Speed Control of Buck-Converter Driven DC Motor based on Smooth Trajectory Tracking

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Abstract:- Speed control is a common requirement in the industrial drives in the presence of varying operating conditions ie. load disturbance, parameter uncertainties . Conventional controllers with fixed parameters are not successful in the real time applications because of the drift in the plants operating conditions **This paper presents the detailed account on the control design of a buck converter driven dc motor Proportional-Integral (PI) and Proportional-Integral-type Fuzzy Logic controller (PI-type FLC) are the Techniques proposed in this investigation to control the speed of a dc motor. The dynamic system composed from converter/motor is considered in this investigation and derived in the state-space and transfer function forms. Complete analyses of simulation results for PI and PI-type FLC technique are presented in frequency domain and time domain, respectively. Performances of the controller are examined in terms of duty cycle input energy, armature current and angular velocity. Finally, a comparative assessment of the impact of each controller on the system.**

I. INTRODUCTION

A common actuator in control systems is a dc motor and is obvious choice for implementation of advanced control algorithms in electric drives, due to the stable and linear characteristics associated with it. It is also ideally suited for tracking control. From a control system point of view, the dc motor can be considered as a SISO plant eliminating the complexity associated with multi-input drive systems. The speed of a driven load often needs to run at a speed that varies according to the operation it is required to perform. The speed in some cases (such as fluctuating loads like rolling mills) may need to change dynamically to suit the conditions, and in other cases may only change with a change in process.

This paper describes the rejection of deviation in speed caused by load disturbance for a separately excited dc motor under various load-disturbing situations, parameter uncertainties and measurement noise with an adaptive control approach resulting in an improved performance. Dc motors are most commonly driven by PWM signals with respect to the motor input voltage. However, the underlying hard switching strategy causes unsatisfactory dynamic behavior. The resulting trajectories exhibit a very noisy shape. This causes large forces acting on the motor mechanics and also large currents which detrimentally stress the electronic components of the motor as well as of the power supply [1]. Since it is usually necessary to add a power supply component, anyway, this contribution shall Present a control for the entire system of buck-converter/dc motor. The combination of dc to dc power converters with dc motors has been reported in [2]. In particular, the composition of a buck converter with a dc motor has been proposed in [3, 4]. The buck type switched dc to dc converter is well known in power- electronics. Due to the fact that the converter contains two energy storing elements, a coil and a capacitor, smooth dc output voltages and currents with very small current ripple can be generated [5]. In this respect, an important issue is the circuit design of the converter in order to obtain, at any time, a high power conversion rate when tracking smooth reference trajectories of the angular velocity. Therefore, this stage is

II. DESIGN OF DC MOTOR

Resistance of the coil windings R_a =Armature winding resistance [ohms];

L_a =Armature winding inductance [Henry];

i_a = Armature current [amps];

i_f =Field current [amps]=a constant;

V_a =Applied armature voltage [volts];

E_b = Back emf [volts];

ω_m = Angular velocity of the motor [rad/sec];

T_m = Torque developed by the motor [Newton-m];

J_m =Moment of inertia of the motor rotor [kg-m^2 or Newton-m/(rad/sec^2)];

B_m =Viscous friction coefficient of the motor [Newton-m/(rad/sec)];

T_w =Disturbance load torque [Newton-m];

The input voltage V_a is applied to the armature which has a resistance of R_a and inductance of L_a.The field current supplied i_f supplied to the field winding is kept constant and thus the armature voltage controls the motor shaft output. The moment of inertia and the coefficient of viscous friction at the motor shaft being J_m and f_m respectively .The speed of the motor is being ω_m radian per second. The related dynamics equati

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + E_b \qquad (2.1)$$

$$E_b = K_b.\omega_m \qquad (2.2)$$

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + K_b \omega_m \qquad (2.3)$$

$$T_m = K_T i_a \qquad (2.4)$$

$$T_m = J_m.\frac{d\omega_m}{dt} + B_m.\omega_m$$

Taking the Laplace transform of equation (3.1)-(3.5), assuming zero initial conditions, we get

$$T_m(s) = K_T I_a(s) \qquad (2.6)$$

$$E_b = K_b \omega(s) \qquad (2.7)$$

$$E_a(s) - E_b(s) = (L_a.s + R_a) I_a(s) \qquad (2.8)$$

$$(J_m.s + B) = T_M(s) - T_L(s) \qquad (2.9)$$

Equation (2.6)-(.9) gives the transfer function between the motor velocity $\omega_m(s)$ and the input voltage $E_a(s)$ is given as below.

$$\frac{\omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(J_m s + B_m) + K_T K_b}$$
(2.10)

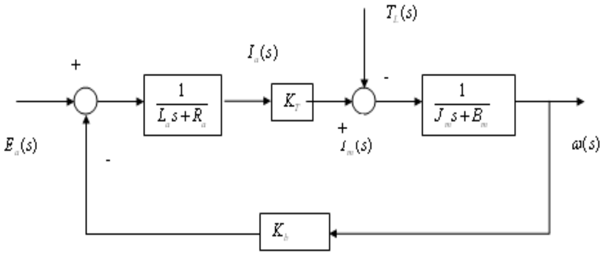


Figure 1 Block diagram of a DC motor (armature controlled) system

III. STATE SPACE REPRESENTATION

Let the armature current ($i_a = x_1$) and angular velocity ($\omega_m = x_2$) be the state variable and the angular velocity be the output variable. Therefore the following state space model can represent the dynamics of dc motor.

$$\frac{di_a}{dt} = -\frac{R_a}{L_a}.i_a - \frac{K_b}{L_a}.\omega_m + \frac{V_a}{L_a} \qquad (3.1)$$

$$\frac{d\omega_m}{dt} = \frac{K_T}{J_m}.i_a - \frac{B_m}{J_m}.\omega_m - \frac{T_w}{J_m} \qquad (3.2)$$

$$\dot{X} = Ax + Bu + Fw \qquad (3.3)$$

$y = Cx$ Where $x = [x_1 \quad x_2]$ state vector

(2.5)

$$A = \begin{bmatrix} -\frac{B_m}{J_m} & \frac{K_T}{J_m} \\ -\frac{K_b}{L_a} & -\frac{R_a}{L_a} \end{bmatrix}; B = \begin{bmatrix} 0 \\ \frac{1}{L_a} \end{bmatrix}; F = \begin{bmatrix} -\frac{1}{J_m} \\ 0 \end{bmatrix}$$

$$C = [1 \quad 0]$$

For the design of MRAC controller the triple (A, B, C) are assumed to be completely controllable and observable. The load changes are considered as changes in motor rotor inertia and viscous-friction coefficient as practically seen in most control applications. Hence plant parameter changes in the simulation studies reflect abrupt load changes of the system.

IV. MODEL OF BUCK CONVERTER

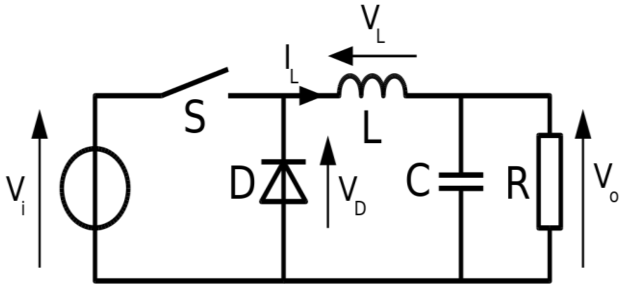


Figure 2: Basic structure **of BUCK CONERTE** scheme

V. REFERENCE MODEL

The objective of control system is to find a direct controller that is differentiator free and the output of the plant should follow the output of the pre-specified reference model. The model is chosen in the form of $W_m(s) = k_m \frac{Z_m(s)}{R_m(s)}$ (5.1)

Where $Z_m(s), R_m(s)$ monic polynomials and km are is constant gain and r is the reference input assumed to be a uniformly bounded and piecewise continuous function of time. The following assumptions regarding reference model are assumed to hold:

M1. $Z_m(s)$, $R_m(s)$ are monic Hurwitz polynomials of degree q_m, p_m respectively, where $p_m<=n$.

M2. The relative degree $n_m^* = p_m - q_m$ of $W_m(s)$ is same as that of $G_p(s)$, i.e., $n_m^* = n^*$.

$$u = \theta^T \omega + \dot{\theta}^T \phi \qquad (5.2)$$

$\dot{\theta}$ is available from the adaptive law, the control law given by the above equation can be implemented without the use of differentiators.

Considering the Lyapunov like function as in the previous case for generating adaptive law

$$V(\tilde{\theta},\bar{e}) = \frac{\bar{e}^T P_c \bar{e}}{2} + \frac{\tilde{\theta}^T \Gamma^{-1} \tilde{\theta}}{2}\left|\rho^*\right| \qquad (5.3)$$

where $P_c = P_c > 0$ satisfies the MKY Lemma.

$$\dot{\theta} = -\Gamma e_1 \phi \,\mathrm{sgn}(k_p / k_m) \qquad (5.4)$$

The signal vector ϕ is expressed as

$$\phi = \frac{1}{s+p_0}\begin{bmatrix}(sI-F)^{-1}.g.u_p \\ (sI-F)^{-1}.g.y_p \\ y_p \\ r\end{bmatrix} \qquad (5.5)$$

Which implies that $\bar{e}, \tilde{\theta}, e_1 \in L_\infty$ and $\bar{e}, e_1 \in L_2$.

VI. SELECTION OF REFERENCE MODEL

The first step in controller design is to select a suitable reference model for the motor to follow. Let us assume that the dc motor is to behave as a second order system whose input is $r(t)$ and the output is $\omega_m(t)$. For a continuous-time system, the reference model can be selected as the ideal second order system transfer function.

$$\frac{\omega_m(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

In this case, speed desired is 57.6 rad/s (550rpm). The damping coefficient (ξ) is taken as one in order to represent critical damping. The above design procedure ensures that the reference model is compatible with the actual motor dynamics..

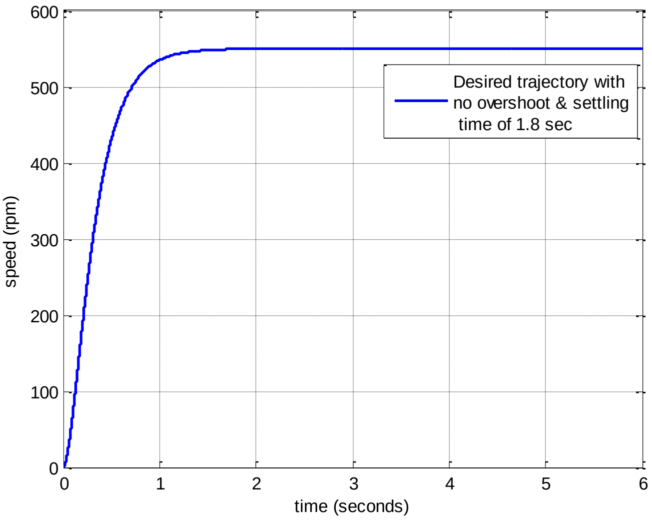
Figure 5. Desired trajectory described by reference model

VII. SIMULATION RESULTS

A separately excited dc motor with nameplate ratings of 1 hp, 220 V, 550 rpm is used in all simulations. Following parameter values are associated with it. **[6]**

J_m=0.068 kg-m^2 or Nm/(rad/sec^2).

B_m=0.03475 Nm-sec or Nm/ (rad/sec).



R_a=7.56 ohms.

L_a=0.055 Henry.

K_T=3.475Nm-A$^{-1.}$

the design maximum control input limit is kept 250 volts and the maximum motor current is 1.5 times of full load current. The adaptation gain of 0.0008 is selected after number of trials, which suits to the rating of the dc motor.

K_b=3.475 V/rad/sec.

In this work the adaptive control scheme (MRAC) is simulated for various loading conditions, parameter uncertainties and measurement noise. The performance of the dc motor is studied from no load to full load and open loop to adaptive closed loop. To test the system performance the data of the dc motor are taken from **[6]**.In Figure 2. Tracking performance at full load (12.95 Nm) applied at t=3 sec.

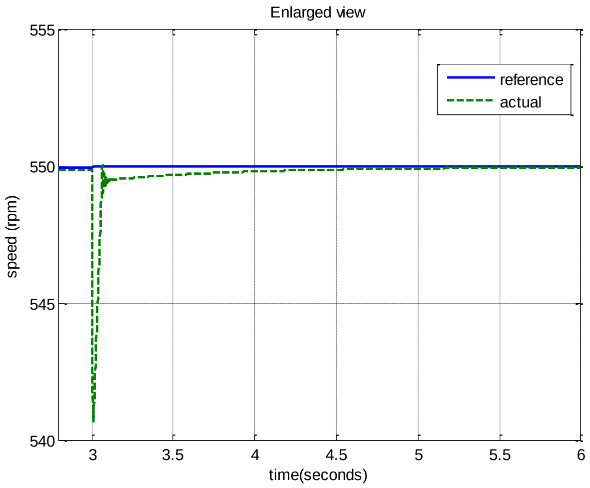


Figure 4. Tracking performance at 125% of full load applied at t=3 sec.

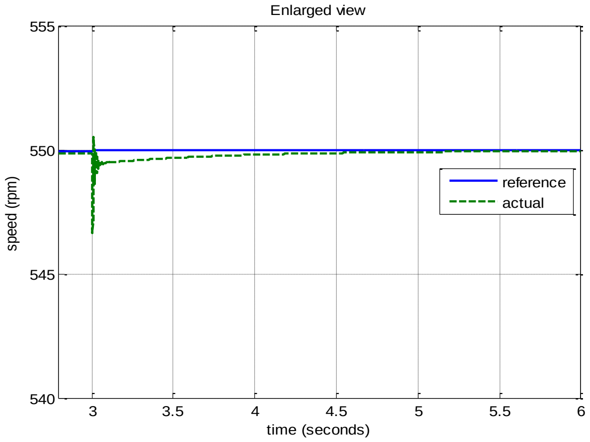


Figure 3. Tracking performance at 75% of full load applied at t=3 sec.

VIII. DISCUSSIONS AND CONCLUSION

From the simulation results it is inferred that for the limiting value of the control input, the value of adaptation gain can be varied up to certain maximum value. If it is further increased controller parameter does not converge to some constant value. Although as the adaptation gain is increased (within that max value) the adaptation becomes faster on account of becoming control input violently high this may not be compatible to the system. It is also inferred that with the increase in adaptation gain the error becomes smaller .All the results are found for the adaptation gain of 0.0008. All the results show the values of control input (armature voltage), input current (armature current) and speed as per the motor ratings (plots are not shown due to space constraints).

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