Tribhuvan University
Institute of Engineering
Pulchowk Campus
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Unit: III- Control Strategies

Class-12:
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Presented by
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Subject Name
EE: Modelling and Control of Electric Drives

Discussed in the Previous Class

In the previous class discussed the following topics:

- ❖ Three Phase Half Controlled Rectifier Control of DC Motor
- ❖ DC Motor Reversing Switch Diagram
- ❖ Dual Converter Control of DC Separately Excited Motor
- ❖ Drawbacks of Rectifier Fed DC Drives
- ❖ Chopper Control of Separately Excited DC Motor

Lecture Outcomes

- ❖ Chopper Control of Separately Excited DC Motor
- ❖ Regenerative Braking of Chopper fed Separately Excited DC Motor
- ❖ Motoring and Regenerative Braking of DC Motor
- ❖ Dynamic Braking of DC Motor
- ❖ Lecture remarks: Key points of today's class

Chopper Control of Separately Excited DC Motor

Chopper Control of Separately Excited DC Motor

Motoring Control:

- A transistor Chopper Control of Separately Excited DC Motor drive is shown in Fig. 1.

- Transistor T_r is operated periodically with period T and remains on for a duration t_{on}. Present-day choppers operate at a frequency that is high enough to ensure continuous conduction.

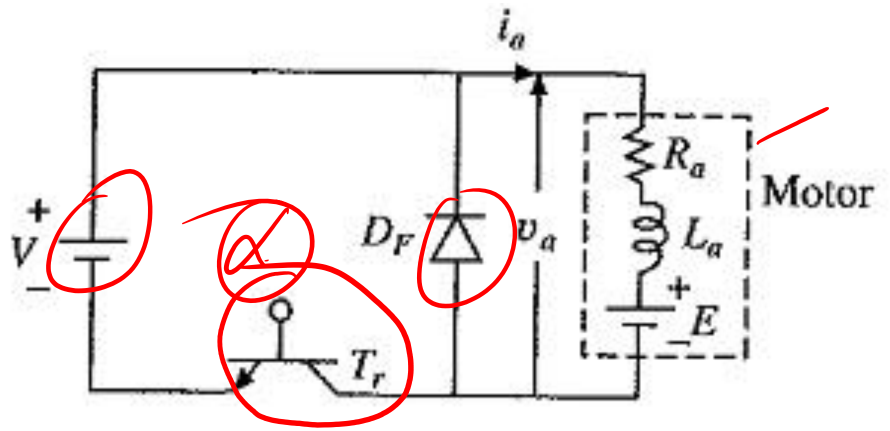


Fig. 1. Circuit diagram of chopper control of the separately excited motor.

Chopper Control of Separately Excited DC Motor

- Waveforms of motor terminal voltage v_a and armature current i_a for continuous conduction are shown in Fig. 2.

- During on-period of the transistor, $0 \le t \le t_{on}$, the motor terminal voltage is V.

$V_m = V_a$ at 0 to t_{on}

t_{on} to T $\Rightarrow$ 0 V

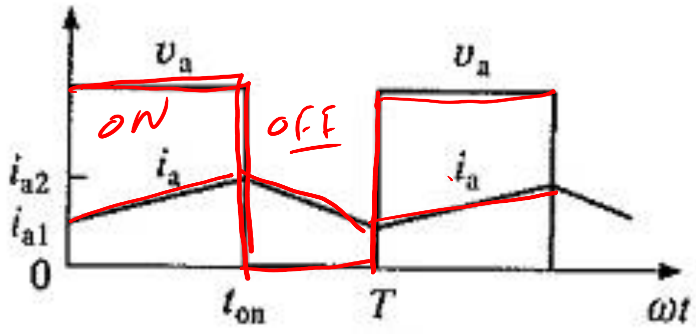
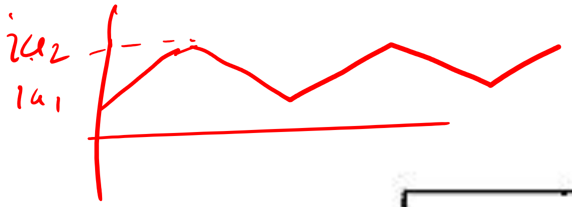


Fig. 1. Waveform of chopper control of the separately excited motor.

Chopper Control of Separately Excited DC Motor

The operation is described by

$$R_a i_a + L_a \frac{di_a}{dt} + E = V, \quad 0 \le t \le t_{on} \qquad (1)$$



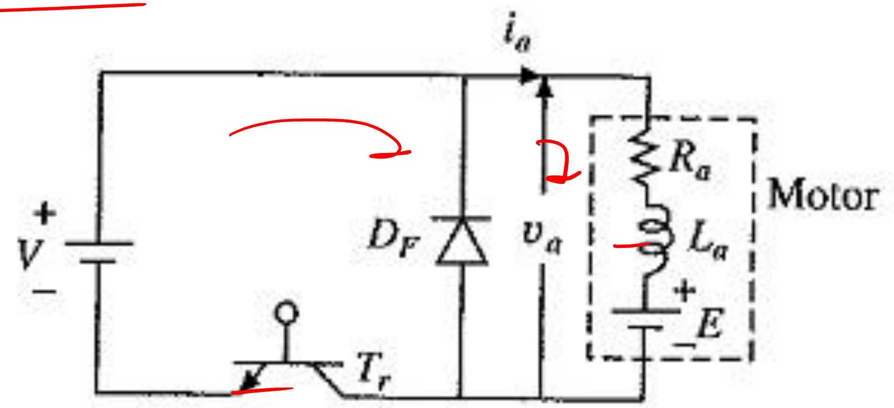


Fig. 1. Circuit diagram of chopper control of the separately excited motor.

- In this interval, the armature current increases from i_{a1} to i_{a2}.
- Since the motor is connected to the source during this interval, it is called **Duty Interval**.

Chopper Control of Separately Excited DC Motor

- At $t = t_{on}$, T_r is turned-off.
- Motor current freewheels through diode D_F and motor terminal voltage is zero during interval $t_{on} \le t \le T$.
- Motor operation during this interval, known as freewheeling interval, is described by

$$R_a i_a + L_a \frac{di_a}{dt} + E = 0, \quad t_{on} \le t \le T \qquad (2)$$

Motor current decreases from i_{a2} to i_{a1} during this interval.

Chopper Control of Separately Excited DC Motor

Ratio of duty interval t_{on} to chopper period T is called **duty ratio or duty cycle** (δ). Thus

$$\delta = \frac{\text{Duty interval}}{T} = \frac{t_{on}}{T} \qquad (3)$$

$$V_a = \frac{1}{T}\int_0^{t_{on}} V\,dt = \delta V \qquad (4)$$

$$I_a = \frac{\delta V - E}{R_a} \qquad (5)$$

$$\frac{V_a - E}{R_a} = \frac{\delta V - E}{R}$$

$$\omega_m = \frac{\delta V}{K} - \frac{R_a}{K^2}T \qquad (6)$$

Regenerative Braking of Chopper fed Separately Excited DC Motor

Regenerative Braking of Chopper fed DC Motor

- Chopper Control of Separately Excited DC Motor for regenerative braking operation is shown in Fig. 1.

- Transistor T_r is operated periodically with a period T and on-period of t_{on}.

- Waveforms of motor terminal voltage v_a and armature current i_a for continuous conduction are shown in Fig. 2.

- Usually an external inductance is added to increase the value of L_a. When T_r is on, i_a increases from i_{a1} to i_{a2}.

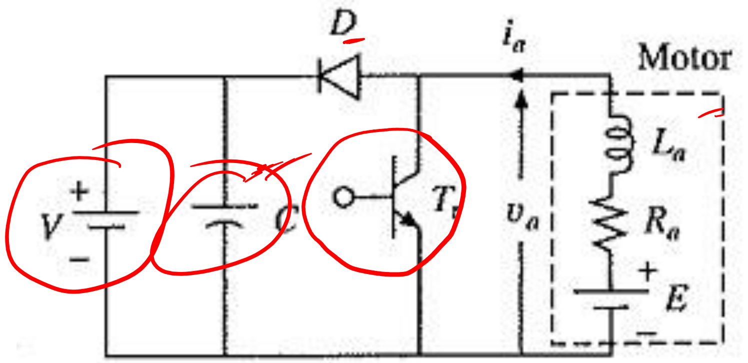


Fig. 1. Circuit diagram of regenerative braking of DC motor.

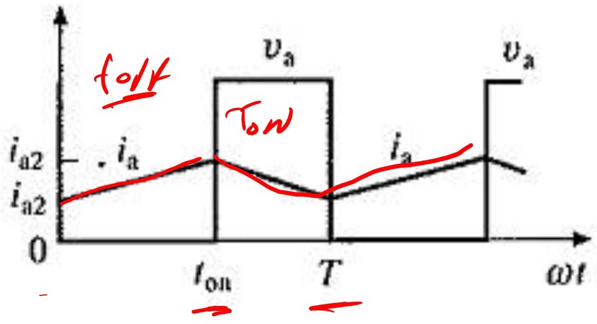


Fig. 2. Waveform of regenerative braking of DC motor.

Regenerative Braking of Chopper fed DC Motor

- The mechanical energy converted into electrical by the motor, now working as a generator, partly increases the stored magnetic energy in armature circuit inductance and the remainder is dissipated in armature resistance and transistor.

- When T_r is turned off, armature current flows through diode D and source V, and reduces from i_{a2} to i_{a1}.

- The stored electromagnetic energy and energy supplied by machine is fed to the source. The interval $0 \le t \le t_{on}$ is now called the **energy storage interval** and interval $t_{on} \le t \le T$ **the duty interval**. If δ is again defined as the ratio of duty interval to period T, then

$$\delta = \frac{\text{Duty interval}}{T} = \frac{T - t_{on}}{T} \qquad (1)$$

Regenerative Braking of Chopper fed DC Motor

From Fig. 2.

$$V_a = \frac{1}{T}\int_{t_{on}}^{T} V\,dt = \delta V \qquad (2)$$

and from Fig. 1.

$$I_a = \frac{E - \delta V}{R_a} \qquad (3)$$

$\frac{1}{T}\int_{t_{on}}^{T} V dt$

$V_a = \frac{1}{T} V(t_{on} - T)$

$V_a = \delta V$

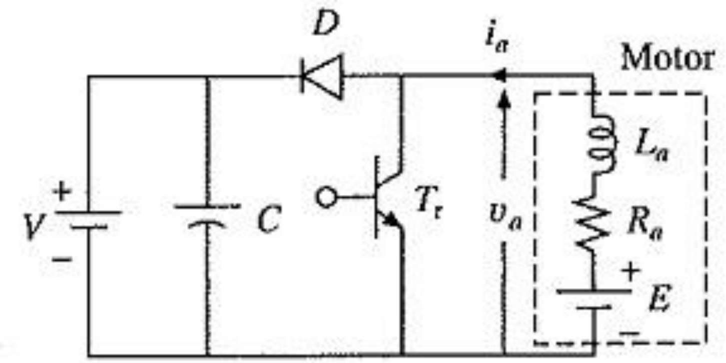


Fig. 1. Circuit diagram of regenerative braking of DC motor.

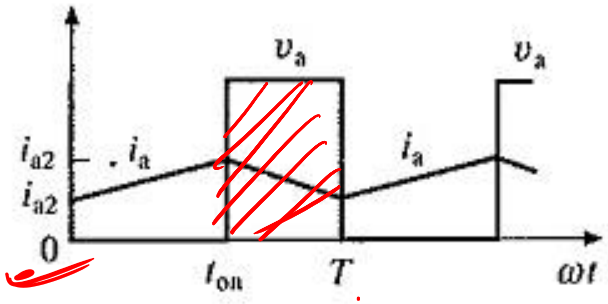


Fig. 2. Waveform of regenerative braking of DC motor.

Regenerative Braking of Chopper fed DC Motor

Since I_a has reversed

$$T = -KI_a \quad (4)$$

From Eqs. (3) and (4)

$$\omega_m = \frac{\delta V}{K} - \frac{R_a}{K^2} T \quad (5)$$

The nature of speed torque characteristic is shown in Fig. 3.

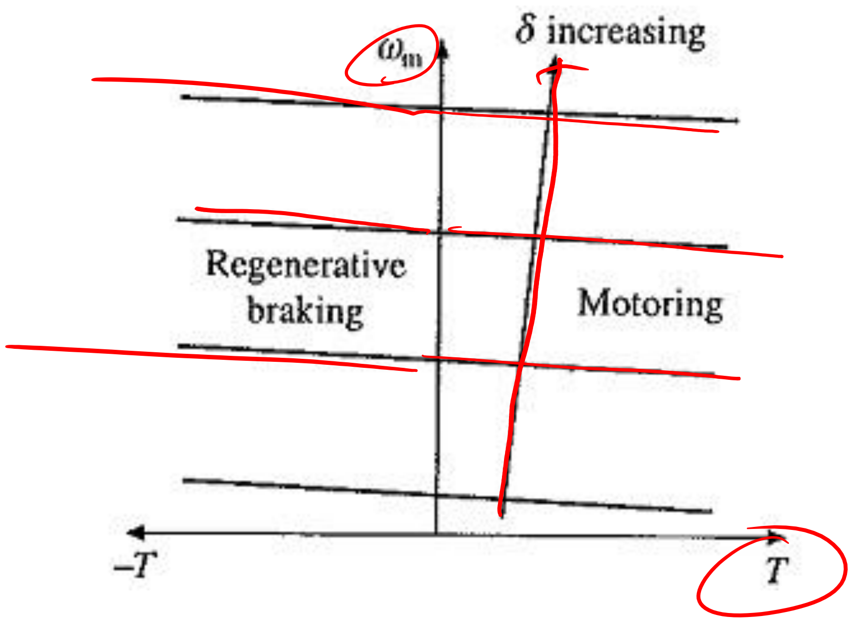


Fig. 3. Speed torque curves of chopper-controlled DC motor.

Motoring and Regenerative Braking of DC Motor

Motoring and Regenerative Braking of DC Motor

- Chopper circuits of Figs. 1 and 2 can be combined to get a two-quadrant chopper of Fig. 4, which can provide motoring and regenerative braking operations in the forward direction.

- Transistor T_{r1} with diode D_1 form a chopper circuit similar to that of Fig. 1, and therefore, provide control for forward motoring operation.

- Transistor T_{r2} with diode D_2 forms a chopper circuit similar to that of Fig. 2, and therefore, provides control for forward regenerative braking operation.

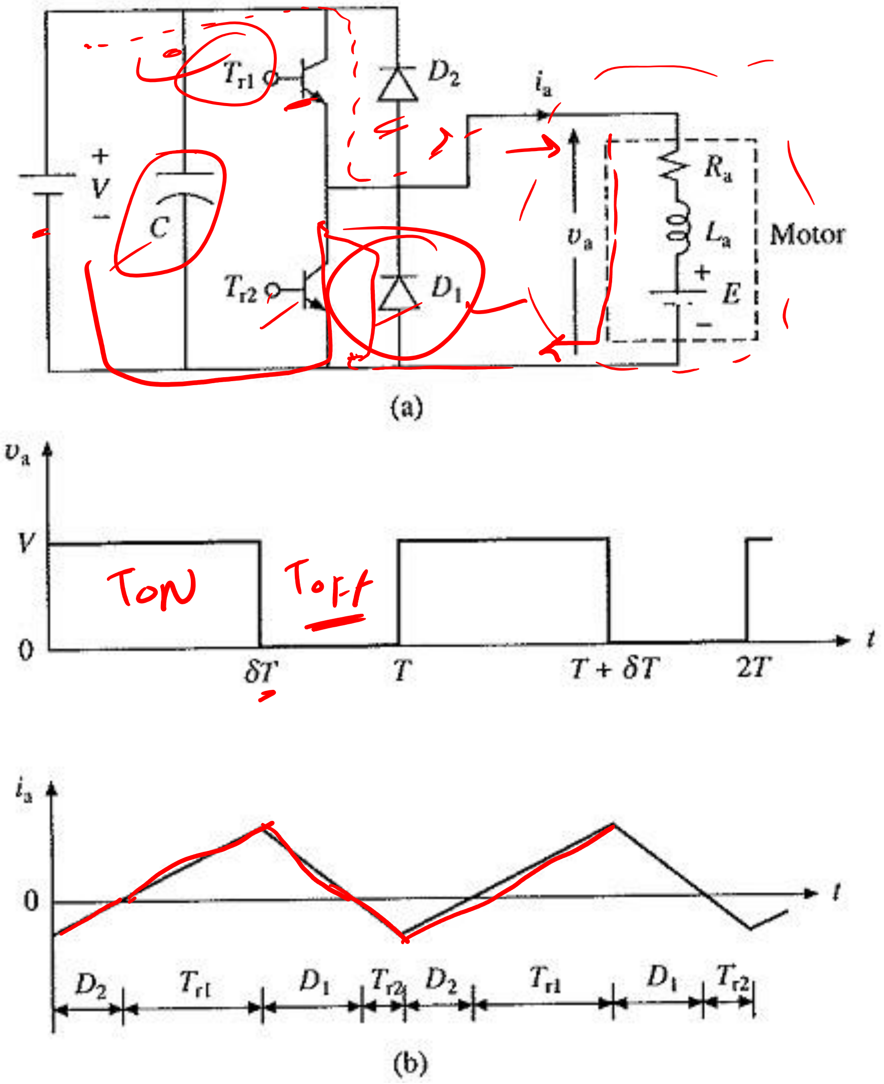


Fig. 4. Chopper for forward motoring and braking control.

Regenerative Braking of Chopper fed DC Motor

- Thus, for motoring operation transistor T_{r1} is controlled and for braking operation transistor T_{r2} is controlled.

- Shifting of control from T_{r1} to T_{r2} shifts operation from motoring to braking and vice versa.

- In servo drives where fast transition from motoring to braking and vice versa is required, both T_{r1} and T_{r2} are controlled simultaneously.

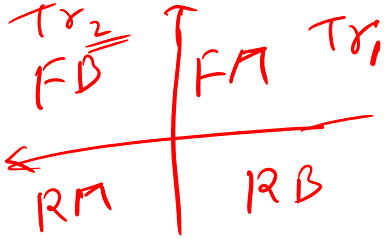
Regenerative Braking of Chopper fed DC Motor

- In a period T, T_{rl} is given gate drive from 0 to δT and T_{r2} is given gate drive from δT to T, where δ is the duty ratio for T_{rl}.

- Therefore, from 0 to δT motor is connected to the source either through T_{rl} or D_2 depending on whether the motor current i_a is positive or negative.

- Since $V > E$, during this period the rate of change of current is always positive.

- Similarly from δT to T, motor armature is shorted either through D_1 or T_{r2} depending on whether i_a is positive or negative and during this period rate of change of current is always negative.



Regenerative Braking of Chopper fed DC Motor

- Motor terminal voltage and current waveforms are shown in Fig. 4 (b).
- From Fig. 4(b)

$$V_a = \delta V \qquad (1)$$

$$I_a = \frac{\delta V - E}{R_a} \qquad (2)$$

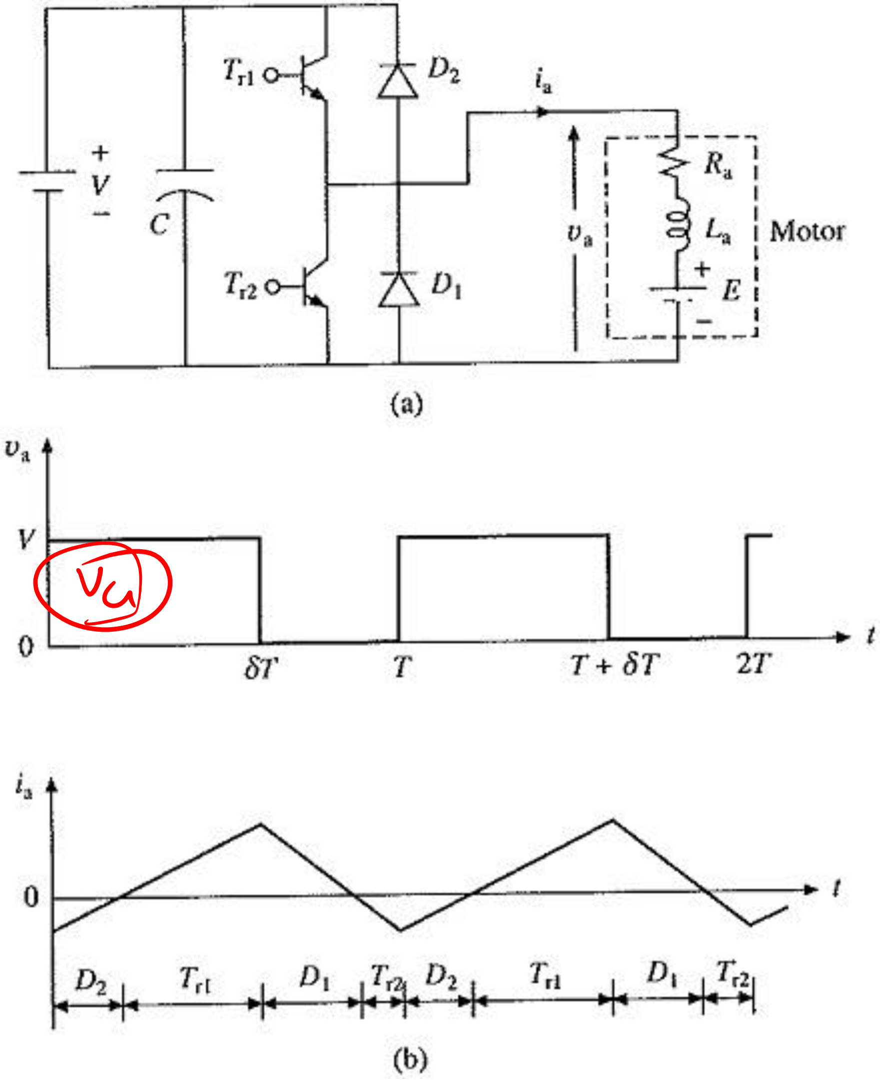


Fig. 4. Chopper for forward motoring and braking control.

Regenerative Braking of Chopper fed DC Motor

- Above equations (1) and (2) suggest that motoring operation (+ve I_a) takes place when $\delta > (E/V)$ and regenerative braking operation takes place when $\delta < (E/V)$ and transition from motoring to braking and vice versa occurs when $\delta = (E/V)$.

- The above equations are similar to those obtained for the chopper of Fig. (1), and therefore, given the same numbers

Dynamic Braking of DC Motor

Dynamic Braking of Chopper fed DC Motor

- Dynamic braking circuit and its waveforms are shown in Figs. 1 and 2, respectively.
- During the interval $0 \leq t \leq t_{on}$, i_a increases from i_{a1} to i_{a2}.
- A part of generated energy is stored in inductance and rest is dissipated in R_a and T_r.
- During interval $t_{on} \leq t \leq T$, i_a decreases from i_{a2} to i_{a1}.

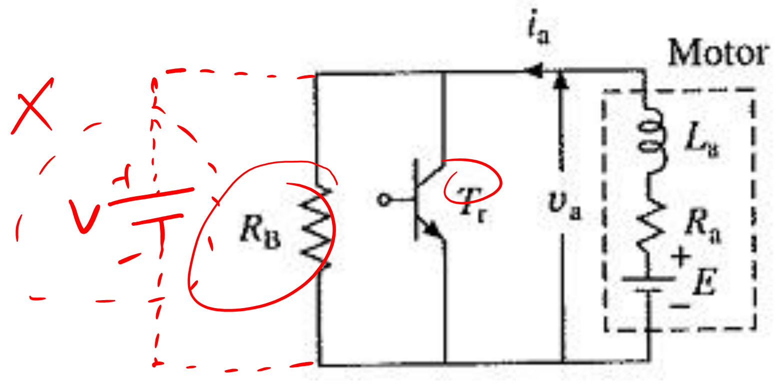


Fig. 1. Dynamic braking of DC motor.

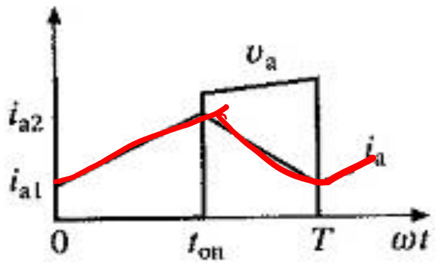


Fig. 2. Waveform of Dynamic braking of DC motor.

Dynamic Braking of Chopper fed DC Motor

- The energies generated and stored in inductance are dissipated in braking resistance R_B, R_a and diode D.

- Transistor T_r controls the magnitude of energy dissipated in R_B, and therefore, controls its effective value.

- If i_a is assumed to be ripple less DC, then energy consumed E_N by R_B during a cycle of chopper operation is

$$E_N = I_a^2 R_B (T - t_{on}) \quad (1)$$

Dynamic Braking of Chopper fed DC Motor

Average power consumed by R_B

$$P = \frac{E_N}{T} = I_a^2 R_B (1 - \delta) \qquad (2)$$

Effective value of R_B

$$R_{BE} = \frac{P}{I_a^2} = R_B (1 - \delta) \qquad (3)$$

Where

$$\delta = \frac{t_{on}}{T} \qquad (4)$$

Key Points from Today's Class

- Chopper Control of Separately Excited DC Motor
- Regenerative Braking of Chopper fed Separately Excited DC Motor
- Motoring and Regenerative Braking of DC Motor
- Dynamic Braking of DC Motor

Key Points from Next Class

In the next class, we will be discussing on the

- ❖ Three-Phase Induction Motor
- ❖ Speed Control of Three Phase Induction Motors

Thank you so much for your attentions

Q & A