consists of a battery and supercapacitors that are connected to the load.

II.5.2. Design of the control structure

From the average circuit model, which is given in equation II.11 and II.12, the state vector of the system is [i_{bat} i_{SC} v_{DC}], the control inputs are the two duty cycles corresponding to each power converter, [α_{bat} α_{SC}], and the disturbance considered is the load current, i_L, which is, of course, reversible. It is also necessary to take into account the voltage of the super capacitor, v_{SC}, as a state variable but, as the dynamic that emerges from it is quite slow compared to the other variables, in this case it was considered a variable parameter with bounded values.

The Figure II.17 shows the overall diagram of the proposed energy management system

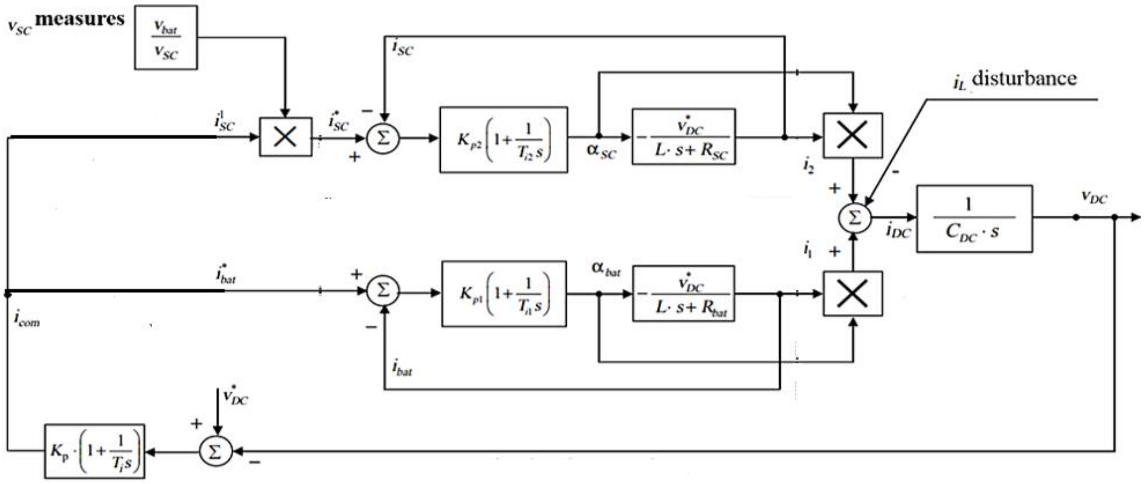


Figure II.17: Global diagram of the energy management system [71].

Because the dynamics of the DC bus voltage and the currents in the inductors may be separated, a traditional two-level control system is intended [72].

The external reference is the bus DC voltage, V^*_{DC}, required at the connection point.

The output of the proportional-integral (PI) corrector, reflecting the total demand for the load current, the reference for the battery current control loop, and the reference for the current control loop in the supercapacitor.

II.5.3. Control of the supercapacitor and the battery current

According to the Equation (II.11 and II.12), the structures of the power converters are the same for the battery and supercapacitor circuits. If we consider that the permissible limits on the DC bus are reached, its voltage can be considered to have a constant value of $V^*_{DC}=V_{DC}$ at this stage in the design of the correctors. Thus, the two low-level structures, either for the battery or the supercapacitor, are linear and invariant. The current supplied at the output of the supercapacitor is expressed by the transfer function in Equation (II.13) (similar modeling is done for the current of the battery, see Equation (II.14) [70]:

$$H_{sc}(s) = \frac{i_{sc}}{\alpha_{sc}} = \frac{-V^*{}_{DC}}{L.s + R_{SC}} \tag{II.13}$$

$$H_{bat}(s) = \frac{i_{bat}}{\alpha_{bat}} = \frac{-V^{*}{}_{DC}}{L.s + R_{bat}} \quad \text{(II.14)}$$

Following this modeling, the classical regulation structure of the proportional-integral (PI) type (with anti-saturation loop) is used to follow the references of the currents of the battery and the supercapacitor [72] respectively.

The general transfer function of the PI correctors used in the low-level control structure has the following form[72]:

$$H_{PI}(s) = K_p.(1 + \frac{1}{T_i s}) \quad \text{(II.15)}$$

where K_p (k_{p1} or k_{p2}) and T_i (T_{i1} and T_{i2}) are the parameters of the PI correctors.
Using Equations (II.12) and (II.17) we can write the transfer function in the general case[72]:

$$H(s) = \frac{- * V_{DC}}{L.s + R} = \frac{\frac{-V^{*}{}_{DC}}{R}}{\frac{L}{R}.s + 1} = \frac{-K}{T.s + 1} \quad \text{(II.16)}$$

where $K = {}^{*}V_{DC} / R$ and $T = L/R$ with $R = R_{bat}$ for the battery converter regulator or $R = R_{SC}$ for the supercapacitor converter regulator.

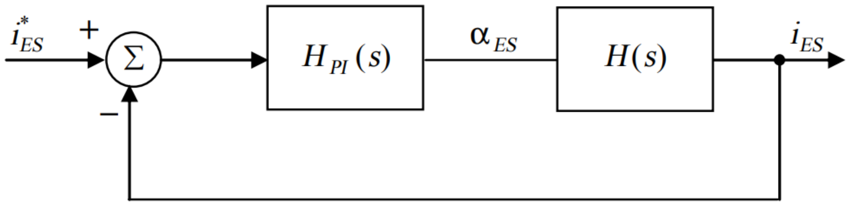


Figure II.18: Control architecture[71]

Using the forms of the transfer functions H (s) and H_{PI} (s), we find the equivalent closed-loop transfer function for the regulatory structure[71]:

$$H_{FTBF}(s) = \frac{H_{PI}(s).H(s)}{1 + H_{PI}(s).H(s)} = \frac{\frac{K_P(T_i+1)}{T_i s}.(-\frac{K}{Ts+1})}{1 - \frac{K_P K(T_i s+1)}{T_i s(T_s+1)}} \quad \text{(II.17)}$$

Finally, the $H_{FTBF}(s)$ function is written in the form [71]:

$$H_{FTBF}(s) = \frac{T_i.s + 1}{-\frac{T_i.T}{K_P.K}.s^2 + \left(-\frac{T_i}{K_p.K} + T_i\right).s + 1} \quad \text{(II.18)}$$

The regulator parameters, K_p and T_i are determined according to the form of the desired closed-loop response, for these two adjustment factors are available: the time constant corresponding to the cut-off frequency, T_0, and the damping coefficient, ξ.
In general, the transfer function of a second order system is expressed as[69]:

$$H_{II}(s) = \frac{K}{T_0^2.s^2 + 2\xi T_0.s + 1} \tag{II.19}$$

We would like a system response of order two for this regulator. Thus, by identification, the relationship (II.19) used to calculate the parameters is as follows[69]:

$$\begin{cases} K_p = \dfrac{1}{K}.(\dfrac{2\xi T}{T_0} - 1) \\ T_i = 2\xi T_0 - \dfrac{T_0^2}{T} \end{cases} \tag{II.20}$$

We imposed a closed-loop response dynamic five times faster than the main dynamic, i.e.
T0 = T / 5 and damping coefficient ξ = 0.85.

II.5.4. Control of the DC bus voltage

Under the realistic assumption that the currents of the internal loops (i_{bat} and i_{SC} are much faster than the DC bus voltage. The power losses of the switching devices are assumed to be negligible. In this context, we can postulate the following [70]:

$$\begin{cases} \alpha_{bat} = \frac{v_{bat}}{v_{DC}} \\ \alpha_{SC} = \frac{v_{SC}}{v_{DC}} \end{cases} \text{ and } \begin{cases} i_1 = \alpha_{bat}.i_{bat} \\ i_1 = \alpha_{SC}.i_{SC} \end{cases} \tag{II.21}$$

The two i_{bat} and i_{SC} currents can be used as control inputs for the DC bus structure with the output v_{DC} voltage. Hence, the total current injected into the DC bus by the two energy sources is written[70]:

$$i_{DC} = i_1 + i_2 = \alpha_{bat}.i_{bat}^* + \alpha_{SC}.i_{SC}^* \tag{II.22}$$

The two channels of influence have different benefits i.e. their duty cycles. It should also be remembered that, with regard to the difference in the voltage of the DC bus and of the battery, the gain of the battery, which is the duty cycle α_{bat}, is almost constant. In order to equalize their effect, an additional gain for the supercapacitor must either be added or the reference current of the supercapacitor must be changed as follows[70]

$$i_{SC}^* = i_{SC}^1.\frac{V_{bat}}{V_{SC}} \tag{II.23}$$

where i_{SC}^{*} is the output current of the high pass filter and the $\frac{V_{bat}}{V_{SC}}$ ratio is the additional gain.

Thus, using Equations (II-21) and (II-23) in Equation (II-22) the current exchanged with the DC bus becomes [70]:

$$i_{DC} = i_1 + i_2 = \alpha_{bat}.(i_{bat}^{*} + i_{SC}^{1}) = \frac{V_{bat}}{V_{DC}}.i_{com} \quad \text{(II.24)}$$

with i_{com} designating the total current considered as the control input within the DC bus voltage regulation loop. By equalizing the gains on the two current channels and replacing by Equation (II-24) the equation of the regulation structure of the DC bus is written as the following way [70]:

$$C_{DC}.\frac{d_{V_{DC}}}{dt} = \frac{v_{bat}}{v_{DC}}.i_{com} - i_L \quad \text{(II.25)}$$

With a PI corrector of the form C (s) = K_p (1 + (1 / Ti.s)) we find the closed loop transfer function [70]:

$$H_{FTBF}(s) = \frac{T_i.s + 1}{\frac{T_i.T_{DC}}{K_P.K_{DC}}.s^2 + \left(\frac{T_i}{K_p.K_{DC}} + T_i\right).s + 1} \quad \text{(II.26)}$$

Finally, using Equations (II-26) and (II-19) by identification, we deduce the expressions of K_p and T_i. [70]

$$\begin{cases} K_p = \frac{1}{K_{DC}}.(\frac{2\xi T_{DC}}{T_0} - 1) \\ T_i = 2\xi T_0 - \frac{T_0^2}{T_{DC}} \end{cases} \quad \text{(II.27)}$$

The values of the time constants T_0 and ξ are therefore chosen to ensure that the current loops provide an almost instantaneous response to the voltage loop.

II.6. Conclusion

In this chapter, we have presented the structure of the electric vehicle selected for different tests.

Next, we will present the different models of the constituent elements of an Electric storage/conversion and mechanical traction series of the selected vehicle.

Chapter III

Simulation Results and Discussion

III.1. Introduction

The simulation results obtained during this analysis will be carried out using the models and control laws established in the previous chapters for the different elements of the electrical vehicle system. One of the objectives assigned to this work is the implementation of the energy management strategy described in this Chapter and also the stability of the DC bus, which is also analyzed from the point of view of voltage regulation.

III.2. On-board hybrid device architecture

To connect a DC bus to two sources, you need to consider the cost, length, total weight and efficiency of the system. The structure shown in figure (III.1) provides the following:

- Maintain consistency of power whatever the load needs.
- Offer very high energy for a short period of time.

The architecture is composed of:

- A continuous capacitive bus with a voltage of 100V.
- The key source of energy represented by a stack of Lead Acid batteries, connected to the DC bus by a bi-directional Buck/Boost converter in current. They have got a Vba voltage and a Pba power.
- Auxiliary energy source: A power source represented by a supercapacitors stack, having a Vsc voltage, providing and absorbing a Psc power. Supercapacitors are connected to the DC bus by a bi-directional Buck/Boost converter to current.

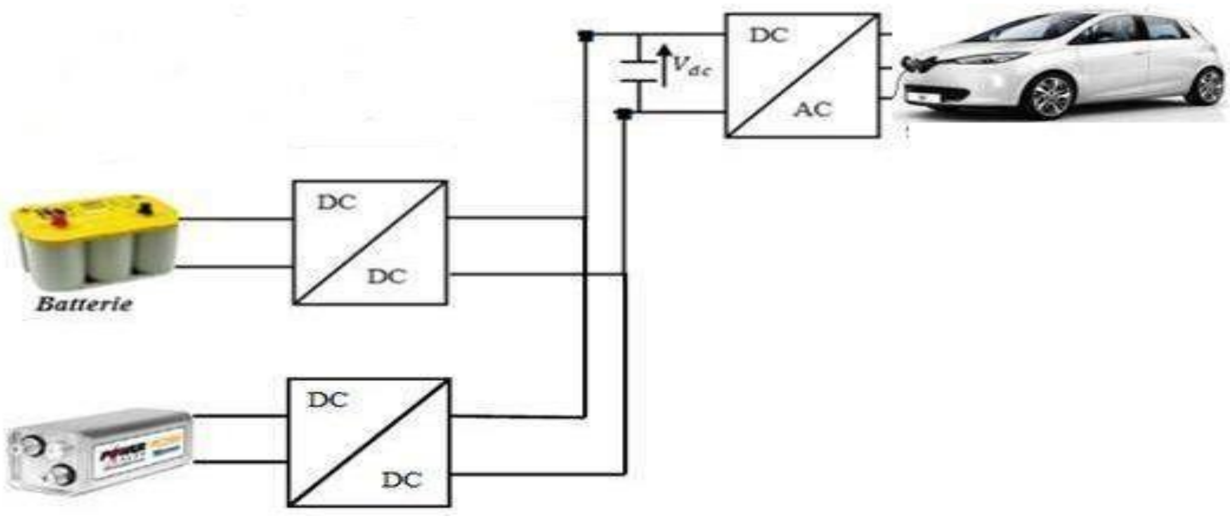
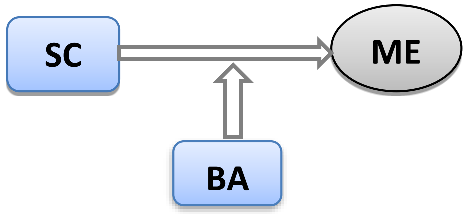
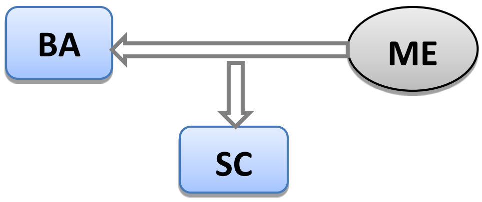
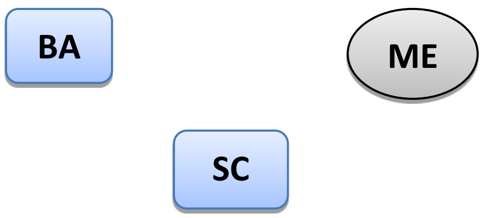


Figure III.1: On-board hybrid device architecture

III.3. Energy Management Principle

The main objective of energy management is to satisfy the power provided by the load and thus to find the best distribution of power between the system's energy sources. The theory of energy management is based on maintaining the consistency of the power required by the load while respecting various operational constraints, such as batteries and superchargers. For this, we adopted the theory set out in the table below.

Table III.1: Energy-management principle

	Modes	Schema of energy flows	**Description**
Traction	Mode 1	 	Battery and supercapacitor power the electric vehicle together.
	Mode 2	 	The battery is only supplied to the electric vehicle
Braking	Mode 3	 	The battery and the supercapacitor recover the energy from braking
stopping	Mode 4	 	No supply of energy

Where: BA: Battery, **ME:** Electric motor, **SC:** Supercapacitor

III.4. Simulation results and discussion

In order to check the theory of the proposed energy management, we have the following:

- Proposed consumption profile shown in Figure.III.1 taking into account three phases: start-up phase, normal phase, recovery phase and shut-down phase.
- The "MATLAB / Simulink" tool has been used.

III.5. Load profile

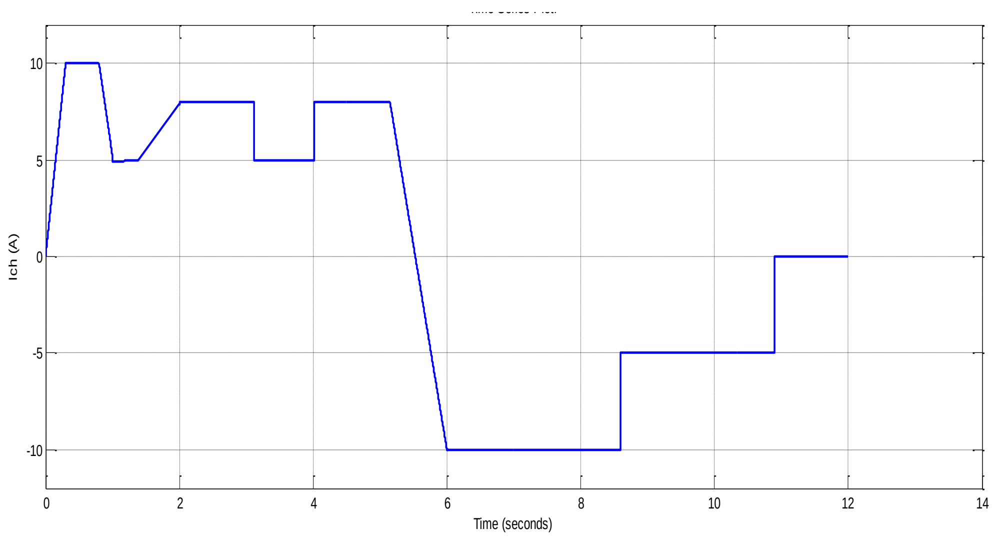


Figure III.2: Load profile

III.6. power simulation results

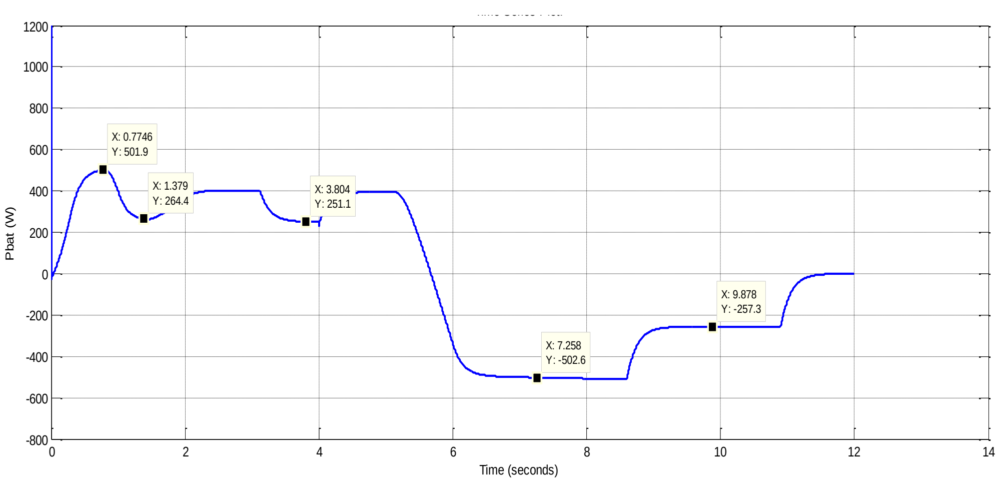


Figure III.3: power of the battery

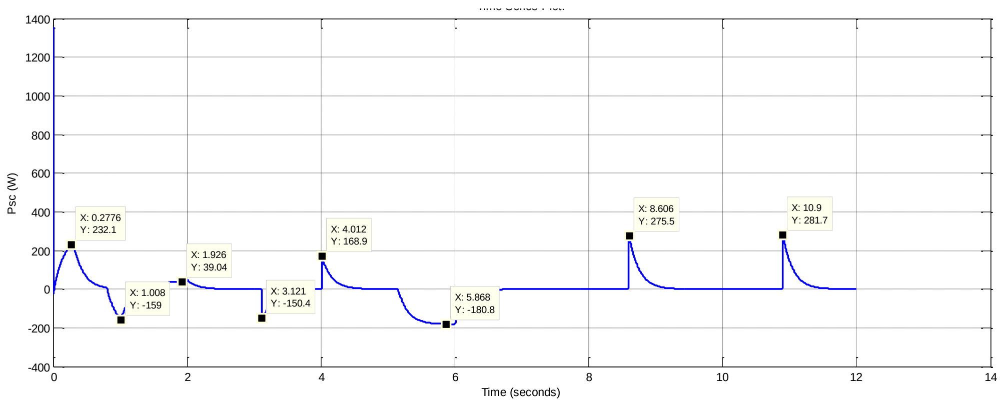


Figure III.4: Power of the supercapacitor

From a Figure.III.3 and a Figure.III.4 we can see that the battery power is at the maximum (501.9W) and also, that the supercapacitor power (232.1W) is still at the range of (0 to 1.5s), it corresponds to the starting step of the M1 mode. In such a way that the battery and the supercapacitor provide energy to the engine at the same time, the life of the electric vehicle will be improved.

In the range of (1.5 to 5s) the power of the battery varies depending on the load demand from (251.1 to 400W), but for the super capacitor power output almost zero and that in the transient points (does not take into account) this is the usual running phase (M2 mode) so that the super capacitance disconnects and only the battery provides the energy to the vehicle.

In the range of (5 to 11s) the power absorbed by the battery varies depending on the power provided by the load from (-502.6 to -257.3W); however for the power absorbed by the super capacitor varies from (0 to -180.8W) in the range of (5 to 6s), it is the braking step (M3 mode). As a result, the vehicle provides energy to the super capacity and the battery.

In the range of (11 to 12s) the energy absorbed by the battery varies from (-257.3 to 0W), but for the power absorbed by the super capacitor is zero, it is the shutdown step (M4 mode). As a result, the vehicle has been absolutely stopped.

III.7. Current Characteristics

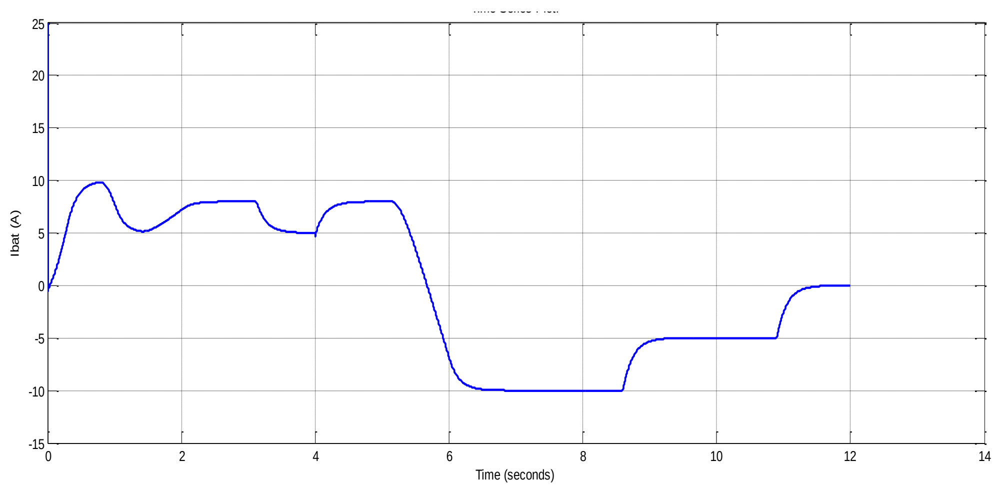


Figure III.5: Current of the battery

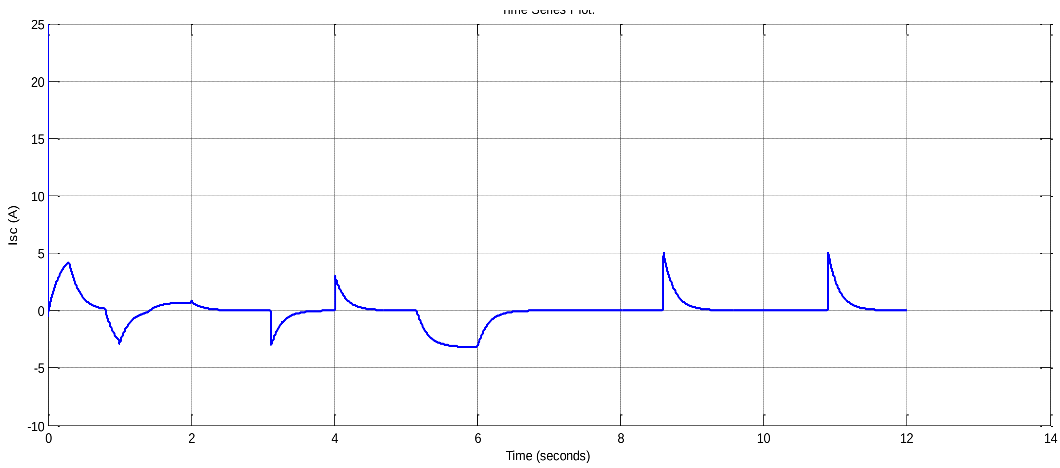


Figure III.6: Current of the super capacitor

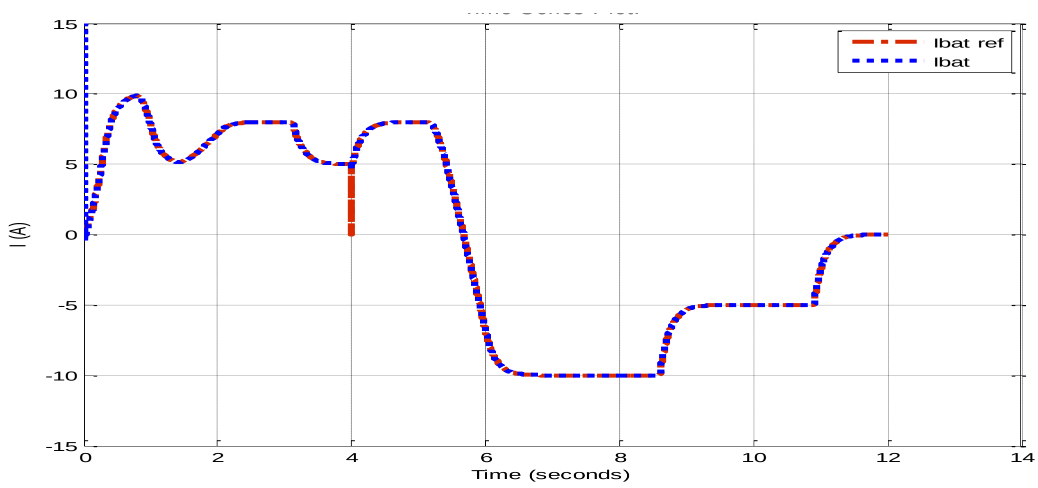


Figure III.7: The current of the battery and its reference

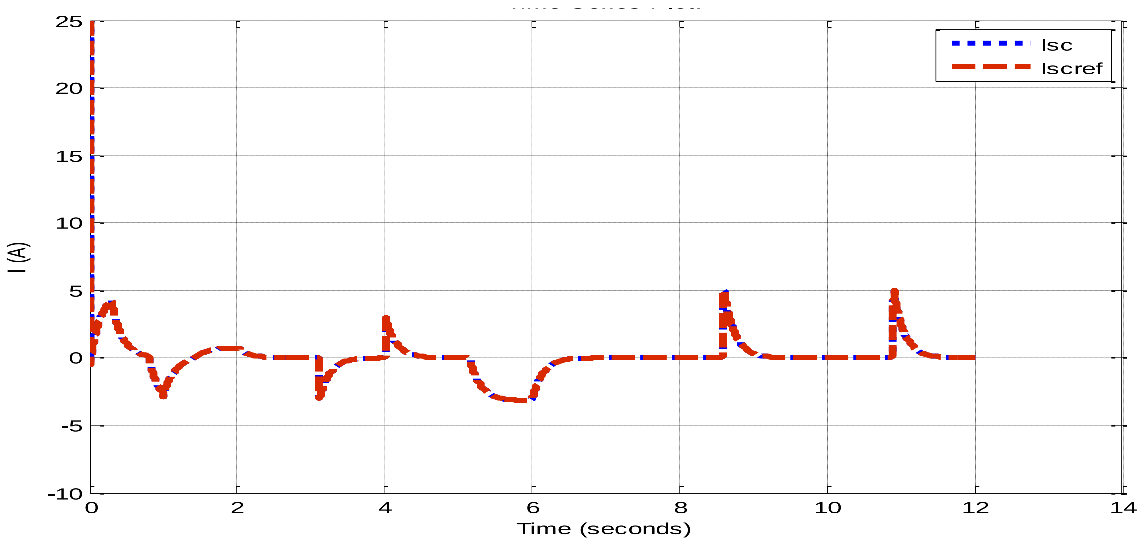


Figure III.8: The current of the supercapacitor and its reference

III.8. Voltage Characteristics

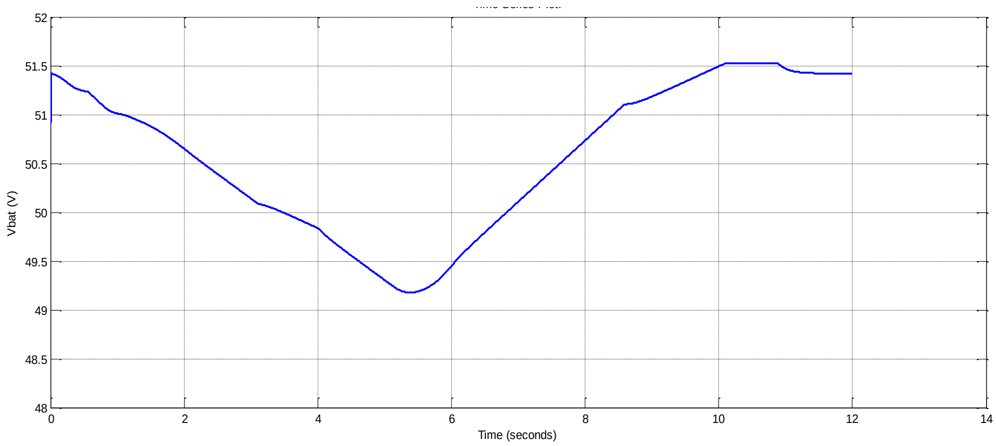


Figure III.9: Voltage of the battery

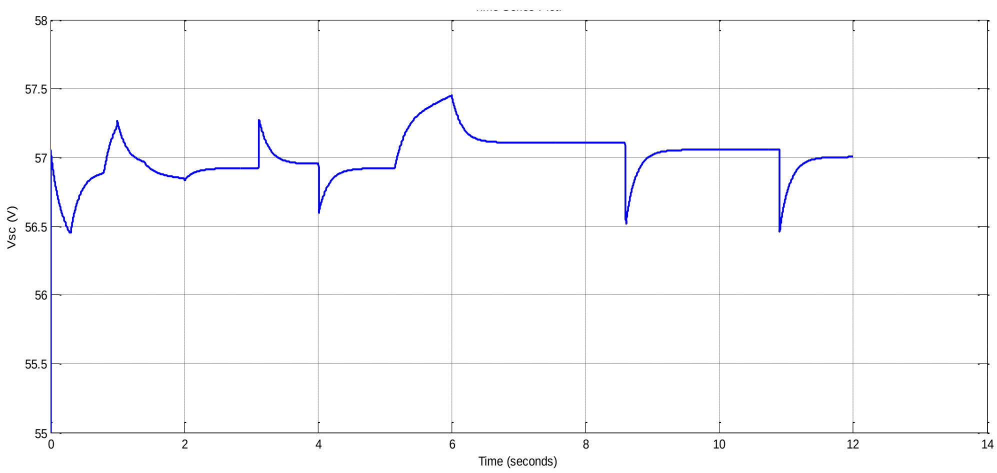


Figure III.10: Voltage of the super capacitor

Analyzing the figures III.9 and III.10, we find that the battery voltage decreases rapidly (from 0 to 1s) it is the starting step (mode M1) and follows the continuous voltage to decrease (from 1 to 5s) it is the regular phase (M2 mode). Then at an instant of 5 to 12 seconds, it starts to grow steadily, proving that the battery is in the charging process mode M3.

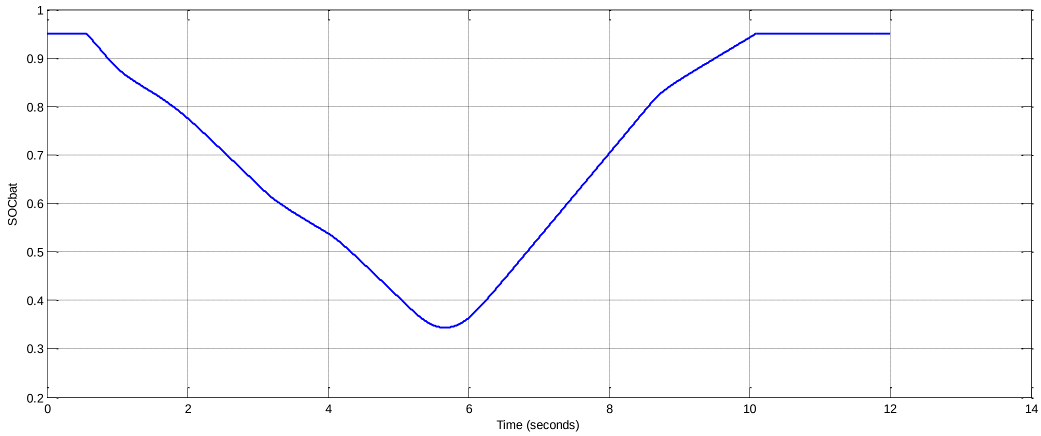


Figure III.11: State of charge of the battery

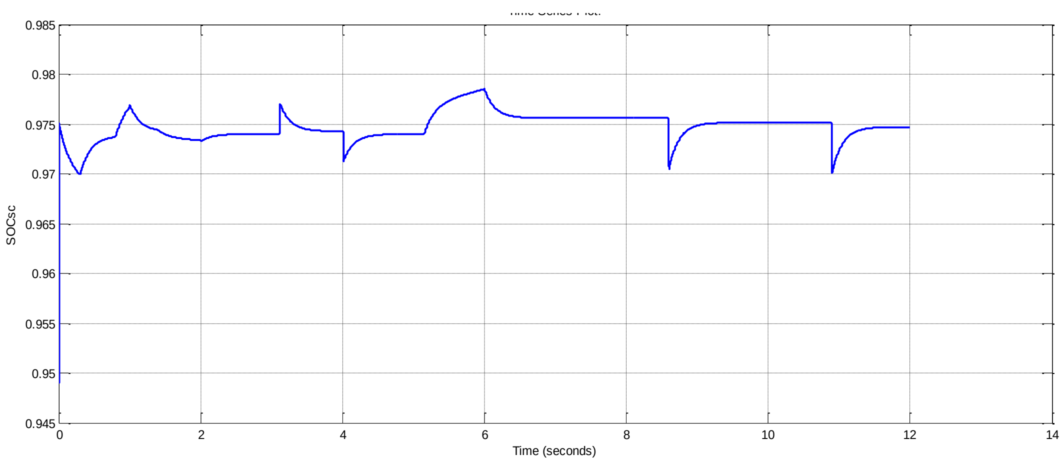


Figure III.12: State of charge of the super capacitor

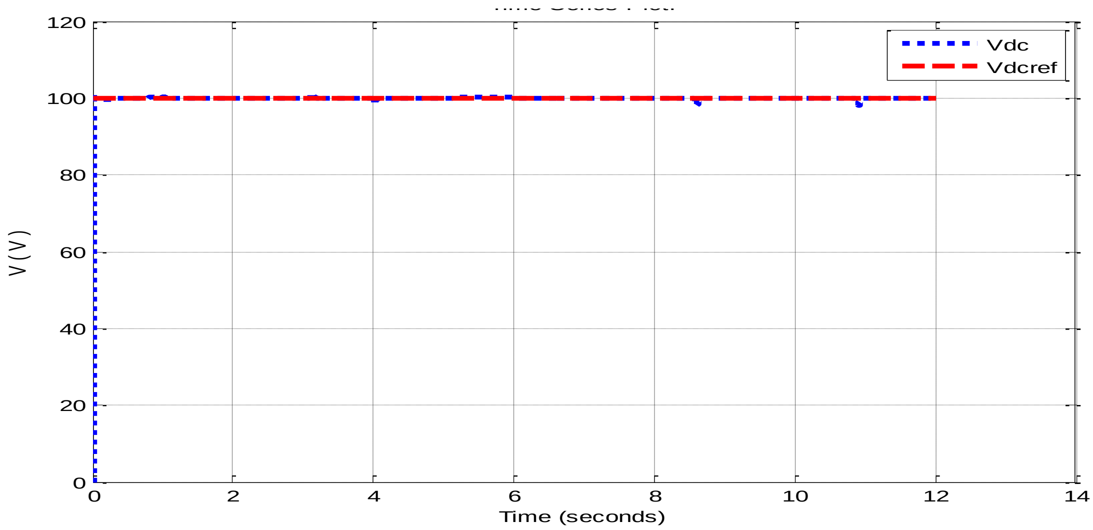


Figure III.13: the DC bus voltage and its reference

III.9. Control Characteristics

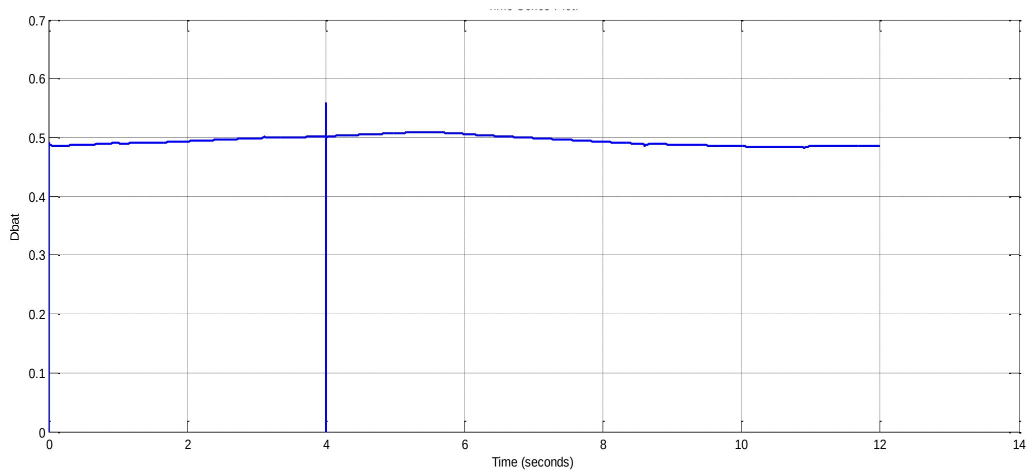


Figure III.14: Battery duty cycle

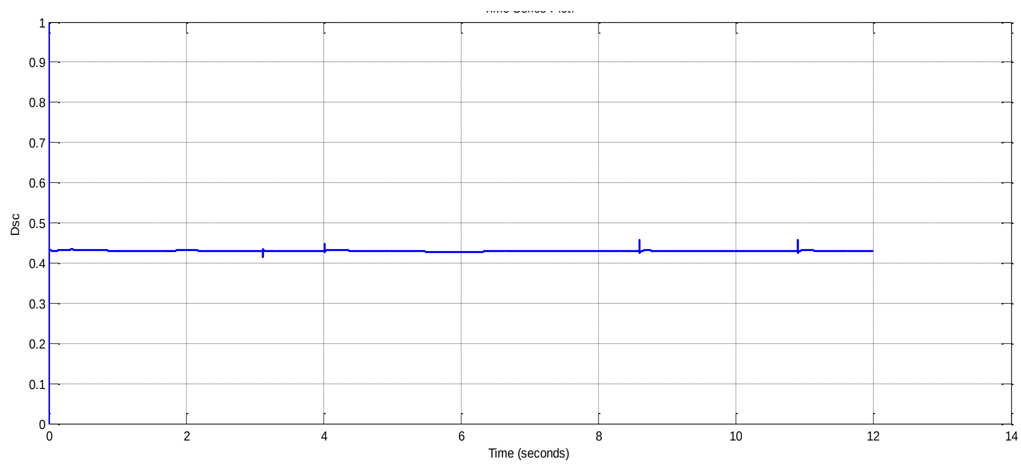


Figure III.15: Super capacitor duty cycle

Analyzing Figure III.14 and Figure III.15 respectively indicate that the battery duty cycle varies about 0.5, while the super capacitor duty cycle varies about 0.43 at the same time, this difference corresponds to the voltage variation of the super capacitor (Figure III.10) when the DC bus voltage is almost constant.

III.10. Conclusion

We addressed the energy management of an autonomous hybrid system in this chapter. The device consists of the lead acid battery pack considered to be the main source, and the super capacitors used as auxiliary sources, not to mention the load modeled by the consumption profile. We conclude from the results obtained that:

- The hybrid source makes it possible to meet the power requirements of the load;
- The final stages of charging the batteries and the super capacitors are acceptable for beginning other driving cycles. As a result, the life of the autonomous hybrid system will be improved.

General Conclusion

GENERAL CONCLUSION

The main objective of this thesis was to improving a life spane of the battery in the electric vehicle by using the super capacitor as a secondary power source. So, the energy management strategies is important for distribution the energy between the main source (battery) and the secondary source (super capacitor).

A key element of the study was to set up a simulation project of the energy management strategies including the role based strategy using mathematical models of the battery and the super capacitor with current profile of the loud.

Through this work, the control of the electric vehicle drive-train and the energy management of its power-train system have been presented. The goal of the drive-train's control was to provide an inversion base control and propose an adaptive operation mode of the studied vehicle.

From the results we can conclude that:

- ✓ Lead acid batteries are really suitable only for vehicles of short range. They remain the cheapest type of battery per unit of stored energy, and they are likely to continue to be widely used for those purposes. Very many useful EVs that don't need a long range can be made. So, by the simple calculation and simple hardware requirements, the proposed method can be easily implemented in all portable devices as well as electric vehicles.
- ✓ The maximum current of the battery can be reduced according by adjusting the separation frequency.so increasing the life span of the battery.
- ✓ The disadvantage of this energy management strategy is to use the filter inside the battery and inside the super capacitor and this filters can produce the electrical disturbance.

In perspective, it would be interesting to:

- Work with batteries of other technologies (lithium)
- Validate experimentally the simulation results of this energy management control approach with PI regulators.

Use other energy management strategies like: artificial neural network

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Abstract

Résumé

الملخص

Abstract

The main objective of this work is to present solutions to improve the performance as well as to increase the control reliability of the dual star induction machine. In order to achieve this objective, new control strategies and fault diagnosis algorithms for the power converters are developed and proposed .

Keywords: Embedded system, Energy management, Battery, Super capacitor, Electric Vehicle.

Résumé:

L'objectif principal de ce travail est de présenter des solutions pour améliorer la performance et augmenter la fiabilité de contrôle de la machine asynchrone à double étoile (MASDE). Afin d'atteindre cet objectif, des nouvelles stratégies de contrôle et des algorithmes de diagnostic des défauts du convertisseur sont développées et proposées .

Un nouvel algorithme de diagnostic des défauts de circuit ouvert dans le convertisseur de puissance est proposé, dans laquelle seuls les courants mesurés sont nécessaires, ce qui évite l'utilisation de matériel supplémentaire ou la connaissance des paramètres du système. La dernière partie du présent travail est consacré au contrôle de la génératrice asynchrone double étoile.

Les résultats obtenus prouvent le bon fonctionnement de la machine asynchrone double étoile en mode moteur et en mode génératrice.

Mots clés : Système embarqué, Gestion de l'énergie, Batterie, Super condensateur, Véhicule électrique.

الملخص

الهدف الرئيسي من هذا العمل هو تقديم حلول لتحسين الأداء وزيادة موثوقية التحكم في الآلة غير المتزامنة ذات النجم المزدوج. من أجل تحقيق هذا الهدف، تم تطوير واقتراح استراتيجيات تحكم وخوارزميات تشخيصية جديدة لأعطال المحولات.

تم اقتراح خوارزمية جديدة لتشخيص أعطال الدائرة المفتوحة في محول الطاقة، والتي تتطلب فقط التيارات المقاسة، مما يتجنب استخدام أجهزة إضافية أو معرفة معلمات النظام. تم تخصيص الجزء الأخير من العمل الحالي للتحكم في المولد الغيرمتزامن ذو النجم المزدوج.

تثبت النتائج التي تم الحصول عليها الأداء الجيد للآلة الحثية ذات النجمتين كوضعية محرك أو مولد.

الكلمات المفتاحية: نظام مدمج، إدارة الطاقة، بطارية، مكثف فائق، مركبة كهربائية.