A PREDICTIVE DYNAMIC CONTROLLER FOR PMDC MOTOR DRIVERS

A.M. Sharaf[1], E. Elbakush[1], Ismail H. Altas[2,*]

[1]*Dept. of Electrical and Computer Engineering, University of New Brunswick Canada,*
E-mail: sharaf@unb.ca and j1tyb@unb.ca

[2]*Dept. of Electrical and Electronics Engineering, Karadeniz Technical University, Trabzon, Turkey*
**: Currently a visiting scholar at the University of New Brunswick Canada*
ihaltas@altas.org

Abstract- This paper presents a novel control scheme for Permanent Magnet DC Motor (PMDCM) drivers. A General Predictive Controller (GPC) is designed to control the speed of the PMDCM under different load excursions. Besides the GPC, the system is also controlled using a classical PI controller for comparison purposes. Both types of controllers are used to control the PWM switching sequences of a DC-DC Chopper that is used to drive the PMDC motor. The performances of both controllers are compared in the bases of their applicability, adaptability, and controllability under various operating conditions. The system is simulated using Matlab/Simulink GUI environment and the results are discussed in the paper.

Key words*:* Predictive Control, Motor Drives, DC-DC Converters, PMDC Motor, PWM, Load excursions

1. INTRODUCTION

High performance permanent magnet dc (PMDC) motor drives are used for a multitude of industrial applications such as in process control, guided vehicles, paper and steel mills, and mining and smelting plants. Precise, fast and effective speed-reference tracking with minimum overshoot/undershoot and small steady state error are the main essential control objectives of such a drive system [1].

Conventional control strategies are of a fixed structure, fixed parameter design [2, 3] hence the tuning and optimization of these controllers are a challenging and difficult task, particularly under varying load conditions, parameter changes, and abnormal modes of operation. Attempts to overcome such limitations [4, 5] using adaptive and variable structure control have had limited success due to complexity, estimation stage requirement, model structure changes due to discontinuous drive mode of operation, parameter variations, load excursions and noisy feedback speed and current signals. New Artificial Intelligence technologies such as rule based, expert systems, General Predictive Control (GPC) started emerging during the last decade and promise to simplify and enhance the robustness of speed/position control designs for PMDC motor drives.

A chopper current is rich in harmonics, a factor which reduces the efficiencies of such dc machines by increasing the amplitude of current harmonics in armature circuits [6]. Some factors which affect the magnitude of harmonic content in the supply current (armature current) are related to the machine parameters, such as the ratio of armature inductance to armature resistance (armature time constant). Meanwhile, other factors depend on the operational conditions of the machine-chopper system such as chopping frequency, f_c, conduction ratio, t_{on}/T, and the induced back emf, E_a, of the machine which is a function of machine speed, [7]. The input power to a machine controlled by chopper circuits; can be considered to be consisting of ac and dc components. The ac component may consist of several harmonics; therefore, conventional measuring instruments may not give accurate results, particularly, when the harmonic contents are high. Besides, the currents with harmonic components cause heat losses in motor coils due to increased coil resistance and eddy currents. Therefore the motor parameters are not constant as they are used in system modeling. Instead they change during the operation resulting in changes in motor operating characteristics. Conventional controllers with constant parameters, which are determined using the preheated motor parameters, fail to overcome the required operating conditions. However, the proposed GPC controller uses a prediction algorithm to predict the new values of the motor parameters as they change during the operation, and update the controller parameters accordingly.

Therefore the proposed GPC in this paper is an advanced predictive based controller that operates as an adaptive controller in nature to handle the parameter changes during the operation. Therefore it is expected to have a smoother, overshoot free, fast and more sensitive speed controller when compared to those of classical ones.

2. PMDCM SPEED CONTROL SCHEME

The operational block diagram of the overall speed controlled system to be used in Matlab/Simulink/Sim-power GUI environment is given in Fig. 1. The complete system consists of a DC power source, a DC-DC chopper driver, a signal generator, a PMDC motor, and a controller. The chopper here is used an interfacing device between the DC source and the motor in order to have a controllable voltage that operates the motor at a desired speed. The operating speed of the motor is used as a feed back signal and compared with the reference speed yielding a speed error, which is used by the controller to generate required control pulses for switching the chopper. The following sections describe the modeling processes of the main components included in Fig. 1.

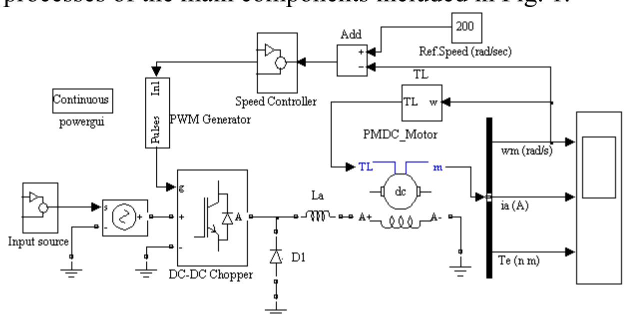


Fig.1. Operational block diagram of DC-DC chopper controlled PMDC motor scheme.

3. SWITCHED MODE PMDC MOTOR

A general circuit diagram of the chopper controlled PMDC motor system under consideration is shown in Fig. 2 where the dc chopper including voltage and current filtering elements is clearly depicted. The chopper duty cycle is obtained in terms of conducting and chopping periods as;

$$C = \frac{T_{ON}}{T_{MAX}} \quad , \quad T_{ON} = CT_{CH} = CT_{MAX} \qquad (1)$$

Where, T_{MAX} is the maximum chopping period.

4. FEEDBACK CONTROLLER

In this section, feedback control designs for the chopper controlled PMDC motor scheme are presented by increasing in complexity from a simple PI controller to GPC controller. Since the PI controllers are well studied in textbooks, it is not going to be repeated here. However, a brief description of the predictive controller will be given. Although the techniques are applicable to PMDC motors of almost any size, specific design details are given for the PMDC motor having the parameters given in Appendix in order to illustrate the approach.

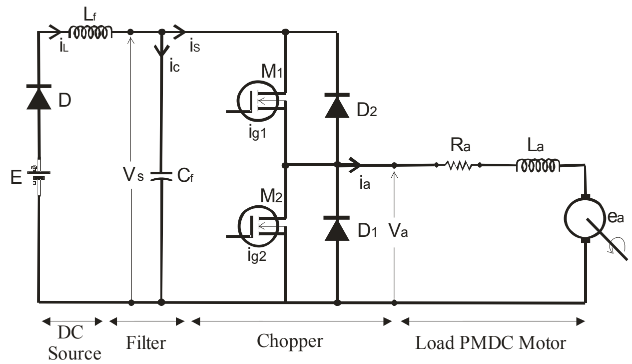


Fig. 2.General power electronic circuit diagram of the chopper controlled PMDC motor scheme.

4.1. THE PREDICTIVE CONTROL CONCEPT

Predictive control algorithms (PCA) have been suggested first in the middle of the seventies from the side of the industrial applications. The main idea was to develop robust control algorithms providing acceptable results, also within difficult circumstances such as unknown precise mathematical model of the plant, parameter changes, noises, and nonlinearities.

The PCA calculates a series of the control signals from the actual time point k minimizing a quadratic deviation of the reference and the output signals of the plant predicted in a future horizon.

The control prediction is based on the minimization of a cost function given as;

$$J = \sum_{n_e=n_{e1}}^{n_{e2}} \gamma_{yn_e}[y_r(k+d+n_e) - \hat{y}(k+d+n_e \mid k)]^2 + \sum_{j=1}^{n_u} \gamma_{uj} \Delta u^2 (k+j-1) \Rightarrow \underset{\Delta u}{MIN} \qquad (2)$$

or in vector-matrix form

$$J = (y_r - \hat{y})^T \Gamma_y (y_r - \hat{y}) + \Delta u^T \Gamma_u \Delta u \Rightarrow \underset{\Delta u}{MIN} \qquad (3)$$

Where,

$$\Gamma_u = diag[\gamma_{u1}, \gamma_{u2}, \ldots, \gamma_{u,nu}] \qquad (4)$$

$$\Gamma_y = diag[\gamma_{y,ne1}, \gamma_{y,ne2}, \ldots, \gamma_{y,ne2}] \qquad (5)$$

Where, k is the discrete iteration counter and (d) is discrete dead time relative to the sampling time. The other notations used above equations are defined below:

$\gamma_r(k+d+n_e \mid k)$ is the reference signal n_e steps over the dead time d, $\hat{\gamma}(k+d+n_e \mid k)$ is the predicted output signal (n_e) steps over the dead time d, and Δu is the control signal increment.

The tuning parameters of the control algorithm are: n_{e2}-n_{e1} is for the prediction horizon, n_u is for the control horizon (the number of the consecutive changes expected in control signal), $\gamma_{yn_{e1}}, \ldots, \gamma_{yn_{e2}}$ are weighting factors of the control error, usually assumed to be equal to 1 (γ_y=1), and $\gamma_{u1}, \ldots, \gamma un_u$ are weighting factors of the control increments, usually assumed to be equal to each other (and denoted then by γ_u).

With the last term the cost function given in (2) punishes big control increments to avoid saturation effects. The control idea is illustrated in Fig. 3 and References [9,10].

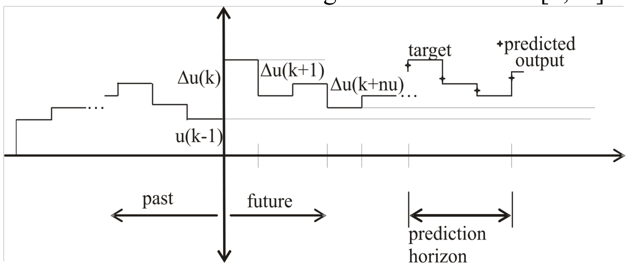


Fig. 3.Predictive control concept

For the calculations different control strategies could be supposed, as the control signal is changed in each sampling point between k and k+n_{e2}-n_{e1}; only n_u number of the consecutive changes in the control signal considered; n_u=1, only one change is taken into account in the current time point; n_u number of equal changes of the control signal is taken into account. With such assumptions the calculations can be simplified, and on the other hand the properties of the control can be influenced.

5. SIMULATIONS RESULTS

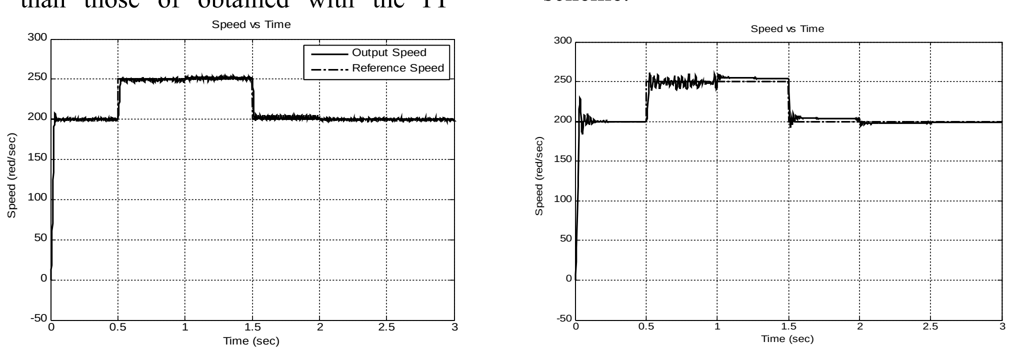
The system is simulated using both GPC and PI controllers with the controller parameters for GPC and PI as np1=1, np2=3, nu=1, λ=0.1 and Kp= 0.1, Ki= 0.1, respectively. Reference speed, running motor speed, and the speed error responses are shown in Figs 4 (a) and (b) for both controllers. Time responses of the armature current are depicted in Figs 5 (a) and (b) for both GPC and PI controllers, respectively. Figs 6 (a) and (b) show the responses of electrical torque developed by the motor with respect to speed and time to indicate the dynamical behavior of the PMDCM under load excursions.

The resultant figures from both controllers are placed side by side on the same page to get a better comparison. The results show that the speed responses obtained using GPC are faster than those of obtained with the PI controller. Besides the shorter settling time, the overshoot damped with the GPC resulting in a more acceptable results. The GPC controller compensates the changes in source voltage resulting in a minimum effect on the motor speed while the speed shows considerable oscillations. However, it can also be seen that the PI controller also give acceptable speed response when the source voltage is kept constant around nominal voltage value of the motor.

6. CONCLUSIONS

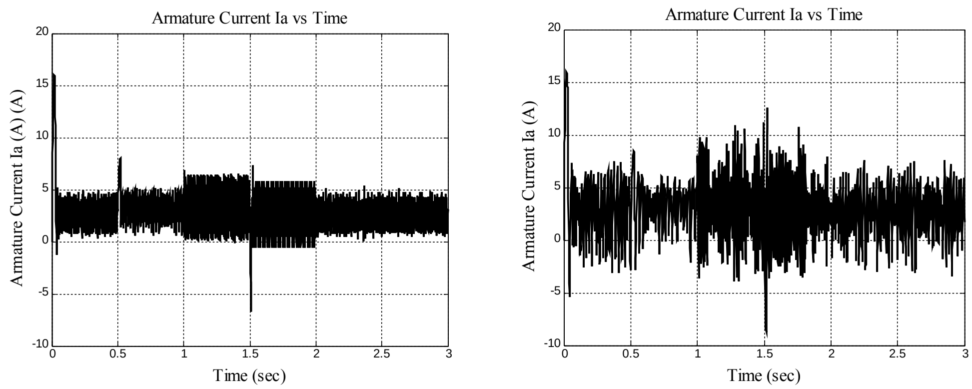
A general predictive speed controller (GPC) is introduced in this paper for speed trajectory control of a PMDC motor running under different operating and load conditions such as being fed by a DC source whose voltage may change ±50% around the rated voltage and driving loads with non-linear torque-speed characteristics. DC sources such as photovoltaic solar arrays generate voltages that are unpredictable depending on the solar insolation levels. Therefore DC choppers are used to control the voltage to the load between acceptable limits. The proposed GPC is used to keep the load voltage between required limits as well as ensuring a desired motor speed. Due to the nature of GPC, the parameter variations are also taken into account so that the controller parameters are adapted by predicting the changes in the motor parameters.

Simulation results using the MATLAB/Simulink/ Simpower software package for a specific two-pulse DC-DC controlled chopper fed PMDC motor are presented for one arbitrarily chosen trajectory. Both controllers exhibit excellent speed tracking performance when the motor and load parameters are exactly known. With the introduction of parameter and load changes and sudden load excursions, only the predictive speed controller was effective and capable in handling all excursions and changes by generating new adequate control action. Since the parameters of the PI controller are all preset and usually constant without any adaptive structure, its dynamic response and performance for changing system parameters is not good as much as the predictive control scheme.



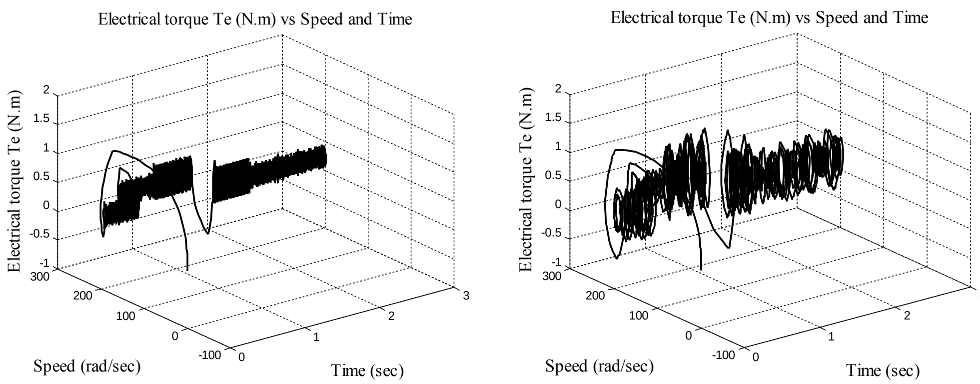
(a) (b)

Fig. 4. Speed control responses for (a) GPC and (b) PI controllers.



(a) (b)

Fig. 5. PMDC motor current responses for (a) GPC and (b) PI controllers.



(a) (b)

Fig. 6. PMDC motor torque responses with respect to time and speed for (a) GPC and (b) PI controllers.

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Appendix

PMDC motor parameters:

R_a= resistance of armature winding =1.4 Ohm
L_a= inductance of armature winding = 0.0805 H
K_m= voltage constant = 0.095 V/rad
K_t= torque constant = 0.095 Nm/A.
J_m= moment of inertia = 0.0007432 kg
B_m= viscous constant = 0.000431 Vs/rad.
V_a= Nominal armature voltage =36 V
N= Turns ratio of the gears = 2.67