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Double Fuzzy Logic Decision in HEV Energy Management

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Abstract

The energy management of Hybrid Electric Vehicles (HEV) see a major scientific effort in recent years. The major challenge is online management of the power required in a HEV within the constraints on state of charge in the storage element and the available energy and the different sources characteristics. This paper focuses on the management of electrical energy for HEV made with fuel cell and super capacitors, the problem is how to distribute instantaneously electrical power requested through the different energy sources by optimizing total consumption of hydrogen on a mission profile.

Keywords: energy consumption, controller, electric vehicle

1 Introduction

In this work, HEV provides two sources of energy: the fuel cell as a primary energy source and super capacitors as a secondary source (Figure1). The problem of energy management is to find the best distribution of power between the different energy sources. This paper presents a method for power management in real-time based on a system of fuzzy rules, this method has been improved by the application of a fuzzy switching of fuzzy rules method.

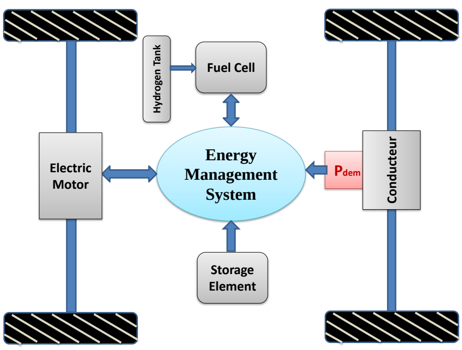

Figure1: HEV basic topology.

2 Management strategy based on fuzzy rules

The management strategy proposed online is based on a system of fuzzy rules; this later is used to identify the instantaneous output power supplied by the FC according to two input variables: state of charge (SOC) of the storage element at the instant t and the power demanded P_{dem}.
The fuzzy inference system is characterized by rules that are optimized offline by a genetic algorithm, it is used to optimize the choice of parameters and fuzzy decision membership function to generate these specific rules for each profile that bind the input variables to the output variable [2] [3].

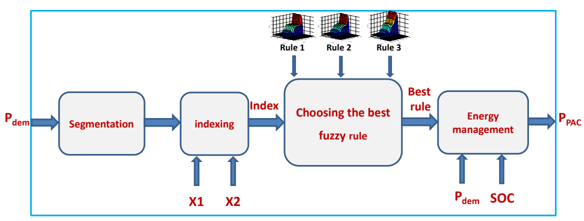

Figure2: Management strategy based on fuzzy rules.

NB: power profiles used are a set of mission's traffic types established by IFSTTAR (French Institute of Science and Technology for Transport, Development and Networks) from a statistical study of a set of actual missions [1].

Once the optimal rules identified, the fuzzy controller is used in the management of energy without prior knowledge of the journey made. In the case of an unknown profile, commutations and decisions must be made in real time. While inadequate rule profile is applied the consumption deteriorates, it is necessary to allow the decision-maker on an unknown profile to use different rules. In this context, a method of switching to manipulate the rules is proposed, depending on the power required via a segmentation method. To improve this method, a second level decision is added to switch if needs a set of rules to another (Figure2). The calibration of this algorithm results in the choice of the position of the terminals X1 and X2 is shown on Figure3, they allow the algorithm to switch between the different rules to choose the best.

The switching algorithm operates as follows:

If power segment is « low » then use « Rule1 ».

If power segment is «medium» then use «Rule2».

If power segment is « high » then use « Rule3 ».

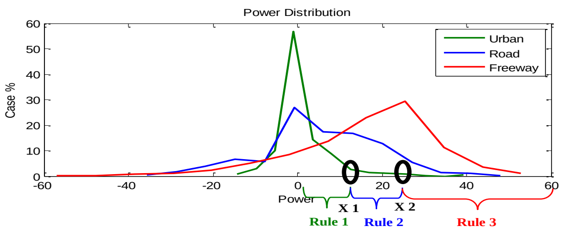

Figure3: Allocation rules in the power range.

To improve the strategy, in the case of an unknown profile, the method proposed add a smart switching between the three first learned rules, an indicator to manipulate the fuzzy rules online according to the Pdem via segmentation method is used. The segmentation method evaluate the average passed power demand and provides the indicator to the index value 1,2 or 3. Offline optimisation (using genetic algorithm) is also used to define X1 and X2 presented in previous works, or a second level of fuzzy rules should be applied, called FSFR. Once the optimal rules are identified and switching terminals are optimized, they will be applied thereafter in the management of the energy for each profile [2] [3] [4].

3 Fuzzy Switching of Fuzzy Rules (FSFR)

To develop and improve the fuzzy method for energy management online, a method for fuzzy switching of fuzzy rules is now presented, this method has proven to be a good choice for use in energy management algorithm for a better management of uncertainties online. The second system of fuzzy decisions adopted in this case serves to identify the best unclear rule to use for each P_{dem}. This fuzzy switching system implemented uses two input variables: the power required at the instant i, and the index corresponding to a prediction factor (Figure4). The output variable of the system is the decision to apply the best fuzzy rule (Figure5) "Urban, Road or Highway" for this power demand at instant i, that is called Fuzzy Switching of Fuzzy Rules (FSFR).

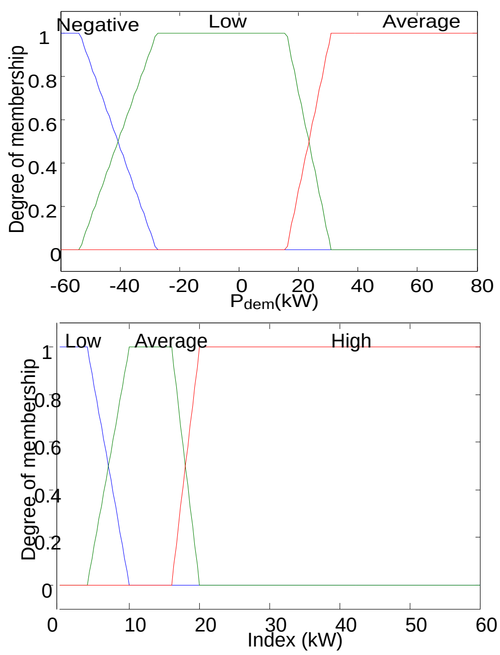

Figure4: Input variables membership functions for fuzzy switching

The choice of the output variable and more specifically, the identification of fuzzy rules to use depend on the input parameters that are formulated in a language description using the fuzzification step. The linguistic description of inference adopted in our decision is as follows:

If P_{dem} is « low » and *Index* is « low » then use « Rule1 ».
If P_{dem} is « medium » and *Index* is « low » then use « Rule1 ».
If P_{dem} is « high » and *Index* is « low » then use « Rule2 ».
Etc.

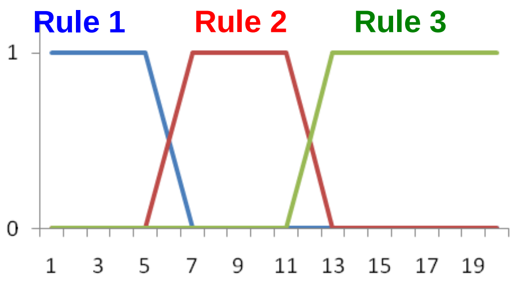

Figure5: Output variable membership function for fuzzy switching.

$$P_{PAC}(i) = 70\% P_{PAC}(i)(withRule1) + 30\% P_{PAC}(i)(withRule2) \quad (1)$$

Consumption obtained by applying FSFR is suboptimal but is not so far. However, there are energy errors (Tab1), these errors exist when the equality constraint (P_{dem}=P_{PAC}+P_{ES}) was not met. To solve the problem, an intervention was made at the optimization algorithm; this change corresponds to cases where the power delivered by the Fuel Cell System, must be calculated by two fuzzy rules at the same time (1). Modification emphasizes the need to always use a single rule "or Urban Road and highway." To improve the fuzzy inference system (Figure6), it is necessary to make an adjustment phase and improvement of parameters. For this purpose, the genetic algorithm allows to optimize the choice of the parameters of fuzzy controller switching (figure7).

Table1: Optimal rule VS FSFR.

	Urban	Road	H.way
Opt rule kWs	3390	11020	19660
error kW	0	0	0
FSFR kWs	3570	11076	20227
error	**34**	**14**	**17**

The modification highlights the need to always use only one rule "Urban, Road or Highway." even the limits X1 and X2 become fuzzy.

Once the rule FSFR is determined, the complete strategy (Figure8) is now applied improving FSFR for any profile.

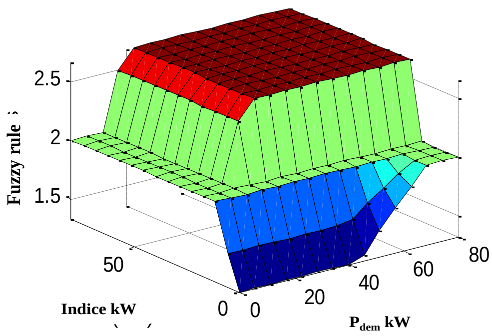

Figure6: Fuzzy rule of FSFR on left the optimized one.

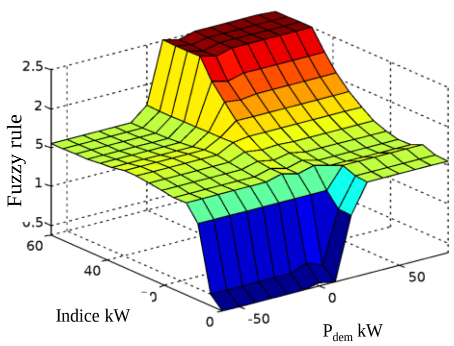

Figure7: Fuzzy rule of FSFR optimized

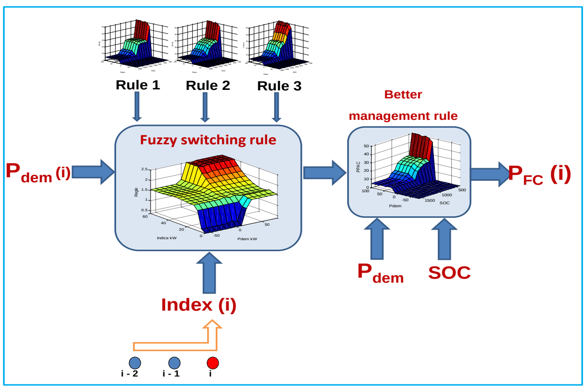

Figure8: management strategy for FSFR in real time.

The results obtained by applying improved FSFR (Table2) show that the fuzzy controller is able to dynamically switch between rules to achieve the best energy splitting with zero error.

Consumption obtained with FSFR decision is now very close to the minimal consumption obtain with a specific rule (Opt. rule) and the power demand is satisfied, so a global optimization on the consumption is obtained on the overall mission.

Table2: Optimal rule VS improved FSFR.

	Urban	Road	H.way
Opt Rule kW.s	3390	11020	19660
error kW	0	0	0
Opt FSFR kW.s	3391	11054	19732
error kW	**0**	**0**	**0**

4 The offline optimization to online prediction

Fuel consumption depends on how the indicator is calculated. Indeed, offline segmentation can be centered (calculated on the interval [i-1, i, i +1]), online can only be calculate the indicator at time'i' according to the power demand to same time, or rather predict the value of the time 'i +1' knowing the current demand and the two previous demands (Figure9).

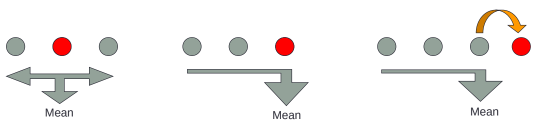

Figure9: principle of segmentation and prediction method.

A layer prediction results presented in Table3 (at the end of the paper) has been developed and has shown that if FSFR strategy is applied, good results in real time are obtained.

The offline results use the centered computation of the proposed indicator and using the future demand 'i+1' allows the controller to be very closed to the optimal consumption on such profile.
Using the average computation using average made on the three previous power demand (online method) is closed to the results too.

Using the three previous power demands to predict the future (i+1 predicted) seems to not be a good solution. The consumption obtained is worse than previous results obtained mainly due to the fact the mission profile is very varying. There is no model to predict the evolution of the power demand. A bad prediction let the algorithm FSFR sometimes to take the wrong decision and that explain the results 'Prediction' provides a higher consumption on the global
To be noticed: using more than three previous power demands did not reveals any improvement in the profiles used in this work.

The proposed strategy FSRF improved gives a satisfactory performance in all missions and gives better consumption than those obtained by applying the dynamic programming (such algorithm is supposed to deliver the optimal consumption values but with too strict constraints to respect and discretization problem [5]), a specific optimal rules have been computed only to show improvement..

Conclusion

This work shows that the energy management strategy based on switching fuzzy rules has improved fuel consumption compared to the application of a single rule optimized on another profile.

A layer of fuzzy decision can switch rules based on a prediction of mission profile and apply the correct set of fuzzy rules, especially on an unknown profile or of rangeland identified as the closest known profiles.

A new management strategy is proposed, this method gave satisfactory results in terms of consumption. Even if he mission is unknown, the results obtained are very close to the optimal consumption with zero error.

This strategy leads the fuel cell to operate at best efficiency point. It has been verified that if this method is applied in real time on an unknown profile, consumption obtained is quasi-optimal.

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Method		Urban	Road	H.way	unknown Profile
Optimal rule kW.s		3390	11020	19660	19010
Improved FSFR kW.s	Off line	3390	11031	19710	12032
	On line	3391	11054	19732	12039
	Prediction	3410	11094	19847	12110

Table3: Real-time prediction and unknown profile