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Neuro-Fuzzy control for four Wheels electric vehicle safety

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Abstract - *This paper present novel approach for traction control of four wheel electric propulsion system for each wheel. This algorithm is necessary to improve the vehicle safety, the independent Machine Control philosophy is employed using an intelligent controller for torque and speed estimation, the proposed system replace the classical PI controller in order to improve vehicle dynamic performances. When the classical proposed control can't ensure the electric vehicle stability in several road topology situation's. The electronic differential system using adaptive fuzzy logic controller permit to vehicle to achieve intelligent driving. To show the efficiency of vehicle system control both of classical and intelligent controller are tested on Matlab Simulink environment ,the results obtained present satisfactory and show clearly the best response of the intelligent control during driving trajectory. The obtained data prove clearly that the worst performances of driving using PI comparing with adaptive fuzzy logic controller with no overshoot and no speed error and less estimated current ,and optimized autonomy.*

Résumé – *L'article présente une nouvelle approche pour le contrôle de la traction de chaque roue d'un système à quatre roues à propulsion électrique. Cet algorithme est nécessaire pour améliorer la sûreté du véhicule, la philosophie de commande machine indépendante est employée en utilisant un contrôleur intelligent pour l'estimation du couple et de la vitesse. Le système proposé remplace les contrôleurs PI classiques dans le but d'améliorer les performances dynamiques du véhicule quand le système classique ne permet plus d'assurer la stabilité du véhicule électrique dans de nombreuses situations de topologie routière. Le système différentiel électronique qui utilise un contrôleur à logique floue adaptative permet au véhicule de réaliser une conduite intelligente. Pour montrer l'efficacité du système de contrôle du véhicule, un système classique et un contrôleur intelligent sont testés dans l'environnement Simulink de Matlab. Les résultats obtenus sont satisfaisants et montrent clairement que le système de contrôle intelligent possède la meilleure réponse de trajectoire de conduite. Les données obtenues prouvent clairement que les performances de conduites lors de l'utilisation d'un PI sont plus mauvaises que celles obtenues pour un contrôleur à logique floue adaptative, sans dépassements, sans erreur de vitesse, un courant estimé plus faible et une autonomie optimisée.*

Keywords: Electric vehicles (EV) - 04 Wheels - Adaptive control - Fuzzy logic controller.

1. INTRODUCTION

Electric vehicle systems (EVs) are fast developing during this decade due to drastic issues on the protection of environment and the shortage of energy sources. While commercial hybrid cars have been rapidly exposed on the market, fuel-cell-powered vehicles are also announced to appear in 5–10 years. Researches on the power propulsion system of EVs have drawn significant attention in the automobile industry and among academics. EVs can be classified into various categories according to their configurations, functions or power sources. Pure EVs do not use petroleum, while hybrid cars take advantages of energy management between gas and electricity [1, 3].

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Indirectly driven EVs are powered by electric motors through transmission and differential gears, while directly driven vehicles are propelled by in-wheel or, simply, wheel motors [2, 6]. The basic vehicle configuration of this research has four directly driven wheel motors installed and operated inside the driving wheels on a pure EV[3, 7-9]. These wheel motors can be controlled independently and have quick and accurate response to the command that the vehicle chassis control or motion control becomes more stable and robust, compared to indirectly driven EVs[5, 6].

Like most research on the torque distribution control of wheel motor, wheel motors [3] proposed a dynamic optimal tractive force distribution control for an EV driven by four motor wheels, thereby improving vehicle handling and stability [5]. The researchers assumed that wheel motors were all identical with the same torque constant; neglecting motor dynamics the output torque was simply proportional to the input current with a prescribed torque constant.

In this paper, a novel control method based on adaptive fuzzy logic control is proposed. Modelling and simulation are carried out using the Matlab/Simulink tool to investigate the performance of the proposed system.

2. FOUR WHEELS DRIVE ELECTRIC VEHICLE DESCRIPTION

The vehicle proposed in this work is one of four wheels drive system using an electronic differential system for speed reference computation ,as it shown in figure 1. The main purpose of the electronic differential is to substitute the mechanical differential in multi-drive systems providing the required torque for each driving wheels and allowing different wheel speeds [2-6, 15, 16].

This electronic differential system present a virtual driver which match the real driver decision with the correct induction motor behavior. The energy source of the electric motors deduced from the Li-ions batteries [3] placed under the seats. Four induction motors are coupled in each of the rear and front wheels.

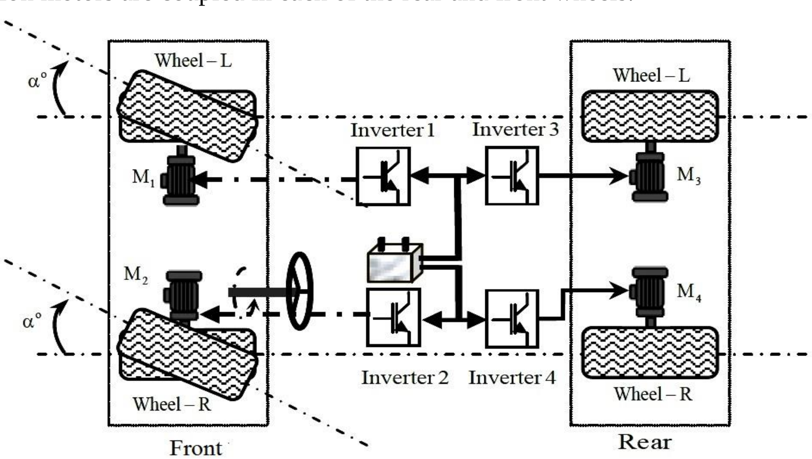

Fig. 1: Electric vehicle with Four-independent-wheels drive.

3. VEHICLE AS MECHANICAL LOAD

The vehicle mechanical load is characterized by three resistive torques [7, 12-15]. The different torques includes:

- The vehicle inertia torque defined by the following relationship:

$$T_{in} = J_v . \frac{d\, w_v}{d\, t} \tag{1}$$

-The aerodynamics torque is:

$$T_{aero} = \frac{1}{2} \rho . S . T_x . R_r^3 . w_r^2 \tag{2}$$

-The slope torque is:

$$T_{slope} = M.g.\sin\alpha \tag{3}$$

- The tire torque is obtained by:

$$T_{tire} = M.g.f_f \tag{4}$$

We obtain finally the global resistive torque:

$$T_V = T_{aero} + T_{slope} + T_{tire} \tag{5}$$

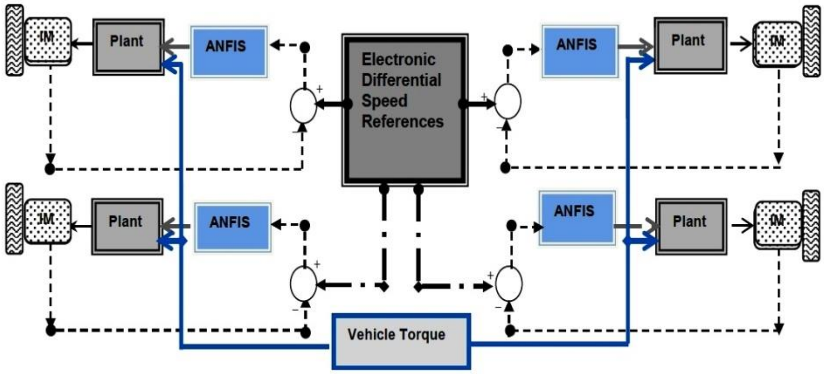

Fig. 2: Propulsion system control for 4WEV

4. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS) CONTROLLER FOR 4 WHEELS EV SYSTEMS

4.1 Adaptive neuro fuzzy inference system structure

The ANFIS is a multilayer feed forward network which employs neural network and fuzzy logic learning algorithms to design a plan from input to output. ANFIS has shown great capabilities in control process [17-20].

A typical architecture of an ANFIS is shown in figure 1, in which a circle indicates a fixed node, whereas a square indicates an adaptive node. For simplicity, it was assumed that the desired logic system has two inputs x, y and one output z. Since the proposed neuro-fuzzy model of the ANFIS similar to the first order Sugeno fuzzy model, laws are considered as follows:

$$\text{Rule1: if } (x \text{ is } A_1) \text{ and } (y \text{ is } B_1), \text{ then } (Z_1 = p_1 x + q_1 y + r_1)$$

$$\text{Rule2: if } (x \text{ is } A_2) \text{ and } (y \text{ is } B_2), \text{ then } (Z_2 = p_2 x + q_2 y + r_2)$$

Where A_i and B_i are the fuzzy sets in the antecedent, p_i and q_i, and r_i are the design parameters that are determined during the training process. As in figure 3, the ANFIS consists of five layers [20].

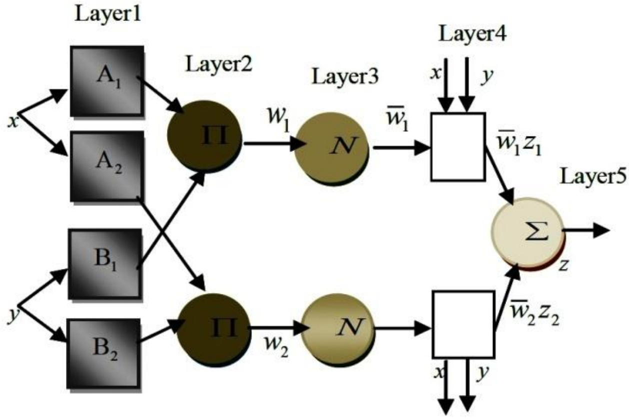

Fig. 3: The ANFIS structure sheme

It **Layer 1**: Every node i in the first layer employ a node function given by:

$$O_i^1 = \mu_{A_i}(x) \qquad i = 1,2$$
$$O_i^1 = \mu_{B_{i=2}}(x) \qquad i = 1,2 \tag{6}$$

Where μ_{A_i} and μ_{B_i} can adopt any fuzzy members ship function (MF).

Layer 2: Every node i in this layer calculates the firing strength of a rule via multiplication:

$$O_i^2 = w_i = \mu_{A_i}(x).\mu_{B_i}(y) \qquad i = 1,2 \tag{7}$$

Layer 3: The i-th node in this layer calculates the ratio of the i-th rule's firing strength to the sum of ail rules fitting strengths:

$$O_i^3 = \overline{w}_i = \frac{w_i}{w_1 + w_2} \qquad i = 1,2 \tag{8}$$

where $\overline{w}_i$ is referred to as normalized firing strengths.

Layer 4: In this layer, every node i has the following function:

$$O_i^4 = \overline{w}_i z_i, \overline{w}_i (p_i x + q_i y + r_1) \qquad i = 1,2 \tag{9}$$

where $\overline{w}_i$ is the output of layer 3, and $\{p_i; q_i; r_i\}$ is the parameter set. The parameters in this layer are referred to as the consequent parameters.

Layer 5: The single node in this layer computes the overall output as the summation of all incoming signals, which is expressed as:

$$O_i^5 = \sum_{i=1} \overline{w}_i z_i = \frac{w_1 z_1 + w_2 z_2}{w_1 + w_2} \tag{10}$$

The output z in figure 3 can be rewritten as [17, 18]:

$$z = (\bar{w}_1 x)p_1 + (\bar{w}_1 y)q_1 + (\bar{w}_1)r_1 + (\bar{w}_2 x)p_2 + (\bar{w}_2 y)q_2 + (\bar{w}_2)r_2 \quad (11)$$

4.2 Adaptive Neuro fuzzy controller Application

The speed control of the electric vehicle requires one ANFIS because of the strategy of machine independent structure.

The two inputs and one output have been considered for the ANFIS, are e_1 (error speed), and the derivate or speed change error $\dot{e}_1$ as it shown in figure 4 [19].

The strategy of the ANFIS control consists to adjust in permanent the values of the corrector gains, the neuro-fuzzy controller developed consists of two inputs, e_i and Δe_i defines as [20].

$$\begin{aligned} e_i(k) &= q_i^* - q_i \\ \Delta e_i &= e(k) - e(k-1) \end{aligned} \quad (12)$$

Where, the structure of ANFIS used is shown in figure 3, where the number of epochs was 50 for training, the memberships r the input variables e and de e' is 5 and 5, respectively the number of rules is then 25 (5 × 5 = 25) and the triangular membership functions is used for the two input. The training and testing root mean square (RMS) errors obtained from the ANFIS are 4 × 10^{-7} and 6 × 10^{-6} respectively[19].

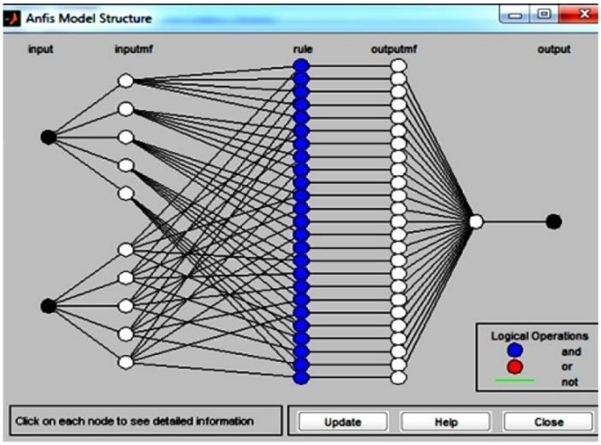

Fig. 3: The ANFIS model structure

In order to show the efficiency of the ANFIS control structure of the 4 wheels electric vehicle drive simulations were carried using the model of figure 2. They show vehicle speed variation for PID and ANFIS controllers in the following road trajectory:

-Slope road at time 2 sec ,then speed variation from 60 to 80 km/h , then curved road at left side at 4 sec Simulation were carried on Matlab Simulink , we obtain the following results:

To compare the efficiency of the two controllers, figure 4 the vehicle have the same test condition. Figure 4 present linear speed for both of PI and ANFIS controllers disturbances effect appear clearly in classical control with an overshoot of 15 % and with significant speed error but in ANFIS case it's appear clearly that this control give good dynamic performance with no speed error and no overshot in this case the vehicle passe the slope in easy way ,with less aerodynamic torque , after that the driver change speed reference and the electronic differential act immediately with no problem in ANFIS case's and with less aerodynamic efforts.

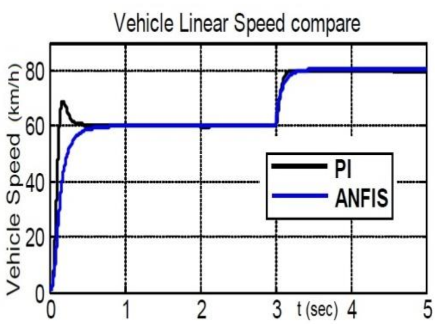

Fig. 4: Vehicle linear speed variation

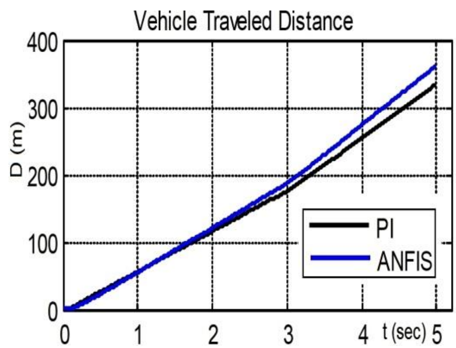

Fig. 5: Vehicle travelled distance variation

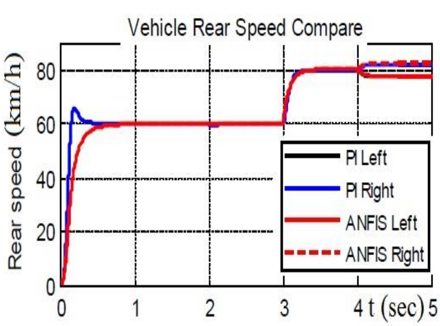

Fig. 6: Vehicle rear speeds compare

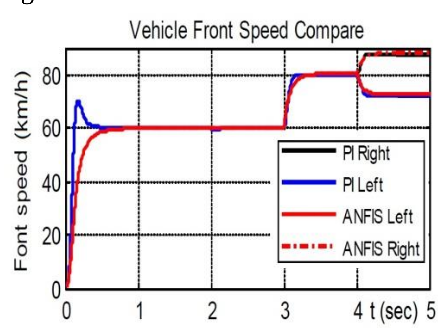

Fig. 7: Vehicle front speeds compare

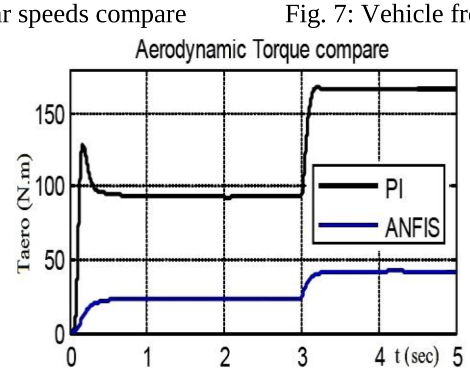

Fig. 8: Vehicle aerodynamic torque compare

- The vehicle turn on left side at 4 sec. In this situation the electronic differential estimate the speed reference of each wheel and compute the estimated current for each motor, in the other hand there are lot of problems of driving in PI case's beginning from slope road with high aerodynamic torque until the worst driving condition on left side curved road. The travelled distance is very important in ANFIS controller compared with PI controller , the results obtained present satisfactory in ANFIS and less performances in PI control as it shown in figure 6, 7 and 4. The **Table 1** present a comparative study of the two controller.

Table 1: Electric vehicle comparative study

Controller	PI	ANFIS
Rising time, sec	0.6	0.8
Overshoot, %	15%	0
Speed error	exist	never
Vehicle torque, Nm	278.6	143.5
Aerodynamic torque	166.6	42
Travelled distance, m	334.4	362.2

5. CONCLUSIONS

The research proposed in this paper has demonstrate the possibility of an improved four wheels vehicle stability which utilize four independent driving wheels for motion by using the adaptive fuzzy logic controller.

The studied four wheels independent wheel control approach structure applied to the electric chain system using the intelligent speed control ensure the driving on slope with high safety conditions.

The results obtained by Matlab simulation proves that this structure permits the realization of intelligent control loop speed based on the inference knowledge system which give a good dynamic performances of electric vehicle.

The proposed control , permit to control independently the driving wheels speeds with high accuracy in flat roads or curved ones in each case. The slope's road do not affect the performances of the driving motor wheels stability comparing with the PI classical controller.

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