Speed control of Electric vehicle with Sliding Mode Controller

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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 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 a 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 Electric vehicles driven by PMSM with Sliding Mode Control. The simulations are carried out in MATLAB.

Key Words: Kinematic vehicle model, Cruise control, Vector control, Sliding mode control

1.INTRODUCTION

An Electric vehicle (EV), also called an Electric drive vehicle uses one or more electric motors or traction motors for propulsion. The major components of an electric vehicle system are the motor, controller, power supply, charger and drive train. The figure 1.1 demonstrates a system model for an electric vehicle. Controller is the heart of the electric vehicle, and is the key for the realization of a high performance Electric vehicle with an optimal balance of maximum speed, acceleration performance and travelling range per charge.

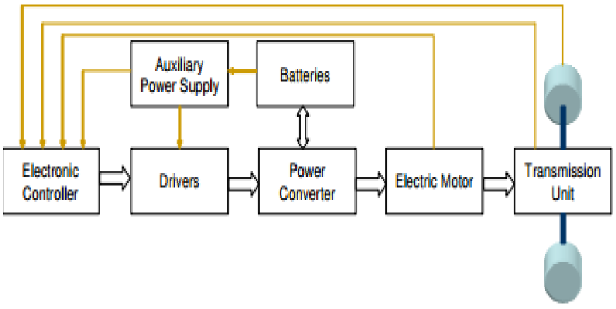

Fig -1: System model of an Electric vehicle

Many techniques have been developed for the speed control of Electric vehicles. In [1], a robust control system for the cruise control 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 was used to design the lower controller for its good performance to suppress the influence of parameter uncertainity and unknown disturbance on cruise control in [3].

1.2 Proposed block diagram

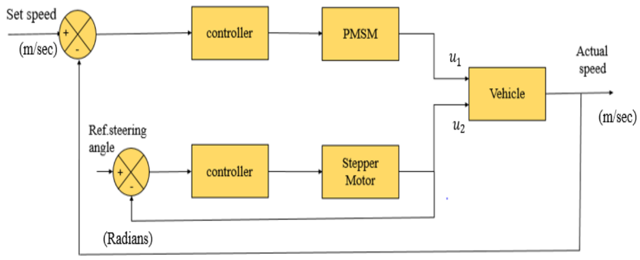

Fig -2: Proposed block diagram

In the proposed work, the plant (vehicle) has two inputs. One input is to provide linear velocity and the other is to provide steering angle input. The linear velocity is provided by a Permanent magnet synchronous motor and the steering angle is given through a stepper motor. Since in cruise control, the system has to maintain a steady speed. So the actual speed from the vehicle is fed back and compared with the input reference speed.

2. MATHEMATICAL MODELLING

2.1 Kinematic vehicle model

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 .

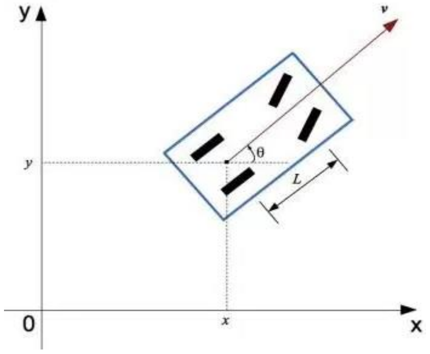

Fig -3: Kinematic vehicle model

The kinematic model equations are given as,

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

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

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

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

2.2 Permanent Magnet Synchronous Motor

Permanent Magnet Synchronous Motor (PMSM) nowadays becoming more and more popular due to its higher energy efficiency, higher torque to weight ratio, higher life and recent development in permanent magnet technology. The PMSM eliminates a commutator, so it is more reliable than the DC motor. Compared with an AC induction motor, since the PMSM produce the rotor magnetic flux with permanent magnets, it has superior advantage to achieve higher efficiency [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,

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

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

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

$$\lambda_q = L_q i_q \quad (8)$$

$$\lambda_d = L_d i_d + \lambda_f \quad (9)$$

2.3 Stepper motor

Stepper motor is used as the steering motor of the vehicle. Stepper motor provides the angular velocity with which the steering rotates. 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 [6].The angle through which the vehicle steering has to be rotated is determined from the rotor position of stepper motor. The steering angle always varies according to the road conditions and traffic. So a control of rotor position is needed. Soa second order system representing the transfer function of stepper motor is used in this work.

3. VECTOR CONTROL OF PMSM

Vector control is also known as decoupling or field orientated 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 [7]. 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. The scheme of vector control is based on coordinate transformation and motor torque equation by means of controlling stator current to improve the performances of motor, and is widely used in the field of PMSM servo system. In the control of a three phase PMSM system, modulated current is supplied to the A-B-C stator windings to build rotated magnetic field and drive the rotor. The vector control strategy is formulated in the synchronously rotating reference frame. Figure 4.1 shows the vector diagram of PMSM. Phase a is assumed to be the reference.

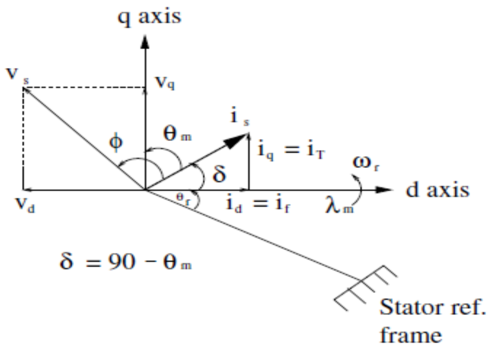

Fig -4: Vector diagram of PMSM

4. SLIDING MODE CONTROL

Sliding mode control (SMC) is a nonlinear control technique featuring remarkable properties of accuracy, robustness, easy tuning and implementation. SMC systems are designed to drive the system states onto a particular surface in the state space, named Sliding surface. Once the sliding surface is reached, sliding mode control keeps the states on the close neighborhood of the sliding surface. Hence the sliding mode control is a two part controller design. The first part involves the design of a sliding surface, so that the sliding motion satisfies design specifications. The second is concerned with the selection of a control law that will make the switching surface attractive to the system state[7]. There are two main advantages of sliding mode control. First is that the dynamic behavior of the system may be tailored by the particular choice of the sliding function. Secondly, the closed loop response becomes totally insensitive to some particular uncertainties. This principle extends to model parameter uncertainties, disturbance and nonlinearity that are bounded. From a practical point of view, SMC allows for controlling nonlinear processes subject to external disturbances and heavy model uncertainties.

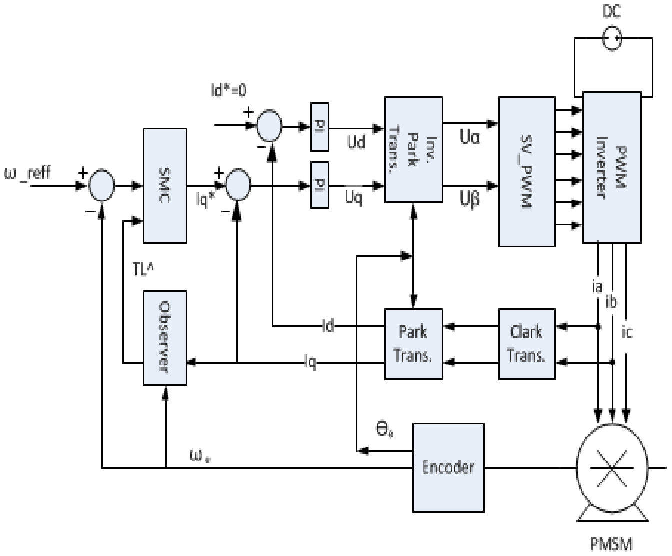

Fig -5: Complete layout of SMC of PMSM

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 ωref with the rotor actual speed ωe. 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 [8].

4. SIMULATION ANALYSIS

The simulations are done in MATLAB. Rated speed, current, rotor angle and sliding surface variable with respect to time are plotter. The machine attains rated speed in 0.01 seconds. Therefore the error speed is zero after 0.01 seconds. In PMSM, the rotor is rotating with respect to stator. So the rotor angle is also increasing.

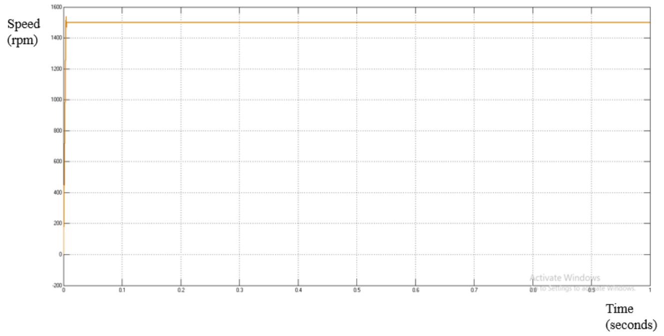

Fig -6: Controlled speed of PMSM (1500 rpm)

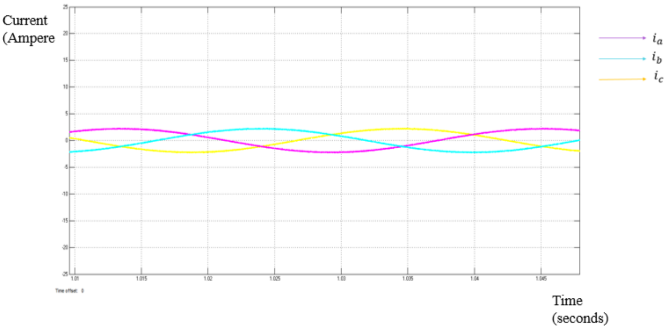

Fig -7: Current of PMSM

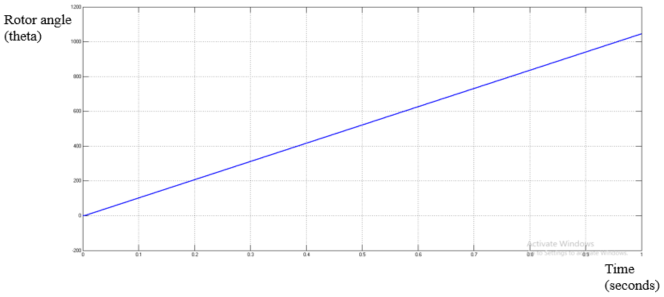

Fig -8: Rotor angle of PMSM

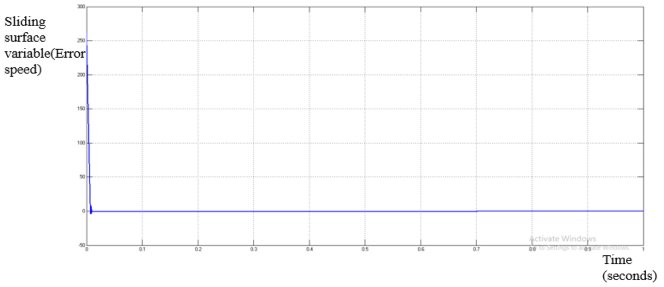

Fig -9: Plot of sliding surface variable Vs time

For the cruise control, a reference speed of 22.5 m/sec is given. The vehicle attains that speed at 0.05 seconds and maintains that speed at 0.1 second after an overshoot of 11%. A gear factor is used to convert the motor's speed to the speed required to drive the wheels.

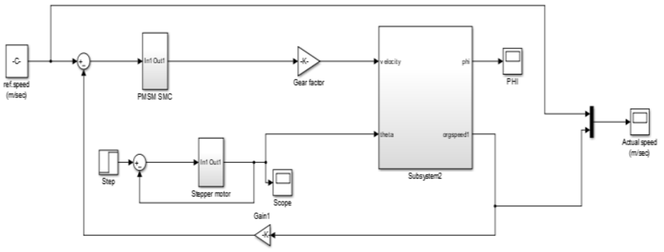

Fig -10: Simulink block of cruise control in Electric vehicle

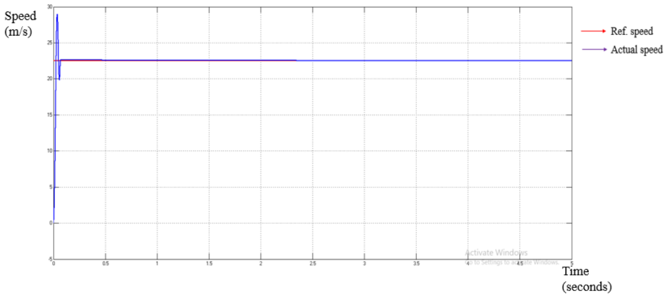

Fig -11: Cruise control of Electric vehicle with SMC

5. CONCLUSION

Cruise control of Electric vehicle with PMSM has done using PI and sliding mode controller. 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 shows the vehicle tracks the input speed.

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