Tribhuvan University
Institute of Engineering
Pulchowk Campus
Accredited by University Grants Commission (UGC) Nepal 2020

Unit: III- Control Strategies

Class-08:
26th January 2024

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:

- ❖ Open-loop and closed-loop control techniques for electric drives
- ❖ Speed control, torque control, and position control methodologies

Lecture Outcomes

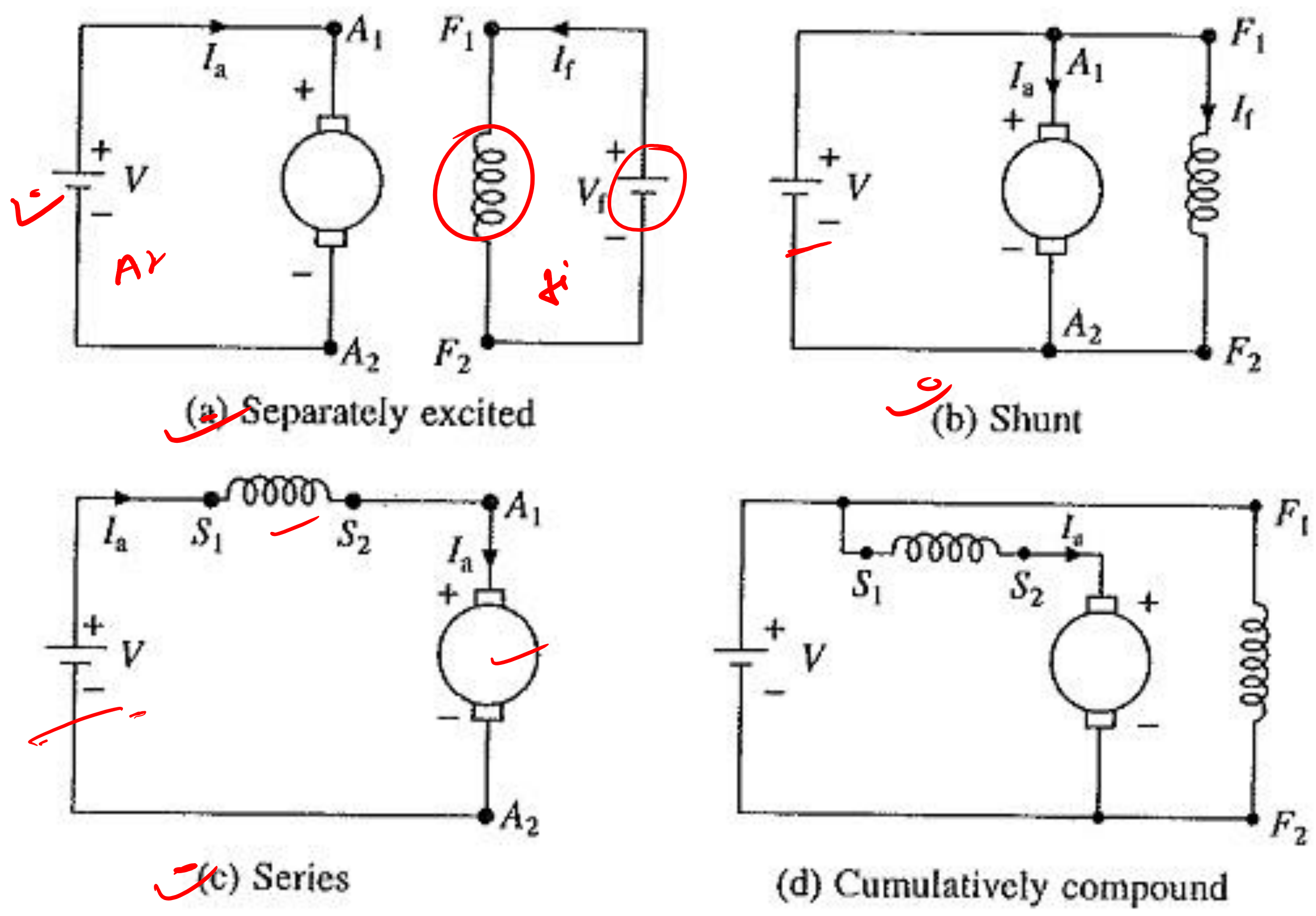
- ❖ Overview of Types of DC Motor Drives
- ❖ Speed Control of DC Motor Drives
- ❖ Armature Voltage Control of DC Motor using Transformer
- ❖ Controlled Rectifier Fed DC Drives
- ❖ Lecture remarks: Key points of today's class

Types of DC Motors

1. Separately Excited DC Motor
2. Shunt DC Motor
3. Series DC Motor
4. Compound DC Motor

Types of DC Motors

The commonly used Types of DC Motor are shown in Fig. 1.



Long shunt + Short shunt DC motor

Fig. 1. Commonly used DC Motors.

Types of DC Motors

- In a ***separately excited motor***, the field and armature voltages can be controlled independently of each other.
- In a ***shunt motor***, field and armature are connected to a common source.
- In the case of a ***series motor***, field current is the same as the armature current, and therefore, field flux is a function of the armature current.
- In a ***cumulatively compound motor***, the magneto-motive (MMF) force of the series field is a function of armature current and is in the same direction as MMF of the shunt field.

Types of DC Motors

- The steady-state equivalent circuit of the armature of a dc machine is shown in Fig. 2.

- Resistance R_a is the resistance of the armature circuit. For separately excited and shunt motors, it is equal to the resistance of armature winding and for series and compound motors it is the sum of armature and field winding resistances.

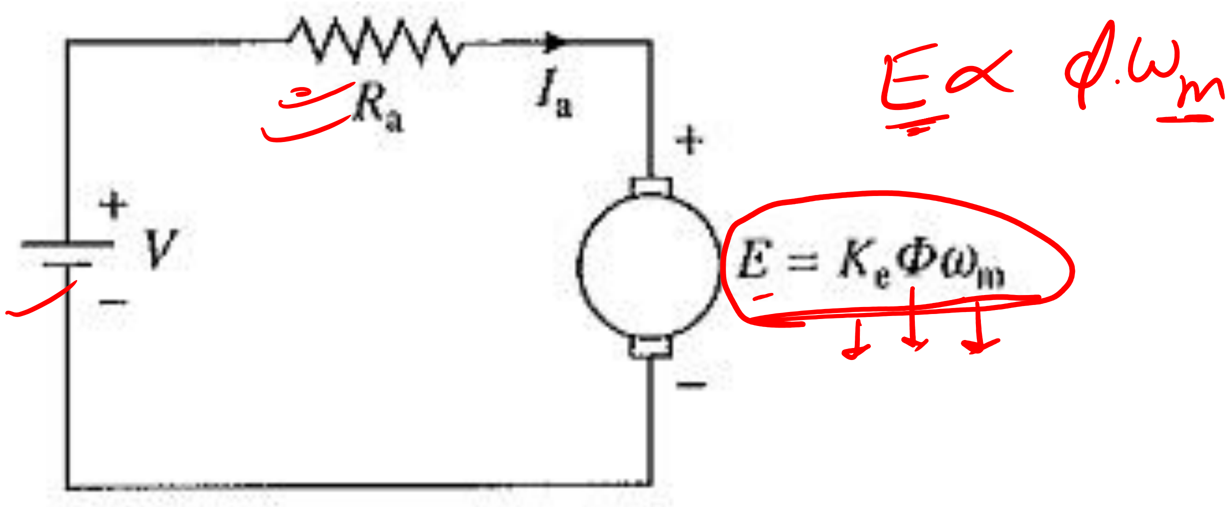


Fig. 2. Steady-state equivalent circuit of the armature of DC motors.

Types of DC Motors

- Basic equations applicable to all Types of DC Motor are

$$E = K_e \Phi \omega_m \quad (1)$$

$$V = E + R_a I_a \quad (2)$$

$$T = K_e \Phi I_a \quad (3)$$

where

Φ – is the flux per pole, Webers;

I_a – the armature current, A;

V – the armature voltage V;

R_a – the resistance of the armature circuit, ohms;

ω_m – the speed of armature, rad/sec;

T – the torque developed by the motor, N-m; and

K_e – the motor constant.

From Eq. (1) to (3)

$$\omega_m = \frac{V}{K_e \Phi} - \frac{R_a}{K_e \Phi} I_a \quad (4)$$

$$= \frac{V}{K_e \Phi} - \frac{R_a}{(K_e \Phi)^2} T \quad (5)$$

Characteristics of DC Motors

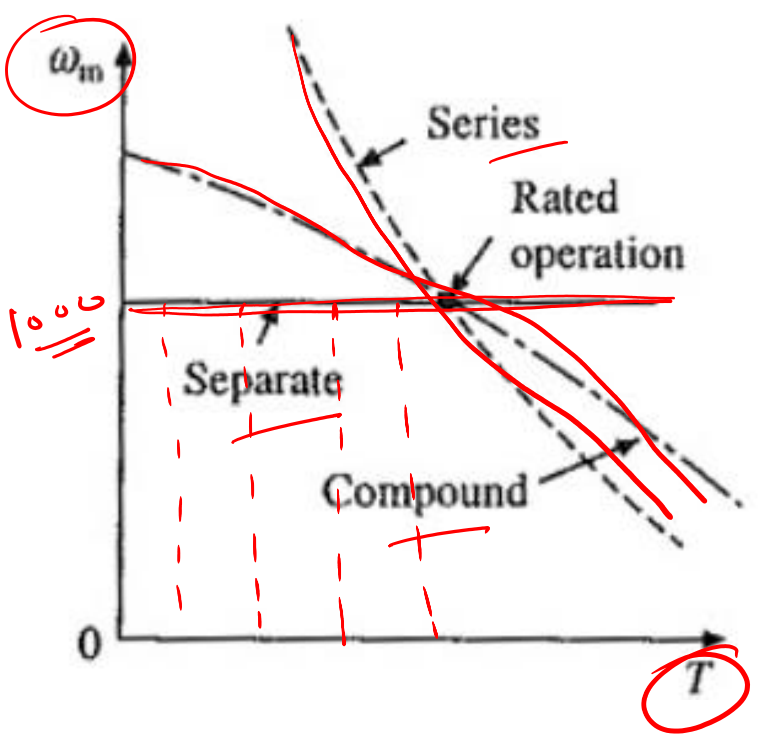


Fig. 3. Speed-torque characteristics.

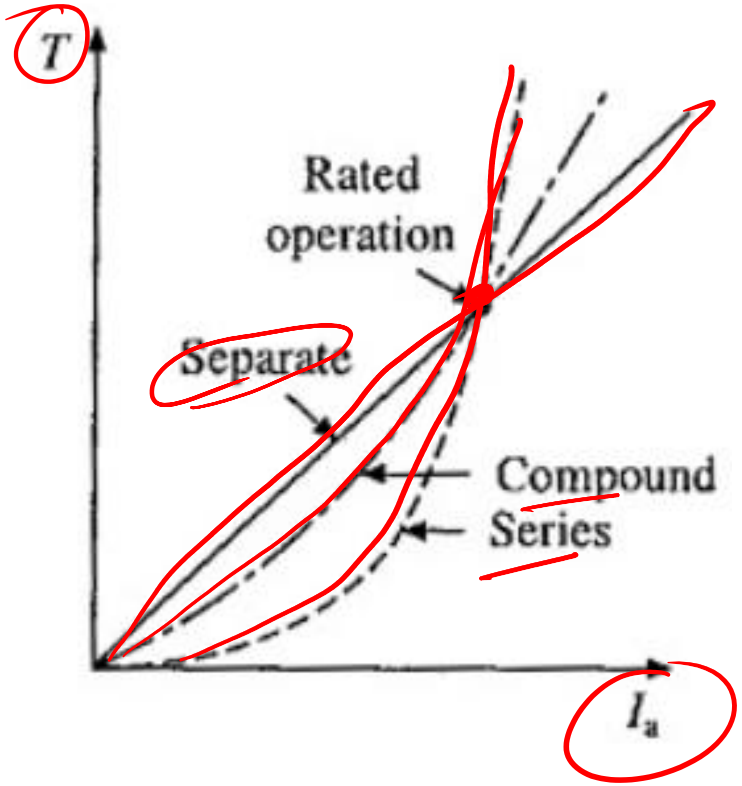


Fig. 4. Torque-current characteristics.

Shunt and Separately Excited DC Motors

In case of shunt and separately excited motors, with a constant field current, the flux can be assumed to be constant. Let

$$K_e \Phi = K \text{ (constant)} \qquad (6)$$

Then from Eqs. (1), (3) and (4) to (6)

$$T = K I_a \qquad (7)$$

$$E = K \omega_m \qquad (8)$$

$$\omega_m = \frac{V}{K} - \frac{R_a}{K} I_a \qquad (9)$$

$$= \frac{V}{K} - \frac{R_a}{K^2} T \qquad (10)$$

Shunt and Separately Excited DC Motors

- The speed-torque and torque-current characteristics of a separately excited motor for rated terminal voltage and full field are shown in Fig. 3.
- The speed-torque curve is a straight line. The no-load speed ω_{m0} is determined by the values of armature voltage and field excitation.
- Speed decreases as torque increases and speed regulation depends on the armature circuit resistance (Eq. (10)).
- The usual drop in speed from no load to full load, in the case of a medium size motor, is of the order of 5%.
- Separately excited motors are employed in applications requiring good speed regulation and adjustable speed.

Series DC Motor

- In series motors, the flux is a function of armature current.
- In an unsaturated region of magnetization characteristic, Φ can be assumed to be proportional to I_a. Thus

$$\Phi = K_f I_a \qquad (11)$$

- Substituting in Eqs. (3), (4) and (5) gives

$$T = K_e K_f I_a^2 \qquad (12)$$

$$\omega_m = \frac{V}{K_e K_f I_a} - \frac{R_a}{K_e K_f} \qquad (13)$$

$$= \frac{V}{\sqrt{K_e K_f}} \frac{1}{\sqrt{T}} - \frac{R_a}{K_e K_f} \qquad (14)$$

Series DC Motor

- where armature circuit resistance R_a is now the sum of armature and field winding resistances.

$R_{eq} = R_a + R_f$

- The speed-torque and torque-current characteristics of a series motor at rated terminal voltage and full field are shown in Fig. 3.

- Series motors are suitable for applications requiring high starting torque and heavy torque overloads.

- Since torque is proportional to the armature current squared, for the same increase in torque, the increase in motor current is less compared to that in a separately excited motor where torque is proportional to armature current.

Series DC Motor

- Thus, during heavy torque overloads and starting, power overload on the source and thermal overloading of the motor are kept limited to reasonable values.
- According to Eq. (14), as speed varies inversely as the square root of torque, the machine runs at a large speed at a light load.
- Generally, the mechanical strength of a Type of DC Motor permits it to operate up to about twice the rated speed.
- Hence, the series motor should not be used in those drives where there is a possibility of the load torque being dropped to the extent that the speed may exceed twice the rated value.

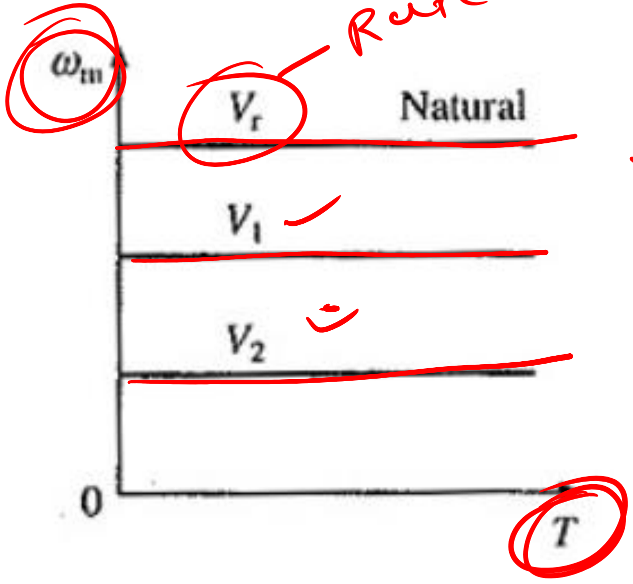
Speed Control of DC Motor Drives

Speed Control of DC Motor Drives

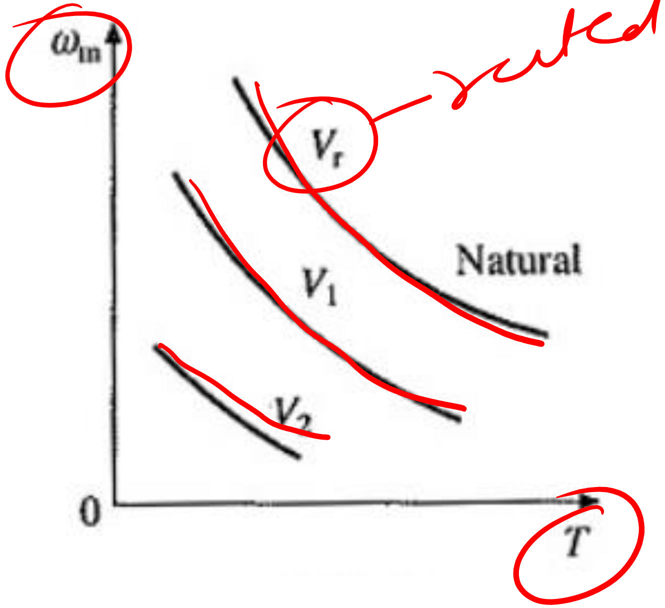
The Speed Control of DC Motor Drives can be any of the following methods:

1. **Armature voltage control** — $\omega_m \propto E$
2. **Field flux control** — $T \propto \phi \propto I \propto \frac{1}{V}$
3. **Armature resistance control** — $\omega_m \propto E \propto R$

Speed Control of DC Motor Drives



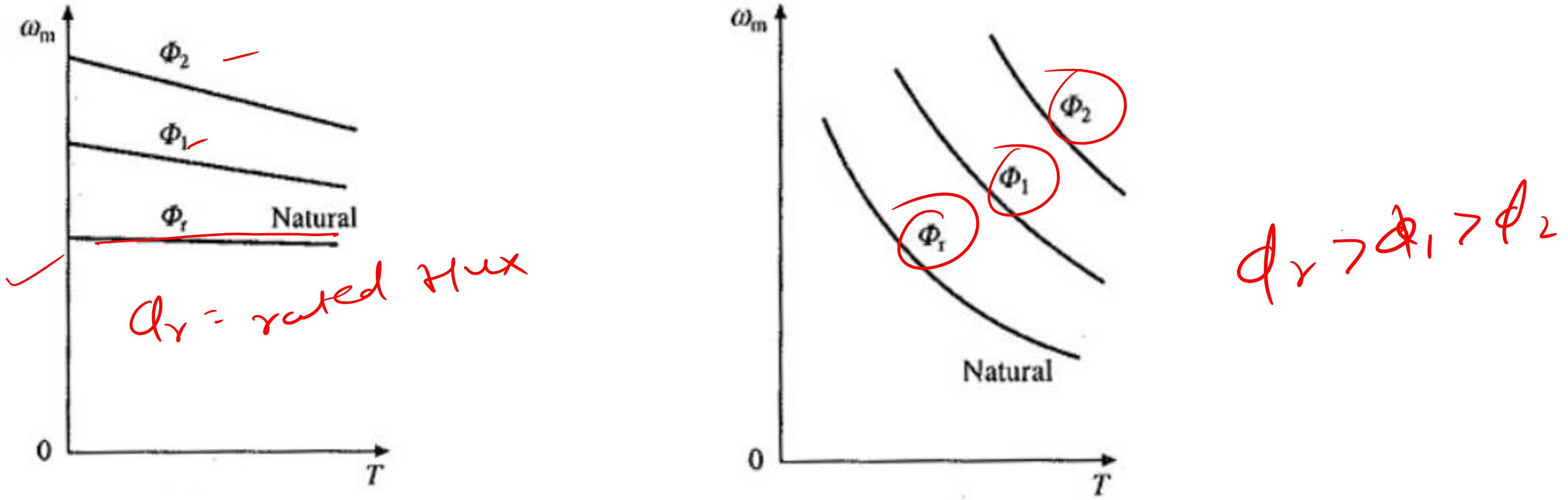
(a). Separately excited DC Motor



(b). Series DC Motor

Fig. 1. Armature voltage control method $V_r > V_1 > V_2$

Speed Control of DC Motor Drives

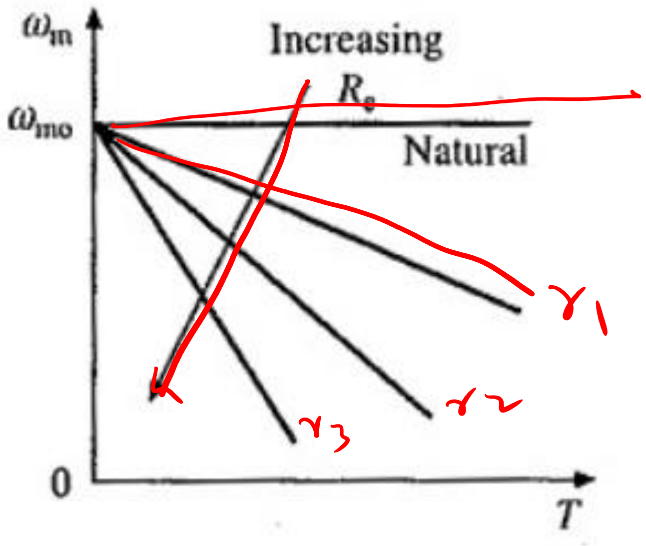


(a). Separately excited DC Motor

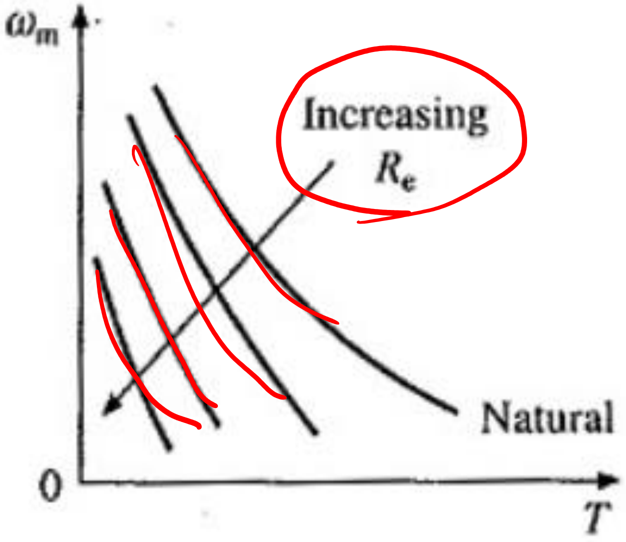
(b). Series DC Motor

Fig. 2. Field flux control method $\varnothing_r > \varnothing_1 > \varnothing_2$

Speed Control of DC Motor Drives



(a). Separately excited DC Motor



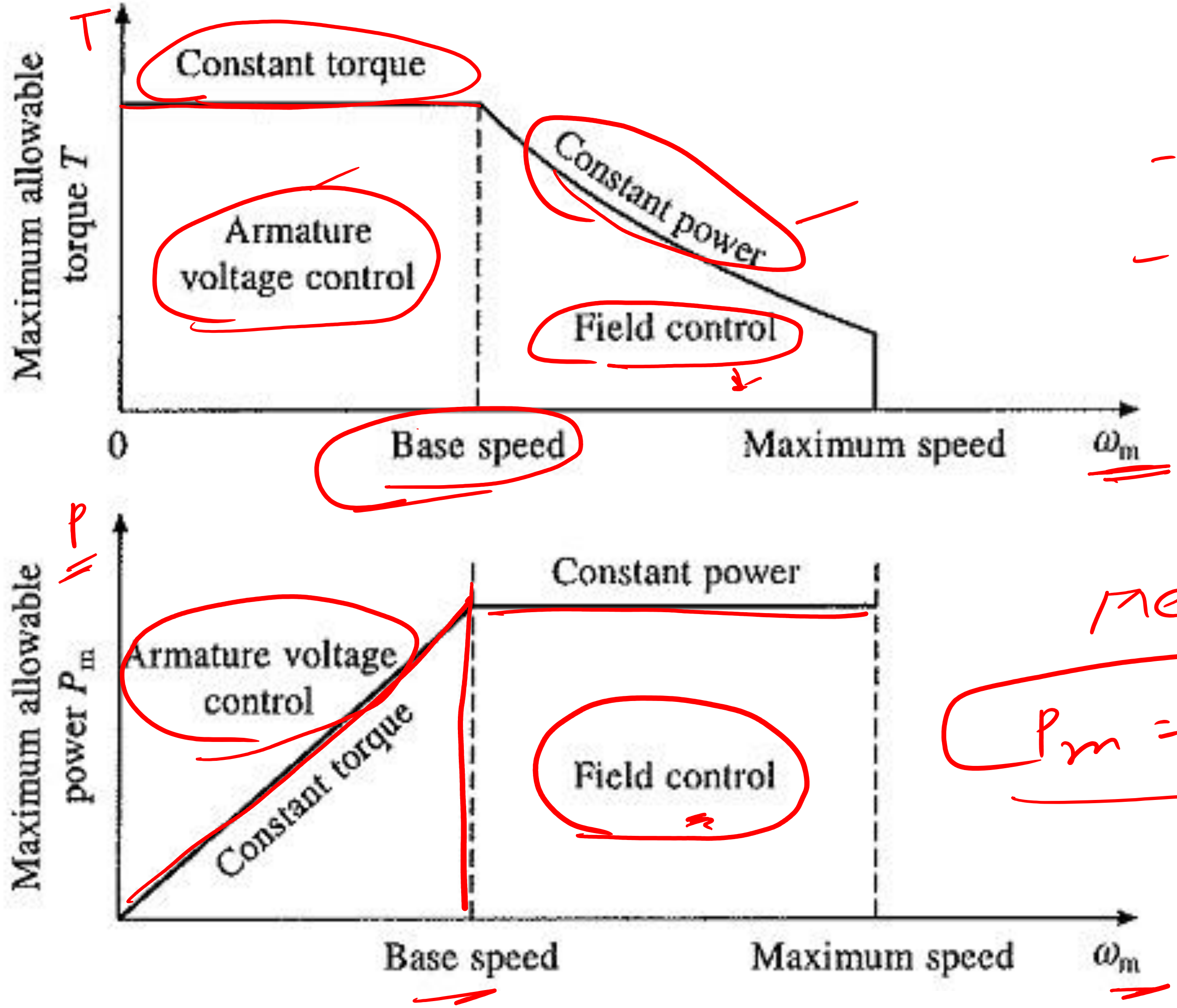
(b). Series DC Motor

Fig. 3. Armature resistance control method: R_e is the external resistor.

Speed Control of DC Motor Drives

- Armature voltage control is preferred because of high efficiency, good transient response and good speed regulation.
- But it can provide Speed Control of DC Motor Drives only below base (rated) speed because the armature voltage cannot be allowed to exceed rated value.
- For speed control above base speed, field flux control is employed.
- In a normally designed motor, the maximum speed can be allowed up to twice rated speed and in specially designed machines it can be six times rated speed.

Speed Control of DC Motor Drives



- Armature
- field flux

mechanical power

$P_m = T \times \omega$

Electrical power

$P_e = V \times I$

$\eta = \frac{P_m}{P_e}$

Fig. 4. Torque and power limitations in combined armature voltage and field control.

Speed Control of DC Motor Drives

- The maximum torque and power limitations of dc drives operating with armature voltage control and full field below rated speed and flux control at rated armature voltage above rated speed are shown in Fig. 4.

- In armature voltage control at full field, $T \infty I_a$ consequently, the maximum torque that the machine can deliver has a constant value.

- In the field control at rated armature voltage, $P_m \infty I_a$ (because $E \approx V = \text{constant}$).

- Therefore, maximum power developed by the motor has a constant value.

Speed Control of DC Motor Drives

- In a separately excited motor, flux is controlled by varying voltage across field winding and in a series motor it is controlled either by varying number of turns in the field winding or connecting a diverter resistance across the field winding.

- In armature resistance control, speed is varied by wasting power in external resistors that are connected in series with the armature.

- Since it is an inefficient method of Speed Control of DC Motor Drives, it was used in intermittent load applications where the duration of low-speed operation forms only a small proportion of total running time, for example in traction.

- It has, however, been replaced by armature voltage control in all these applications.

Armature Voltage Control of DC Motor using Transformer

Armature Voltage Control of DC Motor using Transformer

- Variable voltage for the DC motor control can also be obtained by either using an auto-transformer or a Armature Voltage Control using a Transformer with tapings (either on primary or on secondary) followed by an uncontrolled rectifier as shown in Fig. 1.

- A reactor is connected in the armature circuit to improve the armature current waveform.

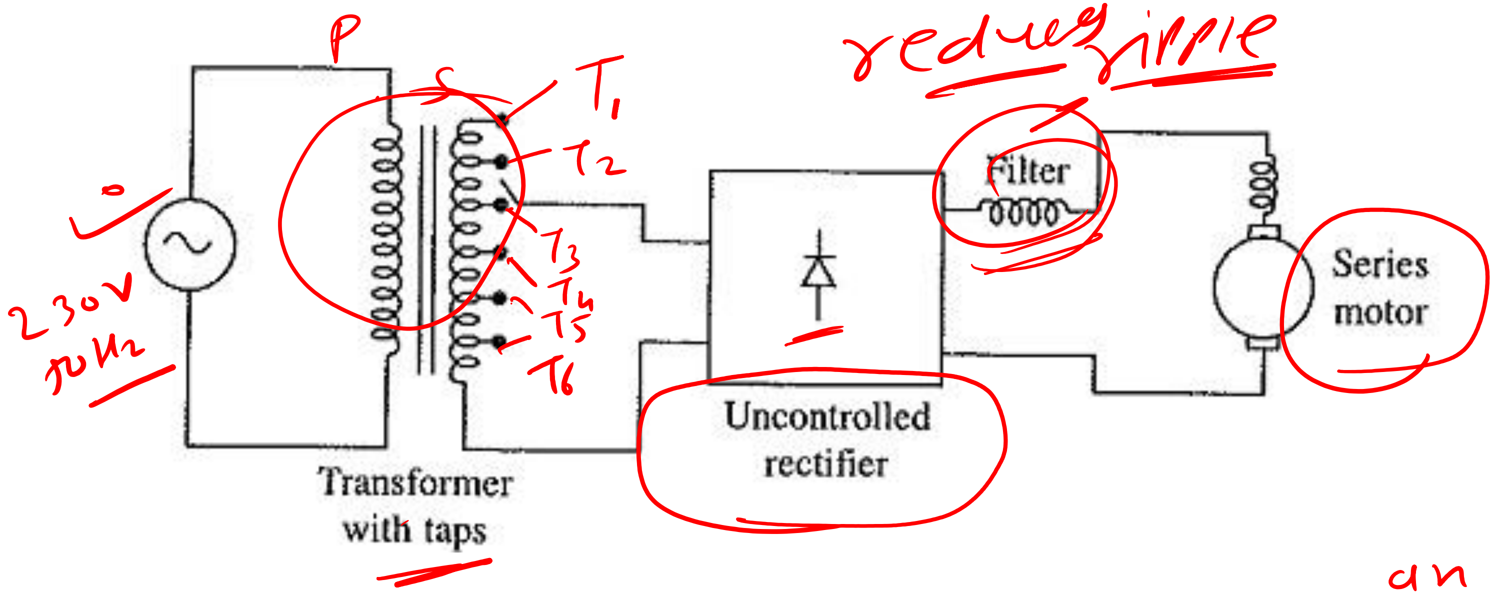
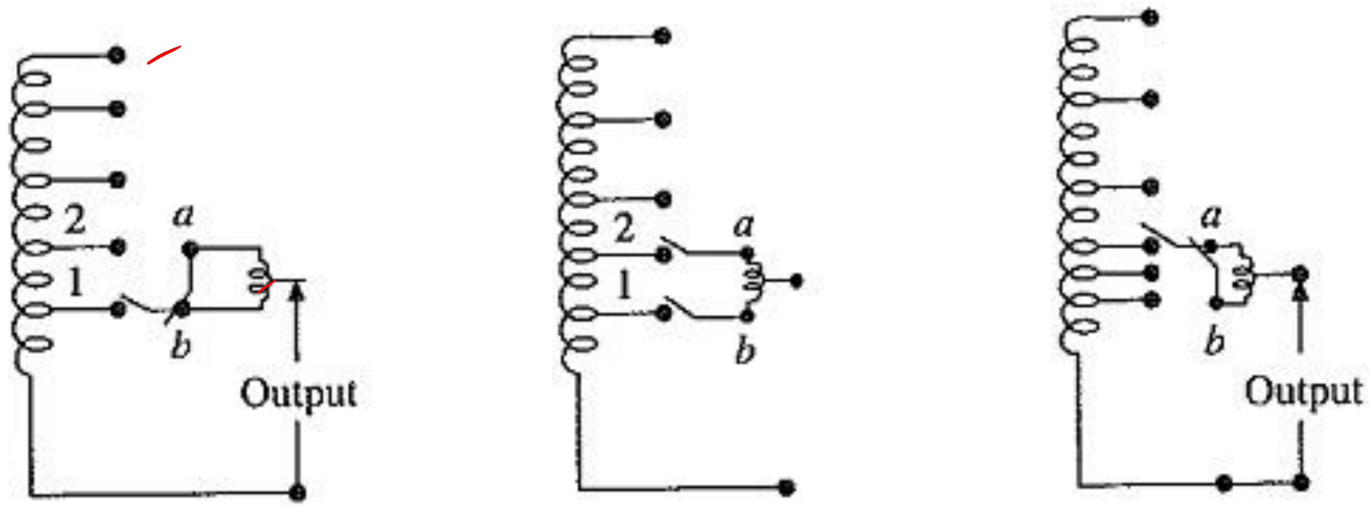


Fig. 1. Armature Voltage Control of DC Motor using Transformer with tap and un uncontrolled rectifier.

Armature Voltage Control of DC Motor using Transformer

- Auto-transformer can be employed only for low power ratings.

- For high-power applications a transformer with tapings is employed and tap changing is done with the help of an on-load tap changer (Fig. 2) to avoid severe voltage transients, produced due to interruption of current in open circuit transition.



(a) On tap 1 (b) Intermediate position (c) On tap 2

Fig. 2. On load tap changer.

Armature Voltage Control of DC Motor using Transformer

- A mid-point auto-transformer is used to carry out on load tap changing.
- When on tap position 1, both the terminals of the auto-transformer are connected together. For changing to tap 2, terminal ‘a’ is first connected to tap 2.
- Terminal is now disconnected from tap 1 and connected to ‘a’.

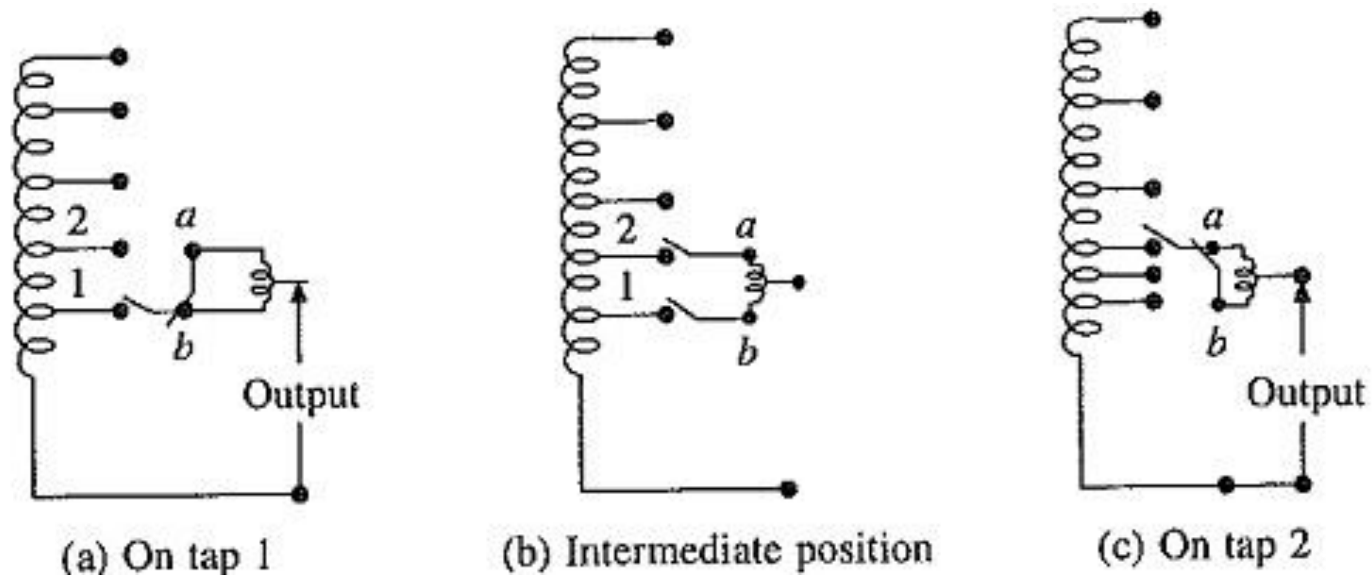


Fig. 2. On load tap changer.

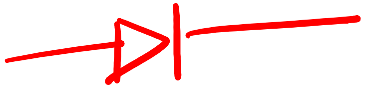
Armature Voltage Control of DC Motor using Transformer

The important features of Armature Voltage Control using a Transformer scheme are:

1. Output voltage can be changed only in steps;

2. Rectifier output voltage waveform does not change as the output voltage in reduced. A good power factor is maintained at the source and current harmonics introduced in the supply lines do not increase abnormally, like in the case of a controlled rectifier when motor voltage is reduced to a small value

3. Because of the use of diode bridge, a circuit is not capable of regeneration.

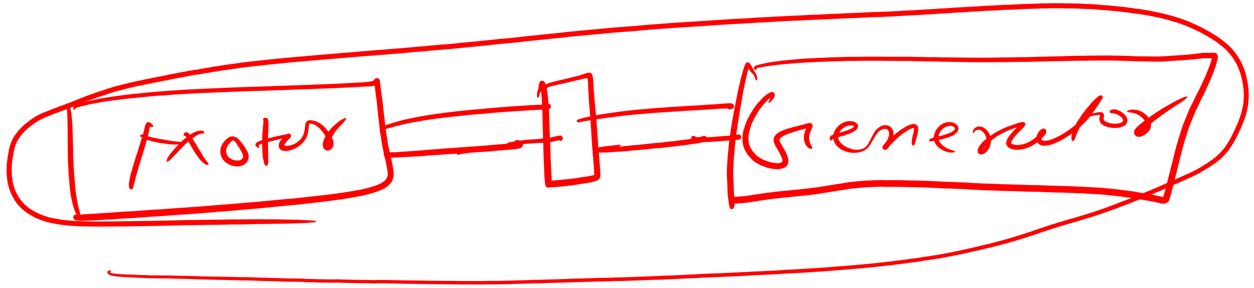


Controlled Rectifier Fed DC Drives

Controlled Rectifier Fed DC Drives

- Controlled Rectifier Fed DC Drives are used to get variable DC voltage from an AC source of fixed voltage.

- Controlled Rectifier Fed DC Drives are also known as Static Ward-Leonard drives.



Controlled Rectifier Fed DC Drives

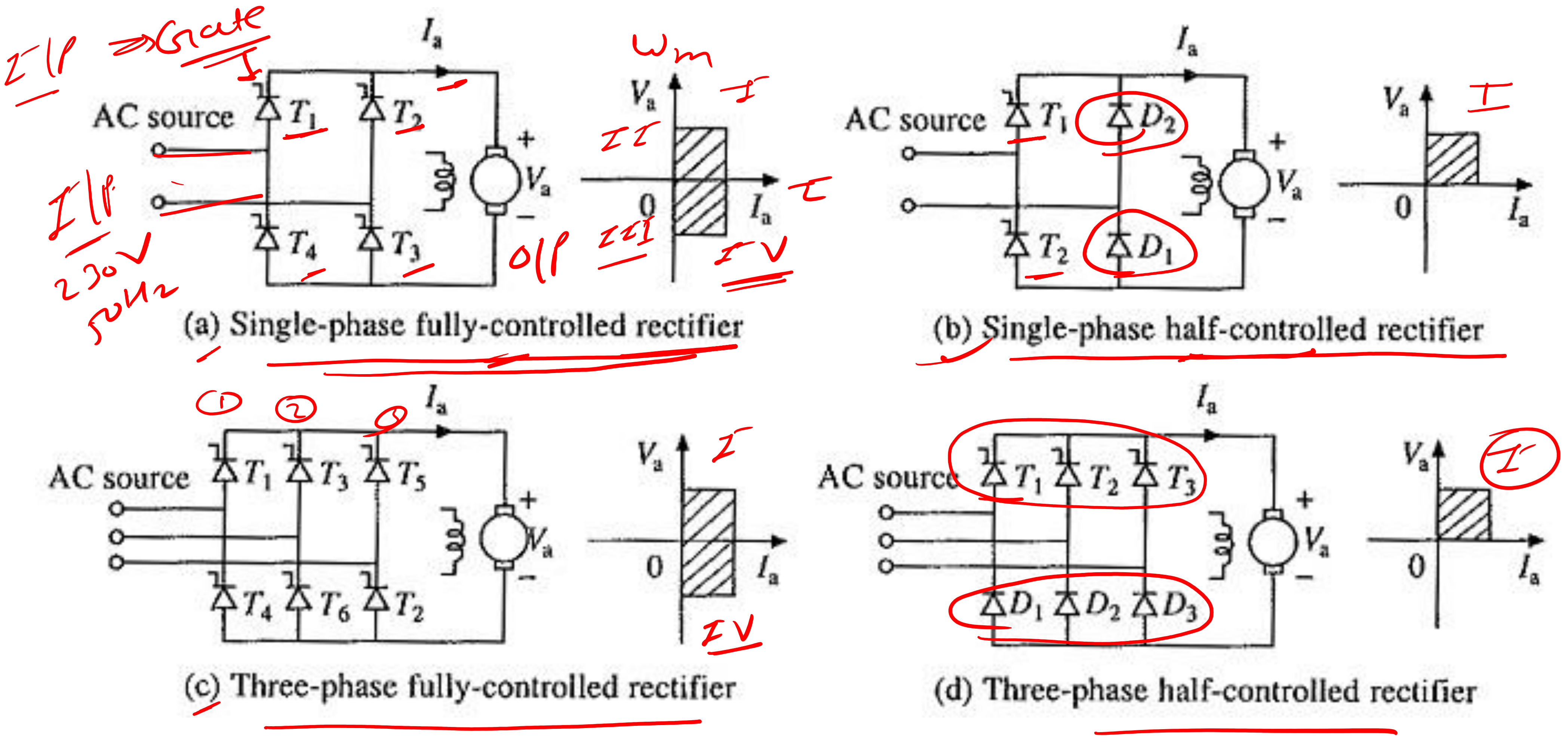


Fig. 1. Single-phase and three-phase controlled rectifier circuits.

Controlled Rectifier Fed DC Drives

- Figure 1 shows commonly used Controlled Rectifier Fed DC Drives and quadrants in which they can operate on V_a-I_a plane.

- As thyristors are capable of conducting current only in one direction, all these rectifiers are capable of providing current only in one direction.

- Rectifiers of Figs. 1(a) and (c) provide control of DC voltage in either direction and therefore, allow motor control in quadrants I and IV. They are known as **Fully Controlled Rectifiers**.

Controlled Rectifier Fed DC Drives

- Rectifiers of Figs. 1(b) and (d) are called **Half Controlled Rectifiers** as they allow DC voltage control only in one direction and motor control in quadrant I only.
- For low-power applications (up to around 10 kW) single-phase rectifier drives are employed. For high-power applications, three-phase rectifier drives are used.
- Exception is made in traction where single-phase drives are employed for large power ratings.

Key Points from Today's Class

- Overview of Types of DC Motor Drives
- Speed Control of DC Motor Drives
- Armature Voltage Control of DC Motor using Transformer
- Controlled Rectifier Fed DC Drives

Key Points from Next Class

In the next class, we will be discussing on the

- ❖ Single Phase Fully Controlled Rectifier Control of DC Motor
- ❖ Single Phase Half Controlled Rectifier Control of DC Separately Excited Motor

① Continuous mode } operation
② Dis continuous mode

Thank you so much for your attentions

Q & A