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Exact Tracking And Error Dynamics And Passive Output Feedback Control Of Buck Converter

S. Ganesh Kumar[1] **and S. Hosimin Thilagar**[2]

[1]ganeshkumar@annauniv.edu,[2]shthilagar@annauniv.edu
DEEE, CEG, Anna University, Chennai-600025,India

ABSTRACT

In this paper exact tracking error dynamics passive output feedback (ETEDPOF) scheme is implemented and compared with the conventional Proportional – Integral (PI) controller. The performance of ETEDPOF controller is verified through hardware implementation in buck converter fed D.C. motor. Results are obtained satisfactorily and it shows the features of ETEDPOF controller.

Keywords Buck converter, DC motor, ETEDPOF, Proportional – Integral (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 [1]. 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 behaviour of the full system. This “energy-shaping” approach is the essence of Passivity-Based Control (PBC) technique which is very well known in mechanical systems [2].

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 in various power electronic circuits, electrical machines and also in some mechanical systems [3]-[7]. Campos-Delgado *et al.* derived a unified frame work for the control of various DC motor configurations except PMDC motor [8]. In the reference [8] Passivity Based Control function was derived in such a way that the non linear terms in the torque equations are eliminated with the achievement of asymptotic velocity reference tracking. Hebertt Sira-Ramirez derived the switching function using PBC for boost-boost converter and three phase rectifier so that the tracking error can be stabilised to zero [9]. PBC technique can be implemented in various Power converters like Boost, Buck and Buck boost converter [9] - [11].

Forouzantabar *et al.* proposed a passivity based architecture, which overcomes the conventional controllers in terms of position and force tracking in the control of bilateral tele operation systems with multi degrees of freedom [12].

Dynamic response, realization complexity and parameter sensitivity properties of single phase PWM Current Source Inverter are compared with Adaptive Digital Control, Sliding Mode Control and Passivity Based Control methods. The comparative result shows that dynamic response of PBC is better when compared with other controllers [13]. Linear average controller, Feedback linearizing controller, Passivity Based Controller, Sliding Mode Controller and Sliding mode plus Passivity Based Controller are implemented in Boost converter with resistive load. The comparison is based on transient and steady state response to steps and sinusoidal output voltage references, attenuation of step and sinusoidal disturbances in the power supply and response to pulse changes in the output resistance [14]. The comparative result reveals that PBC achieved better disturbance attenuation.

In power flow control of Unified Power Flow Controller (UPFC), PBC dominates over PIC with respect to transient response with reduced oscillations in the real power [15]. Tzann-Shin Lee investigated the behavior of PBC + PIC and PIC in three phase AC/DC Voltage Source Converters and from the results, the author concluded that the performance of PBC with PIC is better than PIC [4].

Transient performances of PBC and PIC in H bridge resonant converter were compared by Y. Lu *et al.* [16] and the experimental results reveal that settling time and output voltage overshoot for PBC is lesser than PIC. A. Dell Aquila *et al.* proved that the stability properties of H bridge multi level converter with PBC are better than PIC [17]. Tofighi *et al.* achieved good tracking response, low overshoot and short settling time in photovoltaic system with PBC in comparison with PIC. The authors demonstrated the robustness of PBC in Photovoltaic Power Management system for the change in reference DC voltage, solar irradiance as well as load resistance [6]. However, these papers have compared only PBC with other controllers for Boost converter, UPFC etc., and not for buck converter fed PMDC motor.

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 two schemes has been solely on the transient and steady state response for no load condition and step change in load torque. Further in PBC, ETEDPOF [7], [22] method is preferred in comparison with Energy Shaping Damping Injection (ESDI) method as the former does not requires state computations [8]

This paper is organised as follows: Modeling and control of buck converter is presented in Section 2. Section 3 is devoted for the reference trajectory generation. Section 4 describes the hardware results and the comparative study of the two controllers. The conclusions and the future scope for the work are given in section 5.

2. MODELLING AND CONTROL OF BUCK CONVERTER FED DC MOTOR

Closed loop operation of buck converter fed DC motor is shown in Figure.1. In the previous work [21], load resistance is added in addition to motor load to strongly satisfy dissipation matching condition. Here, resistance is removed to avoid power loss. Dissipation matching condition can be satisfied by using LaSalle's invariance theory [7].

From the figure1 it can be realized that ω^* is the desired profile obtained using Bezier polynomials. Based on the speed profiles, inductor current and armature voltage profiles are obtained easily due to the flatness [7] nature of the system. Based on these profiles, required control input profile is obtained using (1).

$$u(t) = u^*(t) - \frac{\gamma E}{L}(i - i^*) \tag{1}$$

Where

k	EMF constant
L	Buck converter inductance
C	Buck converter capacitance
R_m	Motor armature resistance
R_L	Load resistance
L_m	Motor armature inductance
$u(t)$	Average control input
i	Input current
v	Armature voltage or converter output voltage
ω	Angular velocity of the motor shaft $\left(\frac{2\pi N}{60}\right)$
i_{am}	Motor armature current
T_L	Load torque
N	Speed of the motor shaft
γ	Damping injection > 0

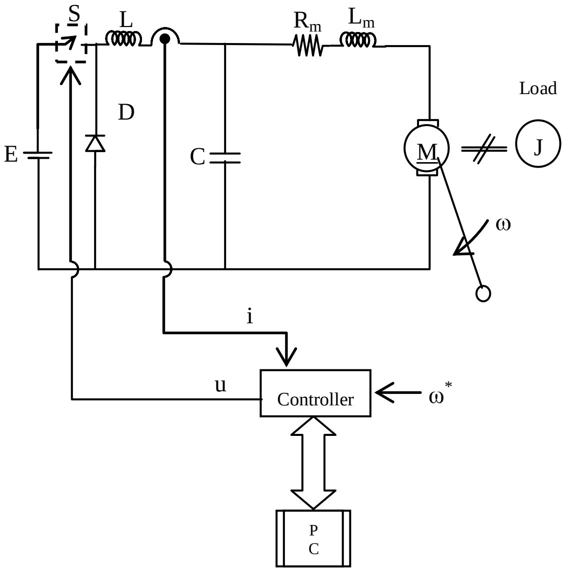

Figure.1 Buck converter fed D.C. motor

Dissipation matching condition for the present case is given by,

$$\breve{R} = \begin{bmatrix} \frac{\gamma E^2}{L^2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{R_m}{L_m^2} & 0 \\ 0 & 0 & 0 & \frac{B}{J^2} \end{bmatrix} \geq 0$$

As dissipation matching condition is weakly satisfied, LaSalle's invariance principle is used for stability study. From that, it is identified that error dynamics of the system becomes asymptotically stable. Due to this stability nature, PBC finds its application in wind mills [18], flight control [19] and in pose control [20].

As (i-i*) plays an important role of current limiting, expression (1) can be used for soft starting. Desired control input profile u* and inductor current i* profiles generated using differential parameterisations which will be discussed in the next section.

3. REFERENCE TRAJECTORY GENERATION

In continuation of the derived feedback law (1), it is necessary to generate voltage and current references for the buck converter circuit i.e., $v^*(t)$ and $i^*(t)$. In order to realize smooth starter, restrictions should be made in the reference profiles so that smooth changes between stationery regimes can be achieved. For the generation of output voltage of buck converter and the buck converter inductor current or input current, differential parameterizations in terms of the desired angular velocity and the estimated load torque which can be assumed piecewise constant, for simplicity. From the state equation (2), v^* and i^* can be derived as in (3) and (4)

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \\ \dot{x}_4(t) \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} & 0 & 0 \\ \frac{1}{C} & 0 & \frac{-1}{C} & 0 \\ 0 & \frac{1}{L_m} & \frac{-R_m}{L_m} & \frac{-k}{L_m} \\ 0 & 0 & \frac{k}{J} & \frac{-B}{J} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \frac{E}{L} \\ 0 \\ 0 \\ 0 \end{bmatrix} u(t) + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{T_L}{J} \end{bmatrix} \tag{2}$$

$$v^*(t) = a_3\ddot{\omega}^* + a_4\dot{\omega}^* + a_5\omega^* + \frac{T_L R_m}{k} \tag{3}$$

$$i^*(t) = a_6\dddot{\omega}^* + a_7\ddot{\omega}^* + a_8\dot{\omega}^* + a_2\omega^* + \frac{T_L}{k} \tag{4}$$

$$u^* = \frac{v^*}{E} \tag{5}$$

Where $a_1 = \frac{J}{k}$; $a_2 = \frac{B}{k}$; $a_3 = \frac{JL_m}{k}$; $a_4 = \frac{BL_m + JR_m}{k}$; $a_5 = \left(\frac{BR_m}{k} + k\right)$; $a_6 = \frac{CJL_m}{k}$; $a_7 = C\left(\frac{BL_m + JR_m}{k}\right)$; $a_8 = \left(\frac{CBR_m}{k} + Ck + \frac{J}{k}\right)$

In order to define the trajectory, Bezier polynomial of tenth order is used [7]. For the desired speed profile, the polynomial is given by,

$$\begin{aligned} \omega^*(t) &= \omega_{ini} && \text{for } t < t_{ini}; \\ &= \omega_{fin} && \text{for } t > t_{fin}; \\ &= \omega_{ini} + \emptyset(\omega_{fin} - \omega_{ini}) && \text{for other values of 't'} \end{aligned} \tag{6}$$

where the expression for $\emptyset$ is given below.

$$\emptyset = 252\left(\frac{t - t_{ini}}{t_{fin} - t_{ini}}\right)^5 - 1050\left(\frac{t - t_{ini}}{t_{fin} - t_{ini}}\right)^6 + 1800\left(\frac{t - t_{ini}}{t_{fin} - t_{ini}}\right)^7 - 1575\left(\frac{t - t_{ini}}{t_{fin} - t_{ini}}\right) + 700\left(\frac{t - t_{ini}}{t_{fin} - t_{ini}}\right)^9 - 126\left(\frac{t - t_{ini}}{t_{fin} - t_{ini}}\right)^{10}$$

4. EXPERIMENTAL SETUP

The experimental setup for the present work is shown in Figure.2. The setup includes buck converter, D.C. motor, controller and the necessary sensors with signal conditioning circuits. The speed output can be measured using phototransistor and encoder disc with frequency to voltage converter arrangement. The machine parameters are estimated by using standard test procedures.

Buck converter and controller are used for controlling the D.C. motor speed under armature control method. Desired PWM pulses for the closed loop operation are obtained using real time hex code generation with the help of dsPIC block sets in MATLAB. Then the generated codes are flashed in dsPIC 30F4011 using MPLAB.

Agilent make MSO is utilized for observing variations in the system variables. The observed waveforms are stored in CSV (Comma Separated Values) format. The specifications for the system of interest are given in TABLE I.

In buck converter IRFP 450N MOSFET is used as switch. dSPIC 30F4011 is used as a controller and it generates the desired PWM pulses during closed loop operation. Speed output is sensed in the case of PIC technique and buck converter filter inductor current is sensed for PBC. U1 4151 is used as frequency to voltage converter and it is connected with speed sensor in order to convert the speed from digital pulses received from speed sensor to analog form..

Fig. 3. represents the speed response of Buck converter fed PMDC motor with PIC. PI constants are obtained using Zieglar,s Nichols method. Values of K_p and K_i are 0.026 and 0.031 respectively. The following observations are made from the waveform. When the motor is started without load torque, the speed reaches the desired reference of 500 RPM after 5.65 seconds. When the speed reference is changed from 500 to 800 RPM without loading the motor, PIC settles the speed to 800 RPM at 8 Seconds. Under loading condition, the speed decreased to 660 RPM and then settles at 800 RPM. The settling time under this operation is 7.66 seconds.

TABLE I SPECIFICATIONS FOR PBC OF BUCK CONVERTER FED D.C. MOTOR

S.No	PMDC Motor		Buck Converter	
	Symbol	Value	Symbol	Value
1.	P_o	0.16 HP	L	2.769mH
2.	V	180 Volts	C	440.1µF
3.	I_a	0.9A	Switching frequency	32 KHz
4.	N	2000 RPM	D.C. Supply Voltage	220 V
5.	L_a	148 mH		
6.	R_a	30 Ω		
7.	K	0.6957		
8.	J	5.3132e-4 kg*m^2		
9.	f	2.029e-3 N-m/rad		

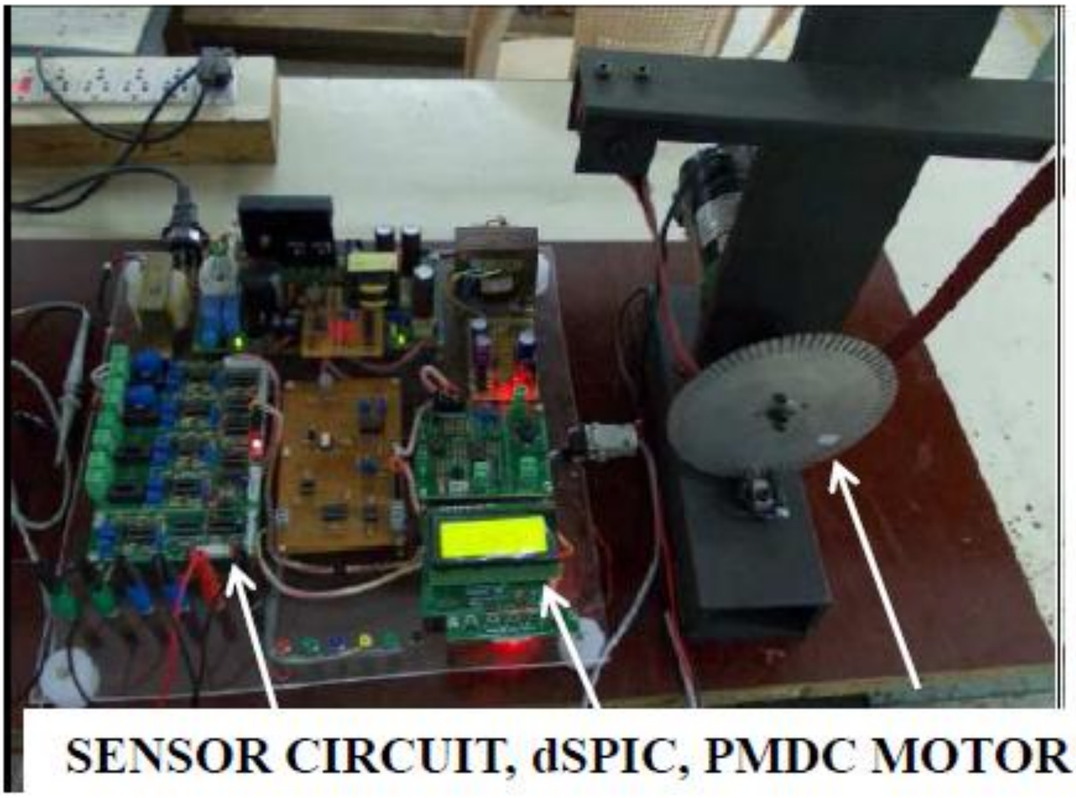

Fig. 2. Hardware set up for Buck converter with PMDC motor.

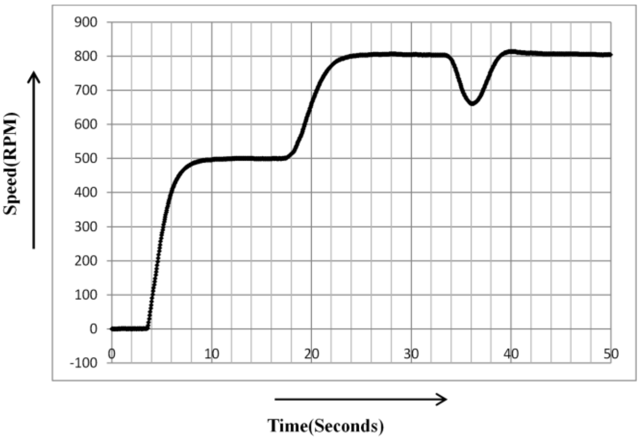

Fig. 3. PIC output speed for Buck converter fed PMDC motor

Fig.4. show the speed response of buck converter fed PMDC motor with PBC. From the results following observations are made. When the motor is started without load torque, the speed reaches the desired reference of 500 RPM after 5.14 seconds. When the speed reference is changed from 500 to 800 RPM without loading the

motor, PBC settles the speed to 800 RPM at 3.33 Seconds. During the loaded condition, the speed decreased to 750 RPM and then settles at 800 RPM. The settling time under this operation is 4.33 Seconds.

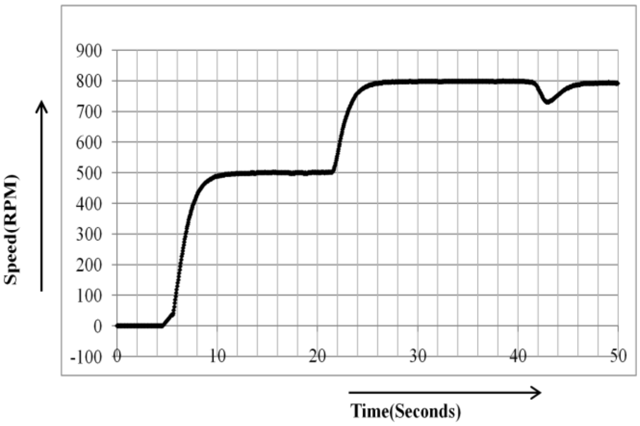

Fig. 4. PBC output speed for Buck converter fed PMDC motor

The above results clearly indicate that PBC performs better than the conventional PIC. TABLE II explains the features of PBC and PIC. The comparative analysis is done for speed references 500 RPM and 800 RPM with and without loading.

TABLE II COMPARISION BETWEEN PIC AND PBC

S.No	Load	N_d (RPM)	Settling Time (Seconds.)	
			PIC	PBC
1.	0	500	5.65	5.14
2.	0	800	8.0	3.33
3.	0.5Kg	800	7.66	4.33

5. CONCLUSION

Thus, different speed profiles are stabilized using ETEDPOF. For achieving this speed profiles, inductor current and control input profiles are obtained using differential parameterisations of speed and load torque. With these profiles, modified control input is obtained and it is used for speed regulation. Further ETEDPOF performance is compared with PI controller for no-load and load conditions. Experimental results confirm that, ETEDPOF performs better than PIC.

Hence, ETEDPOF can be a viable alternative for PIC in industrial applications. The reason for finding the superior performance of ETEDPOF is in progress.

REFERENCES

[1] Gao, Y.; Lu, G.; Wang, Z.; , "Passive control for continuous singular systems with non-linear perturbations," *IETControl Theory & Appl.,* vol.4, no.11, pp.2554-2564, Nov. 2010.

[2] Hebertt Sira-Ramirez ,"Are nonlinear controllers really necessary in power electronics devices? " *EPE*,pp.1-10,Aug.2006.

[3] J. Linares-Flores, J. Reger, and H. Sira-Ramírez, "A time-varying linear state feedback tracking controller for a Boost-converter drivenDC machine," presented at the 4th IFAC-Symp. Mechatron. Syst.,Heidelberg, Germany, 2006.

[4] J. Linares-Flores, J. Reger, and H. Sira-Ramírez, "An exact tracking error dynamics passive output feedback controller for a Buck-Boost converter driven DC motor," presented at the IEEE Int. Power Electron.Congr., Cholula, Pue. México, 2006.

[5] J. Linares-Flores, J. Reger, and H. Sira-Ramírez, "Sensorless tracking control of two DC-drives via a double Buck-converter," presented atthe 45th IEEE Conf. Dec. Control, San Diego, CA, USA, 2006.

[6] Jesús Linares-Flores, Johann Reger,Hebertt Sira-Ramírez," Load Torque Estimation and Passivity-Based Control of a Boost-Converter / DC-Motor Combination". *IEEE Trans. Control Syst. Techn.,* vol. 18, no. 6, pp. 1398-1405, Nov. 2010.

[7] Hebertt Sira-Ramírez and Ramón Silva-Ortigoza "*Control Design Techniques in Power Electronics Devices* ", Springer, London,2006, pp. 136-142.

[8] Albrecht Gensior, Hebertt Sira-Ramírez, Joachim Rudolph, and Henry Güldner , " On Some Nonlinear Current Controllers for Three-Phase Boost Rectifiers", *IEEE Trans. Ind. Electron.*, vol.56, no. 2, pp. 360-370,Feb. 2009.

[9] Ortega R, Loria A, Nicklasson H, Sira-Ramirez H "*Passivity based control of Euler-Lagrange systems: mechanical, electrical & electromechanical applications*",Springer, London, 1998, pp. 135-380.

[10] Tzann-Shin Lee," Lagrangian Modeling and Passivity-Based Control of Three-Phase AC/DC Voltage-Source Converters", *IEEE Trans. Ind. Electron.,* vol. 51, no. 4,pp. 892-902, Aug. 2004.

[11] A. Tofighi, M. Kalantar," Power management of PV/battery hybrid power source via passivity-based control", *Renewable Energy*, vol.36, iss.9, pp. 2440-2450, Sep. 2011.

[12] Campos-Delgado.D.U,Palacios .E,Espinoza – Trejo D.R.,"Passivity Based Control of Nonlinear DC Motors Configurations and Sensor less Applications " *in 2007 IEEE Proc.*,pp. 3379-3384.

[13] Antonio Dell'Aquila, Marco Liserre, Vito Giuseppe Monopoli, Paola Rotondo" An Energy-Based Control for an n-H-Bridges Multilevel Active Rectifier", *IEEE Trans. Ind. Electron.,*vol. 52, no. 3,pp. 670 – 678, Jun. 2005.

[14] Hasan Komurcugil, "Steady-State Analysis and Passivity-Based Control of Single-Phase PWM Current-Source Inverters"*IEEE Trans. Ind. Electron.*, vol. 57, no. 3, pp. 1026-1030, Mar. 2010.

[15] G.Escobar,R.Ortega, H.Sira Ramirez,J-P.Vilain,and I.Zein, “An Experimental Comparison of Several Nonlinear Controllers for Power Converters” *in 1999 Proc.IEEE,* pp. 66-82.

[16] J.Linares -Flores ,H.Sira Ramirez ,”DC motor velocity control through a DC-DC power Converter “ in *2004 Proc. IEEE,* pp. 5297-5302.

[17] M.-Y. Wei T.-H. Liu C.-K. Lin "Design and implementation of a passivity-based controller for sensorless synchronous reluctance motor drive systems", *IET Electr. Power Appli.,* vol.5, 2011, iss. 4, pp. 335–349,Apr. 2011.

[18] Fernando Mancilla-David, Romeo Ortega, “ Adaptive passivity-based control for maximum power extraction of stand-alone windmill systems”, *Control Engineering Practice,* Available online 9 Nov. 2011.

[19] Alexander L. Fradkov, Boris Andrievsky,”Passification-based robust flight control design”, *Automatica*, vol. 47, iss. 12, pp.2743-2748 , Dec. 2011.

[20] Kawai, Hiroyuki, Murao, Toshiyuki, Fujita, Masayuki, “ Passivity-based Visual Motion Observer with Panoramic Camera for Pose Control “, *Journal of Intelligent & Robotic Systems*, vol.64,iss.3, pp. 561-583, Dec.2011.

[21] S.Ganesh Kumar, S.Hosimin Thilagar, “Load torque estimation and Passivity Based Control of Buck Converter”, *The Mediterranean Journal of Measurement and Control,* vol. 9, no.2, pp.51-57, 2013.

[22] S.Ganesh Kumar, S.Hosimin Thilagar, “Soft Sensing of Speed in Load Torque Estimation For Boost Converter fed DC motor”. *IECON 2013 Vienna, Austria, pp 3758-3763.*