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A comparison study using backstepping and PI controllers for Electric Vehicle

***Abstract**. This paper shows a comparative study control design of electric vehicles (EV) to improve behavior and stability under different road constraints conditions. The proposed control is intended to increase the efficiency using backstepping control. For this aim, a model is obtained firstly and it is driven by two DC motors placed on the rear wheels independently controlled by a non-linear controller named Backstepping. Indeed, it contains a powerful electronic differential system to ensure the security of passengers while entering the curved road. Backstepping control is suggested to replace the existing PI controller for high performance motion control systems. The effectiveness of the control algorithm is tested and validated in simulation and experimental bench testing in MATLAB/Simulink environment with dSpace 1104 based Real-Time interface.*

***Streszczenie.** W artykule przedstawiono projekt kontroli porównawczej pojazdów elektrycznych (EV) w celu poprawy zachowania i stabilności w różnych warunkach drogowych. Zaproponowane sterowanie ma na celu zwiększenie efektywności za pomocą sterowania wstecznego. W tym celu najpierw otrzymuje się model, który jest napędzany dwoma silnikami prądu stałego umieszczonymi na tylnych kołach niezależnie sterowanymi przez nieliniowy sterownik o nazwie Backstepping. Rzeczywiście, zawiera potężny elektroniczny system różnicowy, aby zapewnić bezpieczeństwo pasażerom podczas wchodzenia na zakrzywioną drogę. Sugeruje się, aby sterowanie krokowe zastąpił istniejący sterownik PI w wysokowydajnych systemach sterowania ruchem. Skuteczność algorytmu sterowania jest testowana i walidowana w symulacjach i eksperymentalnych testach stanowiskowych w środowisku MATLAB/Simulink z interfejsem czasu rzeczywistego opartym na dSpace 1104. (**Badanie porównawcze z wykorzystaniem regulatorów cofania i PI dla pojazdów elektrycznych**)*

Keywords: Electric vehicle (EV); Electronic differential; Backstepping controller; PI controller; dSpace 1104.
Słowa kluczowe: pojazd elektryczny (EV); Elektroniczny mechanizm różnicowy; kontroler krokowy; kontroler PI; dPrzestrzeń 1104.

Introduction

Electric vehicles have gained significant popularity in numerous major urban areas, particularly in Asian cities. This can be attributed to their various advantages, including their ease of mobility within urban environments, absence of harmful emissions that contribute to environmental degradation, minimal noise pollution[1], enhanced autonomy, limited energy consumption due to the engine's general power output not exceeding 3000w, and their compact size, which allows for more efficient utilization of road space[2].

The use of electric two-wheeler (ETW) technology may be a viable alternative for electrification, particularly in metropolitan areas[3]. In the following part, we will examine an EV equipped with a DC motor (DC). The control of a Direct Current (DC) motor has been successfully implemented using a conventional Proportional-Integral (PI) controller, marking a significant milestone in this field. The performance of the PI controller necessitates enhancement as a result of the observed overshoot and settling time in the speed response[4]. In order to achieve this objective, we have put forward a Backstepping Controller that has significantly enhanced all the attributes of the Direct Current (DC) motor[5]. This improvement is thanks to a recursive control design. This means that the controller for a complex system can be constructed incrementally by designing controllers for simpler subsystems[6]. As each subsystem is addressed, the controller is "stepped back" to handle more of the overall system, which simplifies the design process. The subsequent findings validate these decisions[7].

The present paper is structured in the following form. Section 2 provides a detailed description of the electric vehicle model. The backstepping technique is specifically developed to address the speed and current management aspects of an electric vehicle, as described in section 3. In section 4 a description of experimental test bench

Was presented. The simulation and experimental validation findings are presented in Section 5, which is followed by the conclusion.

Description of the electric vehicle model

Figure 1 illustrates a comprehensive schematic design of an electric vehicle traction system, including a direct current (DC) motor that is regulated by a buck converter, which is powered by a lithium battery terminal.

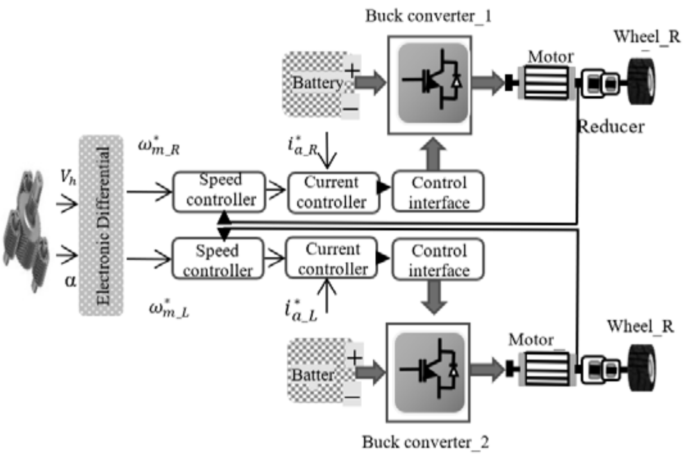


Fig.1. The fundamental concept behind the control of speed in EV

In the present study, we present pure EVs in their basic configuration, i.e two traction DC motors are coupled to the two rear wheels via an electronic differential. We consider the direct-drive EV consisting of: a chassis, two driving and steering wheels equipped with two DC-type motors where each wheel-motor is controlled by a step-down chopper, an on-board electrical energy source , a storage battery as the main source. This involves adapting the rotational speed and torque of each motor to the functional requirements of the vehicle, i.e. the resistive torque[8].

Design of the backsteppingcontrol law

The major objective of the command is that the wheel speed ω_r follows a reference signal ω_ref. From the structure of the subsystem seen previously, we know that we can achieve our objective by controlling the variable v_ of two DC motors [8]. First, in order to achieve the goal of realizing the tracking of the rotational speeds and the amplitudes of the armature currents of the two left and right motors, let us define the tracking errors as[9]:

Speed control

(1) $e_1 = \omega_{rd}^* - \omega_{rd}$ and $\dot{e}_1 = \dot{\omega}_{rd}^* - \dot{\omega}_{rd}$

If the control action is considered, just one Lyapunov function is used, and its temporal derivative is expressed as follows [10]:

(2) $V_1 = \frac{1}{2}e_1^2$ and $\dot{V}_1 = e_1\dot{e}_1$

(3) $\dot{V}_1 = e_1\left[\dot{\omega}_{rd}^* - \left(L_m i_f i_{ad} - f_c\omega_{rd} - C_r\right)/J\right]$

The Lyapunov function can be written in the form

(4)

$$\dot{V}_1 = -k_1 e_1 + e_1\left(k_1 e_1 + \dot{\omega}_r^* - (L_m i_{fd} i_{ad} - f_c\omega_{rd} - C_r)/J\right)$$

If we choose the reference current i_a^* as:

(5) $$i_{ad}^* = \frac{J}{L_m i_{fd}}\left[k_1 e_1 + \dot{\omega}_{rd}^* + \frac{C_r}{J} + \frac{f_c}{J}\omega_{rd}\right]$$

Current control

(6) $e_2 = i_{ad}^* - i_{ad}$ and $\dot{e}_2 = \dot{i}_{ad}^* - \dot{i}_{ad}$

By using equation (5), we have:

(7)

$$e_2 = \frac{J}{L_m i_{fd}}\left[k_1 e_1 + \dot{\omega}_{rd}^* + \frac{C_r}{J} + \frac{f_c}{J}\omega_{rd}\right] - i_{ad}$$

(8)

$$\frac{J}{L_m i_{fd}}e_2 = +k_1 e_1 + \dot{\omega}_{rd}^* + \frac{C_r}{J} + \frac{f_c}{J}\omega_{rd} - \frac{J}{L_m i_{fd}}i_{ad}$$

(9)

$$e_2 = \frac{J}{L_m i_{fd}}\left[\dot{e}_1 + k_1 e_1\right]$$

(10)

$$\dot{e}_1 = \frac{L_m i_{fd}}{J}e_2 + k_1 e_1$$

We can use the Lyapunov function

(11) $$V_2 = \frac{1}{2}e_1^2 + \frac{1}{2}e_2^2$$ its derivative is:

$$\dot{V}_2 = e_1\dot{e}_1 + e_2\dot{e}_2$$

(12) $$\dot{V}_2 = -ke_1\dot{e}_1 - k_2\dot{e}_2$$

The Lyapunov function can be written in the form

(13) $$\dot{V}_2 = \frac{L_m i_{fd}}{J}\left[\dot{e}_1 + k_1 e_1\right] + e_2\dot{e}_2$$

(14) $$\dot{V}_2 = \frac{L_m i_{fd}}{J}e_1 e_2 - k_1 e_1^2 + e_2\left[\dot{i}_{ad}^* - \dot{i}_{ad}\right]$$

The armature voltage Va can be written as follows:

(15)

$$v_{ad}^* = k_2 e_2 L_{ad} + \frac{L_m i_{fd}}{J}e_1 L_{ad} - \dot{i}_a^* L_{ad} + R_a i_{ad} + L_m i_{fd}\omega_{rd}$$

description of experimental test bench

The test bench used for the experimental validation of the motorization of an electric vehicle consists of several part. This test bench facilitates the implementation of the control laws applied to the system. multi-motors, and also to reduce development time in order to increase the quality and performance of the control. The entire experimental test bench is illustrated in Figure 2. it consists mainly of two direct current motors representing the two wheels with reduction gears, two current generators each coupled by an MCC in order to apply the vehicle resistive torque to the two driving wheels, two DC/DC converters to supply the two MCCs by a variable voltage, current sensors, two speed sensors and two ammeters to directly observe the induced current.


(7)

Fig.2. overview of the experimental bench.

Simulation et experimental results

In order to demonstrate the impact of the backstepping controller on system performance, identical tests are conducted using the proportional-integral (PI) controller.

Scenario: Movement with right turn and 10% slope

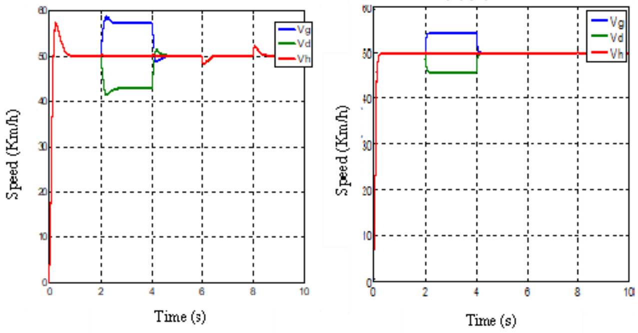
It is assumed in this scenario that the vehicle is walking at a speed of 50 km/h on a straight and flat road and then it engages in a right turn at time t=2 s at the same speed, then it climbs a slope from 10% at t =6 s. (8)

In this case, the two motors start under load, the tire torque, and subsequently the resistive torque increases following the increase in vehicle speed. Figure 3 represents all the curves which explain the behavior of the vehicle during this scenario such as the rotational speeds of the motors, the linear speeds of the wheels/vehicle, the induced currents of the motors, the electromagnetic torques as well as the different torques resistant. (10)

(11)

A. Simulaion results

(12)


a

b

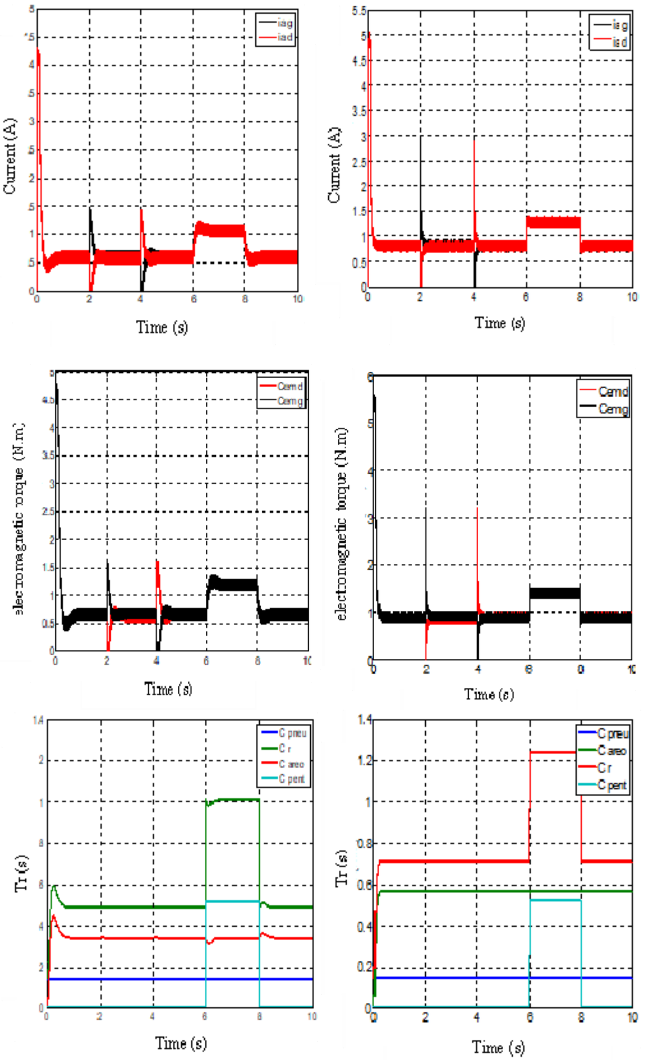


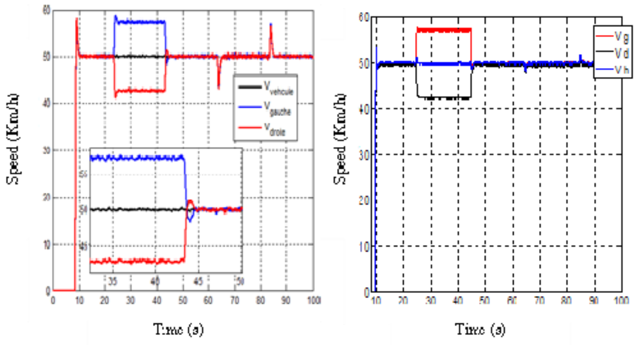
Fig.3. simulation results (a) for PI controller, (b) for backstepping control.

According to the simulation results, can be given:

- improvement in total system performance with the insertion of backstepping controller compared to conventional PI controller
- the speed reaches its set point value along with practically zero overshoot as depicted in Figure 3
- total rejection of perturbation
- the current is limited to its permissible value as illustrated in Figure 3 in backstepping control.

B. Experimental results

a **b**



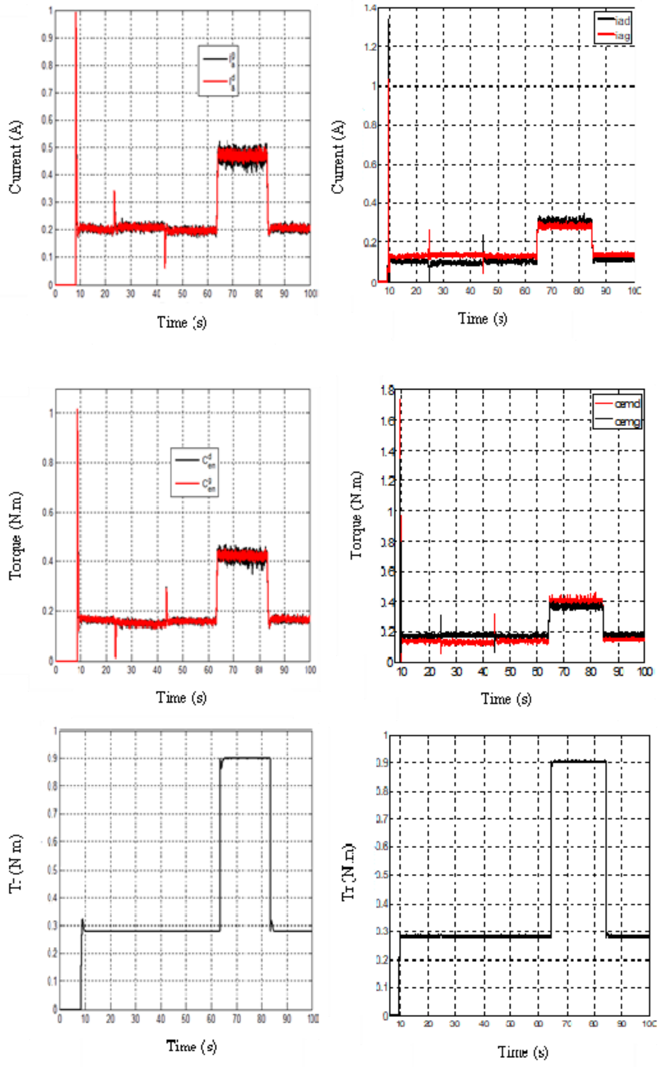


Fig.4. experimental results (a) for PI controller, (b) for backstepping control.

- Apparently, the same previous observations regarding the settling time are also noticed in Fig. 4. The speed follows its reference with a very small settling time which means that the backstepping control is much faster compared to the PI.
- backstepping is more effective than PI when it comes to error cancellation in both transient and steady states.
- Figure 4 shows that there is overshooting in the PI control strategy, the voltage value exceeds its reference value while trying to stabilize against speed changes

Table 1. comparative studies of results

Controller Type	PI CONTROLLER	BACKSTEPPING
Overshoot	20%	5%
Rise time (s)	0.3	0.09
Disturbance rejection	slow	Very fast
Schematic simplicity	Simple	Complex
Reducing ripples	bad	Very good

According to the obtained results as shown in Table (1) and Figures 3 and 4, we can conclude that:

- in Backstepping the driver can drive more easily and safely than with the PI Controller.

- the stability is difficult in PI classical control and the speed losses are clearly visible in this case with a large overshoot. the vehicle cannot pass the slope in a safe manner, and driving became very dangerous.
- The electromagnetic torque is very important in PI compared with Backstepping.
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Conclusion

This paper provides a comparative analysis of two control strategies. The studied controllers are based on conventional PI control and a modern nonlinear technique called backstepping control. These two approaches to electric vehicle control.

This research has demonstrated the feasibility of improved vehicle stability which utilizes two independent back drive wheels for motion. The Backstepping control is able to replace the PI control, this method Improved EV steering and stability during different trajectories. The advantage of the backstepping controller is robustness and performance, their capacity to maintain ideal trajectories for two wheels control independently and ensure good disturbances rejections with no overshoot, and the stability of the vehicle is perfected ensured with the speed variation and less error speed. The electric vehicle proved the best comportment and stability during different road paths by maintaining the motorization error speed equal to zeros and giving a good distribution for deriving forces. The electric vehicle was proven efficient comportment in different road constraints.

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