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SMALL-SIGNAL ANALYZING OF SEPARATELY EXCITED DC MOTOR FED DC - DC CHOPPER

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ABSTRACT

Choppers are widely used in order to get smooth speed characteristics of DC motors. If the load or input voltage is changed, a feedback control technique is used to get the constant speed. To design the proper feedback control, the transfer function of the chopper-motor combination should be known.

In this study, the effort was given to obtain the general block diagram, including the field current and armature current of chopper-fed DC motor. It can be seen from the block diagram that the chopper circuit modifies the transfer function of the DC motor.

DC-DC DARBELEYİCİ İLE BESLENEN YABANCI UYARTIMLI DC MOTORUN KÜÇÜK SİNYAL ANALİZİ

ÖZET

DC motorlardan düzgün bir hız karakteristiği elde etmek için darbeleyiciler çok kullanılır. Eğer yük ya da giriş gerilimi değişirse, sabit hız elde etmek için geribeslemeli kontrol tekniği kullanılır. Uygun bir geribesleme kontrolu tasarlamak için, darbeliyici-motor kombinasyonunun transfer fonksiyonu bilinmelidir.

Bu çalışmada, darbeleyici ile beslenen DC motorun alan akımı ve endüvi akımını da kapsayan genel blok diyağramını elde etmek için çaba gösterilmiştir. Blok diyagramından görülebileceği gibi, darbeleyici devresi DC motorun transfer fonksiyonunu değiştirmektedir.

I. INTRODUCTION

Choppers are widely used for speed control of DC separately excited motors as they offer high efficiency, quick response, wide speed control range and regeneration down to very low speeds [1]. All chopper circuits can be classified into two groups. (a) Load independent choppers, in which the output voltage waveform is either a square wave or can be approximated by a square wave. (b) Load dependent choppers, in which charging of the commutating capacitor is governed by load current. In such cases, the output voltage waveform is neither a square wave nor can be approximated by a square wave. Various methods of analyzing of DC motors fed by a chopper with square wave output voltage are reported in references [2-4].

Figure 1 shows a schematic circuit diagram of a DC separately excited motor fed by chopper.

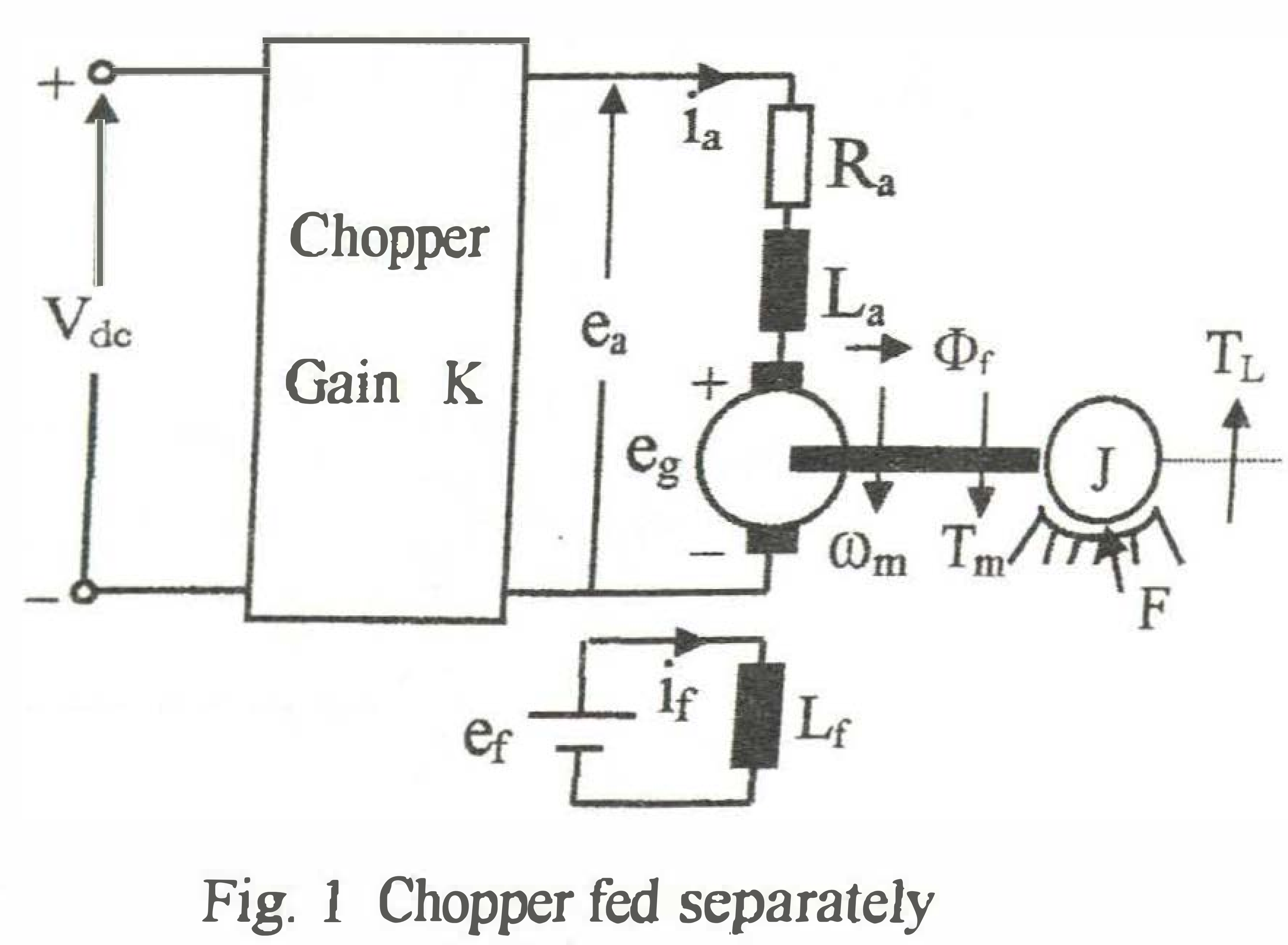

Fig. 1 Chopper fed separately excited DC motor

In this DC motor, back emf coefficient K_E is considered constant and does not change with the armature current. The performance equations of the motor can be written as below [5].

$$e_a = V_{dc}\ K \quad (1)$$

$$e_a = R_a i_a + L_a \frac{d}{dt} i_a + e_g \quad (2)$$

$$e_g = K_E\ i_f\ \omega_m \quad (3)$$

$$T_{em} = K_T\ i_f\ i_a \quad (4)$$

$$T_m = J \frac{d}{dt} \omega_m + F\ \omega_m + T_L \quad (5)$$

Where,

V_{dc} = supply voltage
e_a = armature voltage
K = duty-cycle
T_{em} = electromechanical torque
T_m = mechanical torque
T_L = load torque
F = viscous friction constant.

For analyzing small-signal dynamic performance of the motor-load combination around a steady-state operation point, the following equations can be written in terms of small deviations around their steady-state values [6].

$$\Delta e_a = K\ \Delta V_{dc} \quad (6)$$

$$\Delta e_a = R_a\ \Delta i_a + L_a \frac{d}{dt} \Delta i_a + \Delta e_g \quad (7)$$

$$\Delta e_g = K_E\ \Delta i_f\ \Delta\omega_m = K_E(I_{fo}\Delta\omega_m + \omega_{mo}\ \Delta i_f) \quad (8)$$

$$\Delta T_{em} = K_T \Delta\ i_f\ \Delta\ i_a = K_T(I_{fo}\ \Delta\ i_a + I_{ao}\ \Delta\ i_f) \quad (9)$$

$$\Delta T_m = J \frac{d}{dt} \Delta\omega_m + F\Delta\omega_m + \Delta T_L \quad (10)$$

If we take Laplace transform of these equations, where the Laplace variables represent only the small-signal Δ values in equation 6 through 10.

$$\Delta E_a(s) = K\ \Delta V_{dc}(s) \quad (11)$$

$$\Delta E_a(s) = R_a\Delta I_a(s) + sL_a\Delta I_a(s) + \Delta E_g(s) \quad (12)$$

$$\Delta E_g(s) = K_E(I_{fo}\Delta\omega_m(s) + \omega_{mo}(s)\ \Delta I_f(s)) \quad (13)$$

$$\Delta T_{em}(s) = K_T(I_{fo}\Delta I_a(s) + I_{ao}\Delta I_f(s)) \quad (14)$$

$$\Delta T_m(s) = Js\Delta\omega_m(s) + F\Delta\omega_m(s) + \Delta T_L(s) \quad (15)$$

These equations for the motor-load combination can be represented by transfer-function blocks as in Figure 2. As it can be seen in Figure 2, inputs to the motor-load combinations are the field current $\Delta I_f(s)$, armature terminal voltage $\Delta V_{dc}(s)$ and the load torque $\Delta T_L(s)$.

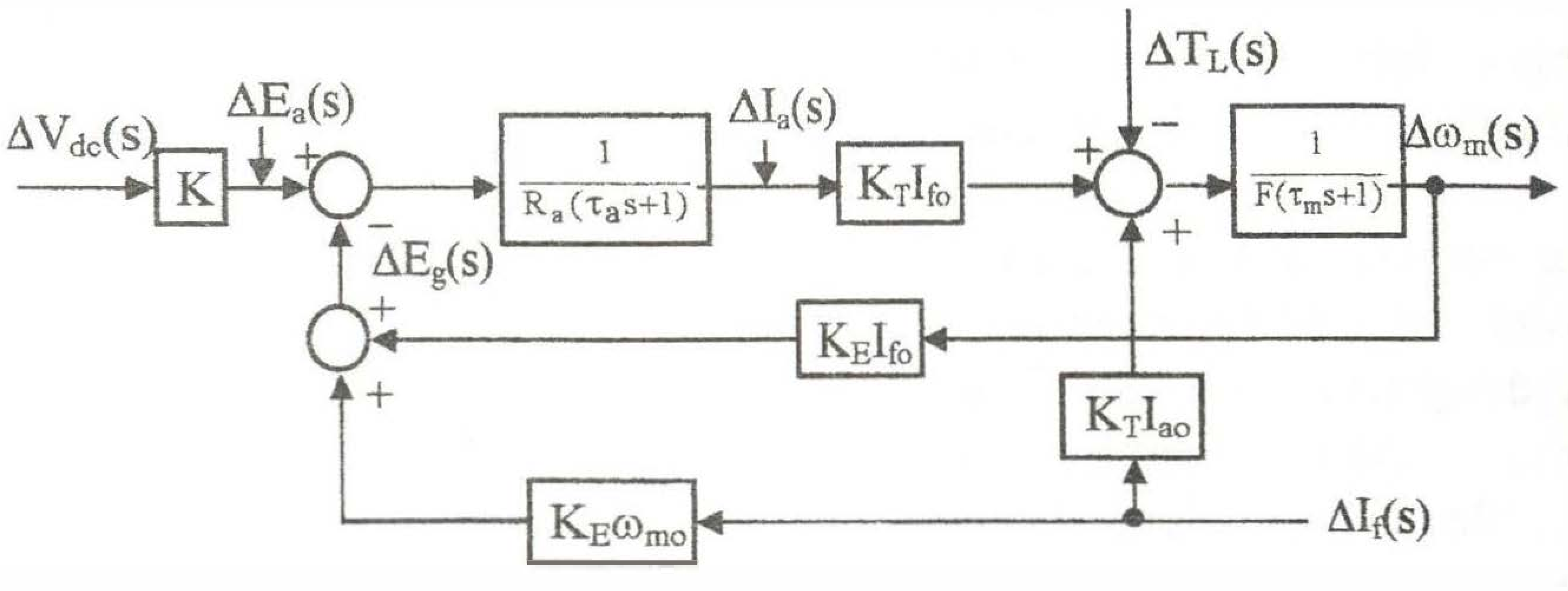

Fig. 2 Open-loop block diagram of the chopper fed separately-excited DC motor.

II.THE CHOPPER-MOTOR COMBINATION

The chopper-motor combination is shown ı Figure 3. It is a step-down chopper, having utstanding feature and ability to start ommutating reliably. In this chopper, T_1 is the ıain switch and T_2 is the auxiliary switch. L_1 and ·₂ are closely coupled inductors.

<u>Assumptions:</u>

- Flux proportional to i_f.
- Commutating time is very short compared to the switching period T, so it can be neglected.
- Chopper is operating in the continuous mode.
- When the main switch $T_1$is ON, the series inductance is $L = L_1 + L_a$ and when the main switch is OFF, the inductance is $L_a = L$.
- L_1 and L_a have close values.

Under these conditions, the block diagram f the chopper-fed separately excited DC motor vill be developed.

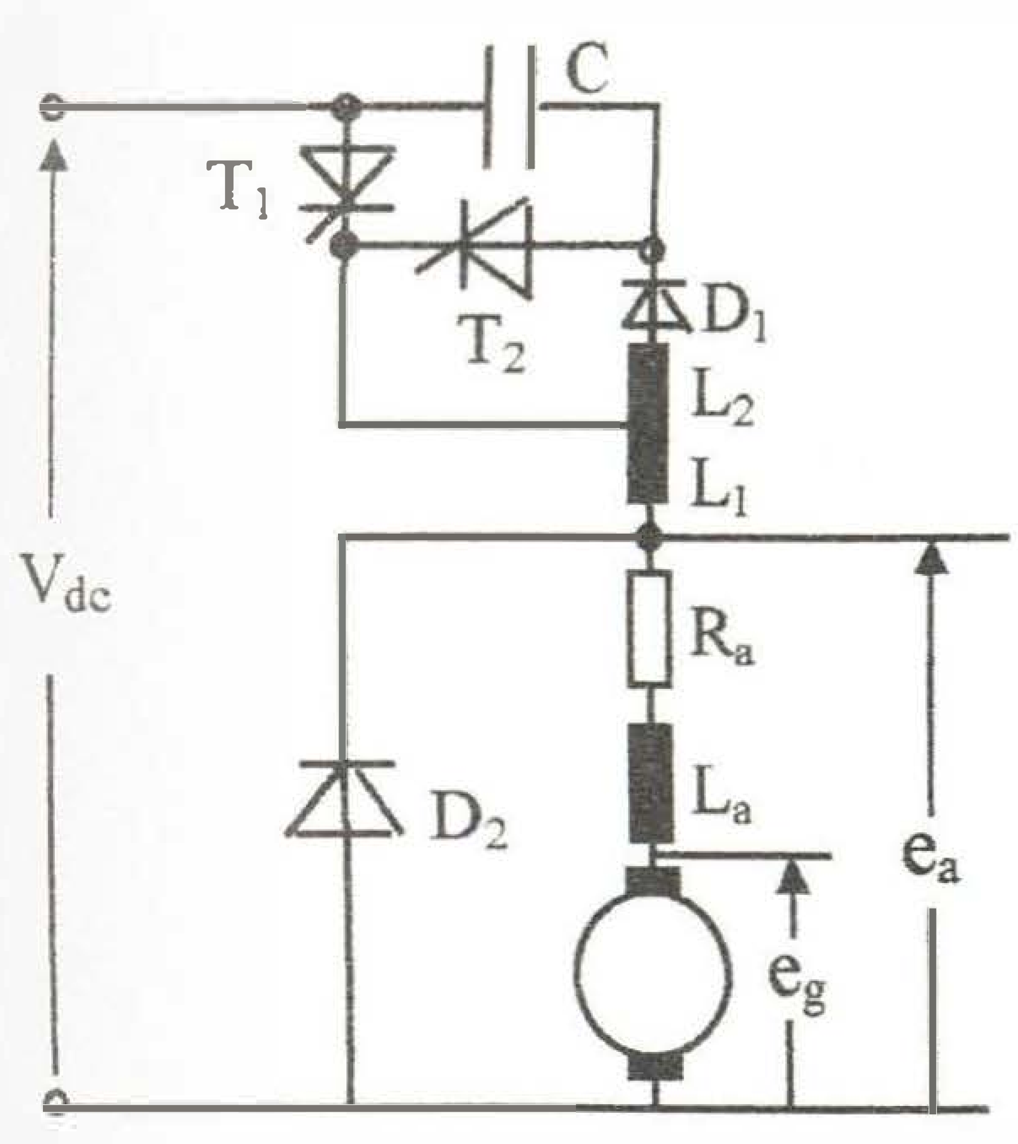

Fig. 3. Chopper-motor combination

II. THE BLOCK DIAGRAM OF CHOPPER FED DC MOTOR

In order to develop the block diagram of 'stem, the state-space averaging method will be used. The considered vectors are as below.

. The input vector $u = (\Delta V_{dc} \quad \Delta T_L)^T$
. The output vector $y = (\Delta e_a \, , \; \Delta T_{em})^T$
. The state variables vector $x = (\Delta i_a, \; \Delta i_f, \; \Delta\omega_m)^T$

The state-space equations are,

$$\dot{X} = Ax + Bu \tag{16}$$

$$y = Cx + Du \tag{17}$$

Where,

$$\dot{X} = \frac{dx}{dt}$$, A, B, C and D are matrixes.

During the operation period, there are two modes of operation. When switch T_1 is closed, a positive loop occurs, mode 1 and when switch T_1 is open, zero loop occurs, mode 2. Therefore, two sets of equation will be required.

<u>Mode 1:</u> Positive loop.

When T_1 is closed, the equivalent circuit is become in Figure 4.

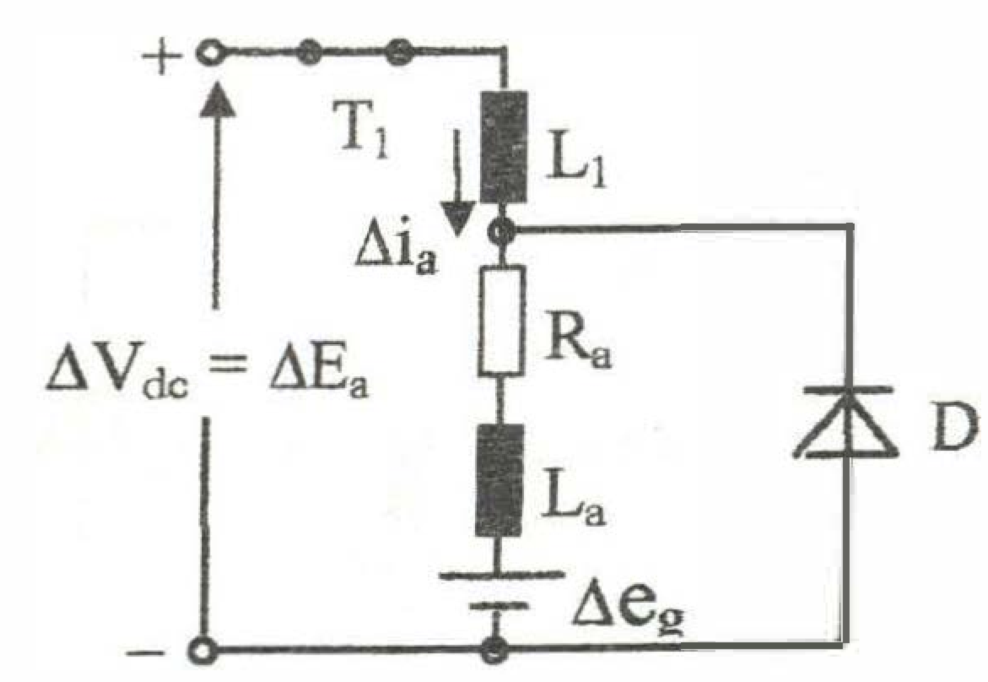

Fig. 4 The equivalent circuit when T_1 is closed

The first mode of operation, the following equations are obtained.

$$\Delta e_a = \Delta V_{dc} \tag{18}$$

$$\Delta e_a = R_a \Delta i_a + (L_1 + L_a)\frac{d}{dt}\Delta i_a + \Delta e_g \tag{19}$$

$$\Delta e_g = K_E(I_{fo}\Delta\omega_m + \Delta\omega_{mo}\Delta i_f) \tag{20}$$

$$\Delta T_{em} = K_T(I_{fo}\Delta i_a + I_{ao}\Delta i_f) \tag{21}$$

$$\Delta T_m = J\frac{d}{dt}\Delta\omega_m + F\Delta\omega_m + \Delta T_L \qquad (22)$$

To obtain the A, B, C and D, matrixes, the equation 18 through 22 are rearranged in the state equation form.

$$A_1 = \begin{bmatrix} \frac{-R_a}{L_1+L_a} & \frac{-K_E I_{fo}}{L_1+L_a} & \frac{-K_E\omega_{mo}}{L_1+L_a} \\ \frac{K_T I_{fo}}{J} & \frac{-F}{J} & \frac{K_T I_{ao}}{J} \end{bmatrix},$$

$$B_1 = \begin{bmatrix} \frac{1}{L_1+L_a} & 0 \\ 0 & \frac{-1}{J} \end{bmatrix},$$

$$C_1 = \begin{bmatrix} 0 & 0 & 0 \\ K_T I_{fo} & K_T I_{ao} & 0 \end{bmatrix}, \quad D_1 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

Mode 2: Zero loop.

When T_1 is open, the equivalent circuit is become in Figure 5.

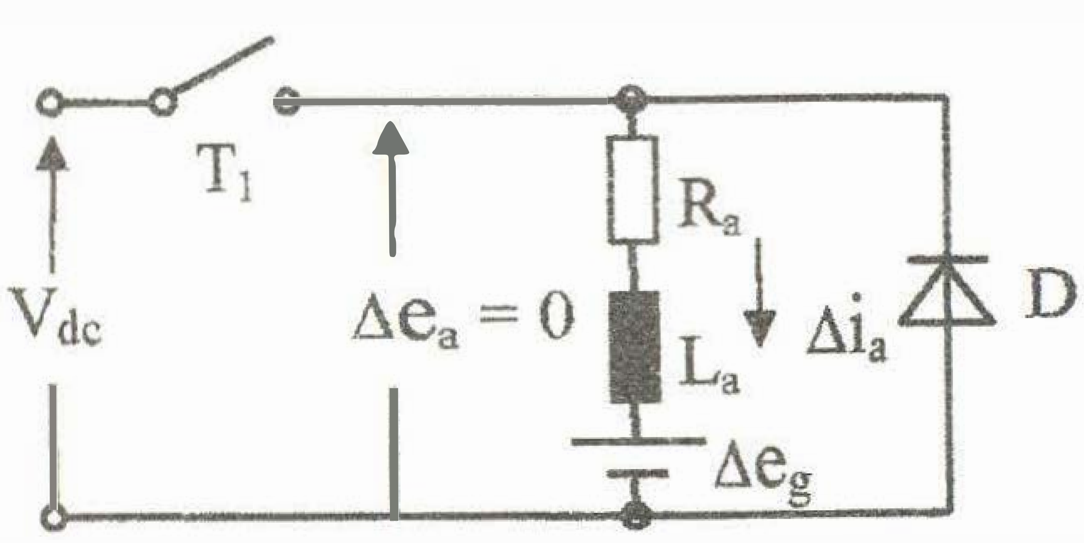

Fig. 5 The equivalent circuit when T_1 is open

The second mode of operation, th following equations are obtained.

$$\Delta e_a = 0 \qquad (23)$$

$$0 = R_a\Delta i_a + L_a\frac{d}{dt}\Delta i_a + \Delta e_g \qquad (24)$$

$$\Delta e_g = K_E(I_{fo}\Delta\omega_m + \Delta\omega_{mo}\Delta i_f) \qquad (25)$$

$$\Delta T_{em} = K_T(I_{fo}\Delta i_a + I_{ao}\Delta i_f) \qquad (26)$$

$$\Delta T_m = J\frac{d}{dt}\Delta\omega_m + F\Delta\omega_m + \Delta T_L \qquad (27)$$

To obtain the A_2, B_2, C_2 and I matrixes, the equations 23 through 27 a rearranged in state equations form.

$$A_2 = \begin{bmatrix} \frac{-R_a}{L_a} & \frac{-K_E I_{fo}}{L_a} & \frac{-K_E\omega_{mo}}{L_a} \\ \frac{K_T I_{fo}}{J} & \frac{-F}{J} & \frac{K_T I_{ao}}{J} \end{bmatrix}$$

$$B_2 = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{J} \end{bmatrix},$$

$$C_2 = \begin{bmatrix} 0 & 0 & 0 \\ K_T I_{fo} & K_T I_{ao} & 0 \end{bmatrix},$$

$$D_2 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

If the state-space averaging model is used, the A, B, C and D matrixes are obtained as follows.

$$A = K A_1 + (1-K) A_2 \qquad (28)$$

$$B = K B_1 + (1-K) B_2 \qquad (29)$$

$$C = K C_1 + (1-K) C_2 \qquad (30)$$

$$D = K D_1 + (1-K) D_2 \qquad (31)$$

The state-space averaged matrixes are become as follows.

$$A = \begin{bmatrix} -R_a\left(\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right) & -K_E I_{fo}\left(\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right) & -K_E \omega_{mo}\left(\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right) \\ \frac{K_T I_{fo}}{J} & -\frac{F}{J} & \frac{K_T I_{ao}}{J} \end{bmatrix}^T$$

$$B = \begin{bmatrix} \frac{K}{L_1+L_a} & 0 \\ 0 & -\frac{1}{J} \end{bmatrix}, \qquad C = \begin{bmatrix} 0 & 0 & 0 \\ K_T I_{fo} & K_T I_{ao} & 0 \end{bmatrix},$$

$$D = \begin{bmatrix} K & 0 \\ 0 & 0 \end{bmatrix}$$

The averaged matrixes can be in the state-space equations.

$$\dot{X} = Ax + Bu$$
$$y = Cx + Du$$

$$\Delta e_a = K\Delta V_{dc} \tag{32}$$

$$\Delta e_a = R_a\left[\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right]\Delta i_a + (L_1+L_a)\frac{d}{dt}\Delta i_a + K_E I_{fo}\left[\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right]\Delta e_g \tag{33}$$

$$\Delta e_g = K_E(I_{fo}\Delta\omega_m + \omega_{mo}\Delta i_f) \tag{34}$$

$$\Delta T_{em} = K_T(I_{fo}\Delta i_a + I_{ao}\Delta i_f) \tag{35}$$

$$\Delta T_m = J\frac{d}{dt}\Delta\omega_m + F\Delta\omega_m + \Delta T_L \tag{36}$$

Transforming equations 32 through 36 in the Laplace transform gives;

$$\Delta E_a(s) = K\Delta V_{dc}(s) \tag{37}$$

$$\Delta E_a(s) = R_a\left[\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right]\Delta I_a(s) + s(L_1+L_a)\Delta I_a(s) + K_E I_{fo}\left[\frac{K}{L_1+L_a}+\frac{1-K}{L_a}\right]\Delta E_g(s) \tag{38}$$

$$\Delta E_g(s) = K_E[I_{fo}\Delta\omega_m(s) + \omega_{mo}\Delta I_f(s)] \tag{39}$$

$$\Delta T_{em}(s) = K_T[I_{fo}\Delta I_a(s) + I_{ao}\Delta I_f(s)] \tag{40}$$

$$\Delta T_m(s) = sJ\Delta\omega_m(s) + F\Delta\omega_m(s) + \Delta T_L(s) \quad (41)$$

Equation 37 through 41 can be put in block diagram in figure 6. From fig.6 it can be seen that the transfer function changes.

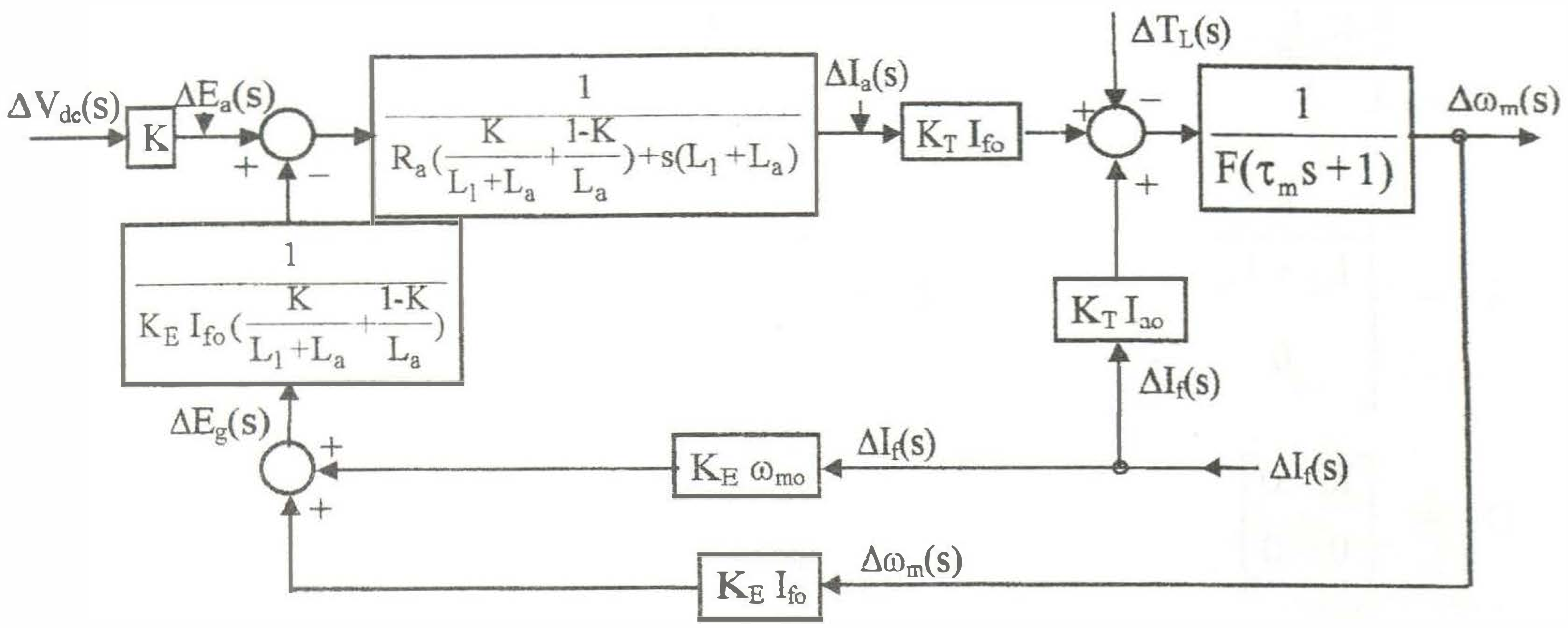

Fig. 6 The open-loop block diagram of separately excited DC motor fed DC-DC chopper

IV. RESULTS

The block diagram for the chopper fed DC-DC separately excited DC motor was obtained using the state-space averaging method. By using the block diagram in Fig. 6, the transfer function can be obtained and analyzed. When the transfe function is obtained, the chopper circuit effect should be taken into account.

V. REFERENCES

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