

Comparative Analysis of Cruise Control in Electric Vehicles with PI and Sliding Mode Control

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ABSTRACT: An electric vehicle, also called an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. Electric motors are mechanically very simple and often achieve 90% energy conversion efficiency over the full range of speeds and power output and can be precisely controlled. Cruise control of electric vehicles automatically controls the speed, thereby increasing the fuel efficiency. The system maintains a steady speed as set by the driver. For simplicity, kinematic bicycle model is used as the vehicle model, it approximates the mobility of car. A stepper motor is used for the steering angle control. Vector control is done for the speed control of PMSM and a sinusoidal PWM is modelled to generate pulses to drive the inverter. The work includes the cruise control of EVs driven by PMSM with PI & Sliding mode control and comparing the results of both. The proposed work shows Sliding mode controller shows better response than PI controller.

KEYWORDS: Cruise control, Kinematic vehicle model, Vector control, sliding mode control

I. INTRODUCTION

An electric vehicle, also called an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or an electric generator to convert fuel to electricity. EVs include road and rail vehicles, surface and underwater vessels, electric aircraft and electric spacecraft. EVs first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. Modern internal combustion engines have been the dominant propulsion method for motor vehicles for almost 100 years, but electric power has remained commonplace in other vehicle types, such as trains and smaller vehicles of all types. In the 21st century, EVs saw a resurgence due to technological developments and an increased focus on renewable energy.

II. RELATED WORK

Many techniques have been developed for the speed control of Electric vehicles. In [1] a robust control system for the cruise controller of a DC motor-driven electric vehicle has proposed. The robust controller is tuned using a numerical optimization design method to compensate the disturbances from the road grade and changes in the vehicle weight. [2] Presents a novel extended ecological cruise control system to increase the autonomy of an electric vehicle by using energy-efficient driving techniques. An active disturbance rejection controller (ADRC) was used to design the lower controller for its good performance to suppress the influence of parameter uncertainty and unknown disturbance on cruise control in [3].

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III. PROPOSED MODEL OF CRUISE CONTROL

Fig.1 shows the proposed block diagram of cruise control in electric vehicles. In the proposed model, a Permanent magnet synchronous motor (PMSM) is used to drive the vehicle and a stepper motor is used for the steering angle control. In cruise control, the system maintains a steady speed as set by the driver. Most of the cruise control systems doesn't allow the cruise control below a certain speed.

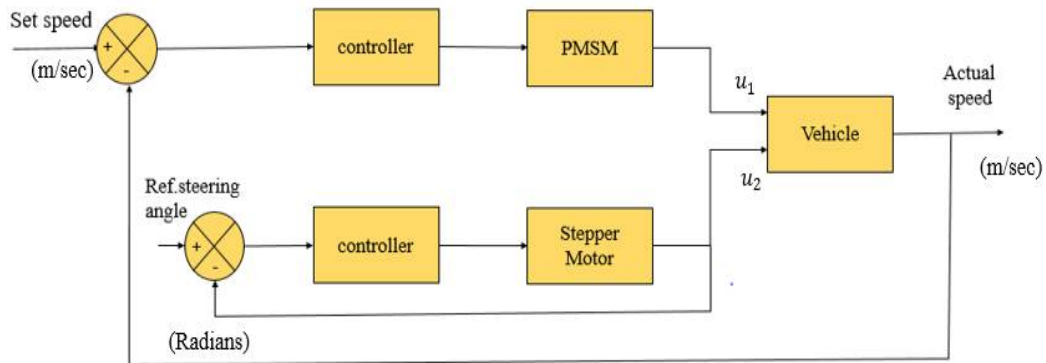


Fig.1: Proposed block diagram of cruise control in Electric vehicles

The two inputs control the vehicle model. In cruise control, the vehicle should follow the set speed whether there is any variations in the steering angle input.

IV. MODELLING OF KINEMATIC VEHICLE MODEL, PMSM AND STEPPER MOTOR

Vehicle kinematic model represents the actual vehicle for the proposed work. Since we are dealing with a moving vehicle, it is necessary to model the mobility of the car and kinematic model approximates the mobility of a vehicle [4]. The vehicle is represented in terms of its position in xy coordinates, orientation with respect to x axis and steering wheel angle with respect to y axis.

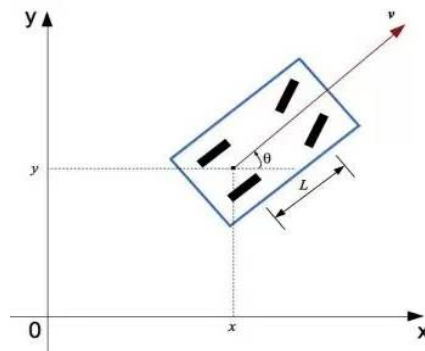


Fig.2: Kinematic vehicle model [4]

The above shown kinematic model is simplified to kinematic bicycle model, since it is a common approximation used for vehicle analysis and for deriving control laws. The figure below shows the kinematic model. The kinematic bicycle

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model, as the name indicates looks like a bicycle. This model approximates the front two wheels into a single wheel and similarly the back two wheels into a single one at the centre of front and rear axles.

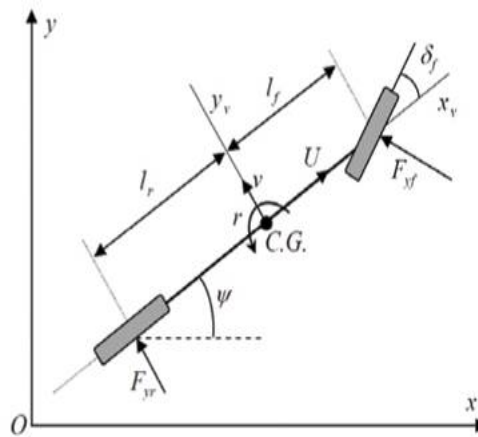


Fig.3:Simplified Kinematic bicycle model [4]

The kinematic model equations are given as,

$$\dot{x} = u_1 \cos \varphi \quad (1)$$

$$\dot{y} = u_1 \sin \varphi \quad (2)$$

$$\dot{\varphi} = \frac{u_1}{L} \tan \theta \quad (3)$$

$$\theta = u_2 \quad (4)$$

Permanent magnet synchronous motor is used here to drive the vehicle. PMSMs are electromechanical motion devices with high performance capability and have so many advantages such as high efficiency, high power density and fast dynamics. The machine has a permanent magnet wound rotor [5]. For the easiness of parameters (current, voltage, flux linkage) calculation, the transformation from three phase rotating (a, b, c) to two phase stationary (α, β) and from stationary reference frame to rotating reference frame (d, q) is necessary [5]. These transformations can be done through Clark's and Park's transformations. Voltage, flux linkage, torque equations and the mechanical torque developed [4] are given by,

$$V_q = R_s i_q + \omega_r \lambda_d + \rho \lambda_q \quad (5)$$

$$V_d = R_s i_d - \omega_r \lambda_q + \rho \lambda_d \quad (6)$$

$$T_e = \frac{3}{2} * \frac{\rho}{2} (\lambda_d i_q - \lambda_q i_d) \quad (7)$$

$$\omega_m = \frac{1}{J} \int (T_e - T_L - B \omega_m) dt \quad (8)$$

Where i_d represents d axis current and i_q represents q axis current, T_e is the motor torque and T_L is the mechanical torque developed.

Stepper motor is used as the steering motor of the vehicle. Stepper motor provides the angular velocity with which the steering rotates [6]. Stepper motor is an electromechanical device which converts digital pulses into equivalent mechanical motions, the step motors have advantages like high torque development at low speed and it can start, stop and reverse the direction of travel at high speeds without any loss of steps. Stepper motors have a central gear shaped iron piece surrounded by multiple toothed electromagnets. An external driver is required to energize the electromagnets [6]. The working is as follows: first, power is given to one of the electromagnet and it attracts the gear's teeth

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magnetically towards it. When the next electromagnet is powered, the first one is turned off and the gear rotates to align with the next one and this process continues. This is how the motor shaft turns and each of these rotations are known as a step. A second order system representing the transfer function of stepper motor is used here. A PID controller is used for the position control.

V. VECTOR CONTROL OF PMSM

Vector control is also known as decoupling or field oriented control. Vector control decouples three phase stator current into two phase d-q axis current, one producing flux and other producing torque. This allows direct control of flux and torque. So by using vector control, the PMSM is equivalent into a separately excited dc machine. The model of PMSM is nonlinear. So by using vector control, the model of PMSM is linear [7]. Fig.4. shows a vector diagram of the PMSM. Phase a is assumed to be the reference. The instantaneous position of the rotor (and hence rotor flux) is at θ_r from phase a. The application of vector control, so as to make it similar to a DC machine, demands that the quadrature axis current i_q be in quadrature to the rotor flux. Consequently i_d has to be along the rotor flux since in the reference used i_d lags i_q by 90° . If i_d is in the same direction as the rotor flux, the d axis stator flux adds to the rotor flux that leads to increase in the net air gap flux.

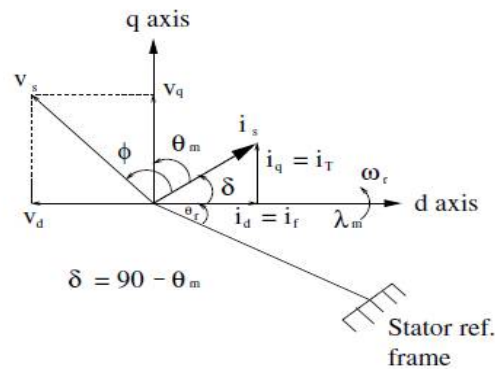


Fig.4: Vector diagram of PMSM[7]

If we make $i_d = 0$ by $\delta = 90^\circ$ then the electric torque equation becomes,

$$T_e = (3/2)(P/2) \lambda_m i_q \quad (9)$$

Hence the electric torque depends only on the quadrature axis current and a constant torque is obtainable by ensuring that i_q is constant. Hence with the application of vector control, independent control of the torque (i_q) and flux (i_d) producing currents are possible [7]. Fig.5 shows the overall block diagram of cruise control in Electric vehicles with PI controller.

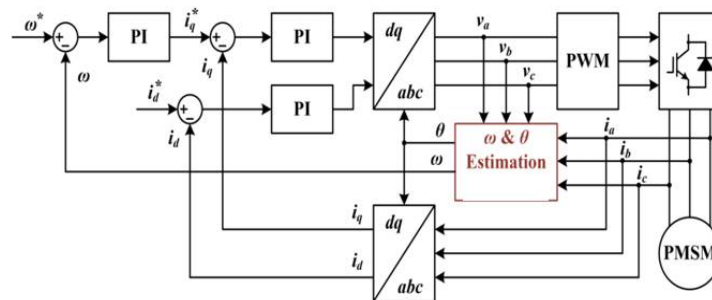


Fig.5: Complete layout of control procedure of PMSM with PI [7]

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Here a reference speed is given and it is compared with the machine speed. From the machine the three phase currents are transformed to two phase rotating d and q axis currents. These are converted to corresponding d axis and q axis voltages. Through Clark's and Park's transformation, these voltages are converted to three phase voltage and given as the input of PWM to drive the inverter [8].

VI. SLIDING MODE CONTROL OF PMSM

The SMC framework consists of two crucial steps. The first step is the design of sliding surface and second one is the design of control such that system trajectory is forced towards the sliding surface, which ensures the system to satisfy the sliding-mode reaching condition. Fig.6 shows the overall block diagram of cruise control in Electric vehicles with Sliding mode control.

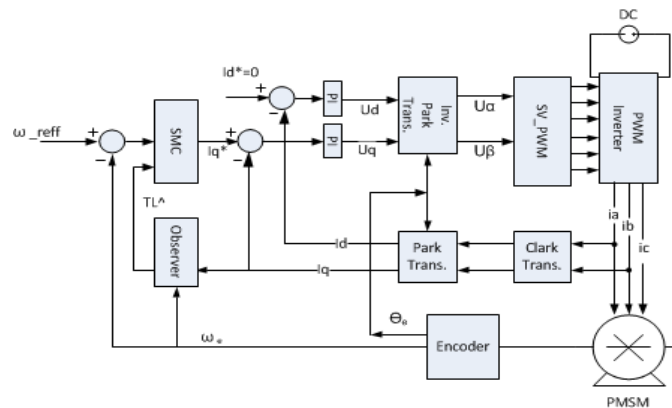


Fig.6:Complete layout of control procedure of PMSM with SMC [9]

The Sliding-Mode controller (SMC) will be used as a tracking controller for the speed of a PMSM. The control objective here is to track a reference speed ω_{ref} with the rotor actual speed ω_e . The error signal written as $e = \omega_{ref} - \omega_e$, which will represent the sliding surface, s . Since the speed control loop of the PMSM is essentially a first order system, the SMC design is based on the Lyapunov stability concept. In order to improve the performance of the system and to compensate for load torque disturbances, an observer based on the error signal will be embedded in the feedback line to estimate the load torque, to compensate for other system variations, making the system robust with respect to uncertainties [9].

VII. SIMULATION RESULTS

The proposed method is verified in matlab. Fig.7 shows the Simulink block of cruise control in Electric vehicles. Instead of packing the car with numerous gears to keep the engine in its happy zone, designers of electric cars just pick a gear ratio that provides a good compromise between acceleration and top speed. Cruise control with conventional PI and sliding mode controller are verified in matlab.

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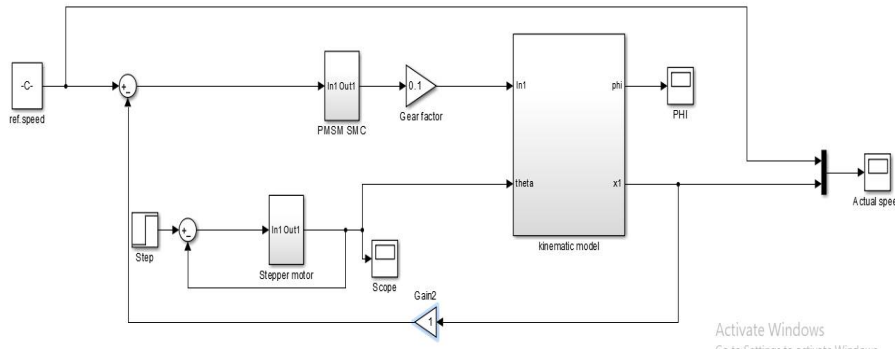


Fig.7:Matlab model of Cruise control in Electric vehicles

Here a reference speed of 22.5 m/sec is given. The first input of the kinematic vehicle model is the linear velocity input and second input is the steering angle input. The model is verified in matlab for different steering angles.

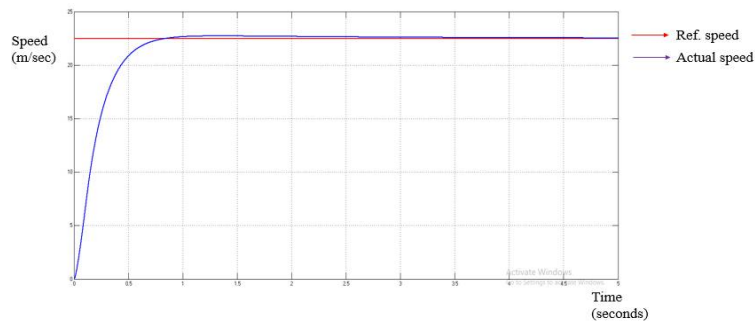


Fig.8:Controlled speed of Electric vehicle with conventional PI controller

Fig.8 shows the cruise speed of Electric vehicle with a reference speed of 22.5 m/sec. the vehicle attains the steady state after 2.6 seconds

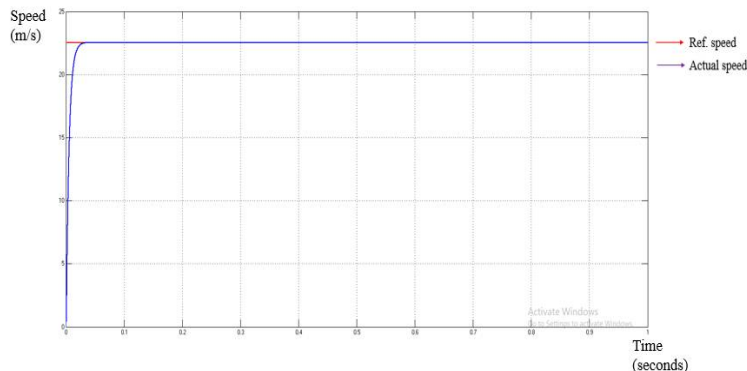


Fig. 9:Controlled speed of Electric vehicle with Sliding mode controller

Fig.9 shows the cruise control of Electric vehicle with sliding mode controller for a reference speed of 22.5 m/sec. Here the vehicle attains the reference speed at 0.03 seconds without any overshoot

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Comparing with conventional PI controller, Sliding mode controller shows better response. With PI controller, the Kinematic vehicle model attains steady speed after 2.6 seconds. But in the case of sliding mode controller, the vehicle attains steady speed at 0.2 seconds.

VIII. CONCLUSION

Modelling of kinematic bicycle model, permanent magnet synchronous motor and stepper motor has done. For simplicity, kinematic bicycle model is used as the vehicle model. Vector control is done for the speed control of PMSM and a sinusoidal PWM is modelled to generate pulses to drive the inverter. A gear factor is used to convert the motor's speed to the speed required to drive the wheels. The simulation results show the vehicle tracks the input speed and sliding mode controller is better than conventional PI controller.

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