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Classical Boolean and Fuzzy Logic Energy Management Strategies for a Parallel Hybrid Electric Vehicle Powertrain System

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Abstract: In this paper, we make a comparative study of fuzzy logic and boolean logic energy management strategies (EMSs) for an hybrid electric vehicle (HEV) with parallel architecture made up mainly of an electric motor (EM) and an internal combustion engine (ICE). EM is used as a main propulsion system for the vehicle. However, the ICE is used as a backup system. This study is developed to manage the energy flow between the two sources by ensuring a balance between the generated and consumed powers, injected or absorbed into the battery and minimizing the ICE operation in order to reduce the fuel consumption and CO_2 emission. The purpose of this study is to investigate the different scenarios for fuzzy logic and classical logic strategies under the Normalized European Drive Cycle (NEDC), NEDC cycle for 1-hour, and combined cycle of Worldwide harmonized Light vehicles Test Procedures (WLTP) and Assessment and Reliability of Transport Emission Models and Inventory Systems (ARTEMIS) cycles. The change of test conditions from NEDC to WLTP and ARTEMIS was shown to lead to a significant reduction of the fuel consumption and CO_2 emission using the fuzzy logic control with results that may attend 50% increase of CO_2 emissions reduction VS the results of boolean logic control. Simulations are made using MATLAB/ Simulink software. Results of both strategies are presented and discussed in this paper.

Keywords: Hybrid Electric Vehicle, Internal Combustion Engine, Electric Motor, Fuzzy Logic, Classical Boolean Logic, Energy Management Strategy.

1. INTRODUCTION

The transport sector contributes in general by 23% of the European Union (EU) transport sector's total CO_2 emission. Indeed, 77.7% of greenhouse emissions are produced by the road transport sector and 45% is caused mainly by the use of vehicles as detailed in the report of the European Environment Agency (EEA), which explain the main impact of fuel consumption on the environment pollution. However, the global growth in polluting greenhouse emissions caused a terrible global warming, which seriously threatened the world over the past 10 decades [1].

Therefore, humanity is faced with the challenge to ensure the best energy balance and to take into account the economic and ecological consequences of their intensive consumption of fossil fuels in the different sectors.

In addition, the percentage of fuel production in the world will decrease from 60 billion barrels to minus 5 billion barrels by around 2050. Therefore, humanity must address this lack with other renewable energy sources.

Consequently, the development of electric transport industry has been proposed as one of the brilliant achievements due to its relying on primary renewable energy sources [1, 2] to produce the final energy to propel the vehicle. However, in different countries, it is not yet

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time for plug-in electric vehicles (PEV) depending on the lack of charge station parks and intelligent infrastructure. Therefore, HEV are an adequate answer for this situation.

HEV is not pure clean vehicles; various efforts are taken to develop different EMSs to manage the energy flow between the different sources as a perfect solution to preserve the environment by reducing the CO_2 emissions and manage the energy flow between electricity and fuel consumption to enhance the range of the vehicle [3, 4].

Challenges associated with the two energy sources of the HEV involve the importance of EMSs [5, 6]: rule based methods and optimization methods. In the literature, many researchers are interested in the rule-based methods, which is split into determined and fuzzy logic methods [7-10] and optimization methods like PSO, APSO, GA, and GWO… [9, 11].

In this framework, we present a HEV with parallel architecture, in which, the electric and thermal motors are mechanically linked, so that the power to the wheels can be supplied simultaneously or alternately by the two motors with minimal energy losses.

The permanent magnet synchronous motor (PMSM) is used as the main source of energy with high performance, perfect autonomy, and long service life to reduce costs and preserve vehicle longevity.

However, the thermal motor is well suited for long drive journeys and high speed. It is generally sufficient to extend the range. For this reason, ICE can be used as a back-up system to handle different situations such as blended battery, lack of electricity charge station, etc…

Facing this issue, the proposed boolean and fuzzy logic strategies have been used for different problems based on rules and constraints. Boolean logic is based on mathematic equations and just two situations true or false (0 or 1) unlike the fuzzy logic one, which is characterized by different situations defined by different aspect such as big, low, tall…to express the real human reasoning [12].

These proposed methods have been used in different fields and applications. Reference [13] can be considered as a wealth as it focuses on the review papers about the boolean and fuzzy logic based methods. It evokes many comparative studies of the two methods in different applications. Reference [14] has dealt with a comparative study of fuzzy and classical logic methods for residential hybrid system to manage the energy of the wind and solar sources.

Works on [15] have adopted the fuzzy logic method to manage the energy flow between batteries and super capacitor of a hybrid system and a grid connected wind power system. In Reference [16], a boolean logic strategy for a plug in electric vehicle (PEV) and smart home interaction is developed to improve the system power demand.

Reference [17] have interested on the energy management of the photovoltaic and storage systems for a commercial building using the fuzzy logic method with purpose to reduce the electricity cost and the CO_2 emission of the whole building.

In our case, we will focus on a comparative study of boolean ad fuzzy logic EMSs to manage the energy flow between the PMSM and the ICE for a parallel HEV to minimize the fuel consumption and CO_2 emission and to reduce the overcharge and deep discharge of the battery.

The general parallel HEV system architecture is presented in Section 2. Section 3; investigates the fuzzy logic strategy. Section 4; describes the boolean logic strategy. Simulation results are presented, discussed and compared in section 5. In Section 6, conclusions are drawn.

2. GENERAL STRUCTURE OF THE PARALLEL HEV PROPULSION SYSTEM

The studied system was composed of a specific configuration, which has been used through these studies [9, 18, 19].

This configuration is specified by a PMSM motor, which is linked to the lithium ion battery by DC/AC converter. This converter is linked to an intermediate DC-bus, and an inverter. Besides, the HEV includes an ICE, which is linked to the continuous variable transmission (CVT) and the reduction gear as described in Fig.1.

Where:

T_{tot} is the total torque.

T_{em} is the electromagnetic torque of the PMSM.

T_{ice} is the thermal torque of the ICE.

T_{ice1} is the output torque of the gear.

Ω_{mec} is the wheels speed.

Ω_{ice} is the rotation speed of the ICE.

U_{dc} is the DC bus voltage and i_{dc} is the DC bus current.

F_{res} is the resistance force.

F_{tot} is the tractive force abandoned the wheels supplied by the motor.

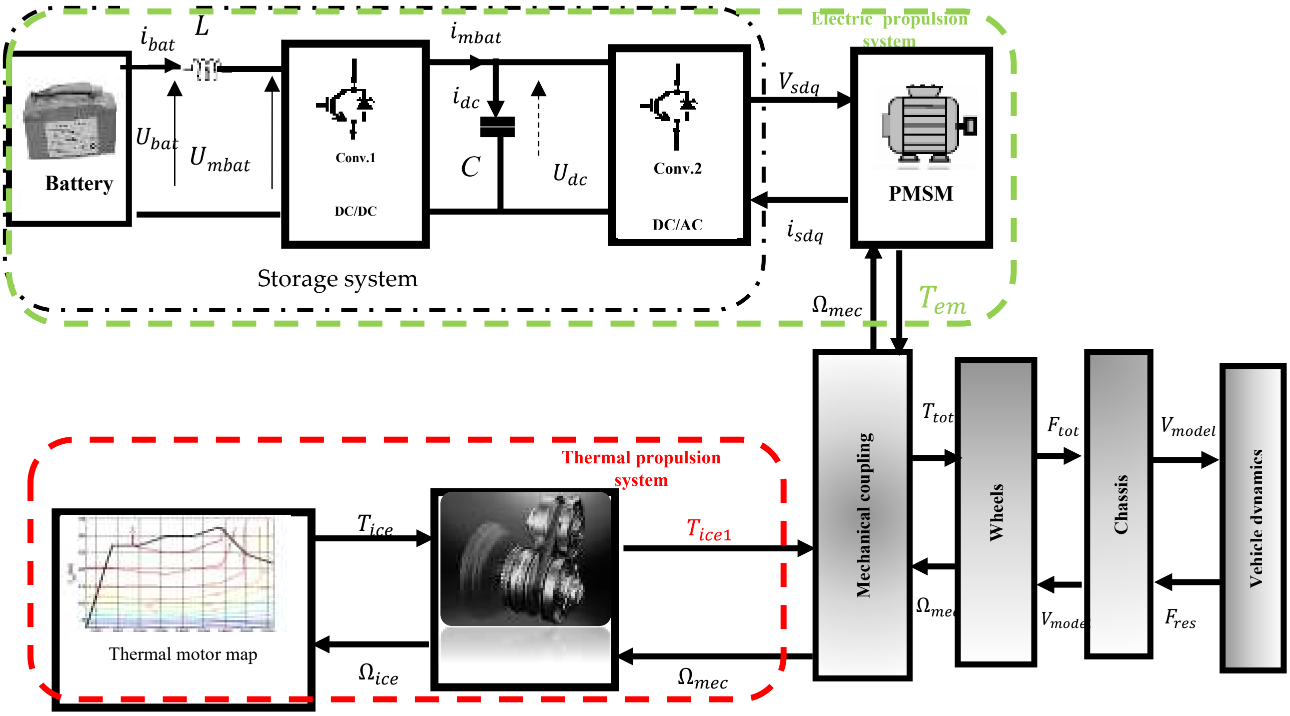
i_{bat} is the battery current.

V_{model} is the model speed.

U_{mbat} is the modulated voltage of the DC/DC converter.

V_{sd} is the direct and quadratic PMSM voltages.

i_{sd} is the direct and quadratic PMSM currents.



Therefore, the overall system of 4.5 kW electric motor and 128Ah lithium ion battery can propel the vehicle in the maximum electric range with degree of hybridization H equal to 0.4268 described with the following equation:

$$H = \frac{P_{em}}{P_{ice+P_{em}}} \quad (1)$$

Where: P_{em} is the power of the electric PMSM motor and P_{ice} is the power of the ICE motor.

In this study, we adopted the convention in which the negative current is dedicated to the battery discharge and the and the positive current is dedicated to battery charge cases as illustrated in Fig.2.

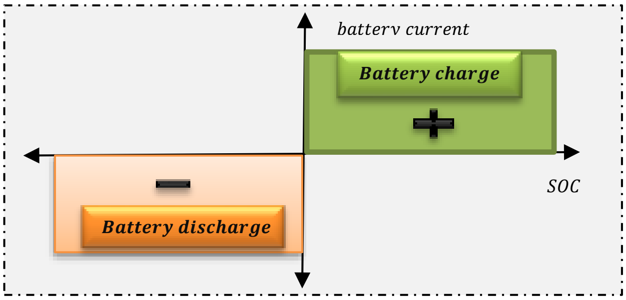


Figure 2. Lithium ion battery charge and discharge convention.

As we can see , to design a general EMS strategy configuration different parameters are have to be known during the simulation step which are the actual battery state of charge (SOC) ,the reference vehicle speed (Vref), propulsion mode (acceleration or deceleration mode) (a) and the EM and ICE torques respectively as described in Fig.3.

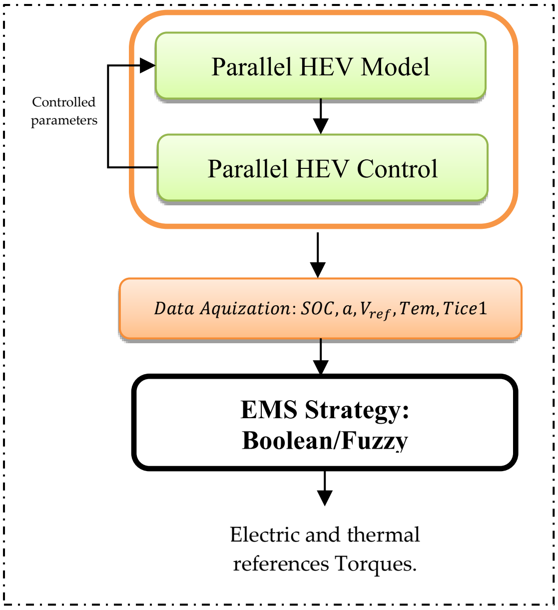


Figure 3. General studied EMS configuration.

3. FUZZY LOGIC STRATEGY

A. Overview

The fuzzy logic method is a control system developed by Lotfi A. Zadeh in 1965 [20]. It is inspired by human reasoning.

In comparison with other control strategies such as proportional integral derivative (PID), proportional integral (PI), and boolean controllers, the fuzzy logic controller is very efficient, robust and simple to implement because it doesn't need a mathematical model. In addition, fuzzy logic control has been enormously successful in different domains [21].

Fuzzy logic is composed of 4 different sections in closed loop control: fuzzifier, interference, rules and deffuzifier blocks as described in Fig.4.

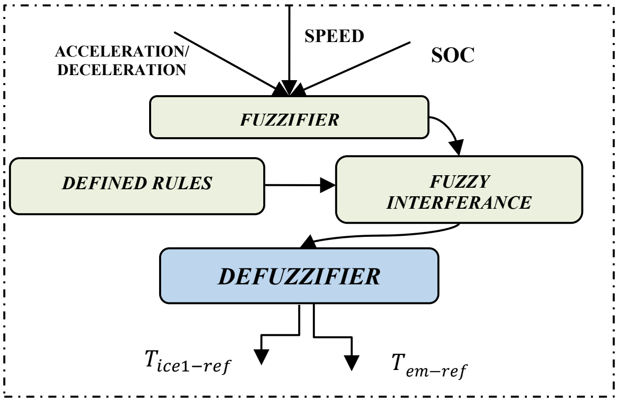


Figure 4. Fuzzy logic scheme.

B. General structure

The general configuration of the fuzzy logic strategy needs specifications; Objectives, constraints and means of action for the control have to be defined as follows:

- Objectives:

✓ Charging the battery from the regenerative braking phase.

✓ Minimizing the ICE operation in order to reduce the fuel consumption and CO_2 emissions.

✓ Controlling battery charging and discharging to prevent overcharging and deep discharging.

Objectives interaction is presented in Fig.5.

- Constraints:

✓ The limit of the storage system capacity.

✓ The limit of the electric motor torque in such demanded speed.

- Actions:

✓ Required PMSM reference torque.

✓ Required ICE reference torque.

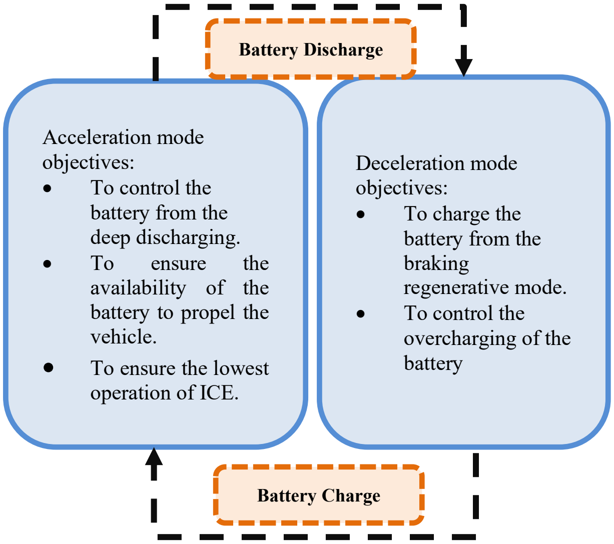


Figure 5. Details of the system objectives.

The fuzzy logic strategy in this study includes three inputs and two outputs as shown in Fig.6. The inputs are battery SOC, reference speed Vref and the acceleration/deceleration action a. System outputs are the electric motor reference torque T_{em-ref} and the thermal motor reference torque of the ICE $T_{ice1-ref}$.

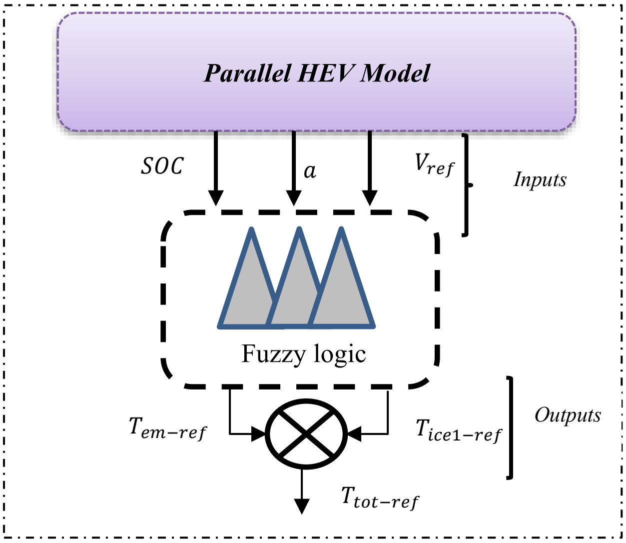


Figure 6. Fuzzy logic inputs and outputs configuration.

The determination of the membership functions for fuzzifier of the input and output variables of the EMS is an important phase of the fuzzy algorithm. It is necessary to define the membership functions for the three input variables: SOC, Vref, and a the membership functions for the two output variables "T_{em-ref}, and $T_{ice1-ref}$".

The input membership functions are used as transitions between the different operating modes of the parallel HEV.

For the membership function of the power variations "SOC", three fuzzy sets are considered: "S (Small)", "M (Medium)", and "B (Big). This membership function is estimated between 0 and 100 %.

The membership function of V_{ref} consist of three levels ("L (Low)", "M (Medium)", and "H (High)"). The low and medium portions are sets ensuring electric motor propulsion mode availability avoiding the ICE use. The "high" set is used to enhance the power energy flow with the ICE propulsion mode and hybrid mode. This membership is estimated between 0 and 35m/s.

The membership function of a consists of three levels ("N (Negative)", "P (Positive)" and "Z (Zero)"estimated between -1 and 1.

The membership function T_{em-ref} consists of three level ("N (Negative)", "Z (zero)", and "P (Positive)".

The membership function $T_{ice1-ref}$ consists of three levels also ("L (ow)", "M (Medium)", and "H (High)").

The different input and output membership functions of the system are presented in Fig.7 and Fig.8 respectively.

Mamdani rules of fuzzy logic strategy are presented as follows:

- If $speed$ is low and SOC is small and acc/dec is positive then $T_{tot-ref} = T_{ice1-ref\ medium}$.
- If $speed$ is low and SOC is medium and acc/dec is positive then $T_{tot-ref} = T_{em-ref\ positive}$.
- If $speed$ is low and SOC is big and acc/dec is positive then $T_{tot-ref} = T_{em-ref\ positive}$.
- If $speed$ is medium and SOC is low and acc/dec is positive then $T_{tot-ref} = T_{ice1-ref\ medium}$.
- If $speed$ is medium and SOC is medium and acc/dec is positive then $T_{tot-ref} = T_{ice1-ref} + T_{em-ref}$.
- If $speed$ is medium and SOC is big and acc/dec is positive then $T_{tot-ref} = T_{em-ref\ positive}$.
- If speed is high and SOC is low and acc/dec is positive then $T_{tot-ref} = T_{ice1-ref\ high}$.
- If $speed$ is high and SOC is medium and acc/dec is positive then $T_{tot-ref} = T_{em-ref} + T_{ice1-ref\ medium}$.
- If $speed$ is high and SOC is big and acc/dec is positive then $T_{tot-ref} = T_{em-ref\ positive}$.
- If SOC is low and acc/dec is negative then $T_{tot-ref} = T_{em-ref\ negative}$.
- If SOC is medium and acc/dec is negative then $T_{tot-ref} = T_{em-ref\ negative}$.

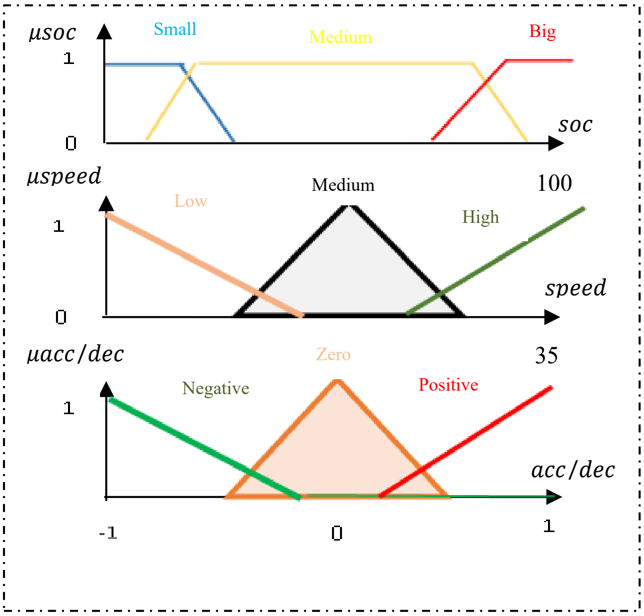


Figure 7. Membership functions of the fuzzy logic inputs.

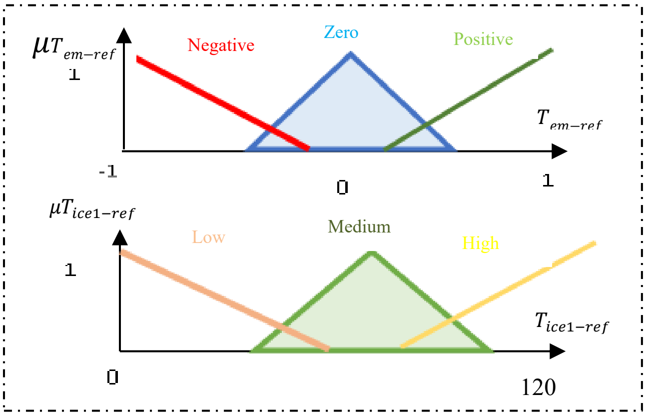


Figure 8.Membership functions of the fuzzy logic outputs.

4. BOOLEAN LOGIC STRATEGY

A. General Structure

The general diagram is presented in Fig.9. Here the following modes of the used control strategy are explained:

- Mode 1: If the parallel HEV is in the acceleration action, the vehicle speed is below the lower limit and the lithium ion battery SOC is above the lower limit, then the ICE is turned OFF and the PMSM is turned ON.
- Mode 2: If the parallel HEV is in the acceleration action, the vehicle speed is above the lower limit and the lithium ion battery SOC is above the lower limit, then the ICE is turned ON and PMSM is turned ON.

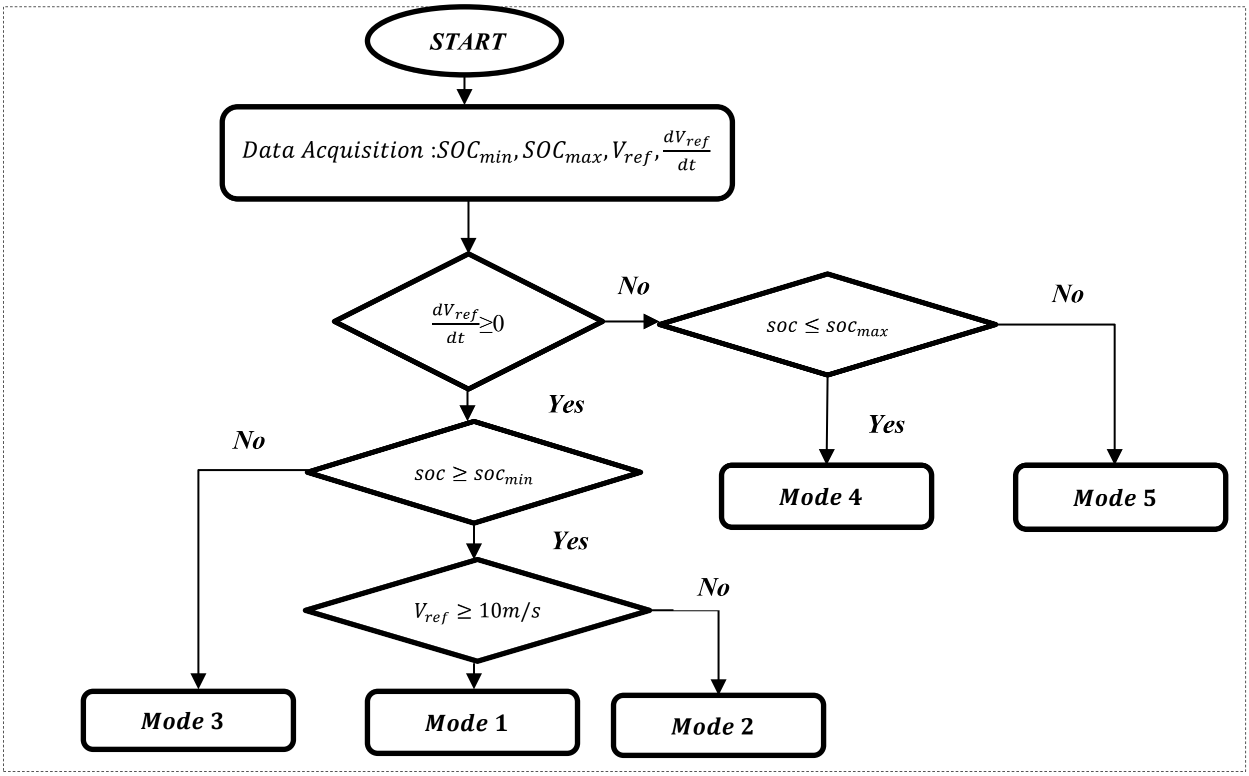


Figure 9. Flow chart of boolean logic strategy.

- Mode 3: If the parallel HEV is in the acceleration action and the battery SOC is below the minimum limit, then, the ICE is turned ON and the PMSM is turned OFF.
- Mode 4: If the parallel HEV is in the deceleration action and the lithium ion battery SOC is below the maximum limit, then, the ICE is turned OFF and the EM is turned ON as a generator.
- Mode 5: If the parallel HEV is in the deceleration action and the SOC of the lithium ion battery is above the maximum limit, then, the battery will not support the extra charge, and the energy will be dissipated as a heat form, which is not an adequate mode. Therefore, there is no power transmitted.

Using in priority the lithium ion battery as a storage system when the ICE is used in the last case, ensuring a balance between generated and consumed powers. Thus, the power balance equation can be written as follows:

$$\boldsymbol{P_{dem} = P_{bat}} \qquad (2)$$

Where:

P_{bat} is the battery power.

P_{dem} is the demanded power.

5. SIMULATIONS RESULTS

The parallel HEV model and control with the EMSs diagrams of the fuzzy logic and boolean logic algorithms were implemented in MATLAB/ Simulink software. To validate the proposed control EMSs the system was simulated under three different cycles.

The NEDC cycle, which is a basic cycle to validate the results with a simple interpretation and combined cycles (WLTP and ARTEMIS) to predate the real vehicle speed evolution.

The parallel HEV system and the different cycle's parameters are detailed in the tables I and II.

TABLE I. CYCLE'S PARAMETERS

Cycles	NEDC	ARTEMIS	WLTP
Distance (m)	11023	4870	23262
Mean speed (m/s)	33.6	17.6	46.5
Duration (s)	1180	993	1800

TABLE II. PARALLEL HEV PARAMETERS

Components	Parameters	Symbols	values
Vehicle	vehicle mass	m	$950kg$
	Frontal surface aerodynamic × drag coefficient	SC_d	$0.608m^2$

	Rolling resistance coefficient	Cr	0.00904
	Gravity acceleration	g	$9.81m/s^2$
	Road slope angle	α	$0rad$
	The density of the air	r	$1.125kg/m^3$
	Wheel radios	ρ	$0.28m$
PMSM	PMSM power	P	$4.5Kwh$
	Pole pair	p	17
	Stator resistance	R_s	0.6Ω
	Stator inductance	L_s	$3mh$
	rotor flux linkage	Φ_m	0.106
ICE	Maximal ICE torque	$T_{ice\max}$	$32.5N.m$
	Speed range	Ω_{ice}	$0-2250rpm$
Battery	Voltage	U_{bat}	$250V$
	Capacity	Q	$128Ah$
CVT and reduction gear	Initial gear ratio	i_1	2
	Final gear ratio	i_2	3

A. Test 1

Test 1 is used with the NEDC cycle under 1180 s. Fig.10 shows the NEDC cycle evolution. We can remark that the parallel HEV model speed V_{model} follows the reference speed V_{ref} .

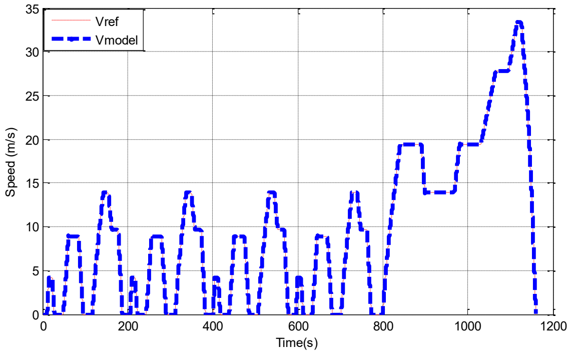


Figure 10. Drive cycle speed.

Fig.11 shows the dynamics of the system power demand during the cycle. The chosen convention in this work demonstrate that the negative powers correspond to the charging mode which the HEV battery store energy regenerative brake mode. However, the positive powers were selected to the discharging mode of the HEV lithium ion battery to propel the PMSM motor.

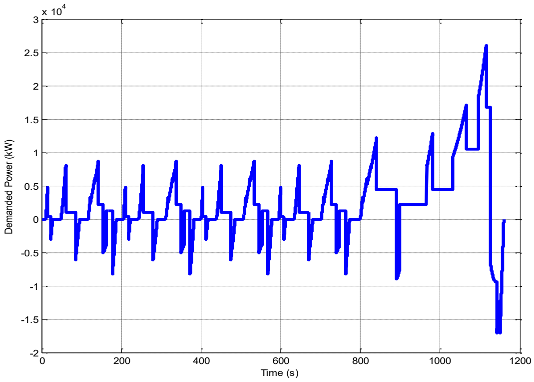
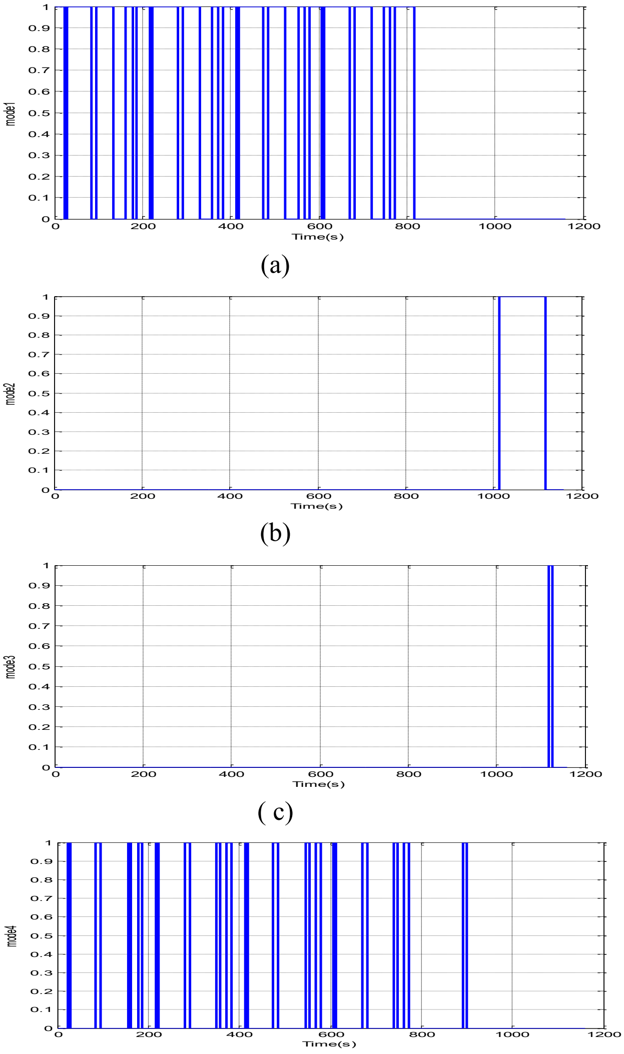


Figure 11. Demanded power evolution for NEDC cycle.

Fig.12 illustrates the five different operating modes obtained from the boolean logic strategy under the test 1 using the NEDC cycle.

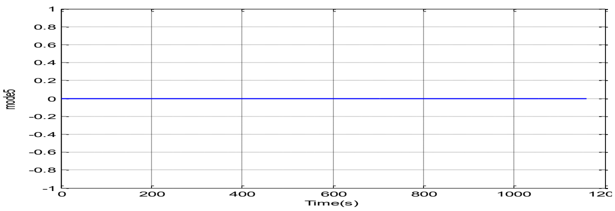


(a)

(b)

(c)

(d)



(e)

Figure 12. Different boolean technique modes : (a) : mode 1, (b) : mode 2, (c) : mode 3, (d) : mode 4, and (e) : mode 5.

Fig.13 points out the comparison of the electric torque evolutions using the boolean and fuzzy logic methods respectively. It is observable that, with fuzzy logic strategy the electromagnetic torque of the PMSM motor is smaller than the boolean logic, which will affect the battery charge and discharge modes.

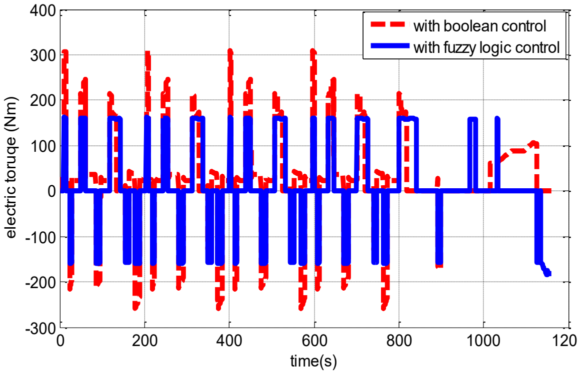


Figure 13. Electric torque evolution under NEDC cycle.

However, Fig.14 shows the comparison of the thermal evolution under the NEDC cycle in the first test with the two methods respectively. We can remark that the fuzzy logic system has the best control system, which divides the thermal torque into low medium and high levels. It is clear that the fuzzy logic results is much smaller than the logic results.

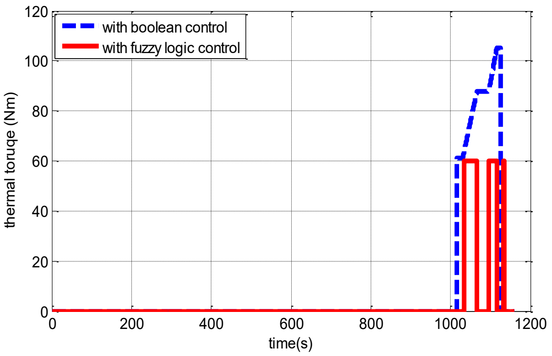


Figure 14. Thermal torque evolution under NEDC cycle.

Fig.15 shows the variations of SOC values under the two control techniques: the fuzzy logic and boolean logic control strategy under NEDC driving cycle.

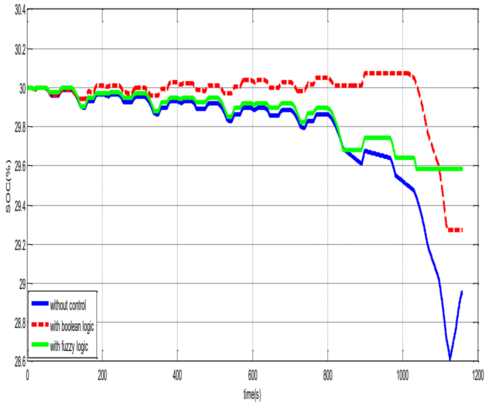


Figure 15. Lithium ion SOC evolution: without control, with boolean logic control and with fuzzy logic control.

We can remark that the SOC value with boolean logic control at the end of the NEDC cycle is smaller than the end value of the fuzzy logic control. Thus, the *SOC* values at the end of the NEDC driving cycle are 29.2751 % and 29.509 % by using the boolean logic and fuzzy logic control strategy respectively in test 1.

This fluctuation of the SOC values under the two techniques method has a positive effect on increasing the effectiveness of the battery discharge, conserve stability of the battery operating, and enhancing the battery life.

The control 3D surface of the output membership function of the fuzzy controller for the electric and thermal reference torques are presented in Fig.16 and Fig.17 respectively.

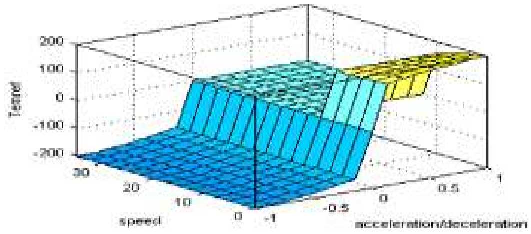


Figure 16. Electric motor output action.

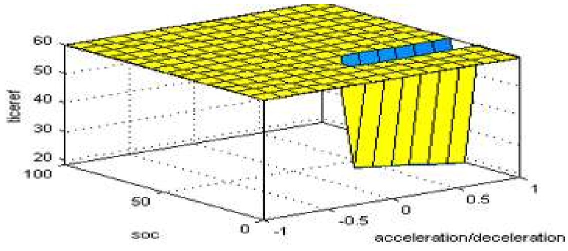


Figure 17. Thermal motor output action.

Same as the comparison study of the battery sustaining operation enhancement. We can distinguish either a comparison study for the instantaneous fuel consumption and CO_2 emission for the parallel HEV.

The results of the two techniques are compared in Table III.

TABLE III. COMPARAISON OF THE HEV PERFORMANCES.

Strategy	Instantaneous fuel consumption (g/s)	CO_2 emission (g)
Boolean logic	0.0026	0.0069
Fuzzy logic	0.0017	0.0045

The simulation time is also another important parameter to compare the different controller rapidity. The different CPU values are presented in Table IV.

Obviously, the boolean logic technique is more rapid than the fuzzy logic system as presented in the following table.

TABLE IV. CPU COMPARATIVE STUDY

CPU(min)	
Fuzzy logic	***Boolean logic***
2.98	1.35

B. Test 2

Test number 2 is simulated with the NEDC cycle repeated for 1-hour. Fig.18 shows the NEDC drive cycle speed over 1-hour evolution.

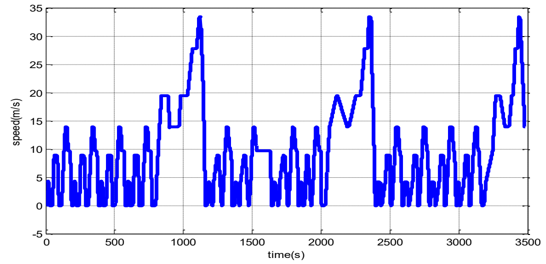


Figure 18. NEDC cycle for 1H.

Fig.19 present the power demanded evolution of the powertrain system under 1-hour drive cycle evolution for test 2.

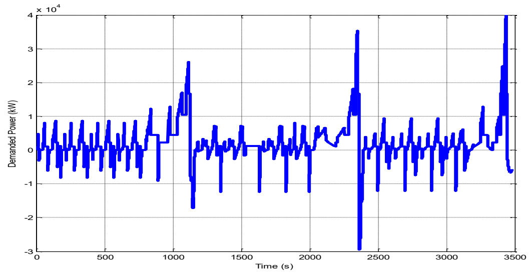
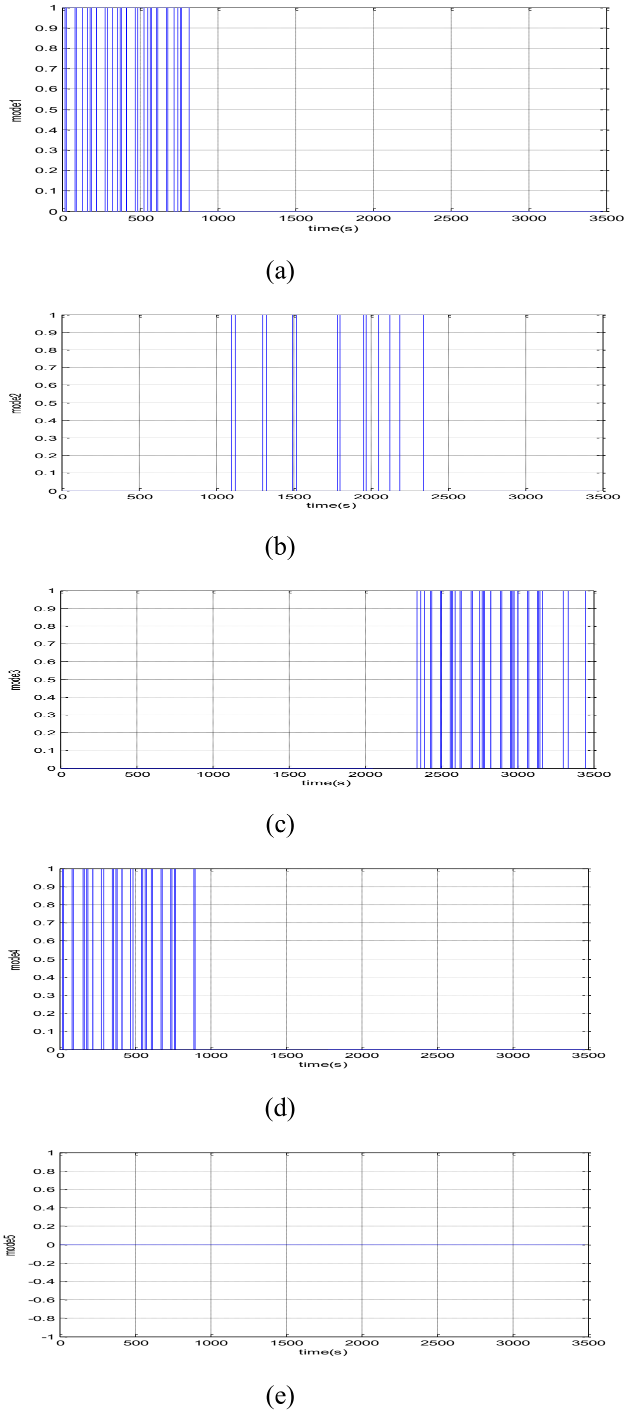


Figure 19. Demanded power for the NEDC 1H cycle.

Fig.20 illustrates the five different operating modes obtained from the boolean logic strategy under 1-hour drive cycle evolution for test 2.



(a)

(b)

(c)

(d)

(e)

Figure 20. Boolean logic modes : (a) : mode 1, (b) : mode 2, (c) : mode 3, (d) : mode 4, and (e) : mode 5.

The electric torque of the PMSM motor for fuzzy logic and boolean logic methods respectively during the defined cycle for test 2 are illustrated in Fig.21.

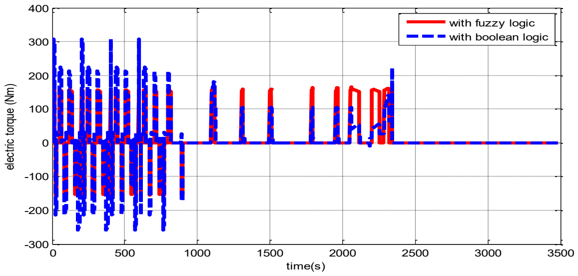


Figure 21. Electric torque evolution under NEDC cycle for 1H.

However, Fig. 22 shows the comparison of the thermal evolution under the 1-hour NEDC cycle with the two methods respectively.

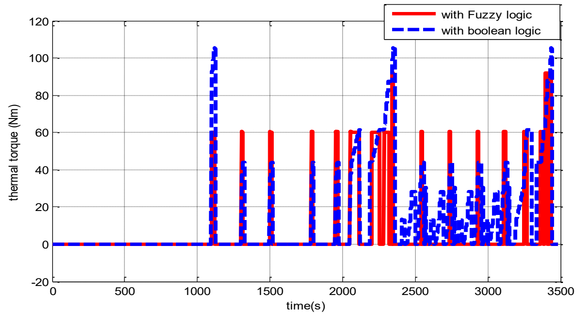


Figure 22. Thermal torque evolution under NEDC cycle for 1H.

We can remark in Fig.23 that the SOC value with Boolean logic control at the end of the NEDC cycle repeated one hours is bigger than the end value of the fuzzy logic control with a small difference. Thus, the *SOC* values at the end of the cycle were 28.7597% and 28.3628 % by using the boolean logic and fuzzy logic control strategy respectively.

Obviously, the two methods are successfully has good improvement of the maintain operation of the lithium ion battery.

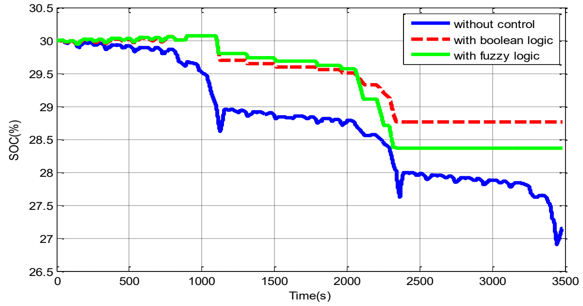


Figure 23. Lithium ion SOC evolution: without control, with Boolean logic control and with Fuzzy control.

The results of the two techniques for the fuel consumption and CO_2 emission are presented in Table V.

TABLE V. COMPARAISON OF THE HEV PERFORMANCES

Strategy	**Instantaneous fuel consumption (g/s)**	**CO_2 emission (g)**
Boolean logic	0.0382	0.1012
Fuzzy logic	0.0196	0.0519

Boolean logic technique is more rapid than the fuzzy logic control system as presented in the Table VI.

TABLE VI. CPU COMPARATIVE STUDY

CPU(min)	
Fuzzy logic	***Boolean logic***
10.53	5.20

C. Test 3

Test on a combined cycle (WLTP and ARTEMIS) for a duration of 2784 s. Fig.24 shows the drive cycle evolution.

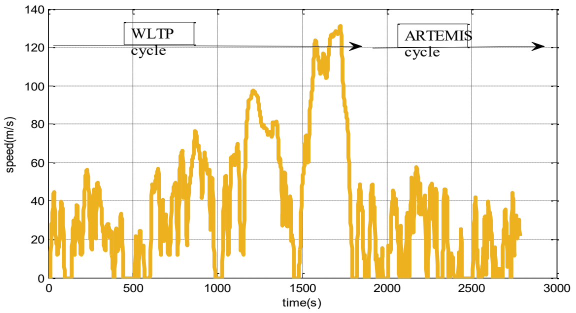


Figure 24. Combined cycle (WLTP+ARTEMIS) evolution.

Fig.25 present the power demanded evolution of the powertrain system under combined cycle evolution for test 3.

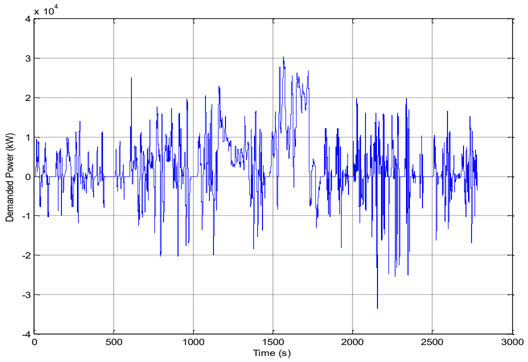
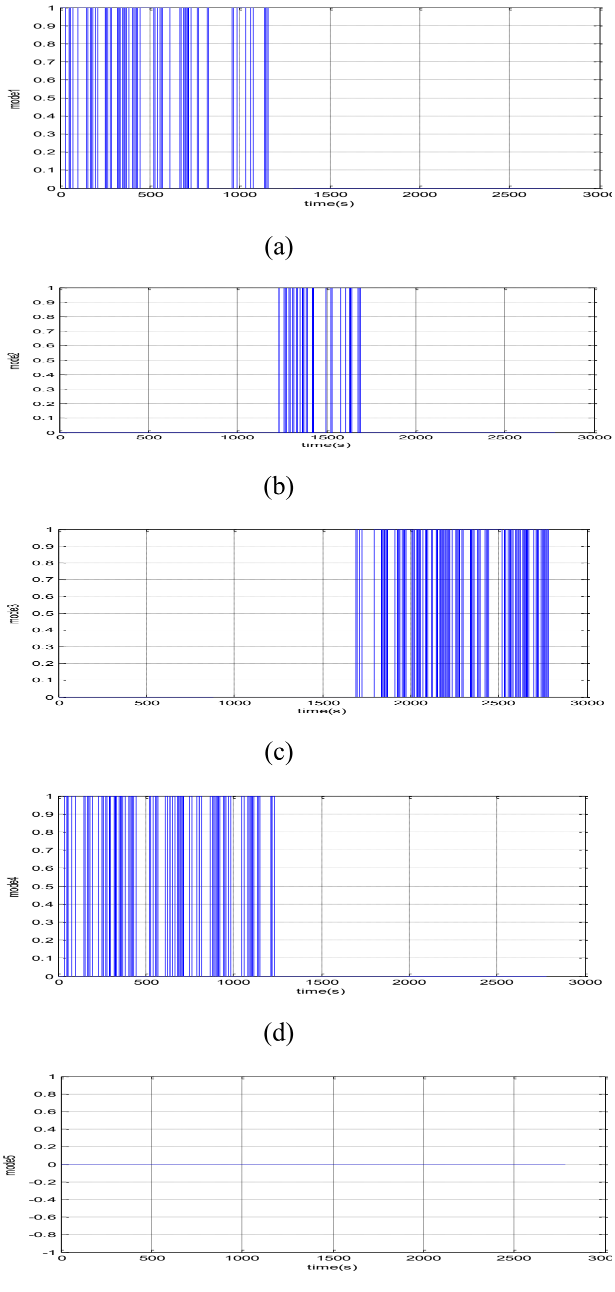


Figure 25. Demanded power for the combined cycle.

Fig.26 illustrates the five operating modes obtained from the Boolean logic strategy for the combined cycle.



(a)

(b)

(c)

(d)

(e)

Figure 26. Boolean logic modes : (a) : mode 1, (b) : mode 2, (c) : mode 3, (d) : mode 4, and (e) : mode 5.

The PMSM torque for the two methods during the defined cycle are illustrated in Fig.27 for test 3.

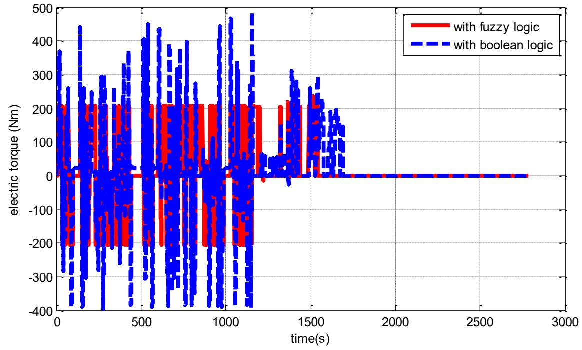


Figure 27. Electric torque evolution under combined cycle.

Fig.28 shows the comparison of the thermal evolution under the combined cycle for test 3 with the two methods fuzzy and boolean logic respectively.

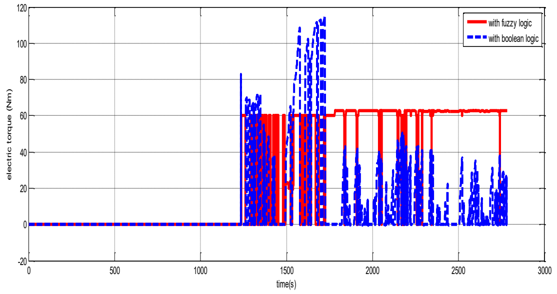


Figure 28. Thermal torque evolution under combined cycle.

We can remark that the SOC value with boolean logic control at the end of the combined cycle is bigger than the end value of the fuzzy logic control with a very small difference as presented in Fig.29. Thus, the SOC values at the end of the driving cycle are 28.6143% and 28.5721 % by using the boolean logic and fuzzy logic control strategy respectively.

Obviously, the two methods are are successful and have good improvement of the sustaining operation of the lithium ion battery under the combined cycle which characterized by a nearest real cycle actions of the driver journey.

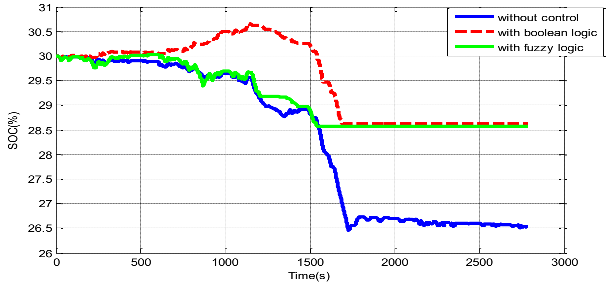


Figure 29. Lithium-ion battery SOC evolution: without control, with Boolean logic control and with Fuzzy logic control.

The results of the two techniques for the fuel consumption and CO_2 emission under the combined cycle are presented in Table VII.

TABLE VII. COMPARAISON OF THE HEV PERFORMANCES

Strategy	**Instantaneous fuel consumption (g/s)**	**CO_2 emission (g)**
Boolean logic	0.0465	0.1232
Fuzzy logic	0.0389	0.1031

Boolean logic technique is more rapid than the fuzzy logic control system as presented in the Table VIII.

TABLE VIII. CPU COMPARATIVE STUDY

CPU(min)	
Fuzzy logic	***Boolean logic***
8.49	4.11

Results of the test 3 using the combined cycle demonstrate that the control strategies of the tested vehicle can achieve, in test conditions closer to real life either, prove the effectiveness of HEV technology to reduce fuel consumption and CO_2 emissions with the appropriate control techniques.

The effects of the thermal motor considering mainly the fuel consumption values under the three different drive cycles using the two different control methods fuzzy logic and boolean logic respectively are reported in Fig.30.

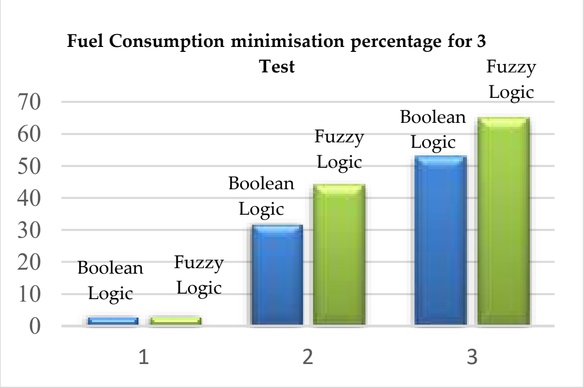


Figure 30. Different percentages of the fuel consumption.

General interpretations of results are presented in Table IX.

TABLE IX. GENERAL INTERPRETATIONS

Characteristics	**CPU Time**	**Fuel consumption**	**Battery sustaining operation**
Boolean logic	☺☺☺	☺	☺☺☺
Fuzzy logic	☺	☺☺☺	☺☺☺

- According to this study, we remark that each method characterized by different advantages and disadvantages.
- The main disadvantage of fuzzy logic is the execution time: longer than conventional logic.
- The main advantage of fuzzy logic is the ability to control the operation of the combustion engine by controlling the operating range in 'Low-medium High' unlike conventional logic, that must be 0 or 1 (true-false) which will introduce a fuel consumption and a CO_2 emissions reduction.
- Concerning the battery operation, we notice that for both methods there is an improvement in SOC evolution.

6. CONCLUSION

In this paper, a study of EMS of the torque split between the PMSM motor and thermal motor of a parallel HEV system was investigated. For that, a comparison study of boolean logic and fuzzy logic have been discussed, implemented and tested on real data sets using MATLAB/ Simulink software using three different cycles. Different criterion were established in this paper such as battery sustain operation, fuel consumption, CO_2 emission and CPU time. Simulations results show the efficiency of the fuzzy logic controller mainly in the ICE control strategies to maintain better fuel consumption and CO_2 emission. However, in terms of rapidity, the boolean logic is the best control strategy. Concerning the battery SOC operation improvement the simulations proves the effectiveness of the two different methods.

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