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Speed Control of Hybrid Electric Vehicle using PSO based PID controller

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***Abstract*—In this paper, a conventional Proportional-Integral- Derivative (PID) and fractional-order PID controller have been designed for the speed control of hybrid electric vehicle. The parameters of both PID and FOPID controller are optimized using Practical Swarm Optimization (PSO) method taking Integral of Absolute Error (IAE) as the fitness function. The performance of the implemented controller is analyzed in terms of transient and steady state specifications. A performance comparison is carried out among the implemented controllers in the presence of vehicle parameter variations.**

Keywords—PID controller; FOPID controller; PSO; Hybrid Electric Vehicle.

I. INTRODUCTION

Over the last few decades, the development of hybrid electric vehicles (HEV) has taken the accelerated pace due to global environmental concern and energy conservation [1-2]. A HEV constitutes two discrete power sources, one being the primary source generally internal combustion engine or ICE and the second is auxiliary source which being an energy storage device generally battery. The electric power used for auxiliary source of HEV can be generated using renewable sources like solar, wind etc. which are environment friendly [3].HEV is a complex dynamical system as it is being powered by two different sources. Modeling of HEV is indispensable to evaluate vehicle performance, technological developments and to improve overall efficiency. Moreover control scheme used directly affects the performance of HEV [4].

In control engineering problems, the conventional PID controller is the first choice for the control engineers due to its advantages like simplicity and easy design. These controllers do not provide effective control to the complex, non-linear and uncertain systems despite their all advantages. With the innovations in fractional calculus, performance of PID controller can be enhanced by providing fractional order derivative and integral instead of conventional integer order derivatives *s* and integrators.

Therefore, besides three parameters namely proportional gain Kp, integral gain Ki, derivative gain Kd of conventional PID controller, there are two more flexibility in the design of PID controller [5-6]. Over the years, several authors have been working on different structures of FOPID controllers for various plants. Zamani *et al*. proposed implementation of fractional order controller for automatic voltage regulator in which parameters of FOPID are optimized using PSO algorithm. In their work, the time domain and frequency domain criteria are taken into consideration for performance evaluation of controller and it has been found that the performance of FOPID controller is better than the PID controller [7]. Delavari *et al*. presented a fractional adaptive PID controller for a robotic manipulator in which the parameters of PID controller have been updated online and the other two parameters fractional derivative and integral are determined offline. The tracking error in fractional controller is less as compare to conventional PID controller [8] Petras reported a hardware implementation of digital FOPID controller for a DC motor wherein the FOPID controller has been implemented based on microprocessor [9].

To attain better performance of system, the parameters of controller have to be optimized whether it is conventional controller or intelligent controller. In the field of engineering, many optimization algorithms, inspired from nature and evolution, such as genetic algorithm (GA) [10], Simulated annealing (SA) [11], Ant colony optimization[12], PSO [13], Firefly algorithm [14] and Artificial bee colony [15] have been proposed. The performance of PSO is better in terms of convergence and has less no. of parameters

The main focus of this paper is to design a FOPID controller for HEV to maintain the performance of HEV, in the presence of parametric variations and external disturbances. The transient response which includes the stiffness of response represented by rise time (tr), the closeness of response to the desired response represented by the overshoot (Os) and the settling time (Ts), the error integral criteria includes IAE, Integral of Square Error (ISE), Integral of Time Squared Error (ITSE) are studied to get the better overall performance of the vehicle.

The rest of paper is organized as follows: Section 2 includes the description of vehicle model undertaken, Section 3 includes the implementation of the fractional order controller, Section 4 presents optimization method used for tuning the parameters of controller, Section 5 shows simulation results and hence conclusion is written in Section 6.

II. MODEL DESCRIPTION OF VEHICLE

The architecture of HEV considered in this paper is the single mode power split series/parallel shown in Figure 1. In this configuration there is planetary gear set which decouples the speed of engine from the wheel speed. The planetary gear set is shown in Figure 2. When the generator speed is negative, the engine power splits into two parts; one is transferred to drive train and other to the generator through which battery is charging and vehicle is operating in series mode. In case when generator speed is positive, hence adding power to the driven wheels and in this case vehicle is operated in parallel mode [16]. The planetary gear set may have an electronic switch which is programmed according to desired vehicle speed with variations in road slope and state of charge of battery. Hence it is necessary to control the speed of vehicle which varies with time and road slope.

$$V_3 = \frac{R_1}{2R_3} V_1 + \frac{R_2}{2R_3} V_2 \qquad (1)$$

$$T_3 = \frac{2R_3}{R_1} T_1 = \frac{2R_3}{R_2} T_2 \qquad (2)$$

where V_1= Generator Speed, T_1= Generator Torque, V_2=Vehicle Speed, T_2=Vehicle Torque, V3= Engine Speed, T_3=Engine Torque

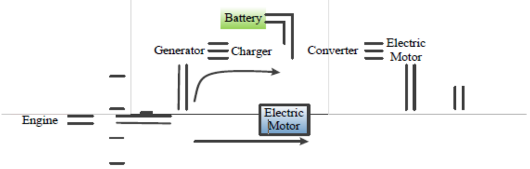

Figure.1.Architecture of series-parallel HEV.

The dynamic equation of the nonlinear vehicle is given as follows [17-18]:

$$m\frac{dV}{dt} = F_e(\theta) - F_{wheel} - F_g \qquad (3)$$

$$\tau_e \frac{dF_e(\theta)}{dt} = -F_e(\theta) + F_{e1}(\theta) \qquad (4)$$

$$F_{e1}(\theta) = F_i + \gamma\sqrt{\theta} \qquad (5)$$

where m= vehicle mass, F_e = engine force that is a function of the throttle position, τ_e= engine time constant, θ = angular throttle position, γ = engine force coefficient, V=vehicle speed, F_g= gravity induced force (function of the road slope β which may be positive or negative) and As a disturbance it is considered a non-deterministic variable and represented by equation (6) :

$$F_g = m.g.\sin\beta \qquad (6)$$

F_{wheel} is force acting on the wheel given by equation (7):

$$F_{wheel} = F_{roll} + F_{drag} + F_{damp} \qquad (7)$$

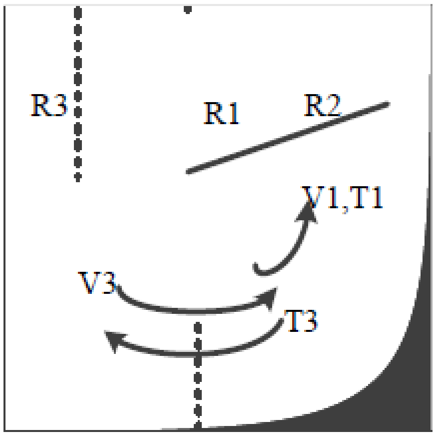

Figure.2.Planetary Gear Unit.

$$F_{roll} = \mu.m.g.\cos\beta \qquad (8)$$

$$F_{drag} = 0.5 \times \rho \times A \times c_d \times V^2 = \alpha V^2 \qquad (9)$$

where A = vehicle effective frontal area (m^2), ρ = density of air (kg/m3), c_d = aerodynamic drag coefficient (Ns^2/kgm), α= drag coefficient

$$F_{damp}=\frac{B_w.V}{R_{tire}} \tag{10}$$

where B_w = Bearing's damping coefficient and R_{tire} = Effective vehicle tire radius.
Substitute equation (8), (9), (10) in equation (7) we get:

$$F_{wheel}=\mu.m.g.\cos\beta+\alpha.V^2+\frac{B_w.V}{R_{tire}} \tag{11}$$

Substitute (4), (5), (6) and (11) in (3) we get:

$$m\frac{dV}{dt}=F_i+\gamma\sqrt{\theta}-\tau_e\frac{dF_e(\theta)}{dt}-\mu.m.g.\cos\beta-\alpha V^2-\frac{b_w.V}{r_{tire}}-m.g.\sin\beta \tag{12}$$

The complete mathematical model of the nonlinear vehicle is described by (12)and the numerical values of non-linear HEV in SI units used for simulation are given in Table I.

III. IMPLEMENTATION OF FRACTIONAL ORDER PID CONTROLLER

The Proportional-Integral-Derivative controller is used in various control applications due to their simplicity, robustness, to improve response time as well as to minimize or eliminate the steady state errors. The error based feedback control is the basic principle of implementation of controller as shown in Figure 3. where error is the difference of reference speed Vr and the measured output speed of vehicle V i.e e(t) = Vr - V and control law is produced based on the linear combination of error, differentiation of error.

The actuating signal for PID controller is given in (13) as below:

$$c(t)=e(t)+K_d\frac{de(t)}{dt}+K_i\int_0^t e(t)dt \tag{13}$$

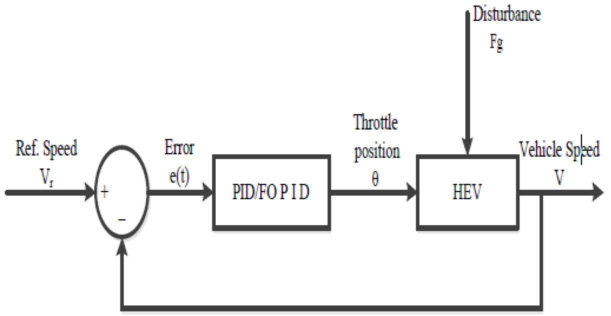

Figure.3. Implementation of PID/FOPID controllers.

By taking the Laplace Transform of (13), transfer function of controller is given by (14)

V. SIMULATION RESULTS

In this Section, the simulation results for PID and FOPID controllers are presented. In this work, the speed of acceleration from 6 – 8 s at the rate of 6 m/s2, after this, the vehicle runs at a constant speed of 32 m/s for 8–12 s; then vehicle runs in a decelerating mode for the time interval of 12– 14 s at 4 m/ from 14– 20 s the vehicle runs at a constant speed of 24 m/s gain. The simulation model for PSO tuned PID and FOPI controllers are shown in Figure.4.

The performance of PSO-FOPID controller is better in terms of tr, Os ,Ts ,IAE, ITSE, ISE as compare to PSO- PID controller .

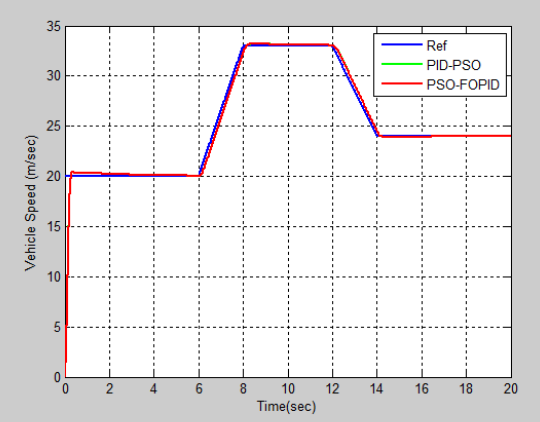

Figure.4. Comparison of PSO-PID and PSO-FOPID response.

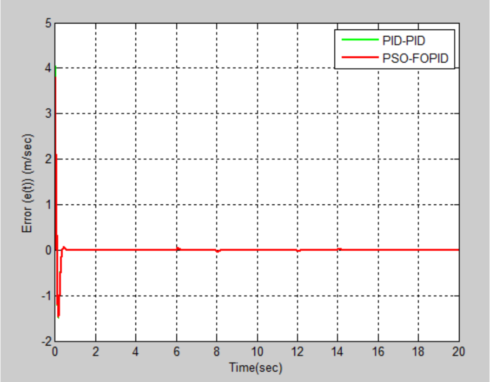

Figure.5.Comparison of FOPID error e(t).

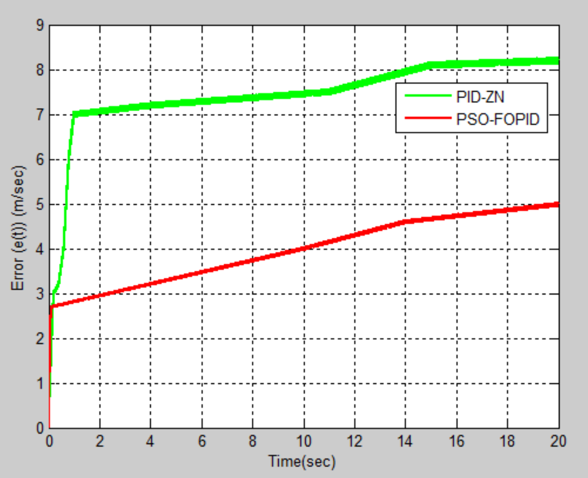

Figure.4. Comparison of IAE for FOPID controller.

VI. CONCLUSIONS

Speed of hybrid electric vehicle has controlled using fractional order and integer order PID controller. The parameters of FOPID and PID controller have tuned using PSO algorithm The performance of PSO tuned PID and FOPID has been compared in terms of IAE, ISE, ITSE, overshoot, rise time and settling time. The FOPID controller offered the better transient and steady state response as compared to integer order PID controller. FOPID offers more flexibility as it requires five parameters to be tuned as compared to conventional PID controller which requires three parameters to be tuned.

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