Control of Nonlinear Phenomena in a DC Chopper-Fed PMDC Drive

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Abstract— the effects of nonlinearity in a PMDC drive are the main problems when apply a conventional control algorithm (p or pi controller). As some system parameter such as the controller gains or the supply voltage is being varied, the nominal period-1 orbit in the drives may lose stability and lead to nonlinear phenomena such as chaos and bifurcation. So that we need to improve controllers that are match the parameter variations. In this paper we use Simulink model to describe fuzzy controller to control the nonlinear phenomena in a dc chopper-fed PMDC drive and compare the results with p and pi controller.

Index Terms—nonlinear phenomena, chaos, p controller, pi controller, FLC, effects of nonlinearity, PMDC drive, period-doubling bifurcation, Neimark-sacker bifurcation and Simulink model

I. INTRODUCTION

The sources of nonlinearity in power electronics are power switching devices (diode, SCR, BJT, power MOSFET and IGBT), reactive components and electrical machine and drives [1].

Nonlinear phenomena such as chaos and bifurcation can lead system to harmful situations. So nonlinear phenomena should be reduced as possible or totally suppressed [12].

In this paper we use fuzzy controller to control nonlinear phenomena in a PMDC drive.

Lotfi Zadeh is the first one who propose fuzzy logic controller in 1965. Fuzzy logic controller used in a lot of intelligent applications [2, 7, 13]. The execution of fuzzy rules depends on the operations done by human operators does not need a mathematical model of the system [3].

The FLC steps is presented in section II, while in section III present studying the stability of DC Chopper-Fed PMDC Drives using Proportional integral (pi) Controller, section IV present Designing of Fuzzy pi controller for the speed control of nonlinear phenomena in a DC chopper-fed PMDC drive and finally in section V present the conclusion for that system.

II. FLC STEPS

Fuzzy logic controller (FLC) consists of fuzzification interface, fuzzy control rules, inference engine and defuzzification interface as shown in fig.1 [4].

![Basic structure of fuzzy logic controller](image)

Where $x_1, x_2$ are the inputs of the FLC, $u_t$ is fuzzy control action, $u$ is the crisp control action and $G_1, G_2, G_3$ are gains of input and output.

A. FUZZIFICATION

The fuzzification strategy converts the crisp input data into fuzzy sets (linguistic variables) and consists of membership functions that describe the fuzzy rules. These functions can be triangle, trapezoidal, quasi-linear and Gaussian shaped. The triangular-shaped is usually used as membership.

B. FUZZY CONTROL RULES

We represent the fuzzy control rules by the form:

**IF (Process state) THEN (actions can be inferred)**

This describe what action should be taken from currently information, which includes both input and feedback if a closed-loop control system is applied [5, 6].

C. INFERENCE ENGINE

Converts the input fuzzy sets to the output fuzzy set. The most important two types of fuzzy inference method are Mamdani and Sugeno fuzzy inference methods [5, 6]. Fuzzy madmani inference system is shown in fig.2
I. INTRODUCTION

The control of nonlinear phenomena in a DC chopper-fed PMDC drive is of great interest in the field of electrical engineering. This paper presents a study on the stability analysis of the system using proportional (P) and proportional-integral (PI) controllers. The parameters of the system are:

\[ R = 7.8 \Omega, \quad L = 5\text{mH}, \quad T_L = 0.087\text{NM}, \quad K_e = 0.0984\text{Vs/rad}, \]
\[ K_t = 0.09\text{NM/A}, \quad \omega_{ref} = 100\text{rad/s}, \quad B = 0.000015\text{Nm rad/sec}, \]
\[ J = 4.8400e-005\text{Nm rad sec}^2, \quad f_s = 20\text{kHz}, \quad T = 0.05\text{ms}, \quad V_L = 0, \quad V_U = 8\text{V}. \]

The nominal behavior of a DC chopper-fed PMDC drive employing the P controller is a period-1 orbit at \( V_{in} = 24\text{V} \) and \( K_P = 2200 \) (Figs. 5 and 6). But as the proportional gain \((K_P)\) or the supply voltage \((V_{in})\) is varied, the period-1 orbit loses stability via period-doubling bifurcation \([1, 11]\) and further variation will lead to chaos. When the proportional gain fixed at 2200 and varying the supply voltage, the fast scale bifurcation occurred at \( V_{in} = 32\text{V} \) (figs.7 and 8). Further variation of the supply voltage leads to chaos (figs.9 and 10).

II. CONTROL OF NONLINEAR PHENOMENA

The control of nonlinear phenomena in a DC chopper-fed PMDC drive employs PI controller is a period-1 orbit at \( V_{in} = 24\text{V} \) and \( K_{P} = 2200 \) (Figs. 5 and 6). But as the proportional gain \((K_{P})\) or the supply voltage \((V_{in})\) is varied, the period-1 orbit loses stability via period-doubling bifurcation \([1, 11]\) and further variation will lead to chaos. When the proportional gain fixed at 2200 and varying the supply voltage, the fast scale bifurcation occurred at \( V_{in} = 32\text{V} \) (figs.7 and 8). Further variation of the supply voltage leads to chaos (figs.9 and 10).

III. STUDY THE STABILITY OF THE SYSTEM WITH PROPORTIONAL (P) CONTROLLER

A. SYSTEM OVERVIEW

This system consists of the power converter (dc chopper), control electronice and PMDC motor. The shaft speed can be controlled by control of the average voltage of the armature via pulse width modulation (PWM). A Schematic diagram of voltage mode controlled DC chopper-fed PMDC drive is shown in Fig.3. And the Simulink model of DC chopper-fed PMDC drive employing the P controller is shown in Fig.4.

B. DYNAMICAL BEHAVIOR OF THE SYSTEM

The nominal behavior of a DC chopper-fed PMDC drive employing the P controller is a period-1 orbit at \( V_{in} = 24\text{V} \) and \( K_{P} = 2200 \) (Figs. 5 and 6). But as the proportional gain \((K_{P})\) or the supply voltage \((V_{in})\) is varied, the period-1 orbit loses stability via period-doubling bifurcation \([1, 11]\) and further variation will lead to chaos. When the proportional gain fixed at 2200 and varying the supply voltage, the fast scale bifurcation occurred at \( V_{in} = 32\text{V} \) (figs.7 and 8). Further variation of the supply voltage leads to chaos (figs.9 and 10).

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IV. STUDY THE STABILITY OF THE SYSTEM WITH PROPORTIONAL INTEGRAL (PI) CONTROLLER

A. SYSTEM OVERVIEW

A schematic diagram of the DC chopper-fed PMDC drive employing the proportional integral (PI) controller is shown in Fig. 11. and the Simulink model of DC chopper-fed PMDC drive employing the PI controller is shown in Fig. 12. The system is consists of three components are PMDC motor, DC chopper and PI controller. The voltage produced from the tacho-generator is proportional to the actual speed, this actual speed compared with the reference speed to obtain an error signal. This error signal is used by the controller to produce a control voltage \( V_{\text{con}}(t) \) that is compared with a sawtooth signal \( V_{\text{ramp}}(t) \) to produce the PWM signal. When the PWM signal is high, the switch turns ON, and the diode will be reverse biased (OFF). But when the PWM signal is low, the switch turns OFF, and the diode will be forward biased (ON), thus providing a return path for the decaying armature current. The mathematical model of the PI controlled PMDC drive is discussed in detail in [1, 10].
B. DYNAMICAL BEHAVIOR OF THE SYSTEM

The nominal behavior of a DC chopper-fed PMDC drive employing the PI controller is a period-1 orbit (Figs. 13 and 14). But as the integral gain (K_i) or the supply voltage (V_in) is varied, the Period-1 orbit loses stability via Neimark-Sacker bifurcation \[1, 11\] and a quasiperiodic orbit is born. Fixed K_p at 1 and K_i at 1580 and varying the supply voltage, the Neimark-Sacker bifurcation occurred at V_in = 57 V (Figs. 15 and 16). Further variation of the supply voltage (V_in = 65 V) convert the system from CCM to DCM (Figs. 17 and 18).

Fig. 11 a schematic diagram of the DC chopper-fed PMDC drive employing the PI controller.

Fig. 12 the Simulink model of DC chopper-fed PMDC drive employing the PI controller.

Fig. 13 period-1 (a) and (b) current trajectories in time domain at V_in = 24 V.

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V. DESIGNING OF FUZZY PI CONTROLLER FOR THE SPEED CONTROL OF NONLINEAR PHENOMENA IN A DC CHOPPER-FED PMDC DRIVE

Fuzzy logic is suitable for a model that is difficult to control and non-linear ones [2, 7]. Fuzzy controller provide better results than other controllers. Fuzzy logic controller (FLC) can decrease the nonlinearity effectiveness in a DC motor and progress the execution of a controller [8].

A. SYSTEM OVERVIEW

The basic structure of fuzzy pi controller is shown in fig. 19.
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Fig. 19 The basic structure of fuzzy pi controller

As shown in Fig. 19 there are two inputs, one is the control error $e(k)$, which is the difference between the reference signal $r(k)$ and the output signal $y(k)$, the other one is the change in this error $\Delta e(k)$ and one output is change of control output $\Delta u(k)$. The equations of inputs and output is expressed as:

1. $e(k) = r(k) - y(k)$
2. $\Delta e(k) = e(k) - e(k-1)$
3. $u(k) = u(k-1) + \Delta u(k)$

Where $r(k)$ is reference speed, $y(k)$ is actual speed, $e(k-1)$ is previous error, $u(k)$ is control output and $u(k-1)$ is previous control output.

Simulink model of the system using Fuzzy pi controller is shown in Fig. 20 and the Simulink model of fuzzy pi controller block is shown in Fig. 21.

Fuzzy mamdani inference developed for the FLC of the system is shown in Fig. 22.

In this design 5 membership functions for each input (error & change in error) and output (change in control signal) are used: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big) and are shown in Fig. 23.

Fig. 20 Simulink model of the system using Fuzzy pi controller

Fig. 21 Simulink model of fuzzy pi controller block

(a) Membership functions for error

(b) Membership functions for change of error

(c) Membership functions for change of control signal.

Fig. 22 Fuzzy mamdani inference developed for the FLC of the system

Fig. 23 Membership functions for inputs and output
In order to model the actions that a human operator would decide the change in the controller output (Δu) according to the error e and its change Δe, it is necessary to observe the behaviors of the error signal e and its change Δe on different operating regions. Therefore, the signs of e and Δe are used to determine the signs of Δu. The sign of Δu should be positive if u is required to be increased and it should be negative otherwise. The fuzzy rule base (fuzzy decision table) is shown in Table I.

<table>
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<tr>
<th>Δe</th>
<th>e</th>
<th>NB</th>
<th>NS</th>
<th>ZZ</th>
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B. DYNAMIC BEHAVIOR OF DC CHOPPER FED PMDC DRIVES EMPLOYING THE FUZZY PI CONTROLLER.

Fuzzy pi controller make the PMDC motor speed control smooth, FLC Performs fast tracking speed and zero or very small steady state error is observed as shown in fig.24. FLC leads to a stable system.

When V_{in}=24 volt the period-1 speed and current are shown in fig.24 and period-1 phase portrait is shown in fig.25. By varying the supply voltage to 57 the system still stable as shown in figs. (26 and 27). Further variation of the supply voltage doesn’t lead to change the stability of the system and still in period-1 as shown in figs. (28 and 29).

Fig.24 period-1 (a) speed and (b) current trajectories in time domain at V_{in}=24 V.

Fig.25 Period-1 phase portrait of speed against current at V_{in}=24 V.
VI. CONCLUSIONS

In this paper we use waveforms and phase portrait to study the occurrence of nonlinear phenomena. Fuzzy pi controller make the PMDC motor speed control smooth, FLC Performs fast tracking speed and zero or very small steady state error is observed. FLC leads to a stable system as shown in V.

REFERENCES


