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CONTROL OF CHAOS IN BLDC DRIVE

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Abstract- **The paper proposes a novel method to control chaos in brush less DC (BLDC) drive. A BLDC drive is a multivariable nonlinear system. A nonlinear system may exhibit chaotic behaviour for some value of system parameters. A BLDC drive also exhibits chaotic behaviour when it is subjected to a particular loading condition and input voltage. When the speed of the BLDC drive becomes chaotic for a particular load, the behaviour may not be desirable. There may be two options available. Either the load for which the drive becomes chaotic is removed or the drive is controlled to give the desired periodic behaviour. With direct feedback method, BLDC drive can be stabilized at one of the equilibrium points or it can be stabilized at the neighbourhood of its equilibrium point. In this paper, the equilibrium points of the system are obtained. The simulation result is obtained using MATLAB SIMULINK to establish the method of control that stabilises the BLDC drive to the desired period-1 stable state.**

Keywords — ***BLDCM, Direct feedback, Eigen-values , Linearization , MATLAB, SIMULINK.***

I. INTRODUCTION

Chaos is a well-known phenomenon of a nonlinear system. Such behaviour is characterized by sensitive dependence on initial conditions and existence of positive lyapunov exponents. In these days, it has applications on many fields like, communication, laser physics etc. L.N. Lorenz [1] reported the existence of chaotic behaviour in a nonlinear system in 1963. N. Hemati [2] showed the existence of chaotic behaviour in BLDC motor. Y.Zhihong et al [3] investigated the effect of nonlinearity in BLDC motor. In 1990, Ott, Grebogi and Yorke [4] developed the method, abbreviated as OGY method, to control any unstable periodic orbits in the chaotic attractor. G. Chen et al [5] offered an overview of the different interpretation and approaches for control of chaos for various nonlinear dynamical systems. Methods to control chaos have become a primary area of research particularly in nonlinear engineering and physical systems. Application of adaptive sliding mode control to control chaos in a class of system has been proposed [6]. An adaptive controller has been proposed in [7] to make the chaotic system robust against external disturbances. Continuous control of chaos by self controlling feedback was proposed by K. Pyragous [8]. There is very little work available in the literature about study of dynamic and control of chaos in BLDC drive. The scheme of sliding mode control was used to control of chaos in BLDC motor [9]. The approach of adaptive dynamic surface based on neural network with minimum weight was applied to BLDC motor for control of chaos [10]. P.P. Ray et al [11] carried out investigation on control of chaos in BLDC motor. The simulation results of the control scheme shows that when the BLDC motor system exhibits chaotic behaviour, it can be forced to zero state of the system so that the speed of the motor becomes zero. But to drive the speed of BLDC motor to zero is not the objective of the present work. Feedback methods are extensively used to stabilize the unstable periodic orbits of any chaotic system. In this paper, we propose a direct feedback method to control the dynamic behaviour of BLDCM system. By using such feedback a BLDC drive system can be stabilized at its nominal periodic-1 orbit.

II. THE DESCRIPTION OF BLDCM

The mathematical representation of BLDC drive system [2] in normalised form is described as

$$\begin{cases} \dot{x}_1 = -\mu x_1 + x_3 x_2 \\ \dot{x}_2 = -x_2 - x_3 x_1 + \gamma x_3 \\ \dot{x}_3 = -\sigma(x_3 - x_2) + v x_1 x_2 \end{cases} \quad \text{.....(i)}$$

Where x_1, x_2, x_3 are state variables representing direct axis current, quadratic axis current and angular velocity respectively.

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With $\mu = 1$, $\sigma = 5.58$ $\gamma = 19.55$ and $v = 0$, the BLDC drive shows chaotic behaviour. Now the transformed mathematical model of BLDCM without considering any external inputs can be expressed as:

$$\begin{cases} \dot{x}_1 = -x_1 + x_3 x_2 \\ \dot{x}_2 = -x_2 - x_3 x_1 + 19.55 x_3 \\ \dot{x}_3 = -5.58(x_3 - x_2) \end{cases} \quad \text{..... (ii)}$$

System (ii) is a typical class of nonlinear system and it can be evident from the simulation results shown in Fig-1 to Fig-6.

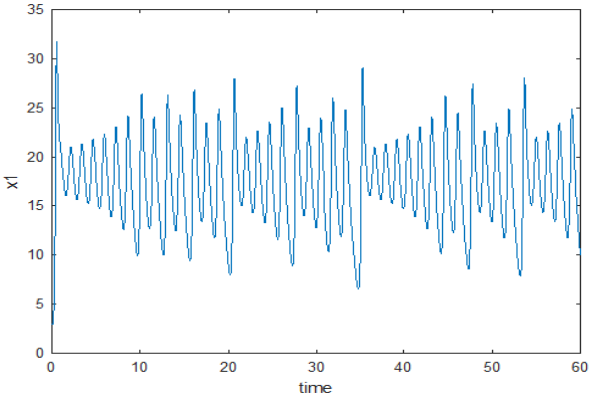

Fig. 1. Time response of direct axis current.

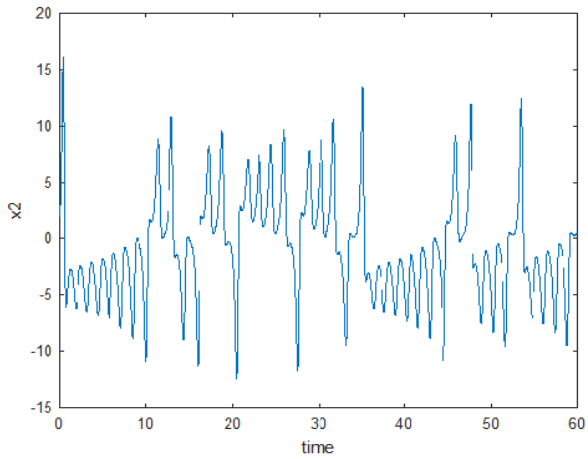

Fig. 2. Time response of quadrature axis current.

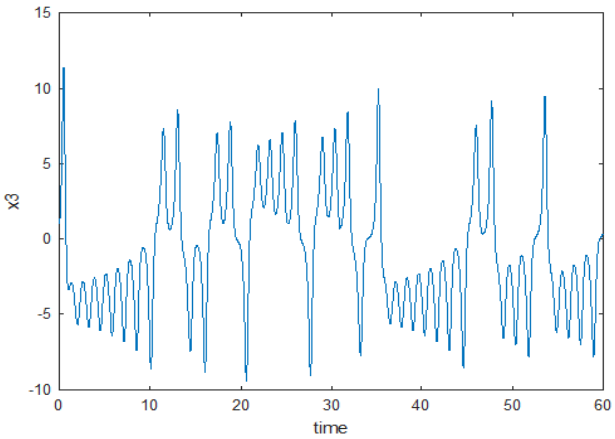

Fig. 3. Time response of transformed angular velocity.

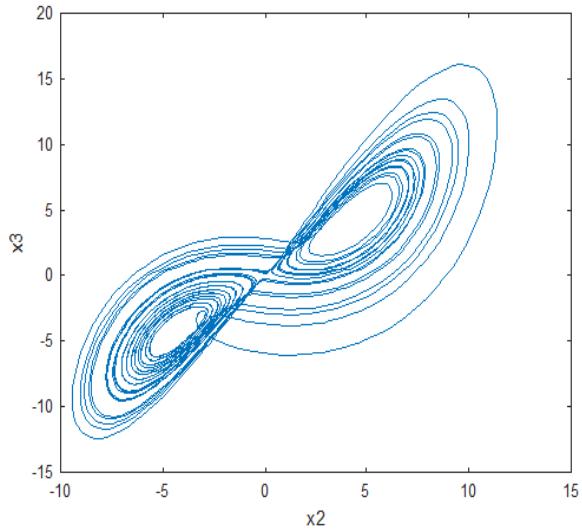

Fig. 4. Phase plane plot x_3 versus x_2.

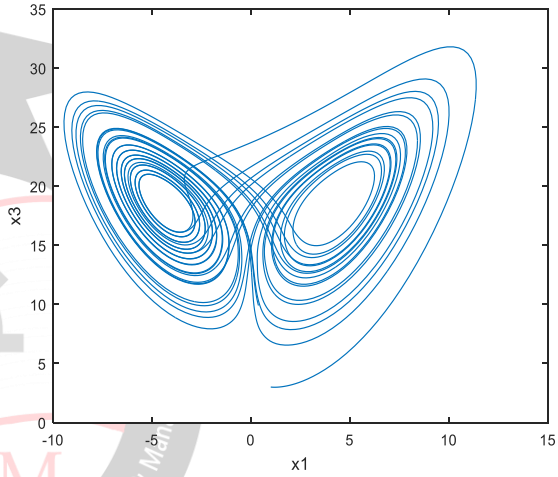

Fig. 5. Phase plane plot x_3 versus x_1.

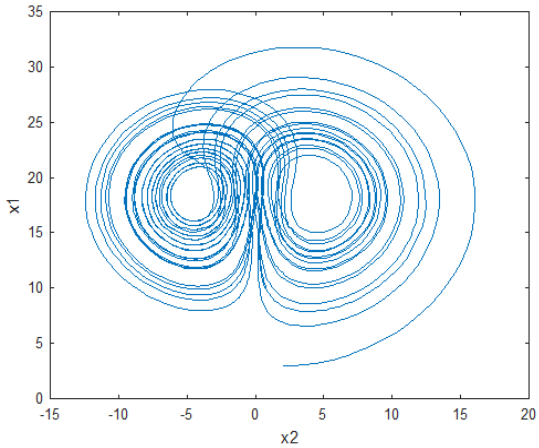

Fig. 6. Phase plane plot x_1 versus x_2.

The time plot of direct axis current, quadrature axis current and angular speed (Fig. 1, 2 & 3) shows aperiodic long-term behavior of the BLDC drive. This is the signature of the chaotic behavior. Moreover, the phase plot shown in Fig. 4, 5 and 6 shows that the trajectory does not converge to a limit cycle but to a strange attractor which is also a signature of chaotic behavior.

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III. THE CONTROL OF BLDC DRIVE SYSTEM USING FEEDBACK METHOD.

System (ii) has three equilibriums points i.e. $S_0 = (0,0,0)$, $S_1 = (18.55, 4.31, 4.31)$ and $S_2 = (18.55, -4.31, -4.31)$.

The BLDC drive system is to be stabilized at equilibrium point S_1 and the limit cycle surrounding S_1 respectively.

For that, the angular speed, x_3', is selected as feedback variable. This feedback variable is added to the third equation of (ii), and then the controlled BLDC drive system can be described as:

$$\begin{cases} x_1' = -1x_1 + x_3 x_2 \\ x_2' = -x_2 - x_3 x_1 + 19.55 x_3 \\ x_3' = -5.58(x_3 - x_2) - k(x_3 - 4.31) \end{cases} \quad \text{.....(iii)}$$

where k is the feedback coefficient of the equation shown.

The value of feedback coefficient is found as follows:

Now Jacobian matrix of system (iii) at S_1 is

$$J(S_1) = \begin{pmatrix} -1 & 4.31 & 0 \\ -4.31 & -1 & 19.55 \\ 0 & 5.58 & -5.58-k \end{pmatrix} \quad \text{.....(iv)}$$

If λ is the eigen value, then the characteristics equation of system (iv) is

$$\lambda^3 + c_1\lambda^2 + c_2\lambda + c_3 = 0 \quad \text{.....(v)}$$

Where

$c_1 = k + 7.58, c_2 = 2k - 78.3529, c_3 = 19.5761k + 103.8$

Now according to Routh –Hurwitz criteria, when $c_1 > 0, c_2 > 0, c_3 > 0$ and $c_1 c_2 - c_3 > 0$,the real parts of all the eigen-values of equation (iv) are negative, then the system (iii) will be stabilized at $S_1 = (18.55, 4.31, 4.31)$. The value of k is obtained as $k > 49$. The feedback variable is compared with a reference value. The error so obtained is multiplied by the gain "k" of the controller.

With the chosen value of $k = 50$, the plot of different state variables obtained from numerical simulation of system (iii) is shown in the fig.7, fig.8, fig.9 and fig 10.

When the critical value of k, the gain of the controller, is greater than 49 i.e. 50, the behavior of the system expressed in (iii) is a limit cycle surrounding S_1. By the same way, the BLDC drive can also be stabilized at S_0 or S_2 or at the desired limit cycle surrounding S_0 or S_2. From numerical solutions, we see that the BLDC drive may exhibit desired periodic behavior with the application of direct feedback controller and the chaotic behavior of BLDC drive disappears when control action is applied.

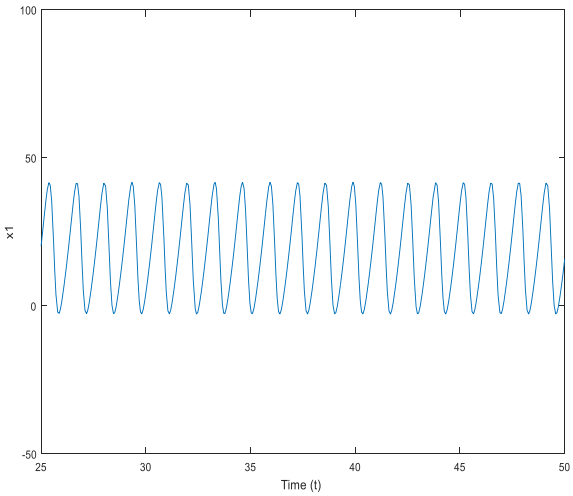

Fig. 7. Time plot of x_1 versus time.

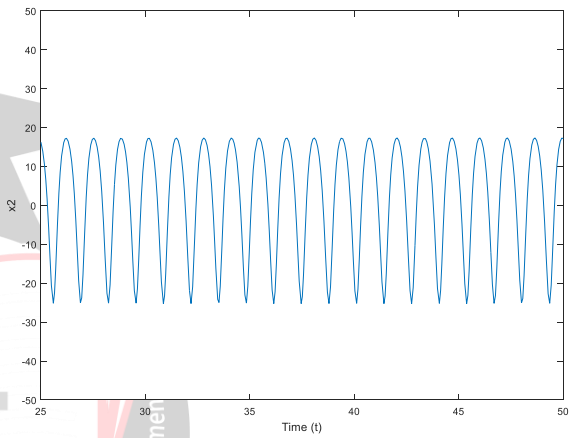

Fig. 8. Time plot of x_2 versus time.

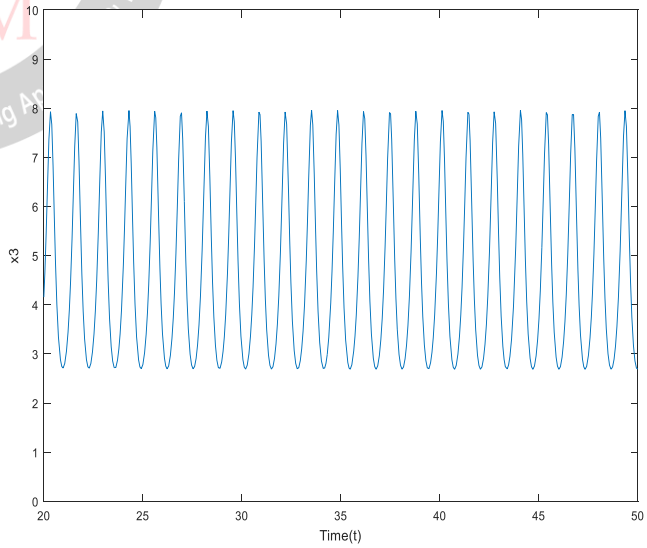

Fig. 9. Time plot of x_3 versus time.

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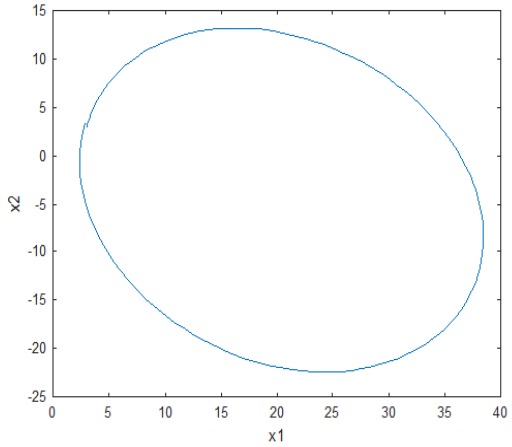

Fig. 10. Plot x_1 versus x_2 .

IV. RESULT

The equilibrium points of the BLDC drive are obtained. The range of value of the feedback coefficient,"K', for stable operation of BLDC drive, is obtained from the nature of values of eigen values of the characteristic equation. It is shown that the proportional controller is capable of controlling the BLDC drive at the desired equilibrium point. The time plot of the direct axis current, quadrature axis current and angular speed obtained from simulation with Simulink of MATLAB are shown in Fig: 7, 8 and 9 respectively. These time plots clearly show the period-1 response of the BLDC drive after application of control action. Moreover, the phase plot of different state variables shown in Fig. 10 confirms the period -1 behavior by a single loop in the limit cycle.

V. CONCLUSION

The proposed feedback controller is capable of controlling the chaotic BLDC drive to any desired equilibrium point. The strange attractor of BLDC drive has infinite number of unstable periodic orbits. Any desired unstable periodic orbit of the BLDC drive can be stabilized by the proposed feedback controller successfully. The value of feedback coefficient (K) can be calculated using Jacobian Matrix and characteristic equation. This method is very simple. The proposed method can easily be implemented in hardware.

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