COMPARATIVE STUDY OF PROPORTIONAL INTEGRAL AND PASSIVITY BASED CONTROL FOR BUCK CONVERTER

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Abstract: Passivity Based Controller (PBC) is said to be following energy shaping approach for the faster stabilisation of output response for the given system. In this paper the PBC is implemented in a buck converter fed D.C. drive system. The drive is tested for desired speed requirements with constant and step change in load torque conditions. MATLAB-Simulink is used for simulating the drive system with PBC. The simulated results confirm that the dynamic response of the PBC is much faster in achieving the desired voltage and speed when compared with conventional PI controller.

1 INTRODUCTION

Energy is one of the fundamental concepts in science and engineering practice, where it is common to view dynamical systems as energy-transformation devices (Ortega et al., 2001). This perspective is particularly useful in studying complex nonlinear systems by decomposing them into simpler subsystems that, upon interconnection, add up their energies to determine the full system's behaviour. This "energy-shaping" approach is the essence of Passivity-Based Control (PBC) technique which is very well known in mechanical systems (Ortega et al., 2000).

Passivity based controllers for power electronic circuits are usually synthesized with a stabilization objective in mind, i.e., to achieve a constant output voltage or a constant current in the circuit branches. In this context Euler Lagrange equations were used earlier for deriving PBC (Ortega et al., 1998) in various power electronic circuits and also in some mechanical systems. A unified frame work for the control of various DC motor configurations using PBC was derived (Campos-Delgado et al., 2007) in such a way that the non linear terms in the torque equations are eliminated. Fundamental equations are derived for the switching function using PBC (Hebertt Sira-Ramirez, 2005.) so that the tracking error can be stabilised to zero. This method is utilised in this paper for deriving the control function of Buck converter fed PMDC motor.

PI Controller (PIC) is implemented for a dc motor drive with inner and outer control loops (P. C. Sen, 1975). PIC for buck converter fed DC motor is derived with (Ned Mohan, 2002; Krishnan, 2001) two control loops.

Transient performances of PBC and PIC were compared for the H bridge resonant converters (Y. Lu et al.). It has also been proved that the stabilisation performances of PBC is superior to that of PIC for the case of H bridge multi level converter (A. Dell Aquila et al., 2002)

In the present paper PBC is used for buck converter fed PMDC motor and its performance is compared with conventional PIC. The comparison of the behaviour of the two schemes has been solely on the transient and steady state response for constant load torque and step change in load torque.

This paper is organised as follows: Passivity Based Control theory is presented in Section 2. The Section 3 is devoted for the Implementation of PBC. Section 4 describes the simulation results and the comparative study of two controllers. The conclusions and the future scope for the work are given in section 5.

2 PASSIVITY BASED CONTROL THEORY

Planning of stabilised trajectories is mandatory in power electronic converter applications such as

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Power quality, DC & AC Drives etc. In these applications feedback regulation is accomplished through proper control functions. Passivity based controllers for power electronic circuits are usually synthesized with a view to achieve a constant output voltage or a constant current in the circuit branches. Passivity concept was introduced by Willems (1972). The motivation for adopting the PBC approach in this paper is due to the following facts.

1. PBC of dc-dc converters is simple as well as robust.(Marfa and Hebertt, 1998).
2. In power factor correction applications desired output voltage with upf at the input side are possible with PBC and Sliding mode Control (G. Escobar and, H. Sira, 1998)
3. PBC can be used as a soft starter for DC motor and it can be implemented for speed control with out any speed sensor. (J. Linares and H. Sira, 2004).
4. In the parallel operation of Inverters with non linear loads proper current sharing between the inverters as well as sinusoidal output current can be achieved using PBC.(Gustavo et al., 2006).
5. Using PBC, exponential stability and high dynamic performance can be obtained.(Daniel and Gerardo, 2007).

A study of the linearized models of the dc-to-dc power converters exhibit a clear “energy management ” structure. Also the conservative part, the dissipative part of the system and the energy acquisition part of the system dynamics are clearly indicated. Based on Lyapunov stability theory, a desired time varying trajectory for the linearized dynamic state is proposed. This results in the need to inject damping into the desired system dynamics and to force the incremental energy (energy of the tracking error system) to be driven to zero by suitable feedback. For this reason, the method is better known as the “Energy shaping + Damping Injection” (ESDI) methodology. It turns out that for the linearized models of the studied dc-to-dc power converters, the ESDI method produces simple dynamic output feedback controllers. The block diagram for implementing PBC and PIC is shown in figure 1.

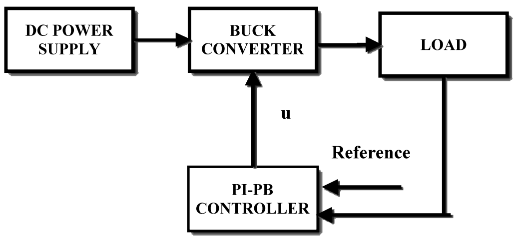

Figure 1: Block Diagram for Buck Converter with PI/PB Controllers.

3 IMPLEMENTATION OF PBC

Most of the power electronic converters clearly exhibit the following structure.

1. Conservative vector field characterised by the product of skew symmetry matrix with the state vector. The important property of skew symmetry matrix is that it does not intervene in the system stability considerations.
2. A dissipative vector field characterised by the product of a constant symmetric positive semidefinite matrix with the state vector.This term accounts for the dissipative forces in the system due to resistances and frictions.
3. The control inputs which entitles a constant matrix multiplying with the input vector. A time varying or alternatively constant vector field representing the external forces.Such a general model is given below.

$$A\,(dx/dt) = Jx - Rx + Bu + E;\; y = B^T x \qquad (1)$$

where:

x is an n-dimensional state vector,

A is a symmetric, positive definite, constant matrix

J is a skew symmetric Matrix.

B is a constant n x m matrix

y is an m dimensional output vector.

u is the average control input vector of m dimension.

E is a n-dimensional smooth vector function of t or, sometimes, a vector of constant entries.

R represents the dissipative field of the system.

3.1 Procedure for Implementing PBC

To implement PBC the following procedure can be followed.

1. The state model for the system is obtained.
2. The desired static control function (i.e. u^*) is derived by setting dx/dt = 0.
3. The dissipation injection term is introduced in the calculated error state variables (i.e. $[x-x^*]$) multiplied with the input matrix B^T.
4. The difference in Energy Function ‘V’ for the state variable(x) and the desired state variable(x^*) is calculated.
5. With the derived feedback control function (2), dV/dt is found and it is verified whether dV/dt is negative definite or not.
6. If it is so, then the tracking error vector $e(t) = x(t) - x^*(t)$ is stabilized to zero when the following linear time-varying tracking error feedback controller is used.

$$u=u^{*}-\Gamma\,[B(t)]^{T}e \qquad (2)$$

Where

Γ- Diagonal matrix with Dissipation terms,

e- Error between desired value of state variable and instantaneous value of state variable.

3.2 Modelling of Buck Converter Fed PMDC Motor

A Buck converter fed PMDC motor is a circuit constituted of power electronic components with PMDC motor connected as shown Fig 2. The variation of u determines the value of output voltage v of the converter as well as the speed of the motor. The state space model for Buck converter fed PMDC motor is given below:

$$dx_1/dt = (k/J)x_2 - (f/J)x_1-(T_L/J) \qquad (3)$$

$$dx_2/dt = (R_m/L_m)x_2 - (k/L_m)x_1- (x_3/L_m) \qquad (4)$$

$$dx_3/dt = (1/C)x_4 - (1/C)x_2 \qquad (5)$$

$$dx_4/dt = (uE/L)-(1/L)x_3 \qquad (6)$$

Where x_1, x_2, x_3 and x_4 represent the average values of the angular velocity ω, the dc motor armature current i_a, the converter output voltage v and the converter inductor current i, respectively . The state matrix (A_1) and Input matrix (B) are given below.

$$A_1=[-f/J\ k/J\ 0\ 0;-k/L_m\ R_m/L_m\ -1/L_m\ 0;\ 0\ 0\ -1/C\ 1/C\ ;\ 0\ 0\ -1/L\ 0];B^T = [0\ 0\ 0\ E/L]$$

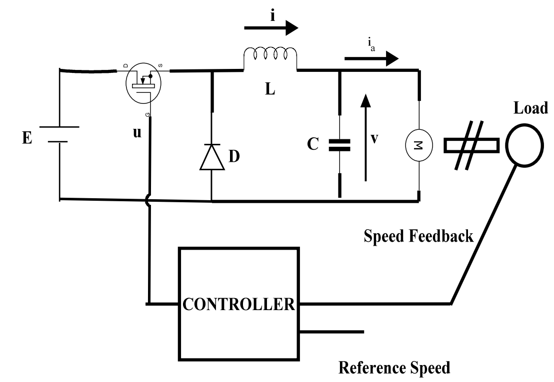

Figure 2: Buck Converter Circuit with Motor Load.

3.3 Passivity based Control for Buck Converter Fed PMDC Motor

In this section the various steps to be adopted in the implementation of PBC based Buck converter fed PMDC motor are discussed as follows. .

In the first step the static duty cycle is found by equating dx/dt =0 which gives $u^{*}=v^{*}/E$. Then in step two u^{*}, Γ,$(x-x^{*})$,B^T are substituted in (2).Then the expression obtained is

$$u= (v^{*}/E) - \Gamma\,[i-(v^{*}/R)]*(E/L) \qquad (7)$$

Where v^{*} - Desired Voltage

Γ - Damping Injection coefficient

4 SIMULATION RESULTS

The buck converter fed PMDC motor is simulated in MATLAB Simulink with the specification of the parameters given below.

L=20 mH
C=400 µF
k=0.046
J=7.06e-5 kg*m^2
f=8.42e-4 N-m/rad
L_m=2.63 mH
R_m=2.0 ohm
E=12 V
T_L=Varying from 0.05 to 0.1N-m at one second,
ω_d= Speed Reference 50, 25 &75rad /Sec
K_p=0.0072,K_i=0.1.

For the sake of comparison both PIC &PBC are implemented in buck converter fed PMDC motor and the corresponding simulated results are shown in figure 3 and figure 4 respectively.

Figure 3 indicates the speed, armature current and Torque responses of Buck converter fed PMDC motor with PIC. The following observations have been made.

1. When the motor started with a constant load torque of 0.05 Nm ,the starting current rises up to 2.35A. PIC settles the current to 2A and speed reaches the desired reference of 50 Rad/Sec after 0.9 seconds.
2. At one second, the load torque is increased to 0.1Nm.When the load torque changes instantaneously the speed is decreases to 37 Rad/Sec and then settles at 50 Rad/Sec after 0.7 Seconds.This is shown in Figure 3(ii) . During this operation the current settles at 3.089 A without overshoot.
3. At two seconds the speed reference is changed from 50 to 25 Rad/Sec.Due to this change, there is an undershoot in the current response upto 2.23A and the response settles at 2.63A with the desired speed of 25 Rad/Second after 0.7 seconds.

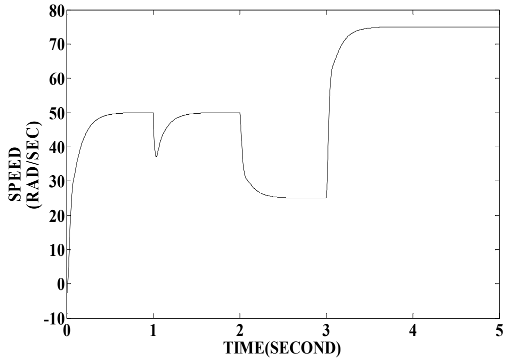

Figure 3(i): Speed Vs Time.

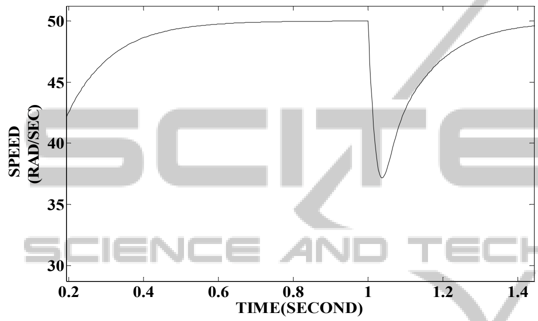

Figure 3(ii): Speed Vs Time(Expanded View around 1Seconds).

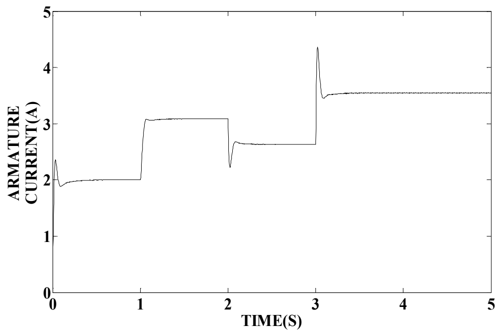

Figure 3(iii): Armature Current Vs Time.

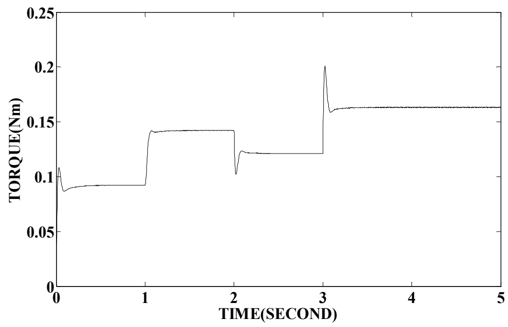

Figure 3(iv): Torque Vs Time.

Figure 3: PIC for buck converter with PMDC motor.

Figure 4 represents the speed, armature current and Torque responses of Buck converter fed PMDC motor with PBC.

1. When the motor is started with a constant load torque of 0.05 Nm ,the starting current rises up to 2.523A.PBC settles the current to 2A and speed reaches the desired reference of 50 Rad/Sec after 0.5 seconds.
2. At one second the load torque is increased to 0.1Nm.When the load torque changes instantaneously the speed is decreases to 49.13 Rad/Sec and then settles at 50 Rad/Sec after 0.29 Seconds.This is shown in Figure 4(ii). During this operation the current rises upto 3.375A and then settles at 3.089 A.
3. At two seconds the speed reference is changed from 50 to 25 Rad/Sec.Due to this change, there is an undershoot in the current response upto 2.525A and the response settles at 2.63A with the desired speed of 25 Rad/Sec after 0.5 seconds.

This shows the dynamic capability of PBC i.e. it can stabilise the current with less time, even though the overshoots and undershoots occur in the current response.

So it may be concluded that PBC settles the speed of buck converter fed PMDC motor with 0.5 seconds for various speed references and constant load torque of 0.05 Nm. When the load torque is changed from 0.05 to 0.1 Nm there is less undershoot in the speed and it settles at the desired speed after 0.29 Seconds. But in the case of PIC, settling time was 0.9 seconds for the speed reference of 50 Rad/ Sec with the applied load torque of 0.05 Nm and the settling time for step change in load torque to 0.1 Nm is 0.7 seconds. When there is a decrease in speed reference from 50 to 25 Rad / Sec, PIC settles the speed to 25 Rad/Second after 0.7 Seconds.

Table 2 indicates the performances of both PIC and PBC for Buck Converter fed PMDC motor with various speed references (ω_d) with and without step change in load torque (T_L).The comparative analysis of PBC and PIC is done for the change of speed reference made at zero, two and three seconds with constant load torque of 0.05 Nm. Also the performances are analysed with the change of load torque (0.1 Nm) made at one second. From the tabulated results it is concluded that PBC performs faster than PIC.

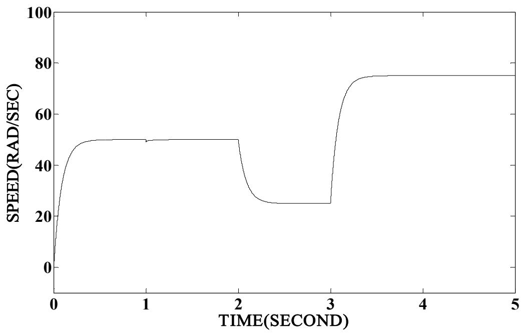

Figure 4(i): Speed Vs Time.

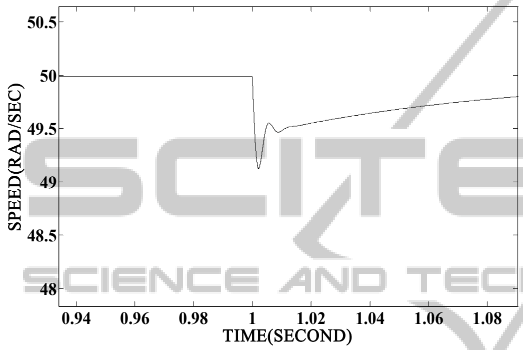

Figure 4(ii): Speed Vs Time (Expanded View around 1Sec).

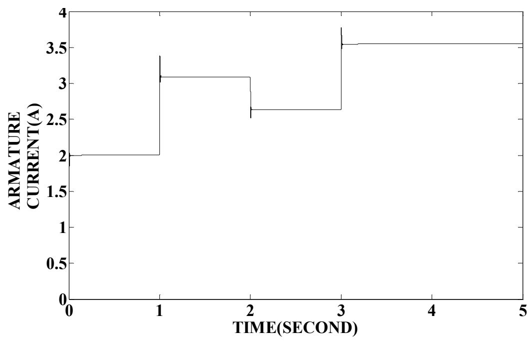

Figure 4(iii): Armature Current Vs Time.

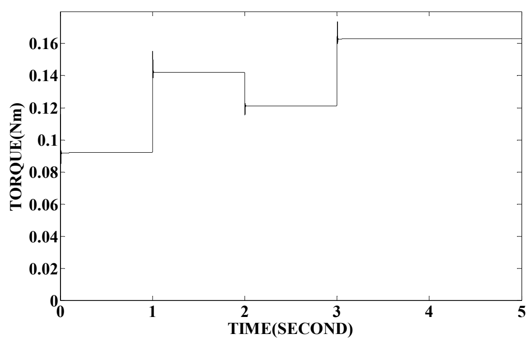

Figure 4(iv): Torque Vs Time.

Figure 4: PBC for buck converter fed PMDC Motor.

Table 2: Comparison between PIC and PBC.

S.No	Time Duration (Sec.)	T_L(Nm)	ω_d (Rad/Sec)	Settling Time(Sec.)	
				PBC	PIC
1.	0-1	0.05	50	0.5	0.9
2.	1-2	0.1	50	0.29	0.7
3.	2-3	0.1	25	0.5	0.7
4.	3-5	0.1	75	0.5	0.7

5 CONCLUSIONS

In this paper the performance of PBC based buck converter fed dc drive system has been simulated and studied. The study shows that PBC facilitates the drive response to settle faster as against the PIC without any speed sensor. Since the performance of PBC in electric drive application is found to be very promising it can be applied for other drive system also. Both the controllers are being tested experimentally for their robustness and dynamic performance.

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