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Research Article

CHAOTIC BEHAVIOUR OF DC DRIVES

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Abstract: Chaotic dynamical behaviour of a chopper fed dc drive has been investigated. Bifurcation behaviour of the system is observed by varying system parameters. The route of transition from periodic behaviour to chaos has been investigated and quantified by maximum Lyapunov exponent.

Keywords: Chaos, Bifurcations, DC drive.

1. Introduction

Chaos is aperiodic long-term behaviour in a deterministic system that exhibits sensitive dependence of initial condition. Most of the system available are nonlinear in nature. But most of the time and energy is spent in understanding a linear system. Moreover analysis of nonlinear system is also carried out with the help of theory developed for linear systems. But there are limitations of the analysis of nonlinear system in the light of linear control theory. This analyses the behaviour of a nonlinear system by local linearization. But this approximation fails to reveal actual behaviour of the nonlinear system. A fascinating phenomenon of a nonlinear system is the occurrence of chaos. The crucial importance of chaos is that it provides an explanation for random behaviour of nonlinear system that depends on neither noise nor complexity. Chaos theory provides with tools to carry out this analysis.

A DC drive is extensively used in the industry. To know the behaviour of the DC drive is of importance for its proper functioning and design. Since PWM controlled DC drive is nonlinear in nature, the occurrence of chaos and routes to chaos has been investigated in the light of chaos theory.

Chakrabarty et al. [1,2] reported chaos in PWM controlled dc series drive by numerical simulation. Chaotic behaviour of simple industrial motor drives with permanent magnet DC motor has been reported in [3]. Chau et al. [4] investigated the nonlinear dynamics and chaotic behaviour of chopper fed permanent magnet motor drive. Bifurcation behaviour of dc series drive has been reported by Chakrabarty et al. in [5]. Chaoization of dc motor has been reported by Chakrabarty et al. in [6].

The behaviour of the DC drive has been investigated by the use of a simulation tool. Simulation test is particularly useful if model creation of real system is complicated and time consuming. MATLAB- Simulink (MATLAB 1992, Simulink 1992) is used in this simulation test because of the following reasons:

- An apparently simplified procedure that exonerates a designer from encoding his mathematical model in the programming language adopted.
- A possibility of a multiple of the basic mathematical models gathered at the libraries and combined as needed.
- A possibility of the examining system with models having appreciable extended ranges of parameters in particular to systems used for investigation of bifurcation behaviour and chaos.
- A possibility of comparing theoretical and experimental results.
- A relatively short simulation time due to rapid and effective calculating algorithm built in the package.
- A possibility of visualization of the calculation result and their recording for further use.

So, in this work, chaotic behaviour of DC drive has been virtually experimented by MATLAB simulation. Behavioural change of the system due to change in input voltage has been reported by bifurcation diagram.

2. The System

The block diagram and equivalent circuit of the DC drive circuit is shown in the Fig. 1and 2 respectively. The output of the speed sensor (ω) is compared with the reference speed (ω_{ref}) in the comparator A_1. The difference of ($\omega - \omega_{ref}$) is compared with a ramp voltage. The output of the comparator A_2 is used to switch on the switch for the chopper drive. When control voltage V_{co} exceeds ramp voltage power switch of the chopper is off and diode is on; otherwise the power switch is on and diode is off. The system is linear in nature except the switch. The chaotic behaviour of the system is due to switching nonlinearity.

3. Modeling of Drive

With reference to Fig. 2, i(t) is the armature current, R, armature resistance, L, armature inductance, V supply voltage, K_E back emf constant, K_T torque constant, B viscous damping, J load inertia and T_l load torque.

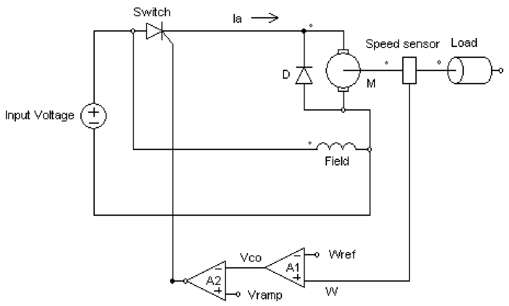

Fig.1. Schematic diagram of DC drive

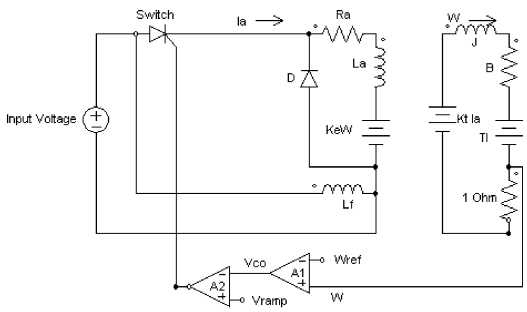

Fig. 2. Equivalent circuit of DC drive

The system equations are given by

$$L\frac{di}{dt} = -R_a i - K_E\omega + V$$
$$J\frac{d\omega}{dt} = K_T i - B\omega - T_l \qquad (1)$$

Motor speed, ω is controlled by naturally sampled constant frequency pulse width modulation. The operational amplifier A1 has gain G. The control signal, $V_{co}(t) = G[\omega(t) - \omega_{ref}(t)]$

where, $\omega(t)$ and ω_{ref} are instantaneous motor speed and reference speed respectively, compared with a ramp signal V_{ramp} in the comparator A2. The ramp is given by:

$$V_{ramp} = V_l + (V_u - V_l)\frac{t}{T},$$

where V_u and V_l are upper and lower level of ramp having period T.

As shown in Fig. 1, a simple dc chopper fed PM dc motor drive operating in the continuous current mode is used. This corresponding equivalent circuit as is shown in Fig. 2. The system can be divided into two stages depending on the switching conditions.

The switch will be 'on' when $V_{co}<V_{ramp}$. The corresponding system equations are:

$$\frac{d}{dt}\begin{bmatrix} i(t) \\ \omega(t) \end{bmatrix} = \begin{bmatrix} \frac{-R}{L} & \frac{-K_E}{L} \\ \frac{K_T}{J} & \frac{-B}{J} \end{bmatrix} \begin{bmatrix} i(t) \\ \omega(t) \end{bmatrix} + \begin{bmatrix} \frac{V}{L} \\ \frac{-T_l}{J} \end{bmatrix}$$

The switch will be 'off' when $V_{co}>V_{ramp.}$ The corresponding equations are:

$$\frac{d}{dt}\begin{bmatrix} i(t) \\ \omega(t) \end{bmatrix} = \begin{bmatrix} \frac{-R}{L} & \frac{-K_E}{L} \\ \frac{K_T}{J} & \frac{-B}{J} \end{bmatrix} \begin{bmatrix} i(t) \\ \omega(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{-T_l}{J} \end{bmatrix}$$

By defining the state vector X (t) and the following matrices A, E_1, E_2, The system can be rewritten as

$$A = \begin{bmatrix} \frac{-R}{L} & \frac{-K_E}{L} \\ \frac{K_T}{J} & \frac{-B}{J} \end{bmatrix}, E_1 = \begin{bmatrix} \frac{V}{L} \\ \frac{-T_l}{J} \end{bmatrix}, E_2 = \begin{bmatrix} 0 \\ \frac{-T_l}{J} \end{bmatrix}$$

as $\dot{X}(t) = AX(t) + E_K$. Where K= 1, 2. K changes the value depending on 'on' or 'off' condition of the switch. Thus, the closed loop drive system is a second order non-autonomous dynamical system

4. Matlab Simulation

In order to study dynamic behaviour of the DC drives, parameters of drive system are as follows: $V_l=0, V_u=2.2$, $T=8ms$, $G=0.8$, $R=7.8\Omega$, $L=30.$ mH, $B=0.000654, J=0.00971, T_l=0.5$ Nm, $w_{ref}=100$ rad/sec. $K_T=0.1324$, $K_E=0.1356$.

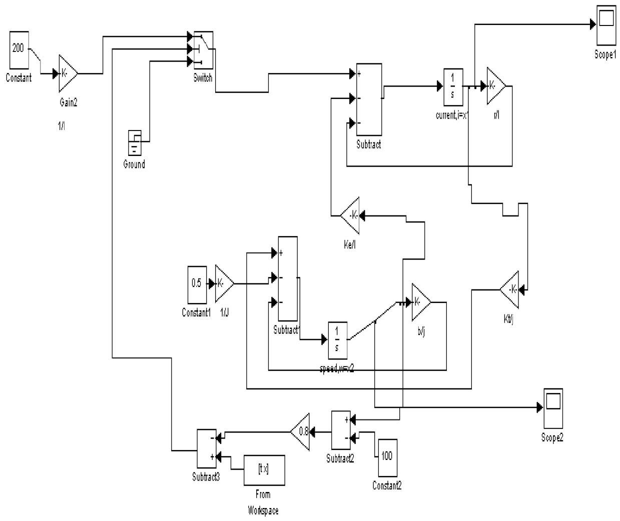

Fig. 3. Equations of the drive simulated with MATLAB.

5. The Result

The dynamic behaviour of the DC drive has been found from the simulation with MATLAB (Fig.3) at different values of parameters. The time plot of armature current has been shown in Fig.4 showing P-1 behaviour of the drive system. Fig.5 shows the time plot of speed and phase plot for period -1 behaviour at input voltage of 100 V. As input voltage is increased there is qualitative change of the behaviour of the dynamics. This is evident from Fig.6. Fig.6 shows time plot of armature current showing period-2 behaviour. The phase plot of the period-2 behaviour is shown in Fig.7. The time plot of armature current, speed and phase plot at input voltage 160 V has been shown in Fig.8 showing period-4 behaviour. Further increase of input voltage shows the change of dynamics from period-4 to period 8 and then to chaos as shown in the Fig.9,10 and 11 respectively. The phase plot at input voltage 200 V showing chaos is shown in Fig.12

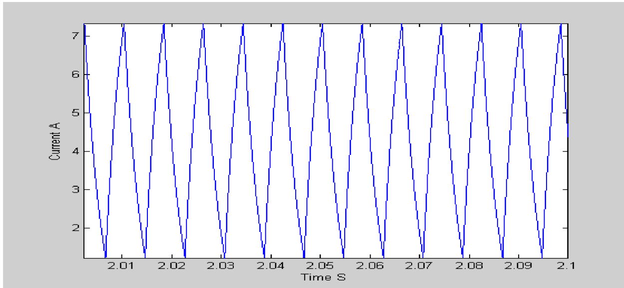

Fig.4. Time plot of armature current showing P-1 at input voltage 100V

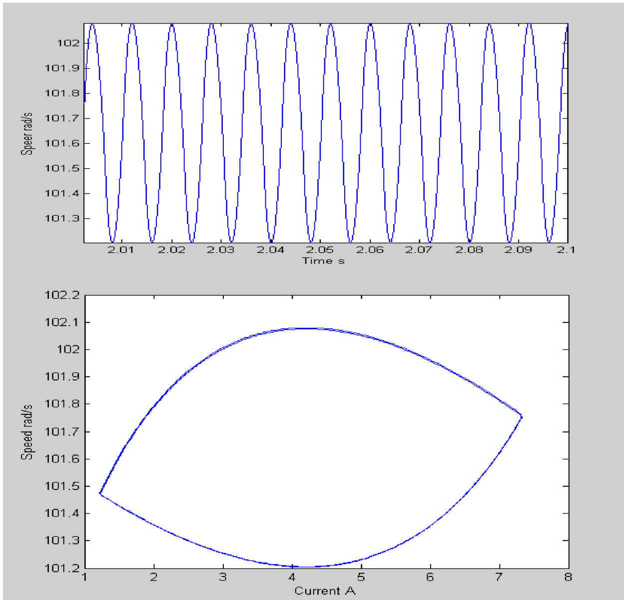

Fig.5. Upper: Time plot of speed; Lower: Phase plot of armature current and speed showing P-1 at input voltage 100V

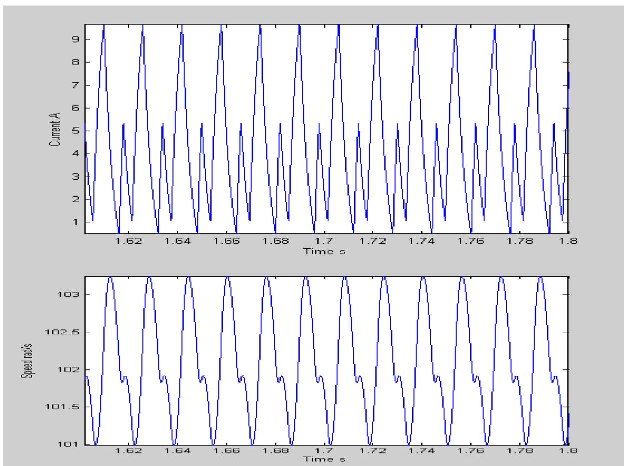

Fig. 6 Time plot of armature current, speed showing P-2 at input voltage 120 V

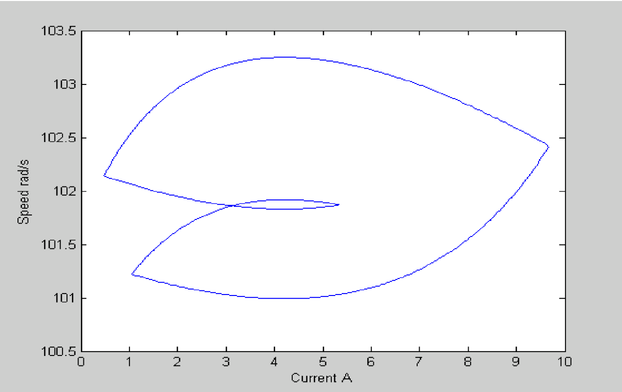

Fig.7. Phase plot showing P-2 at input voltage 120V

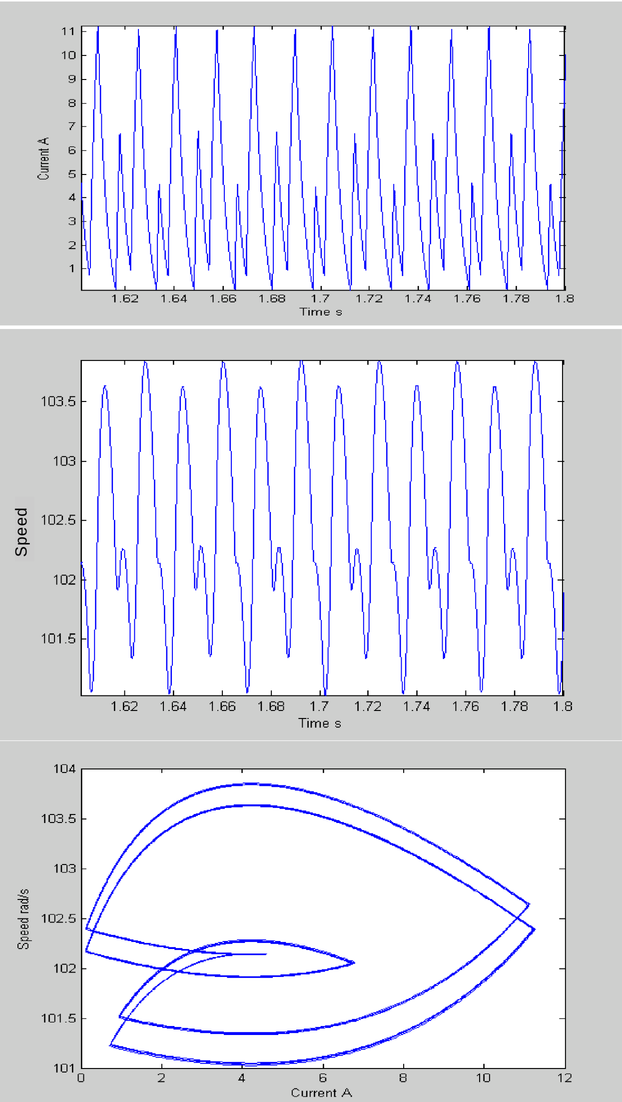

Fig: 8. Time plot of current, speed and phase plot showing P-4 at input voltage 160 V

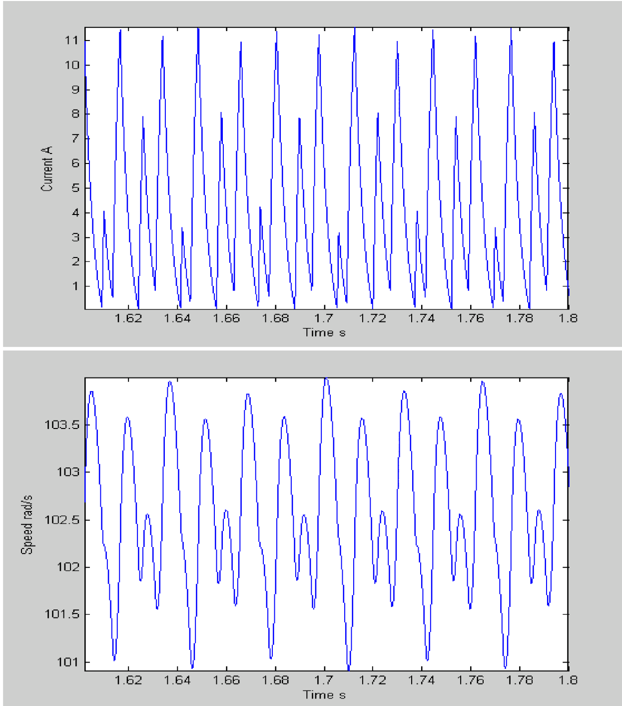

Fig: 9 Time plot of current and speed showing P-8 at input voltage 170.5 V

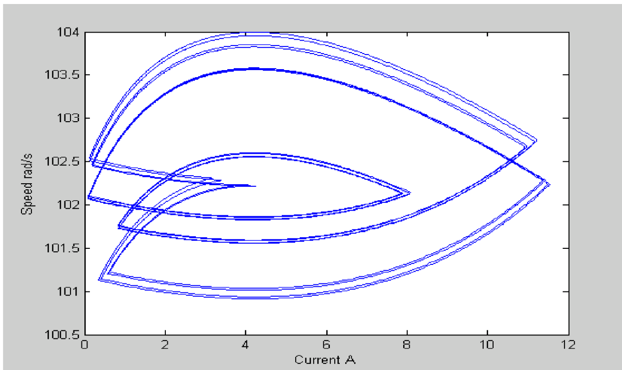

Fig: 10. Phase plot showing P-8 at input voltage 170.5V

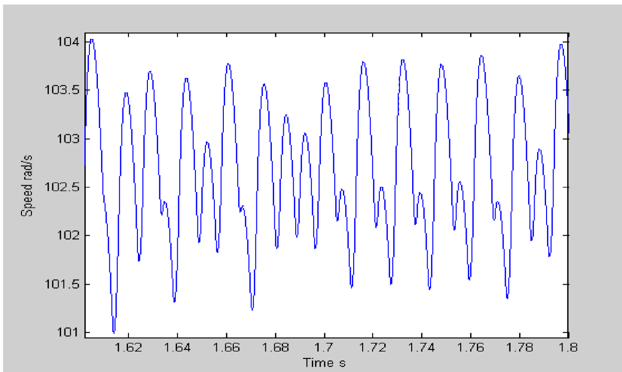

Fig.11. Time plot of speed showing chaos at input voltage 200V

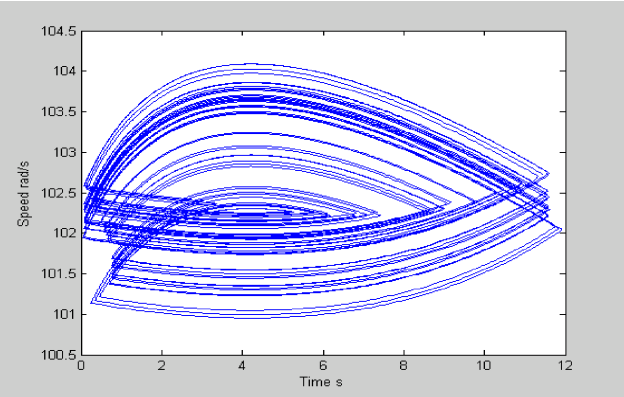

Fig: 12. Phase plot showing chaos at input voltage 200 V

The bifurcation diagram shown in Fig. 13 shows that a period doubling route to chaos is followed. The occurrence of chaos is quantified by maximum lyapunov exponent as show in Fig.13. The Period -1 behaviour is observed up to input voltage, 115V. Bifurcation to different periodic orbit and chaos is observed with the increase of input voltage. The system bifurcates to period-2 after period-1. After period-2, period-4 behaviour starts at voltage 158 V and continues up to 170 V. Period-8 behaviour is observed after that. The period-8 converges to chaos at 170.5 V.

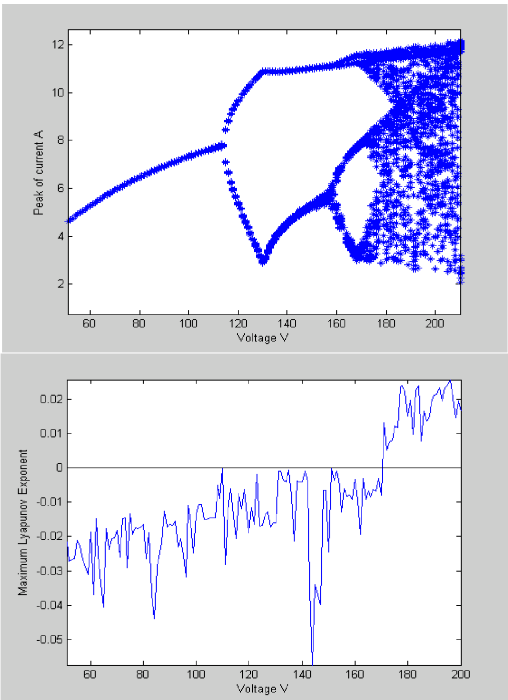

Fig.13. Bifurcation diagram with input voltage as parameter and plot of maximum Lyapunov exponent

6. Conclusion

In this paper occurrence of chaos has been demonstrated by MATLAB simulation. The bifurcation diagram drawn gives the behaviour of the system at different parameters. This information is very important for the designer to design the drive system.

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