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A Technique to Simulate Two Quadrant DC Chopper Fed Drives

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***Abstract*--This paper proposes as traditional control schemes, open-loop Hysteresis and closed-loop pulse –width-modulation (PWM) have been used for the separately excited motor (SEW) current controller. The Hysteresis controller induces large unpleasant audible noises because it needs to vary the switching frequency to maintain constant Hysteresis current band. In contract, the PWM controller is very quit but difficult to design proper gains and control bandwidth due to the nonlinear nature of the SEM. In this paper, ac small signal modelling technique is proposed for linearization of the SEM model such that a conventional PI controller can be designed accordingly for the PWM current controller. With linearized SEM model, the duty cycle to output transfer function can be derived, and the controller can be design with sufficient stability margins. The proposed PWM controller has been simulated to compare the performance against the conventional Hysteresis controller based system. It was found that through the frequency spectrum analysis, the noise spectra in audible range disappeared with the fixed switching frequency PWM controller, but was pronounced with the conventional Hysteresis controller.**

Keywords: - Chopper circuit, SEDM, Speed control.

I. INTRODUCTION

Although the dc machine is more expensive, the control principles and the converter equipment required are somewhat simpler compared to ac machines. The simplicity and flexibility of control of dc motors have made them suitable for adjustable speed drives. Also fast torque response has favoured their use in high performance servo drives. Class-C type chopper is widely used specially in the speed control of dc motors in industry as a drive circuit. The dc motor fed by a chopper is usually modelled by the average value of armature terminal voltage [11]. However this modelling does not include the ripples due to chopping of armature voltage.

II. MODELLING OF THE SYSTEM

Closed-loop speed control system in this studyconsists of a separately excited dc motor, chopper speed controller and current controllers.Block diagram representation of the system is asgiven in *"Fig. 1,"*.

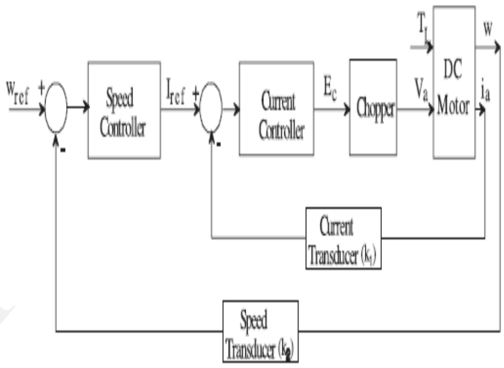

Fig.1 Block diagram of the DC motor speed control system

A. Modelling of DC Motor

The mechanical and electrical behaviour of a DC motor is described in continuous time domain bythe following well known equations [2]. as shown in *"Fig. 2,"*

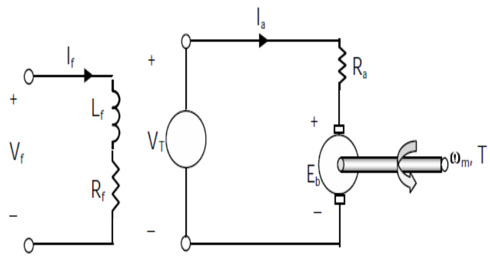

Fig.2 DC motor

$$Va = Ia.Ra + La\frac{dIa}{dt} + Eg \quad (1)$$

$$Eg = Ka\,.\varphi\,.\omega \quad (2)$$

$$Te = Tl + J\frac{dw}{dt} + Bv\,.\omega \quad (3)$$

$$Te = Ka\,.\varphi\,.Ia \quad (4)$$

Where,
Va:Armature voltage (Volt)
Ra:Armature resistance (Ohm)

Ia:Armature current (Ampere)
La: Armature inductance (Henry)
ω: Motor speed (rad/sec)
Eg: Back electromotive force voltage (Volt)
$Ka\,.\varphi$: Back electromotive force and torque constant (Volt/rd/sec or Nt-m/Ampere)
Te: Electromagnetic torque developed by the motor (Nt-m)
Tl: Load torque (Nt-m)
J : Total moment of inertia (kg-m2)
Bv: Viscous friction constant (Nt-m/rd/sec).

Since, in this study, the field current isassumed constant, $Ka\,.\varphi$ in Equation (2) andEquation (4) will be taken constant. The effectof armature current on the saturation has beenneglected. Consequently, Equations (1) to (4)can be written in the state-space form as

$$\frac{d}{dt}\begin{bmatrix} i_a(t) \\ w(t) \end{bmatrix} = \begin{bmatrix} -R_a/L_a & -K\varphi/L_a \\ K\varphi/J & -B_v/J \end{bmatrix} \cdot \begin{bmatrix} i_a(t) \\ w(t) \end{bmatrix} + \begin{bmatrix} 1/L_a & 0 \\ 0 & -1/J \end{bmatrix} \cdot \begin{bmatrix} V_a(t) \\ T_L(t) \end{bmatrix}$$

follows

(5)

or in the compact form

$$\frac{d}{dt}X(t) = A.X(t) + B.u(t) \qquad (6)$$

And the output equation can be written as given Below

$$Y = CX + DU \qquad (7)$$

Therefore the transfer function matrix is

$$H(s) = C.(SI - A)^{-1} \qquad (8)$$

Where
X is the state vector
U is the input vector
Y is the output vector
H is the transfer function vector
I is the unity vector
A, B, C, D is coefficient of appropriate dimension.
The transfer function model of separately excited DC Motor as shown in *"Fig. 3,"*

B. Modelling of Chopper

In this study, a class-C chopper whose loadvoltage is positive whereas load current is bothpositive and negative is considered. The chopper circuit and its output PWM Voltage waveform is given in "Fig. 4," In the circuit, the time ton inwhich load is connected to input voltage can bechanged via control signals, I_{c1} and I_{c2}.

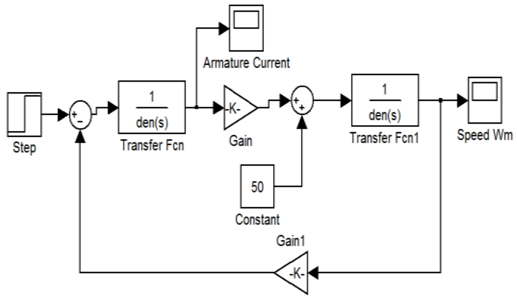

Fig.3 Transfer function model of separately excited DC Motor

In theclosed-loop system, I_{c1} and $I_{c2}$are related to thecurrent controller output signal (E_c) and thepeak value of saw tooth signal (E_{sw}) as being seenin Figure4, and the following equations can bewritten

$$t_{on} = \frac{T}{E_{sw}} E_c; \text{ For } 0 \leq E_c \leq E_{sw} \qquad (9)$$

$$t_{on} = T \;; \text{ For } E_c > E_{sw} \qquad (10)$$

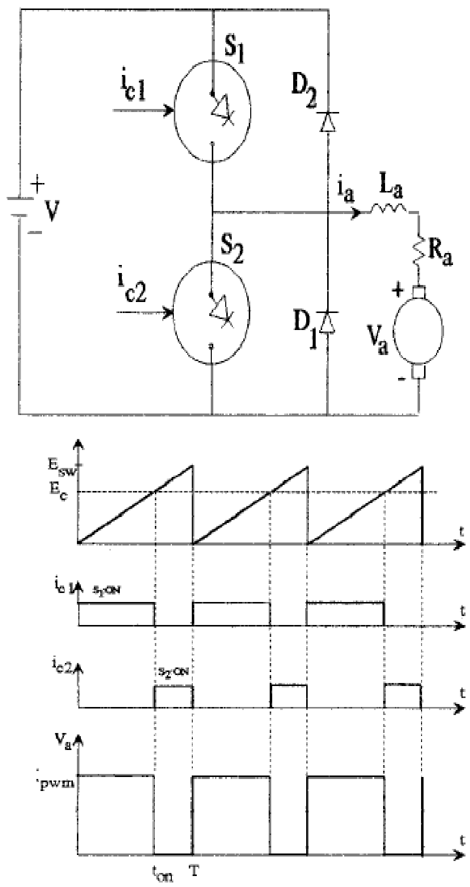

Fig. 4 *Class-C chopper circuit and related Waveforms*

Therefore, the problem in the simulation ofthe system is to generate the real time modelling of the PWM waveform in each period as a function of the duty cycle (α) defined as ton/T.This can be accomplished via Mat lab if the ztransformationof the PWM waveform during aperiod is known. If it is assumed that the PWMsignal is high at the beginning of a period, thenthe z-transform of the PWM waveform over oneperiod whose amplitude is K_{pwm}volts [3]. The Simulink model of class- C chopper as shown in "Fig. 5,"

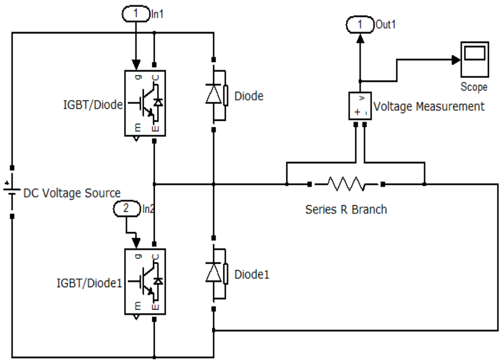

Fig.5 *Simulink model of class- C chopper.*

III. COMPLETE MODEL OF SPEED CONTROL OF DC CHOPPER DRIVES

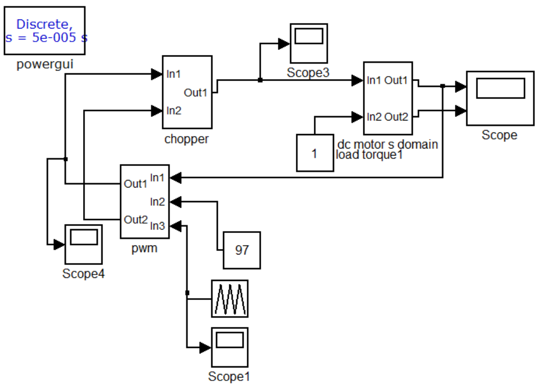

Fig. 6 Block diagram representation of Simulink model

The speed control circuit of a SEDM using Simulink is shown in "Fig. 6,".

IV. SIMULATION RESULTS

Simulation has been performed with the help of the software named Simulink [5]. The Simulink model of the system used for the simulation is given in the figure6. The discrete transfer functions of the speed and current controllers in the Simulink model are given in equations. The blocks "Step Fun" and "Step Fun" represents the reference speed and load torque respectively. The subsystem named "DC motor" consists of transfer functions given in figures. The PWM waveform at the output of the chopper has been generated by comparing the output of the current controller to the saw tooth waveform. This comparison is performed by receiving the value of Ec, from the simulation program. The computation of the duty cycle depending on this value of saw tooth wave is made in a dedicated program written in Mat Lab. Receiving the duty cycle as a result of this computation. The PWM waveform has been generated as mentioned and the data is transferred to the Simulink in order to continue to the simulation of the system. This communication between Simulink and dedicated program is carried out via the blocks given in "Fig. 6," once in every sampling period. In this study 110 volt,2.5hp, 1800rpm separately excited DC motor having the following parameters is used. Ra=1ohm, La=46mH, J=0.093kgm2,Bv=0.008Nt-m/rd/sec, K=0.55volt/rd/sec. the other parameters used in the simulation are as follows amplitude of PWM armature voltage Kpm=110volt,peak value of saw tooth waveform E=12vol,reference speed Wref=80 rad/sec, load torque Tl=0.in addition, the linear gain of current and speed transducer have been chosen unity. "Figs. 7," & 8 shows therotor speedand variation of the armature current in time obtained from the simulation of the system for the chopping frequency of 1 kHz. The"Fig. 10," shows change of the armature current and rotor speed obtained from the average value model. The ripple on the current waveform in figure8 is a result of the discrete modelling of the PWM,however, the smooth variation of the same waveform in "Fig. 9," reflects the continuous change of armature voltage in average value modelling. Figure11 shows the waveform at the PWM generator.

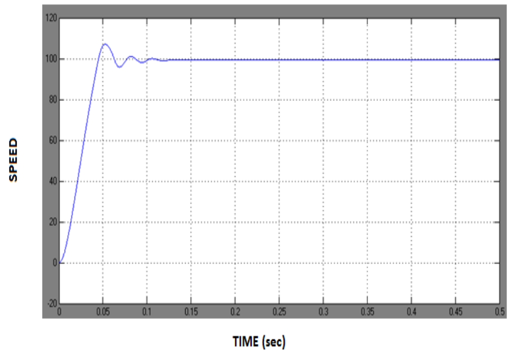

Fig.7 Controlled Speed waveform of dc drive

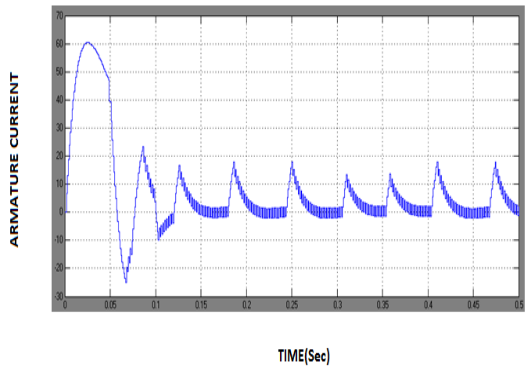

Fig.8 Armature current control waveform of class –C chopper using Z-Transform

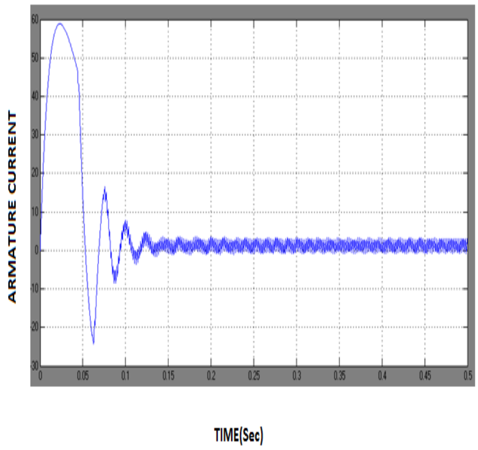

Fig.9 Armature current control waveform of class –C chopper using Laplace Transform

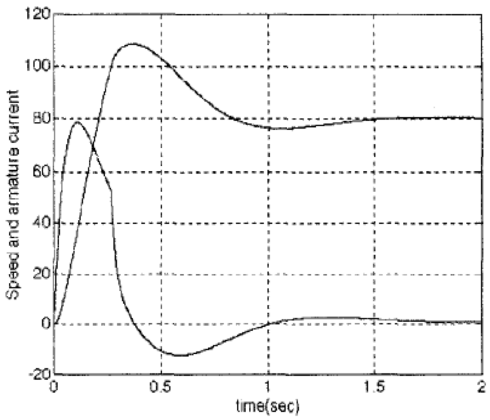

Fig.10 Results from the average value model.

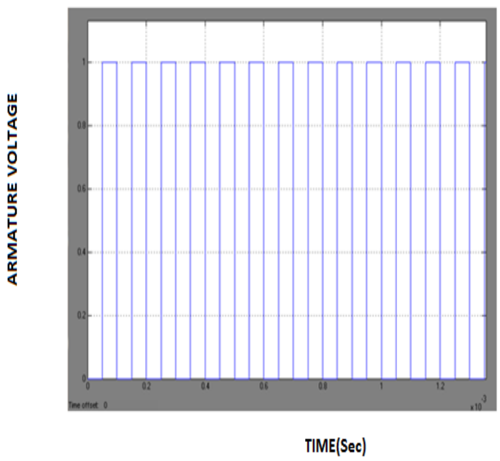

Fig.11 PWM waveform at the armature Terminal

V. CONCLUSUON

A separately excited DC motor controlled by the class-c chopper and current & speed controllers is modelled in Simulink model.
Therefore, all the harmonics of the PWM waveform are covered by the model andthe model is brought into the linear form with outputs.

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