A SOFT-COMPUTING ROBOTIC SHIFT FOR A HYBRID VEHICLE

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Abstract

In the present paper we present a control system of robotic shift in hybrid vehicles that utilizes fussy logic as well as optimization techniques (genetic algorithms) aimed at improving, with the automatic choice of the shifting, the objective-functions previously chosen (minimum consumption, suitable dynamic performances). Following the working out of a model in Simulink environment, which is suitable for the simulation of the behavior of a hybrid vehicle equipped with different shifts (manual, robotic, robotic fussy-logic) we carried out tests in a virtual lab and compared the results with those obtained with models previously built by others (CRF) that had been validated on real vehicles. The results of the simulations have shown, on the one hand, the validity of the robotic shift relative to the manual shift, and, on the other hand, the effectiveness of the application of soft-computing for the development of the robotic shift relative to a vehicle equipped with a traditional robotic shift, in which the logic of shifting is managed by static maps.

1. Introduction

The aim of this investigation is to develop a control system of the shift in a hybrid vehicle with parallel architecture, designed to carry passengers or goods in predominantly urban areas. The primary objective is to improve the overall performance of the hybrid powertrain through the development of a logic of shifting that is more easily implemented and, at the same time, improves the behavior of the vehicle in terms of consumption, efficiency, and performance. The control of the shift we designed exploits the possibilities of Soft -Computing, whose use has yielded interesting results in the development of controls in other systems [1] [2]. In order to improve the elasticity or behavior of the system and to improve its efficiency, the system of fussy control, already proposed by others, is here optimized through the use of genetic algorithms.

In the parallel hybrid vehicles [3], in contrast with the serial hybrids, in which the traction force is provided by the electric motor fed by a thermal motor and by batteries, both the thermal motor and the electric motor can dosage the impulse to the wheels. Their action is combined through a generic mechanical organ, *torque coupler* that can be of various mechanical types and allows to channel the action of two independent transmissions to a single transmission axis. For example, Toyota, in the Prius has adopted an eoicycloidal gear. The combination of the forces can be obtained in other way: each motor is equipped with a driving axis, the thermal and electric motors are integrated, and in this case the electrical motor that also work as starter.

The numerous hybrid solutions that have been developed by scientists, although technologically valid, are beset by problems with their realization, because they are excessively complicated, costly, and difficult to integrate in the vehicle.

In this scenario, so-called minimal solutions have been created, in which the sizing of the hybridizing part is given only as potential. These solutions envisage, in the case of serial hybrids, the evolution of the pure electrical component battery, with a hybridizing thermal component with a support function to the other. Contrariwise, in the case of the parallel hybrid, the minimal solutions envisage an evolution of the conventional thermal vehicle with a hybridizing electrical component in support of the thermal. In this scenario the Ecodriver *"Energy Conversion and DRIVeline Efficient Reengineering"*, developed and

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patented by the Centro Ricerche Fiat (CRF), is a hybrid solution minimal electric in parallel coaxial configuration.

The group motodriver EcoDriver is realized by interposing axially between the thermal motor and the mechanic automated shift, known as *Selespeed,* an electric machine capable to operate both as motor and as generator. This group is of modest length to allow the installation of the hybrid propeller in the space allocated to the motor.

The Ecodriver system is equipped with an inverter (an electronic power converter that feeds and controls the electrical machine) and by a battery pack of high voltage appropriately sized for the acceleration and the breaking of the vehicle, with its unit of management and control. Through an additional electro–hydraulic clutch, along with the conventional clutch of the shift, it is possible to connect and to disconnect the electrical machine from both ends. This configuration, by virtue of an effective control strategy of the motopropeller block, permits the typical functions of a thermal vehicle electrically assisted, to wit:

- advanced stop&go, that is achieved starting the vehicle in electric mode and turning on the thermal motor when the vehicle is in motion, without the need for a starter.
- electric booster in electric power-couple during acceleration, which is obtained by adding the couple generated by the two motors, with both clutches closed.
- regenerating breaking, obtained in force of the reversibility of the electrical machine, and maximized through the opening of the clutch of the motor side.
- motion in pure electric mode, with zero emissions (ZEV), which occurs at low speed opening the clutch of the thermal motor side and utilizing the electric machine as driving motor.

With this system it is possible through the eventual undersizing of the thermal motor and the possibility to manage its heating after the start differently from the conventional vehicle, to obtain a sharp reduction of consumption of over 30%, with an emission level extremely contained. It is also possible to avoid a reduction of the performance of the vehicle, with the attendant drop in market attractivity.

When the motogenerator is not involved in the traction, for instance when the electric motor is not working at the maximum power, it can serve as generator, either recharging the batteries or feeding the electric loads.

With reference to the robotic shift selespeed, which belongs to the ecodriver group, it is a member of the family of automatic or semiautomatic shifts, and is made up of a mechanical transmission, with a monodisc clutch, and synchronized mechanical shift with a hydraulic servomechanism and an electronic module. The design of the transmission system selespeed pursues the aim of improving the performance of the component of the manual mechanical transmission, of avoiding the need for the driver to control the clutch and the shift, while still providing the pleasure that stems from the direct control of the transmission.

There are two modalities: the first semiautomatic (or manual) in which the driver requests directly the shift of gear through the lever placed over the tunnel or by pushing the buttons on the steering wheel, and the second, automatic (or auto), in which the system decides autonomously when to shift gear. This modality is selected by pushing a specific button.

In the present investigation, relatively to the automatic (auto) selespeed shift, we carried out a *fuzzy* control optimized with genetic algorithms, that could regulate the working of the powertrain via control in real time of the more suitable transmission ratio.

2. Building the control

The application of *fuzzy* logic to the shift of a hybrid vehicle has been explored by several investigators, but without the employment of *Soft-Computing* [5], and thus without methods of optimization that use genetic algorithms.

Prior to the implementation of the control, in order to be able to make meaningful comparisons, without, however, resorting to direct experimentation on the vehicle with the proposed system, we developed an energetic-dynamic model of the hybrid parallel vehicle in Matlab-Simulink environment, which is able to identify the parameters that are needed for the optimization of the *fuzzy* control of the shift with regard to acceleration, drivability, and consumption. The model is called energetic because it takes into accounts the power involved in the performance of a given action. It is also called dynamic because it analyzes a vehicle in motion with specific speed and acceleration in terms of acceleration, drivability, and consumption. We first checked the quality of the program in Matlab-Simulink by simulating the behavior of the hybrid vehicle equipped with robotic shift managed by static maps, and comparing the results of the simulation with those obtained for the same vehicle with a model developed at CRF and previously validated experimentally at the same Center. The verification process of this drivetrain was possible because we had available some critical and indispensable information about the real vehicle, like

the value of the current, voltage, speed, couple and the charge state of the batteries.

After the quality of the model was verified, we substituted the module of the control strategy based on static maps with the strategy fuzzy proposed, and set out the optimization phase through genetic algorithms.

The overall architecture of the controls in the hybrid parallel vehicle is an ensemble of modules each dedicated to the control of the various subsystems, hierarchically arranged and coordinated by a supervisor at the vehicle level. The supervisor, fig. 1, is made up of an electronic module called Vehicle Management Unit (VMU).

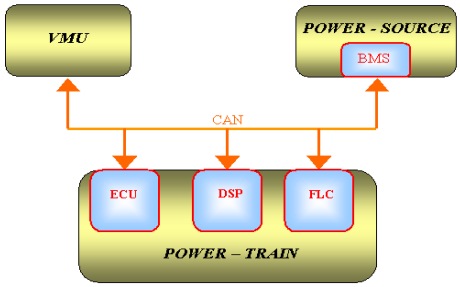


Figure 1. Scheme of the general architecture.

This unit acquires information from the various subsystems and optimizes the power emission for the traction of the vehicle. Parallel to the VMU there is a control module for the accumulation system that is called *Bass Management System* (BMS), while for the powertrain there are three different control modules: one for the thermal motor *Electronic Control Unit* (ECU), one for the electric machine *Digital Signal Processor* (DSP) and one for the shift, which, in this case is of the type *Fuzzy Logic Control* (FLC). The control modules are interconnected through a serial communication line of the type *Control Area Network* (CAN) at high speed.

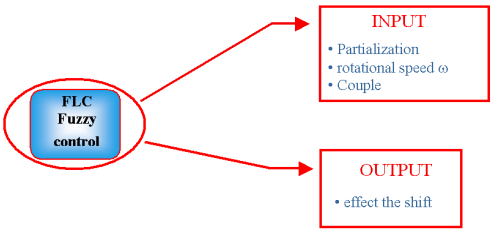


Figure 2. Input and Output of the *fuzzy* control

The logic of the fuzzy control we adopted, fig. 2, involved the preselection of the input variables, output variables and of the rules, as outlined below:

the control module receives as input:

- the signal of the pedal position of the accelerator or partialization, that is acquired through the potentiometer of the accelerator pedal.
- the rotational speed of the wheels that is acquired through the phonic wheel of the ABS
- the signal of couple provided by the thermal motor;

in the output the control provides the signal to effect the shift of gear.

The electronic management of the shift collects the signals of the sensors, elaborates the information within the fuzzy control module, and makes the decision to insert the gear. If it becomes necessary to shift gear the control sends a signal to the organs that regulate and effect the actions, and they disengage the clutch and effect the shift of gear. If, contrariwise, there is no need for a shift of gears the cycle is repeated.

For the synthesis of the fuzzy control, fig. 3, it was necessary to determine for each variable the number of the fuzzy ensembles and the shape of the related functions. Specifically, the field of variation was divided into four functions called *Low, Medium, High and Very High.* For the first and last *fuzzy* we chose sigmoid curves, whereas for the central ones we chose gaussians.

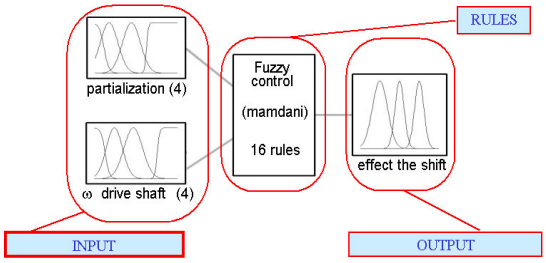


Figure 3. General scheme of the working of the fuzzy control of the shift

For the output signal of the fuzzy algorithm the range of variation is a number between -1 and 1, subdivided in three fuzzy sets with gaussian profile whose averages were set at -1, 0, and 1, as shown in fig. 10, and refer to the situations of powering, maintenance, or increment of gear.

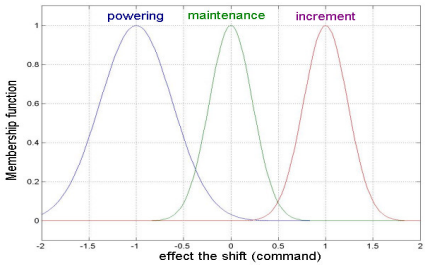


Figure 4. Membership functions for the "command" output

Lastly we turned to the determination of the rules that, taken together, allow the modeling of the choice of the ideal gear. To characterize them we needed to translate into simple linguistic rules what is known about gearshift, as shown in table I.

		PARTIALIZATION			
		Low	***Medium***	***High***	***Very High***
ω	***Low***	*powering*	*powering*	*powering*	*powering*
	Medium	*maintenance*	*maintenance*	*maintenance*	*powering*
	High	*maintenance*	*increment*	*maintenance*	*maintenance*
	Very High	*increment*	*increment*	*increment*	*increment*

Tab. I: Rules of the *fuzzy* algorithm

The determination of these rules leads to a map of fuzzy control, which is shown in fig. 5.

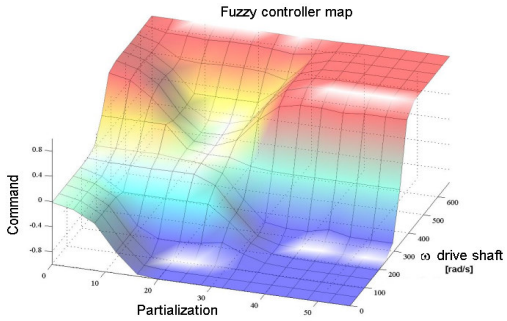


Figure 5. Control map of the *fuzzy* algorithm

It is important to note that the surface of fig. 5 represents the output values of the fuzzy control. These values, however, do not represent those actually sent to the hydraulic effectors, which command the movement of the clutch and the movement of insertion and selection of the gears. In fact these values are continuous in the output range -1 to 1, in order to give the fuzzy control maximum freedom to place the output memberships, while the hydraulic effectors receive only discrete signals (-1, 0, 1).

Thus within the control is envisaged an arithmetic module that, downstream of the fuzzy control, effects the rounding via a function in which, in effect, the range is divided into three equal parts. After an initial attempt at optimization, we saw that the best results were obtained by setting the threshold for the discretization of the signal at 0.35, that is to say, the output values of the fuzzy strategy comprised between -1 and 0.35 are to be rounded to -1 (the effectors receive the command to lower gear unless the protection intervenes), for a second zone comprised between -0.35 and 0.35, the output is rounded to zero (no signal is sent to the effectors), and a third zone between 0.35 and 1, in which the signal is rounded to 1 (the effectors receive the command to insert a higher gear). We thus obtain a three-color map, as shown in fig. 6. Starting from this criterion we proceeded to the optimization of the positions of the functions for the various control values. Of course the optimal positions obtained with these functions are slightly dependent on the initial choice of the thresholds of the discretization of the signal. Thus, having realized the synthesis of the fuzzy control, and analyzed the membership functions, for a better utilization of the shift control in the real situation we moved on to the optimization through the use of genetic algorithms. The procedure we propose involves the choice of the parameters fuzzy to be optimized and the definition of the objective function.

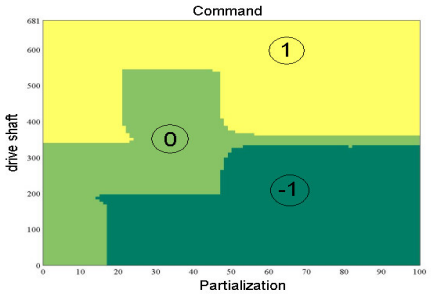


Figure 6. Discretized map

The chromosomal composition takes place through the choice of the genes, that is to say, those parameters that constitute the *membership* of input and output to be optimized. With regard to the antecedent we chose as parameters to be optimized the average and the standard deviation, whereas for the consequent we chose only the standard deviation, since the average values coincide with the signal to be sent to the effectors of the shift, i.e. -1, 0, and 1.

For the definition of the objective function it is important to keep in mind our preset aims. In particular, we wanted to realize a fuzzy control that managed the shift in such a way as to exploit optimally the hybrid powertrain relative to what can be achieved with the static maps of the CRF. An improved utilization entails on the one hand the optimal working of the thermal motor, with fuel savings and a consequent higher index of combustion, while, on the

other hand, retaining good performances (acceleration from 0 to 100 km/h, rapidity in the take over maneuvers) of the hybrid vehicle. Bearing in mind what said earlier, the objective function was thus defined:

$$F_{ob} = P_1 \cdot T_{prestazion\ i} + P_2 \cdot \frac{consumo_{\ NEDC}}{640} +$$
$$+ P_3 \cdot \frac{consumo_{\ cliente}}{250} + P_4 \cdot [1 - RMS\ (\eta_{NEDC}\ )] +$$
$$+ P_5 \cdot [1 - RMS\ (\eta_{cliente}\ )]$$

where:

- P_1, P_2, P_3, P_4 e P_5 are weights through which one can optimize the control as a function of the specific mission of the vehicle, in the present case all equal to 1.
- $$T_{prestazion\ i} = \frac{T_{100\ km\ /\ h}}{20} + \frac{1}{2} \cdot \frac{T_{50\ km\ /\ h}}{10}$$

  $T_{100km/h}$ = time in seconds to accelerate from 0 to 100 km/h

  $T_{50km/h}$ = time in seconds to accelerate from 0 to 50 km/h

  The intervals thus defined were normalized to 20s and 10s, which are the plausible times the vehicle should take to accelerate from 0 to 100 km/h and from 0 to 50 km/h, respectively.

  The first performance, i.e. that from 0 to 100 km/h was weighted twice as the first, to give more importance to the brusque accelerations, which are useful in taking over or in emergency situations.

- $consumo_{NEDC}$ = fuel consumtion in the NEDC cycle [g/ciclo]

  640 g/cycle is the consumption limit, given as objective in the unfolding of the NEDC cycle.

  NEDC cycle belongs to the European driving cycles, which are simulated in the lab in treadmills that are characterized in terms of travel distance, velocity profile, and slope. They are also modal cycles, i.e. characterized by segments in which velocity is constant. In particular, the NEDC cycle is the combination of various European cycles and is composed initially by four ECE cycles, which represents the urban driving, with a speed below 50 km/h, low loads of the thermal motor, and low temperature of the emission gases. These four cycles are followed by another European cycle, i.e. the EUCD cycle, which represents an extra-urban itinerary, with top speed of 120 km/h, at the end of which the vehicle speed up to highway speed.

- $consumo_{cliente}$ = fuel consumption in the client cycle [g/ciclo]

  250 g/cycle is the limit, placet as objective, in the deployment of the RMS(μNEDC) client cycle = quadratic average of the yields in the NEDC cycle

  The "client" cycle is employed by CRF to simulate an urban itinerary with various slopes and it is exactly for this reason hat it was chosen in this phase of the optimization.

- RMS(μcliente) = quadratic average of the yields in the client cycle

The results of the optimization are shown in fig. 7, that shows the evolution of the objective function in the various generations.

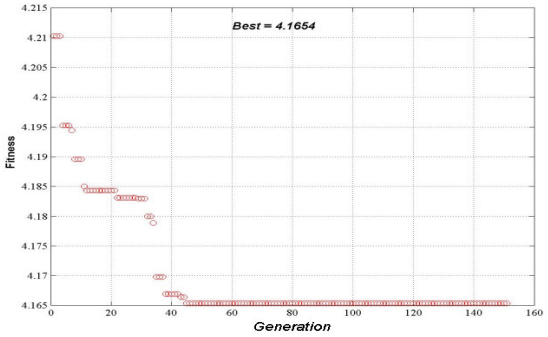


Figure 7. Optimization of the objective function

It can be seen that the value of the objective function decreases rapidly at first up to about 35 generations, with the characteristic stepwise progression (generally due to the occurrence of mutations). Subsequently, up to about 45 generation, the function still improves, but with decreasing rate. Around the 60th generation the objective function remains stable at a value around 4,1654. We ran a total of 150 generations before interrupting the simulation. The behavior observed is consistent with the evolution of the genetic algorithm in which the early generations originate from an initial population of randomly chosen individual, and thus the room for improvement between two consecutive generations can be large. As better variants are selected, the margin for further improvement is reduced. In accordance with this process of optimization we obtained the new position of the membership functions, fig. 8, for the input and output variables of the fuzzy controller. From the analysis of the discrete control map it can be noted that for modest partialization values up to 40% the shift control governs the transmission as to achieve the shifting at a

relatively low number of rotations. Contrariwise, for higher partialization values, there is a trend toward a higher vehicle performance, as, for instance, during taking over.

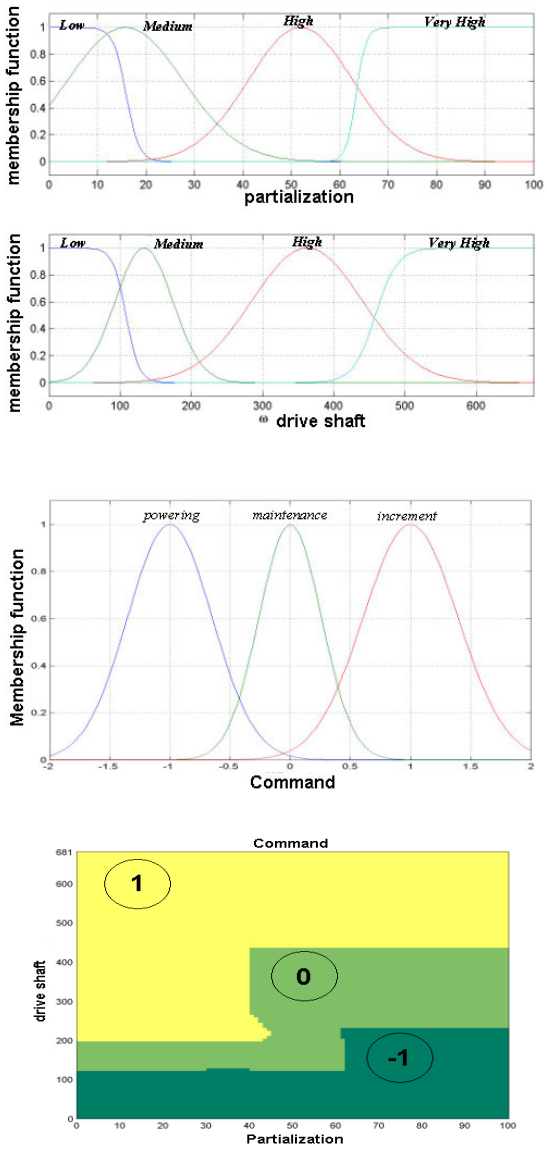


Figure 8. Behavior of the membership functions and of the optimized control maps

3. Modality of simulation and results

The results of the simulation, obtained with the hybrid parallel vehicle equipped with a robotic shift governed by the logic of *Soft-Computing* (*fuzzy logic + genetic algorithms*) proposed by us (hereafter referred to as *Hybrid Fuzzy)*, have been compared with those obtained equipping the hybrid vehicle with robotic shift governed by static maps (hereafter referred to as *Hybrid CRF*). In addition the results were compared with those obtained with a conventional vehicle (non hybrid, but equipped with the same thermal motor) equipped with a robotic shift governed by static maps (*Conventional),* and, lastly, with those of a conventional (non hybrid) model with and ordinary manual shift, in which the shift sequence is the one established by the EU in the NEDC cycle (*Conventional manual shift).*

Fig. 9 shows the consumptions observed in the NEDC cycle for the four types of settings simulated. From the analysis of the histograms the superiority of the parallel hybrid drivetrain in terms of consumption appears evident. Moreover the additional benefit accrued by the fuzzy control of the shift relative to the CRF is apparent.

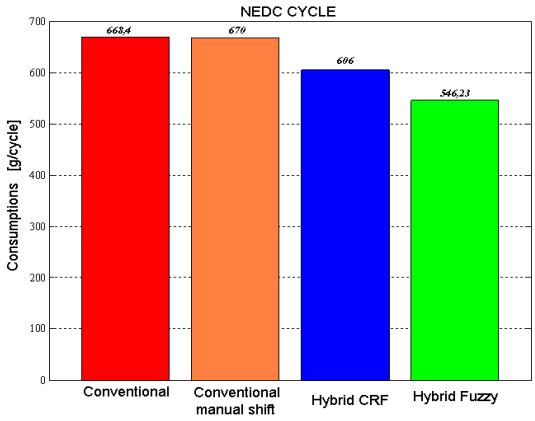


Figure 9. Bar diagram of the consumptions in the NEDC cycle

For a better understanding and an effective comparison of the effect of the automatization of the shift, we illustrate below the results of the simulations that were obtained for the three settings with robotic shift, in the form of balloon diagrams (fig. 10), whose sizes measure consumption. On the x-axis we have the index of performance that measures the time needed to accelerate from 0 to 100 km/h; while the y-axis measures the consumption of the vehicle in g/cycle. The employment of the fuzzy control leads to an evident advantage in terms of consumption at the cost

of a slight lowering of the performance, hardly noticeable by the client.

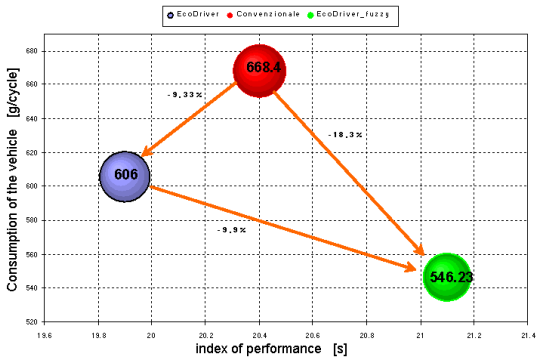


Figure 10. Riduction of consumption in the NEDC cycle

The diagram in fig. 11 plots along the x-axis the yield of the thermal motor, and along the y-axis the consumption. It can be noted that the parallel hybrid architecture, relative to the conventional one, offers an advantage in terms of efficiency in the management of the thermal component of the powertrain, and this advantage increases with the application of the fuzzy logic of shift. To show the intelligence of the fuzzy control, i.e. the ability to adapt to the various condition that may prevail on the road, we implemented a cycle that simulates a double take over in which at point the driver steps on the accelerator all the way to overtake another vehicle. This moment is easily discernible by looking at the red zone in fig. 12, and in particular to the moment the partialization becomes 100%.

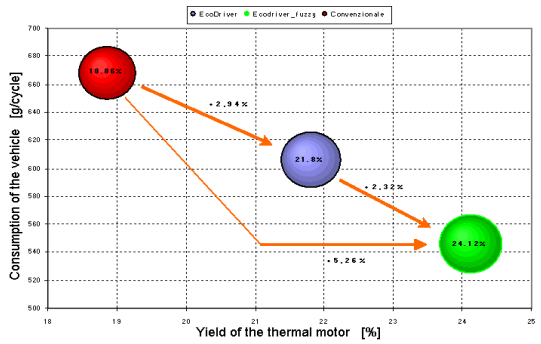


Figure 11. Increased yiels in the NEDC cycle

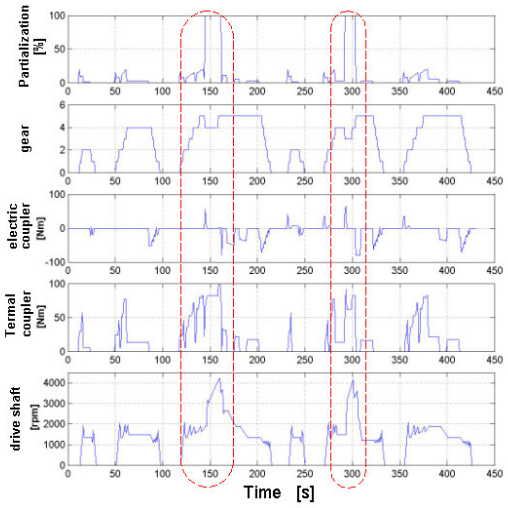


Figure 12. Takeover cycle

As can be noted, initially the pedal of the accelerator is depressed in a constant manner and the control understands that the driver requires an economic handling of the vehicle, In a later stage, however, the driver wants to make a take over and steps on the accelerator all the way, and in this case the control understands that the maximum power is required. By observing the number of rotations of the driving axis in relation to the request for maximum power, the control understands that the rotational regimen is too low and independently elects to exploit more fully the gears, lowering gear and arriving at a rotational speed of about 4,200 rpm before inserting the higher gear, thus making the maneuver safer and smoother.

The analysis of the simulations carried out under various conditions, not all shown here for limitations of space, shows that this behavior can be observed also at lower speeds when the need to downshift arises, for instance from fourth to third gear.

4. Conclusions

In the work presented here we have applied the Soft-Computing methodology for the development of the logic of control for an automatic shift in a hybrid parallel vehicle. In particular, the control fuzzy logic, already proposed by other authors, was optimized with the use of genetic algorithms, making the system of control more dynamic and efficacious.

We compared in simulation the behavior of the vehicle under various conditions (NEDC and Client cycles) and for various types of shift, taking as

reference the data of a simulation that had been validated at the CRF with reference to the behavior of an automatic shift with a strategy based on static maps.

The advantages observed in the employment of the fuzzy logic, optimized through the use of genetic algorithms, relative to other technologies, can be summarized in the ability to adapt automatically to the different driving conditions, and in the simplicity of synthesis of the control, for which it is sufficient a simple translation in linguistic rules of the logic of the functioning of the shift.

This application represents an evolution relative to the logic of traditional control systems of automatic shifts, in which, nearly always, the shift points are optimized for either an economic or a sport management of the vehicle, and for whose maps in these cases a vast amount of empirical data is needed which are difficult to find and to synthesize.

The use in simulation of the control of shifting developed here has allowed to show, through comparative simulations, in itinerary cycles of reference, a reduction of consumption without a decrease in the level of performance of the hybrid vehicle.

The analysis of the simulations has revealed that the control logic we propose is able to recognize, from the way the accelerator is used, a driving style economic or sport, and to adapt to the style without forcing the driver to activate the switch selector of the shift program as is the case in the traditional logic.

In fact if the accelerator is depressed in a constant manner, as is the case in the NEDC cycle, urban and extra urban, the gearshifts are effected in a manner that minimize consumption and thus maximize the yield of the thermal motor. Contrariwise, if the frequency of change of the accelerator position is high, the control responds with a sport behavior, and the gears are used more fully, as can be seen analyzing the performance cycles and the taking over.

In closing we would like to underline how in terms of sensors the realization of the fuzzy control of the shift does not involve the application of additional sensors relative to those already present in the selespeed shift.

References

[1] “A Soft Computing Approach to Fuzzy Sky-Hook Control of Semiactive Sospension” R. Caponetto, O. Diamante, G. Fargione, A. Risitano and D. Tringali - IEEE TRANSACTIONS on Control System Technology-Vol.11 N°6 November 2003.

[2] “A Soft Computing Methodology applied to ABS” G. Fargione, D. Tringali Design 2004 Conference Dubrovnik - Maggio 2004

[3] “Application of Trasmission System for Different Drivelin Configurations in Passenger Cars” G. Wagner- SAE TECHINICAL PAPER 2001-01-0882

[4] “Validation process of HEV system Analysis model” A. Rousseau, P. Sharer, M. Pasquier - PSAT, SAE TECHICAL PAPER 2001-01-0953- 2001

[5] “Devlopment of fuzzy logic and neural network control and advanced emission modelling for parallel hybrid vehicles” A. Rajagopalan, G. Washington, G. Rizzoni, Y. Guezennec- The National Renewable Energy Laboratory (NREL) Golden, CO – 2001

[6] G. Rizzotti, M. Lavorgna, M. Lo Presti, (1996) Metodologie per la sintesi e l’analisi di controllori fuzzy, Cavallotto Edizioni.

[7] L. Fortuna, G. Rizzotto, M. Lavorgna, G. Nunnari, M.G. Xibilia, R. Caponetto, (1999) Soft Computing e Valenze Applicative, Cavalletto Edizioni.

[8] Toyota (2001) Consumer Information Regulations, Rollever resistence-Dynamics rollever testing. Docket No. NHTSA 2001-9663.

[9] Goldberg D. E., (1989) Genetic Algorithmes in Serach, Optimazation, and Machine Learning. Addison Wesley.

[10] Cordon O., Herrera F., Hoffman F. and Maglalena L., (2002) Genetic Fuzzy System, Word Scientific.