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A new application for fast prediction and protection of electrical drive wheel speed using machine learning methodology

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ABSTRACT

This paper introduces a non-linear implementation of the speed control technique of permanent magnetic synchronous motors (PMSM) using electronic differential (ED) command. Artificial neural network (ANN) coupled with particles swarm optimization (ANN-PSO) are implemented to control wheel speed and steering angle. The main purpose of the PMSM system and its application is the command of electric vehicles (EV). In the controller design, three-phase currents and rotor speed shall be measurable and eligible for feedback. Our propulsion platform consists of two PMSM in the back. The study with implemented ANN-PSO is performed after collecting the data from the ED to manage the control of speed EV, Left and right of steering angle and steering ahead. Based on this strategy, a new application can be provided in the GPS application to give the information as input (curved path angle) to ANN-PSO. Next, the application of ANN-PSO can estimate the parameters of ED to avoid the slip, as well as improves better performance and dynamic stability of electric vehicle drive systems.

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1. INTRODUCTION

In the last two decades, effective vehicle stability systems have significantly reduced the number of road accidents. These devices allow the driver to maintain the vehicle's stability in difficult driving situations such as high speeds, abrupt lane changes and rough road conditions, with high stability control systems adoption rates. Serious road accidents still kill people every day. Therefore the vehicle needs to build more sophisticated stability control into roads and wheels in a curved way. Vehicle stability control systems require vehicle states to monitor wheel slips, vehicle yaw rate, and side-slip angle. Longitudinal and lateral velocity contribute significantly to traction and stability control mechanisms. Based on the previous information, global positioning system (GPS) can be used to extract the way information. The electric wheel vehicle has the advantages of a simple transmission system independent and precise control of the torque of the driving wheel. It can have a major advantage in the vehicle driving dynamics, driving distribution of torque and driving safety [1], [2]. Electrical and conventional car wheels have a great difference in structure, where they cannot be used to complete the traditional mechanical differential. Thus electronic differentiation has become a focus of electric vehicle research [3]. Permanent magnetic synchronous motor (PMSM) has been widely used in variable-speed motor drives such as electric vehicles, machine tools, home appliances, military forces or medical and industrial robots due to its broad range of high power density and conventional service. Set gain PD, PI, PID controllers are commonly used in most industrial drive applications as referred in references [4]. Command techniques based on recent modern theories are suggested to satisfy the high-performance design criteria of industrial drive applications. Fuzzy logic-based controllers are robust for parameter fluctuations and external disturbances because their architecture is independent of the controlled device. However, professional expertise is important for the real-time use of these controllers [5]. Managing variable structure in a dangerous sliding position has been extensively studied due to its reliability against conventional instability, parameter disturbances, and external disturbances, as presented in references [6], [7].

One of its most serious weaknesses is the gossip phenomenon surrounding a steady state, which limits its use. Control is a contemporary recursive and systematic approach for the feedback regulation of unexpected non-linear systems, particularly those with related uncertainties [7]-[10]. With the help of multiple recursive stages that never exceed the order of the method, this strategy solves the challenges in getting control of Lyapunov's function. Each step generates a virtual control variable, simplifying the original high order system. As a result, the final control data may be systematically analyzed using the proper Lyapunov's functions. A robust non-linear adaptive controller has been extracted directly from this PMSM speed control approach [8]-[15]. The controller is resilient against stator resistance, viscous friction instability and unpredictable load torque disturbance. Nonetheless, this method employs feedback linearization to cancel all undesirable non-linearities [16]-[20].

In this paper, based on the information about the sliding in a curved path, a new application is developed and implemented to solve this problem using machine learning artificial neural network coupled with particles swarm (ANN-PSO) which adapt the electronic differential (ED) parameters where the required information i.e, Curved path angle can be extracted by GPS. The remainder of the paper is structured as shown in: In the second part, the mathematical model of PMSM is presented. The third part describes the overall design of the control which is given in connection with the Lyapunov's stability theory. In section 4, the electrical traction system elements and the electrical differential system are outlined in section 5. Section 6 describes the components of the electrical traction system and the electrical differential system in section 5. The accomplishments of the proposed controller are described in the last section.

2. MODELLING OF PMSM DRIVE SYSTEM

We have four types of electric cars for the design described in this paper. The first type is electric cars withan electric motor or numerous motors attached to the wheels. The second type is a hydrogen-powered car. The third kind is a hybrid electric car, andthe last is motorcycles. In our study, we have considered the mechanism of the two-drive rear wheels of an electric vehicle powered by a PMSM, more details can be found in the last sections.

2.1. Machine equations

In the park transform, the transformation in the reference frame of the rotor (d–q) is defined mathematically. Thus the mechanical and electrical equations of the PMSM model are given by the expressions as (1):

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} R_s + pL_d & -w_r * L_q \\ w_r * L_d & R_s + pL_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 \\ w_r * \varphi_f \end{bmatrix} \tag{1}$$

$R_s$is the stator resistance,$w_r$is the angle velocity of the rotor.i_d, i_q,v_d, v_q is the current and voltage of the stator, L_d, L_q: Inductances, respectively. $\varphi_f$is the permanent magnetic flux connection.

The amplitude of the binding stator flux(φ_s)is:

$$\varphi_s = \sqrt{\varphi_\alpha^2 + \varphi_\beta^2} \tag{2}$$

The mechanical dynamic equation shall be calculated by (3):

$$J\frac{dw_r}{dt} = p(T_e - T_L) - fw_r \tag{3}$$

where T_e the electromagnetic torque, p is the pole pairs, J is the inertia of PMSM, f is the factor of friction and T_L the Load torque. Using (1)-(3), the dynamic model of the PMSM can be described as (4):

$$\begin{cases} \begin{pmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \end{pmatrix} = \begin{bmatrix} -\frac{R_s}{L_d} & 0 \\ 0 & -\frac{R_s}{L_d} \end{bmatrix} \begin{pmatrix} i_a \\ i_b \end{pmatrix} + \begin{bmatrix} -\frac{1}{L_d} & 0 \\ 0 & -\frac{1}{L_d} \end{bmatrix} \begin{pmatrix} E_a \\ E_b \end{pmatrix} + \frac{1}{L_d} \begin{pmatrix} v_a \\ v_b \end{pmatrix} \\ T_e = \frac{3}{2} pf (i_b \cos q_r - i_a \sin q_r) \\ \frac{dw_r}{dt} = \frac{p}{J}(T_e - T_L) - \frac{f}{J} w_r \end{cases} \tag{4}$$

3. ELECTRICAL VEHICLE TRACTION DEVICE MODELLING ELEMENTS

Figure 1 presents the general scheme for an electric traction system using PMSM machines. This scheme is supplied by a voltage inverter connected to a lithiumion battery. This section can explain clearly the electrical vehicle traction modeling.

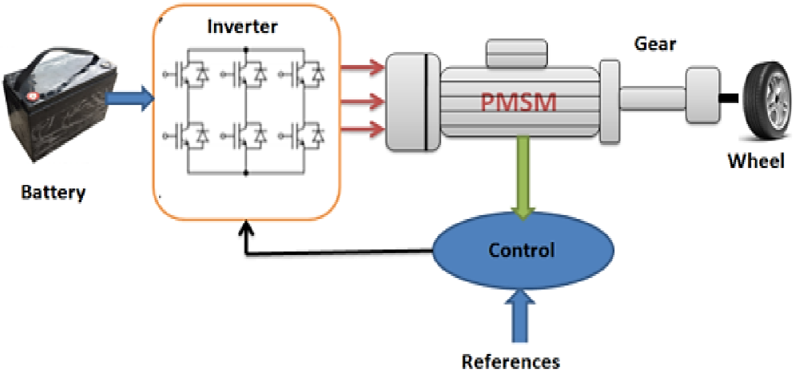


Figure 1. Electromechanical drive chain of the vehicle

3.1. Source of energy

The global energy source concentrates on renewable energies, and the lithium battery system typically provides good battery power. Each type of battery has distinct advantages in energy and endurance over other types of rechargeable batteries.

3.2. Model of the inverter

In this electrical traction system (ETS), an inverter is used to generate three balanced phases of alternating current with variable frequency from the current battery expressed as (5):

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{U_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \tag{5}$$

3.3. Dynamics analysis of the vehicle

Based on the vehicle dynamics and aerodynamics principles [12], the load on the road $\mathrm{F_{res}}$ is composed by (6)-(9):

$$\mathrm{F_{res}} = \mathrm{F_{roll}} + \mathrm{F_{slope}} + \mathrm{F_{aero}} \tag{6}$$

$$\mathrm{F_{roll}} = \mu \mathrm{Mg} \tag{7}$$

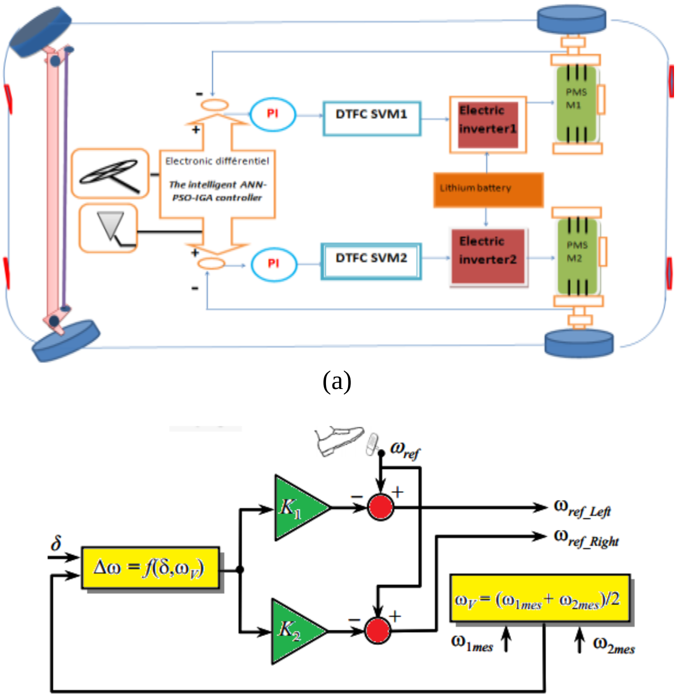
$$\mathrm{F_{slope}} = \mathrm{Mg} \sin(\alpha) \tag{8}$$

$$\mathrm{F_{aero}} = \frac{1}{2} \rho \mathrm{C_x A_f} (\mathrm{v} - \mathrm{v_0})^2 \tag{9}$$

where, $\mathrm{F_{roll}}$: is the rolling resistance, $\mathrm{F_{slope}}$: is the slope resistance, $\mathrm{F_{aero}}$: is the aerodynamic drag.

4. THE ELECTRICAL DIFFERENTIAL AND THE APPLICATION

Figure 2 shows schematic diagram of electric vehicles (EV) propulsion and control systems with direct torque and flux control (DTFC) in device applied to an electric vehicle in the MATLAB/Simulink setting as shown in Figures 2(a) and 2(b). The proposed control system is composed of the following components: i) Electrical driven rear wheels whose speed is controlled by ANN-PSO control technology; ii) Two electric motors using speed control technology; iii) Four wheels and lithium battery and two inverters; and iv) Speed sensor.



(a)

(b)

Figure 2. Schematic diagram of EV propulsion and control systems with DTFC, (a) block diagram and (b) shows the use of the electronic differential

The speed of the car varies depending on the direction of the road in the straight line. The speed of the two rear wheels is equal. However, in the non-straight line, the two rear wheels are driven directly by two-speed engines and the speed of the outer wheel would be higher than the speed of the inner wheel during the steering manoeuvres. This process of checking for good results requires several conditions, including the speed difference method of the two motors, which is called a technique using artificial neural network coupled with particles swarm isogeometric analysis (ANN-PSO-IGA) control technique for electronic differential (E-D). The latter provides us with good results using advanced techniques in artificial intelligence, which allows an increase in the speed of the external motor of the winding and a decrease in the speed of the internal motor to avoid traffic accidents. Nevertheless, if the location encoder is employed to determine the angular position of the steering wheel, this requirement is readily met. The pedal accelerator sequence then determines the standard reference speed Wref.

The actual reference speeds for the left drive Wref–left and right drive Wref–right is then obtained by modifying the common reference speed Wref using the location encoder output signal. When the vehicle turns right, the speed of the left wheel increases while the speed of the right heel remains constant with the Wref's usual reference speed. As both vehicle turns left, the speed of the right wheel increases while the speed of the left wheel remains constant utilizing the ANN-PSO-IGA control approach for the electronic differential (E-D) [13]-[17]. Modern automobiles do not employ pure Ackermann-Jeantaud steering since it lacks key dynamic and compliant effects, although the principle is sound for low-speed manoeuvres [18]-[26]. This is illustrated in Figure 3. The difference in angular velocity of the wheel engines is expressed as shown in (10):

$$\Delta w = w_{mes1} - w_{mes2} = -\frac{d_w \tan\sigma}{L_w} w_v \quad (10)$$

From (10) the block diagram of the electronic differential [16] is reconstructed as shown in Figure 2(b).

5. ELECTRONIC DIFFERENTIAL OF SPEED CONTROL USING ANN-PSO

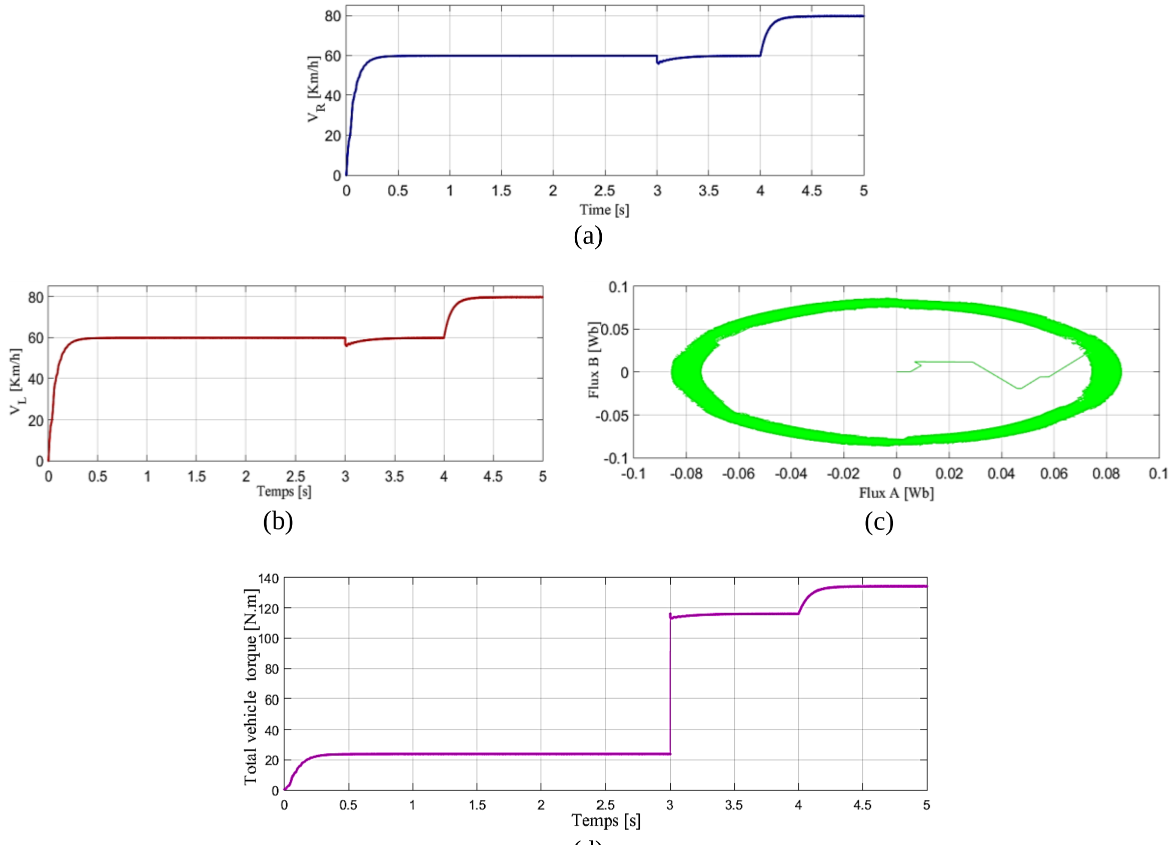
ANN-PSO-IGAcontrol is a technique of control which, in the presence of uncertainties, can effectively linearize a non-linear system like PMSM. Unlike other linearization feedback techniques, ANN-PSO-IGA control has the flexibility to keep useful non-linearities intact while stabilizing. ANN-PSO-IGA control is essentially about stabilizing a virtual control state. It, therefore, produces a corresponding error variable that can be balanced by choosing the right control inputs carefully. Those inputs can be determined from the Lyapunov's stability analysis. Because of the interaction between speed and electric currents, as shown in (1) shows that PMSM's dynamic model is exceedingly non-linear. In order to align all of the related flux in the d-axis and produce optimal torque per ampere in accordance with vector control theory, the direct axis current Id is frequently made to be zero.

6. SIMULATION RESULTS

In this section, the electric rear-wheel drive PMSM speed regulation is simulated using the DTFC command. The ANN-PSO-IGA technology is added in the classic electronic differential setting. The simulation is carried out using the model shown in Figure 2(a) to characterize the steering system's behaviour and show the engine current and the variable speed of each motor.

6.1. Straight route case

In this section, fuzzy adaptive proportional-integral (PI) vontroller for (DTFC) is used as a reference and applied on an EV [8]. EV velocity is equal to 60 Km/h. Figure 3 shows that EV has two phases. The first phase is between [0 4] s and the second phase is between [4 5] s with speed equal to 80 Km/has mentioned in Figure 3(a) and Figure 3(b). As it is known, the two back wheels have similar speed. This proves that in this case the electronic differential does not work. The slope effect results in a significant improvement of the torque of the electromagnetic motor both on the left and right of each motor. For the flux, is presented in Figure 3(c). When Fpente=5.81, the Figure shows that the only change occurs in the direct torques see Figure 3(d).



(a)

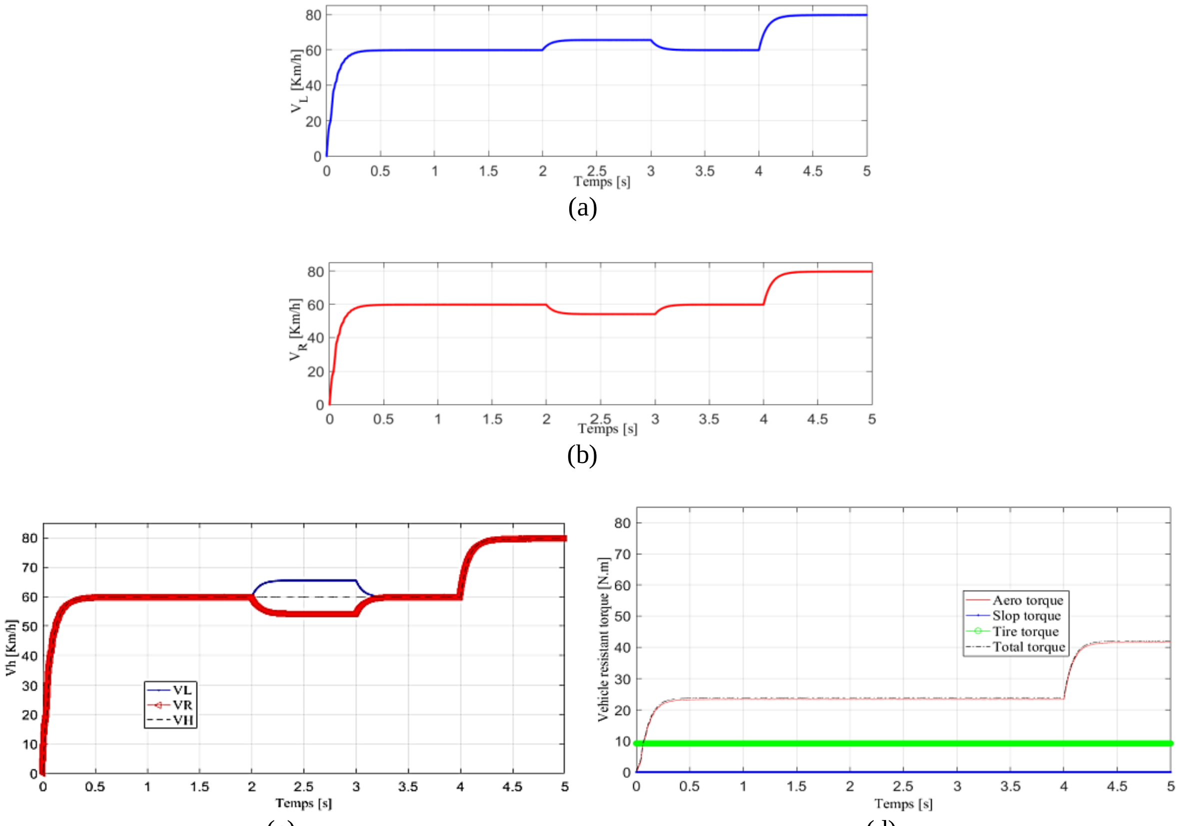
(b) (c)

(d)

Figure 3. Straight route, (a) right wheel speed, (b) left wheel speed, (c) flux, and (d) total vehicle torque

6.2. Case of Curved road at a speed of 60km/h on the right

In this section, the fuzzy adaptive PI controller for (DTFC) applied for the curved track. The EV speed is equal to 60 km/h. Figure 4 shows that the electric vehicle has two stages: the first stage is between [0 2] s and the second stage is between [3 5] s at a speed of 80 km/h. At a speed of 80 km/h, the car drives on a curved road to the right. The steering wheels take different tracks in this case, the new electronic differential in the new ANN-PSO-IGA method controls the car and the wheels rotate in the same direction but at different speeds. The steering wheel speed on the right side decreases by a known value and the speed of the left wheel increases. All the required parameters for left and right wheels are plotted in Figure 4(a) and Figure 4(b), vehicle speed in right turn in curved way is presented in Figure 4(c), for the resistive torques in right turn in a curved way is presented in Figure 4(d). If this speed is stabilized, the torque returns to its initial value corresponding to the total resistance torque applied to the engine wheels.



(a)

(b)

(c)

(d)

Figure 4. Curved line to the right, (a) left wheel speed, (b) right wheel speed, (c) vehicle speed in right turn incurved way, and (d) resistive torques in right turnin curved way

7. IMPLEMENTATION OF THE PSO-ANN METHODOLOGY

Artificial neural network (ANN) can be applied for a wide range of fields comprising classification, pattern recognition, identification, and image processing and control system. Based on the previous section, fuzzy adaptive PI controller for (DTFC) is used as tool to compute the speed and torque then used as in input and output (Input: speed and curve angle. Output: wheels speed) in ANN.

The dominant characteristic of ANN is its capacity to learn through experience to improve performance. In this paper, we employed ANN combined with PSO to predict the speed wheel left and right direction. Basically, a network of ANN has three key components comprising the input layer. The estimated number of parameters employed by the network (weight and biases). Following the construction of the ANN model's structure, training using known input and output sets is undertaken to determine optimal weights and biases using PSO [17]-[23]. The goal is to reduce the network's root-mean-square error (RMSE), which is represented by (11):

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{l=1}^{n}(O_l - l_l)^2}{nd}} \qquad (11)$$

where, O_l is the output corresponding to lth data point in the training set by the network, l_l is the actual output as considered in the target set, nd is the number of data points considered in the training data-set. After collecting the data the regression of ANN technique is presented in Figure 5. Four scenarios are considered to predict the left and right wheel speeds. Based on the provided results in Table 1 and Figure 6, ANN-PSO can predict with more accurate the suitable wheels speed in a curved way with less central processing unit (CPU) time.

Table 1. Real and predicted results of the left and right wheels based on ANN-PSO

No	Tests		Speed Real		Speed Estimated	
	speedV_h	α	Left (L)	Right (R)	Left (L)	Right (R)
1	7.5	5π/180	08.09	06.86	08.01	06.93
2	17.5	5π/180	18.90	16.00	18.76	16.11
3	57.5	π/180	58.25	56.35	58.31	56.32
4	52.5	π/180	53.20	51.45	53.12	51.39

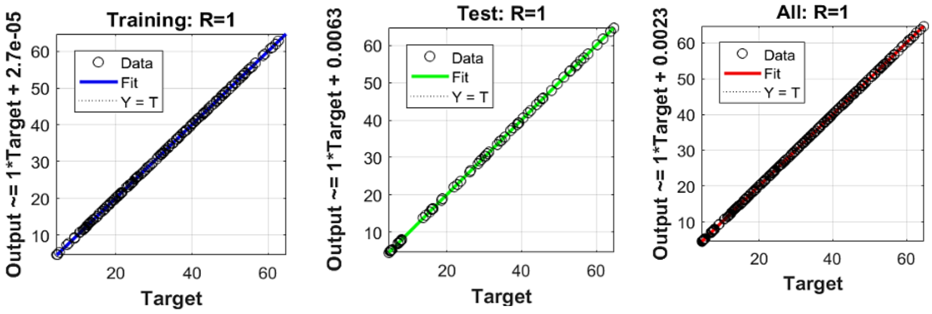


Figure 5. Regression after collecting 44 data

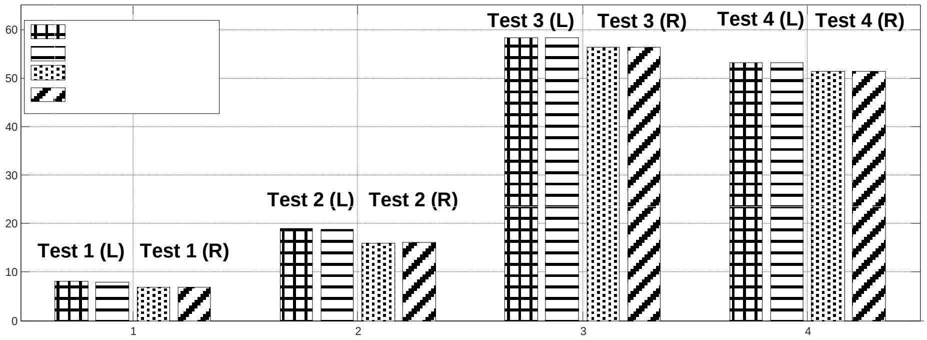


Figure 6. Real and predicted results of the left and right wheels based on ANN-PSO

8. CONCLUSION

In this paper, the non-linear control of the PMSM placed in the rear drive wheels of the electric vehicle is designed and presented taking into consideration the vehicle dynamics. Based on the linear method of input and output, the proposed non-linear control is evaluated on the EV model. Control technology allows for linearity and separation of the system. In speed electronic differential control, the non-linear control of a permanent synchronous magnetic drive, based on the linear traction control algorithm, for traction control provides fast response and simple configuration and can be a good candidate for the electric vehicle propulsion system. Next, a new application is proposed to solve this problem using machine learning (ANN-PSO) to adapt the ED parameters. The required information (Curved path angle) can be extracted by GPS. Results of simulation show that this structure allows for electronic differentiation, which can guarantee good stable and dynamic performance. The electronic differential (ED-ANN-PSO) decreases the speed of the steering wheels with high force on both left and right curved paths as well as the change in vehicle speed depending on the road location and conditions. The analysis of the approach results shows better performance and dynamic stability of electric vehicle drive systems.

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