CONCEPT OF V/F METHOD

- THE CONSTANT V/F CONTROL METHOD IS THE MOST POPULAR METHOD OF SCALAR CONTROL.
- IF THE RATIO OF VOLTAGE TO FREQUENCY IS KEPT CONSTANT ,THE FLUX REMAINS CONSTANT.
- BY VARYING THE VOLTAGE AND FREQUENCY THE TORQUE AND SPEED CAN BE VARIED.
- THE TORQUE IS NORMALLY MAINTAINED CONSTANT WHILE THE SPEED IS VARIED.
- THIS ARRANGEMENT IS WIDELY USED IN LOCOMOTIVES AND INDUSTRIAL APPLICATIONS.
- THE PURPOSE OF THE VOLTS HERTZ CONTROL SCHEME IS TO MAINTAIN THE AIR GAP FLUX OF AC INDUCTION MOTOR CONSTANT IN ORDER TO ACHIEVE HIGHER RUN TIME EFFICIENCY.

$$\phi = \frac{V}{f}$$

CASE 2 : DECREASING FREQUENCY AND VOLTAGE KEEPING FLUX CONSTANT-V/F CONTROL

$\phi = \frac{V \downarrow}{f \downarrow}$

$\phi \downarrow$ Constant

$N_s \downarrow = \frac{120 f}{P} \downarrow$

$N_0 \downarrow$

$T_m \propto \left(\frac{V}{f}\right)^2$

$T_s \propto \frac{1}{f}$

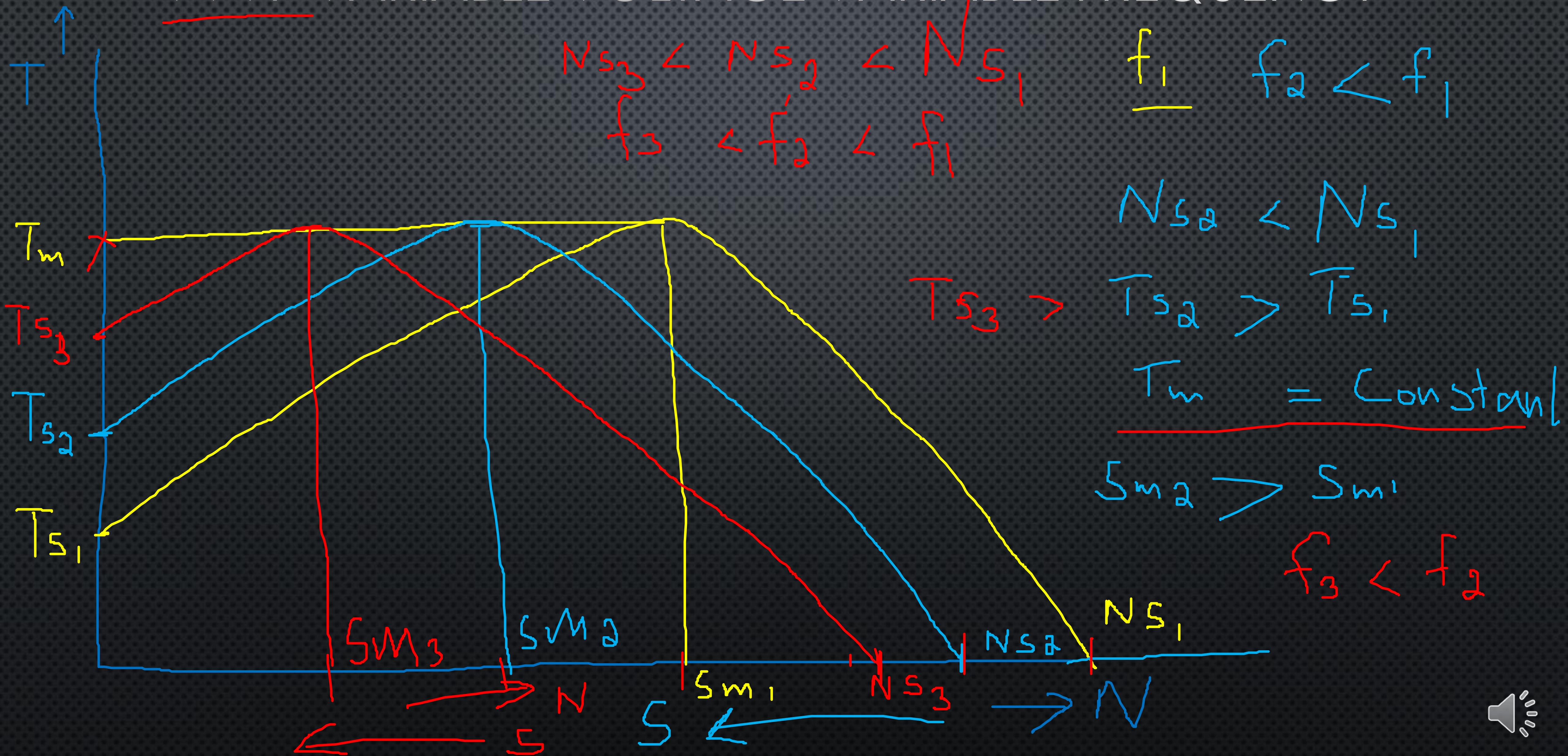
$S \propto \frac{1}{f}$

~~$T_m \rightarrow$ constant~~ ✗

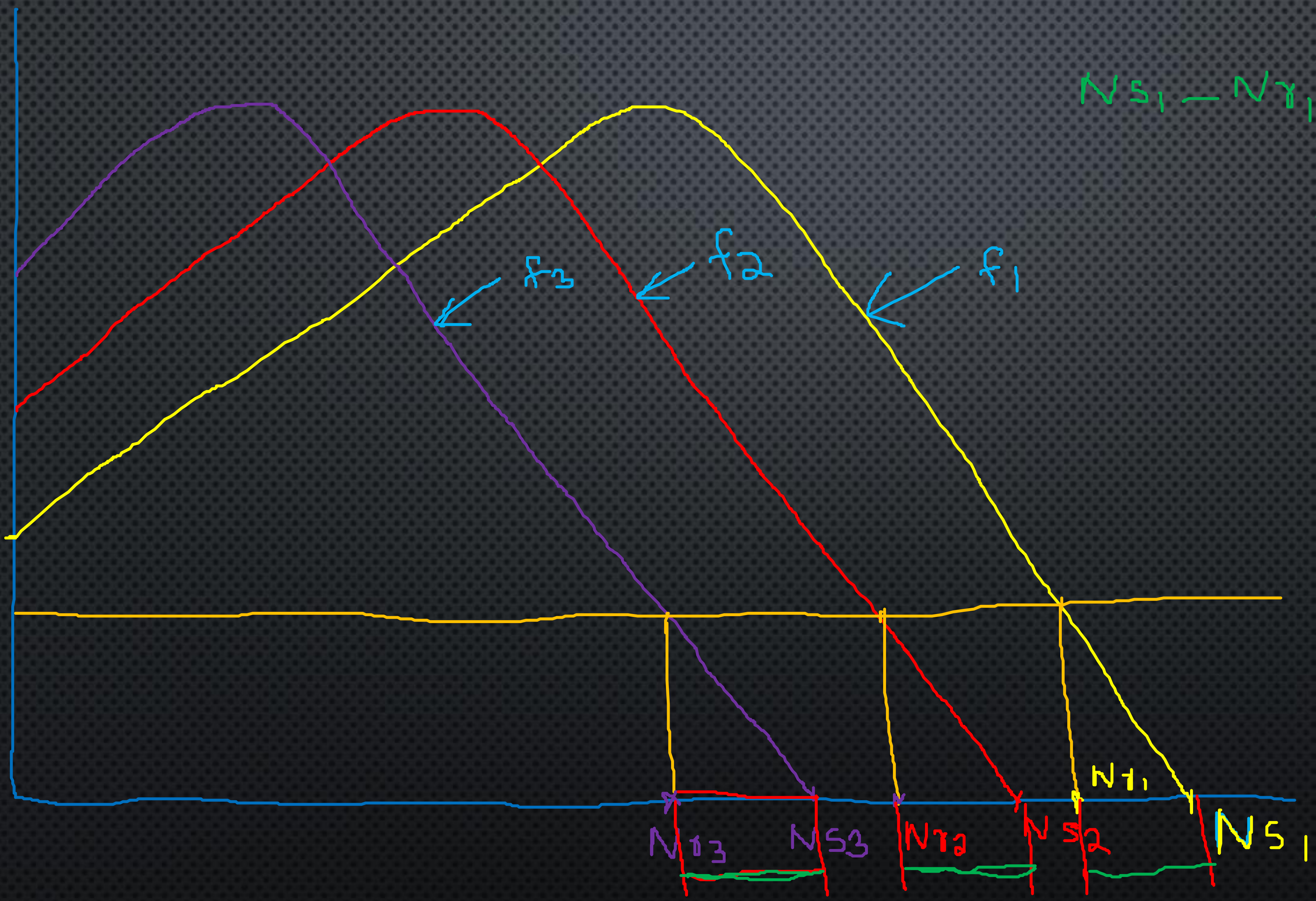
$f \downarrow$ $T_s \uparrow$

$S \uparrow$

VVVF-VARIABLE VOLTAGE VARIABLE FREQUENCY



LOAD TORQUE CONSTANT



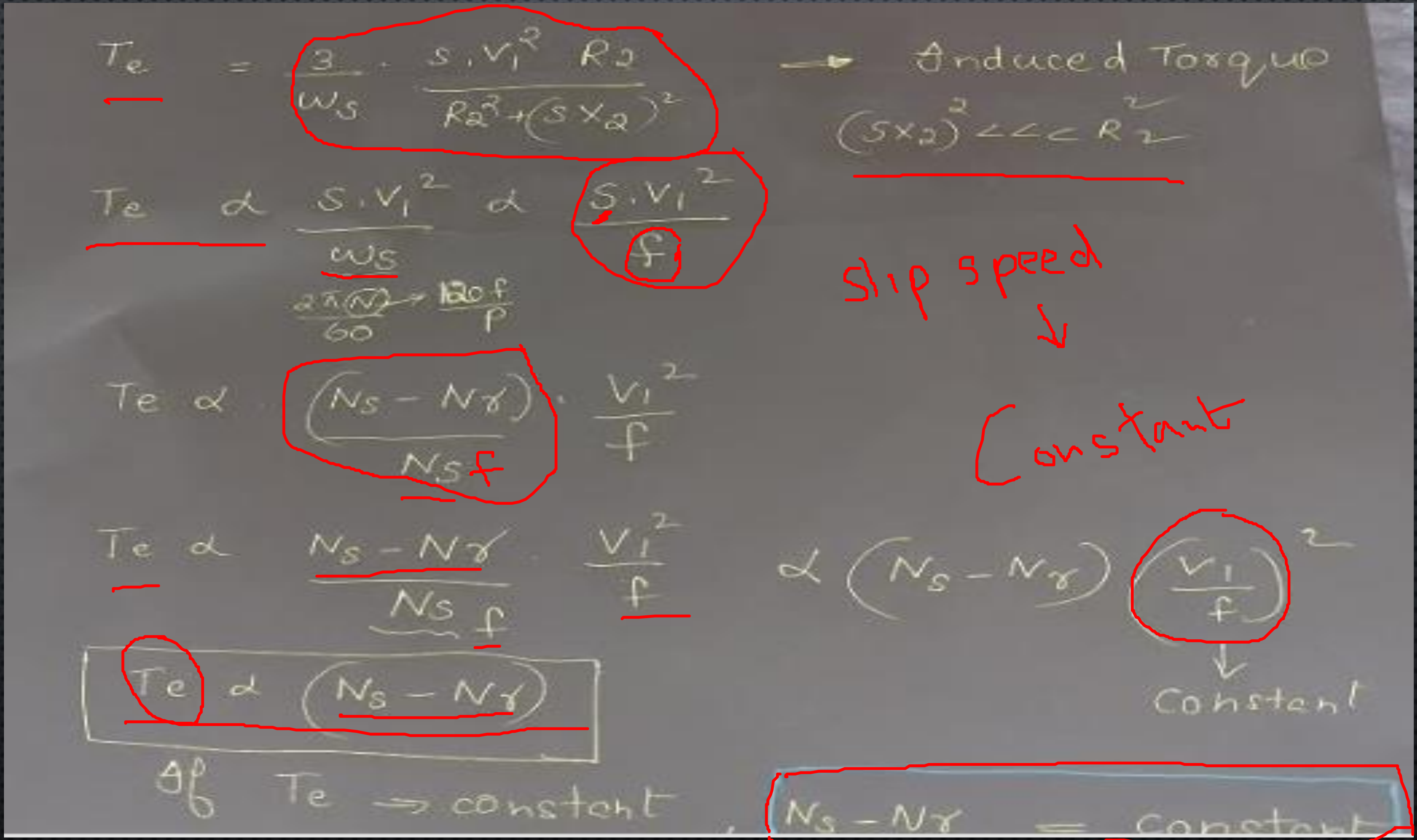
$$N_{s1} - N_{r1} = N_{s2} - N_{r2}$$

$$= N_{s3} - N_{r3}$$

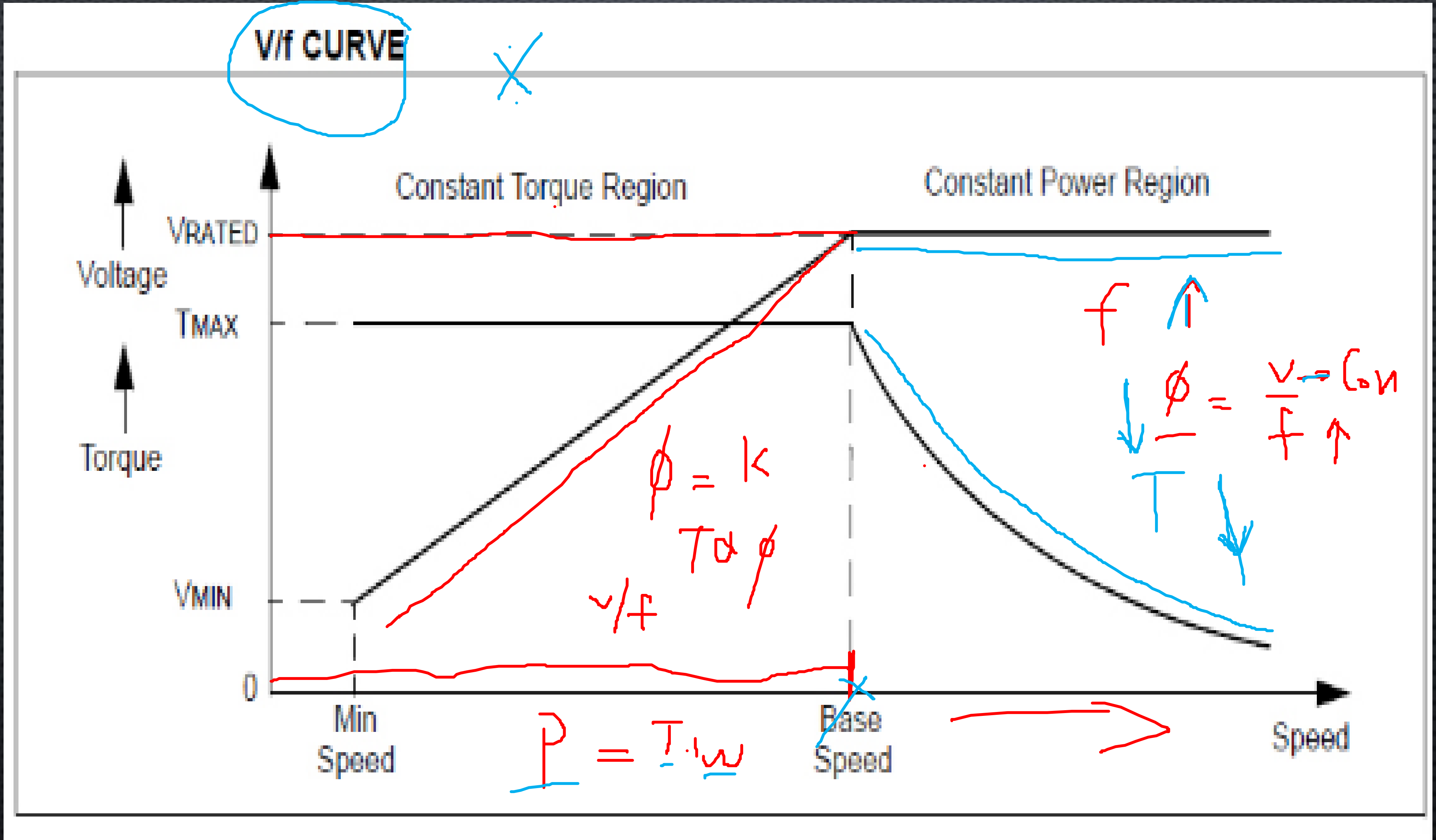
$T_l \rightarrow K$

slip speed $\rightarrow K$

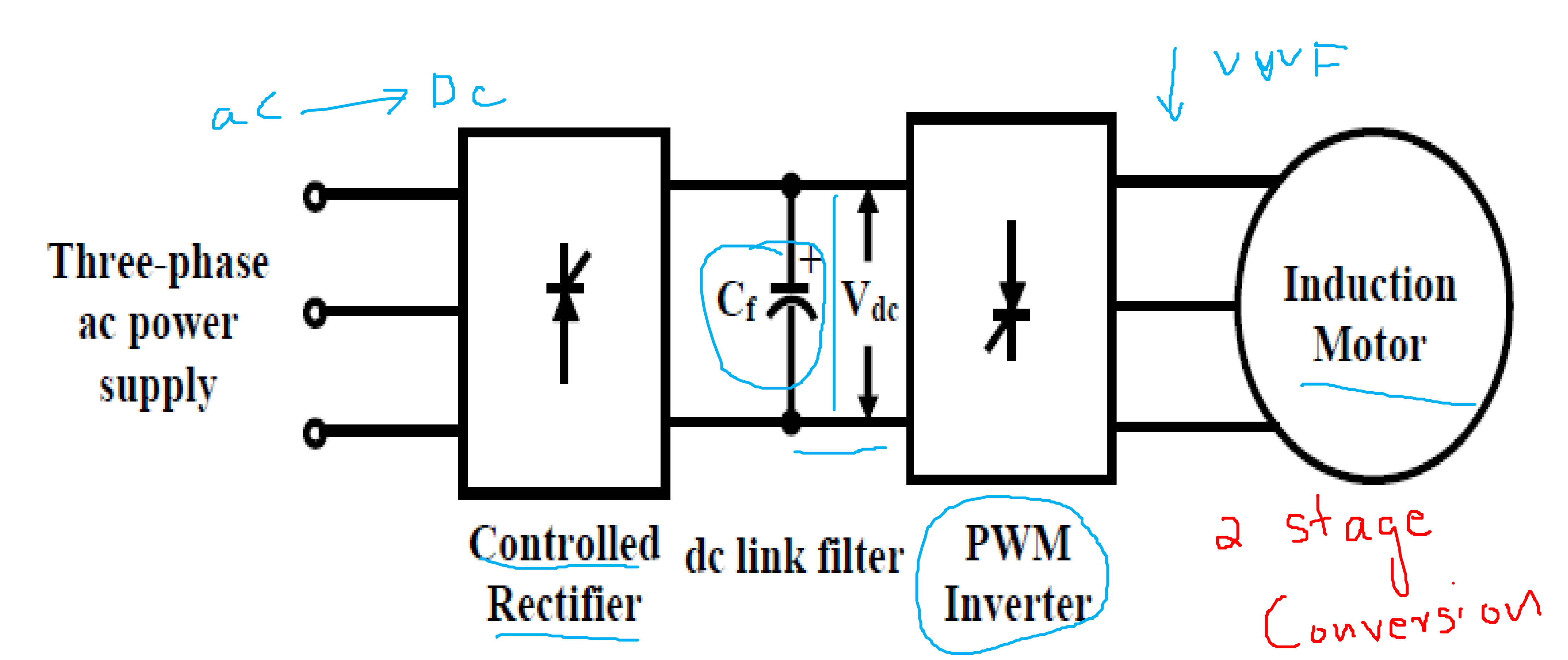
SLIP SPEED IS CONSTANT FOR CONSTANT LOAD TORQUE



V/F CURVE


V/f CURVE
Constant Torque Region
Constant Power Region
Voltage
Torque
VRATED
TMAX
VMIN
0
Min Speed
Base Speed
Speed

FOR CONTROLLING THE SPEED OF THREE PHASE INDUCTION MOTOR BY V/ F METHOD WE HAVE TO SUPPLY VARIABLE VOLTAGE AND FREQUENCY WHICH IS EASILY OBTAINED BY USING CONVERTER AND INVERTER SET.



Variable-voltage, variable-frequency (VVVF) induction motor drive

ADVANTAGES OF V/F CONTROL

- SPEED CONTROL AND BRAKING OPERATION ARE AVAILABLE
- DURING TRANSIENTS(STARTING, BRAKING AND SPEED REVERSAL) THE OPERATION CAN BE CARRIED OUT AT MAXIMUM TORQUE WITH REDUCED CURRENT GIVING GOOD DYNAMIC PERFORMANCE
- COPPER LOSSES ARE LOW AND EFFICIENCY AND PF ARE HIGH AS THE OPERATION IS RESTRICTED BETWEEN SYNCHRONOUS SPEED AND MAX TORQUE POINT AT ALL FREQUENCIES.

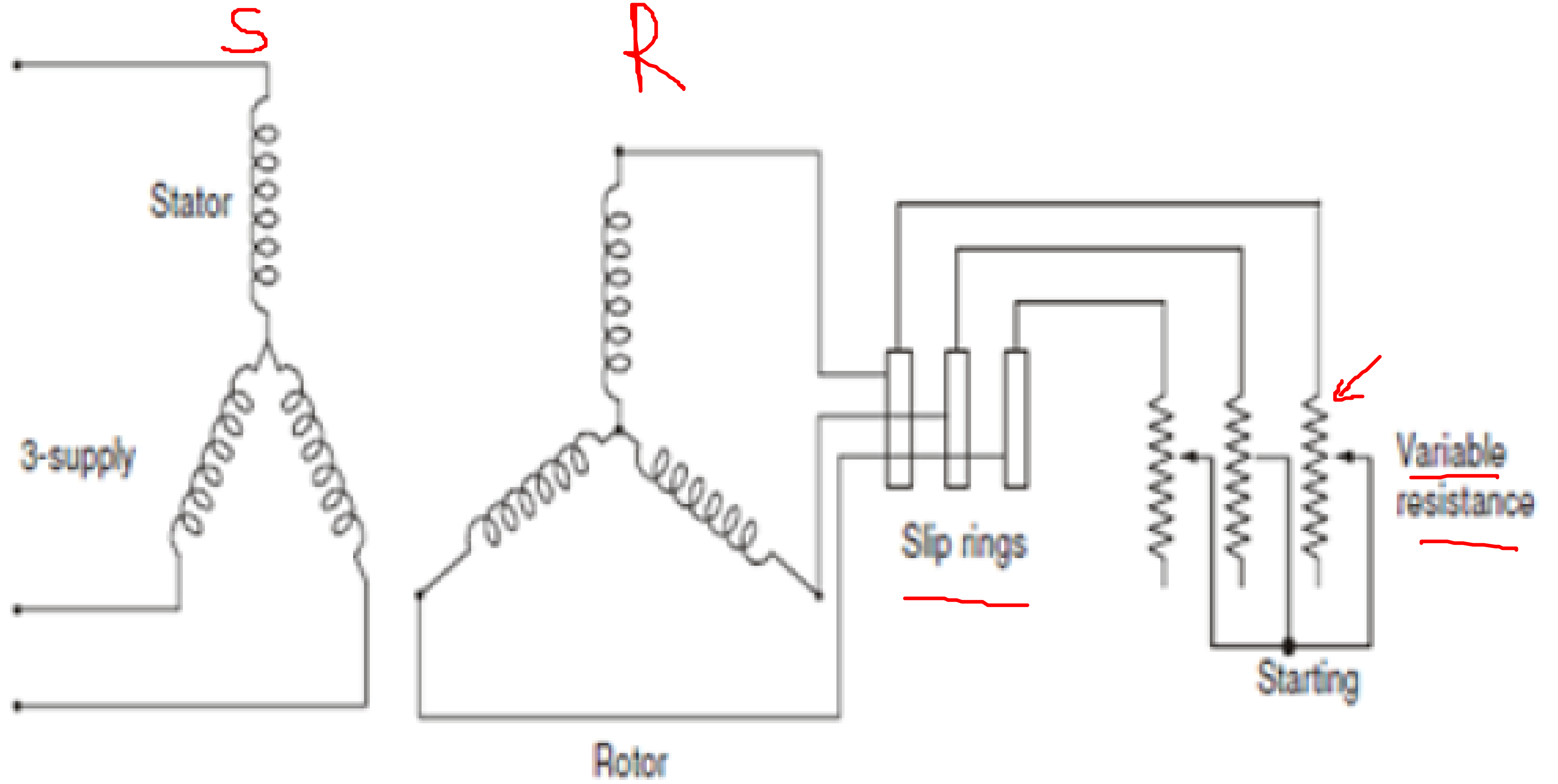
$T_m \rightarrow k$

DISADVANTAGES OF V/F CONTROL

- FLUX MAY DRIFT AND THE TORQUE SENSITIVITY WITH SLIP MAY VARY.
- LINE VOLTAGE VARIATION,INCORRECT V/HZ RATIO,STATOR DROP VARIATION BY LINE CURRENT AND M/C PARAMETER VARIATION MAY CAUSE WEAKER FLUX.
- IF THE FLUX BECOMES WEAK,THE DEVELOPED TORQUE WILL DECREASE AND THE MACHINE'S ACCELERATION/DECELERATON CAPABILITY WILL DECREASE

THREE PHASE INDUCTION MOTOR SPEED CONTROL FROM THE ROTOR SIDE

CONVENTIONAL SCHEME



Speed control of three phase Induction motor by Varying the rotor resistance (Conventional Scheme)

EQUATIONS

Adding external resistance on rotor side - In this method of speed control of three phase induction motor external resistance are added on rotor side. The equation of torque for three phase induction motor is

$$T_e = \frac{3}{\omega_s} \cdot \frac{V_1^2}{\left(r_1 + \frac{r_2}{s}\right)^2 + (x_1 + x_2)^2} \cdot \frac{r_2}{s}$$

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

T_{max}

$sX_2 << R_2$

The three phase induction motor operates in low slip region. In low slip region term $(sX)^2$ becomes very very small as compared to R_2. So, it can be neglected . and also E_2 is constant. So the equation of torque after simplification becomes,

$$T \propto \frac{s}{R_2}$$

T_{max} $R_2 = sX_2$

T_{max} Independent of R_2

CONVENTIONAL METHOD

- Torque depends on motor resistance.
- Therefore, increasing the rotor resistance at a constant torque causes a proportionate increase in the motor slip with decrease in rotor speed.
- Thus, the speed for a given load torque may be varied by varying the rotor resistance. The function of this resistance is to introduce voltage at rotor frequency, which opposes the voltage induced in rotor winding.
- Conventionally, the rotor resistance is controlled manually and in discrete steps.
- The main demerit of this method of control is that energy is dissipated in rotor circuit resistance, internal and external, and this energy is wasted in the form of heat.
- Because of the waste-fullness of this method, it is used where speed change are needed for short duration only.

$R_2 \uparrow \quad S \uparrow \quad N_r \downarrow$

$$T \propto \frac{3}{\omega_s} \frac{s V_1^2 R_2}{R_2^2 + (sX_2)^2}$$

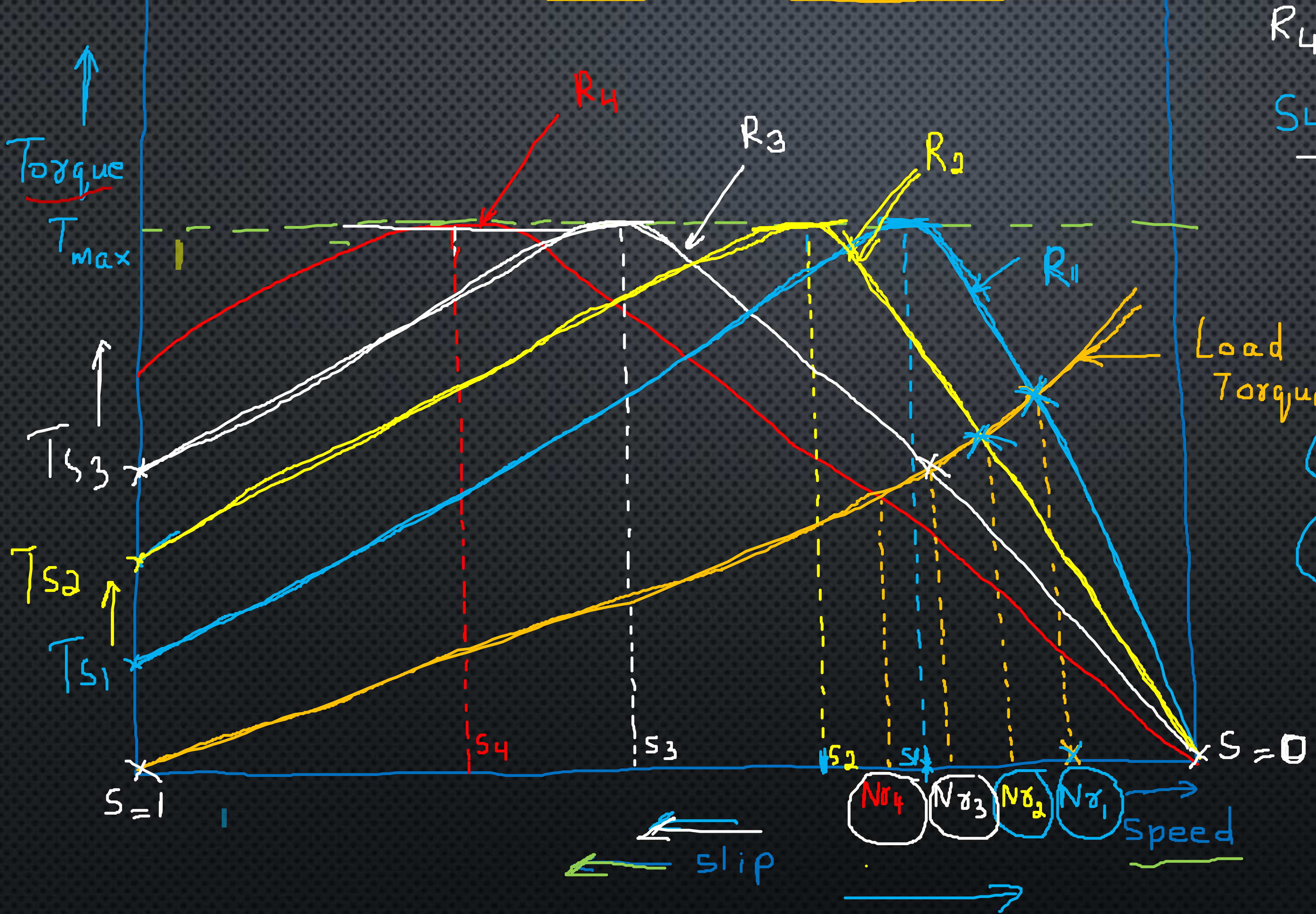
$$T_{st} \propto R_2$$

- Now if we increase rotor resistance, R_2 torque decreases but to supply the same load torque must remains constant. So, we increase slip, which will further results in decrease in rotor speed.
- Thus by adding additional resistance in rotor circuit we can decrease the speed of three phase induction motor.
- The main advantage of this method is that with addition of external resistance starting torque increases

$$S = \frac{N_s - N_r}{N_s}$$

$$S = 1$$

Speed - Torque Characteristics



$N_{r4} < N_{r3} < N_{r2} < N_{r1}$

$R_4 > R_3 > R_2 > R_1$

$S_4 > S_3 > S_2 > S_1$

con

$T \propto \frac{S}{R}$

$N_r = (1 - S) N_s$

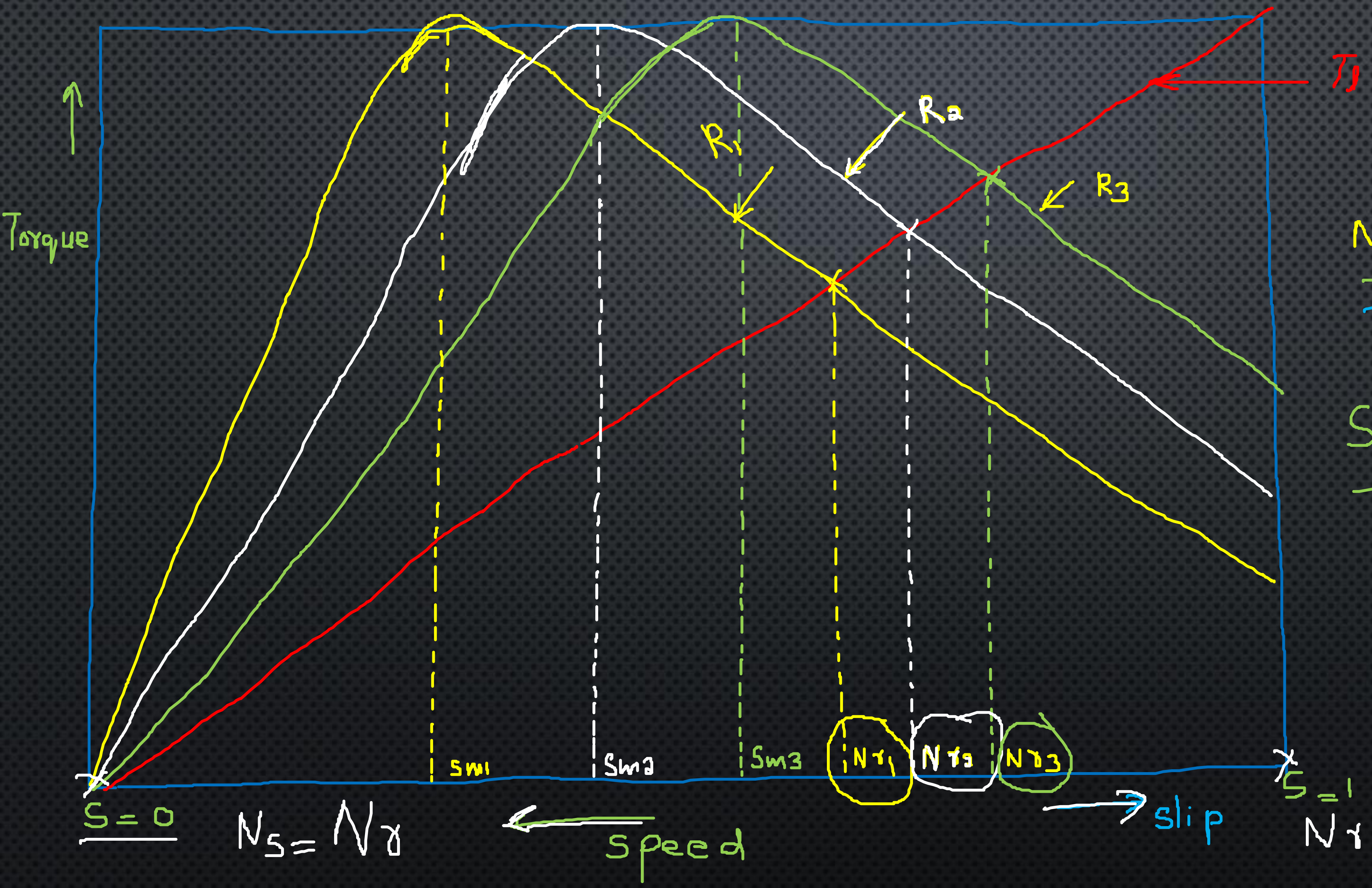
$R \uparrow \quad S \uparrow \quad T \rightarrow$ Constant

$N_r \downarrow$

$S_{m1} > S_{m2}$

$S_2 > S_1$

$N_{r2} < N_{r1}$



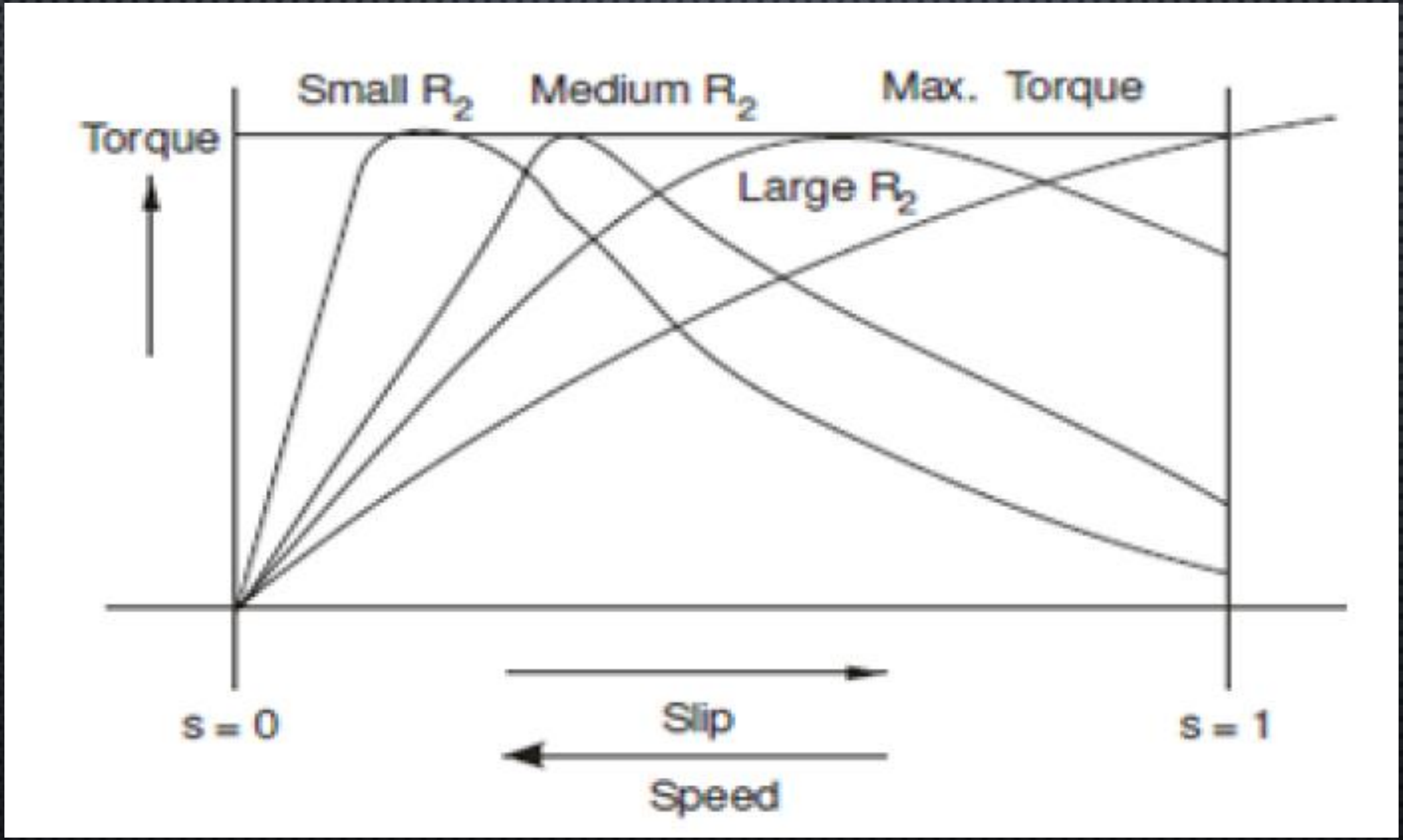
$R_3 > R_2 > R_1$

$N_{r3} < N_{r2} < N_{r1}$

$T_{max} \rightarrow$ constant

$S_{m3} > S_{m2} > S_{m1}$

SPEED –TORQUE CHARACTERISTICS FOR ROTOR RESISTANCE CONTROL



DISADVANTAGES

- THE SPEED ABOVE THE NORMAL VALUE IS NOT POSSIBLE.
- LARGE SPEED CHANGE REQUIRES LARGE VALUE OF RESISTANCE AND IF SUCH LARGE VALUE OF RESISTANCE IS ADDED IN THE CIRCUIT IT WILL CAUSE LARGE COPPER LOSS AND HENCE REDUCTION IN EFFICIENCY.
- PRESENCE OF RESISTANCE CAUSES MORE LOSSES.
- THIS METHOD CANNOT BE USED FOR SQUIRREL CAGE INDUCTION MOTOR.
- BECAUSE OF THE WASTE-FULLNESS OF THIS METHOD, IT IS USED WHERE SPEED CHANGE ARE NEEDED FOR SHORT DURATION ONLY.

Speed control of three phase induction motor using frequency control

Torque Equations

Maximum torque is given by

$$T_m \cong \frac{3V_1^2}{2\omega_s X_2'}$$

$$T_m \propto \left(\frac{V_1}{f}\right)^2 \implies (1)$$

STARTING TORQUE OF AN INDUCTION MOTOR IS GIVEN BY

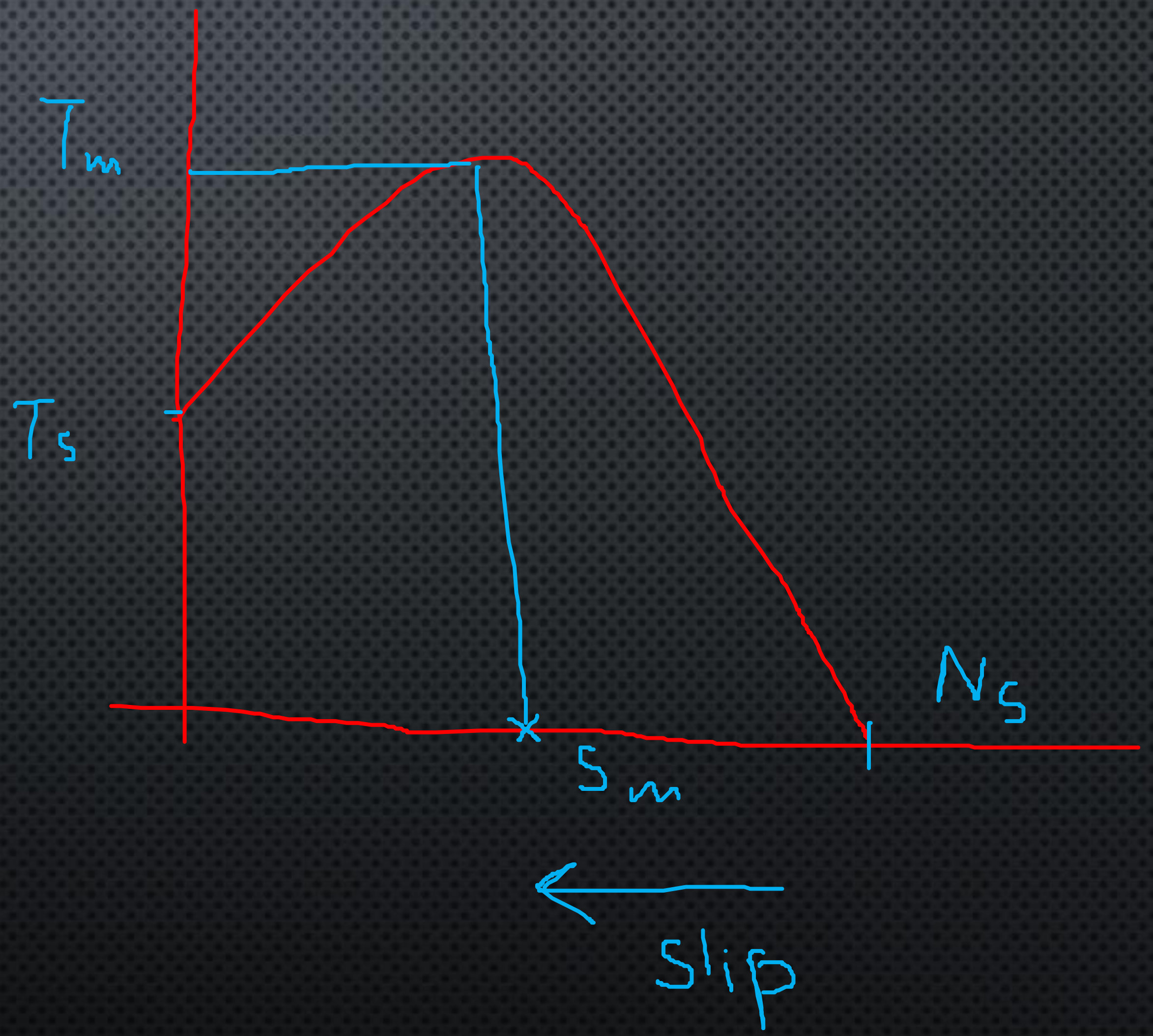
$$T_{st} = \frac{3V_1^2}{\omega_s (X_2')^2}$$

$f \qquad f^2$

$$T_{st} \propto \frac{V_1^2}{f^3} \propto \left(\frac{V_1}{f}\right)^2 \times \frac{1}{f}$$

SLIP CORRESPONDING TO MAXIMUM TORQUE IS GIVEN BY

$$\uparrow S \propto \frac{1}{f} \downarrow$$



SPEED EQUATIONS

$$\uparrow N_s \downarrow = \frac{120 f \uparrow \downarrow}{P}$$

$$\downarrow N_r \uparrow = (1 - s) N_s$$

$$\phi \propto \frac{V}{f}$$

FREQUENCY CONTROL

- CASE 1 : FREQUENCY DECREASED BY KEEPING VOLTAGE CONSTANT
- CASE 2 : FREQUENCY DECREASED ALSO VOLTAGE DECREASED KEEPING FLUX CONSTANT (V/F CONTROL)
- CASE3 : FREQUENCY INCREASED BY KEEPING VOLTAGE CONSTANT

CASE1 : FREQUENCY IS DECREASED BY KEEPING VOLTAGE CONSTANT

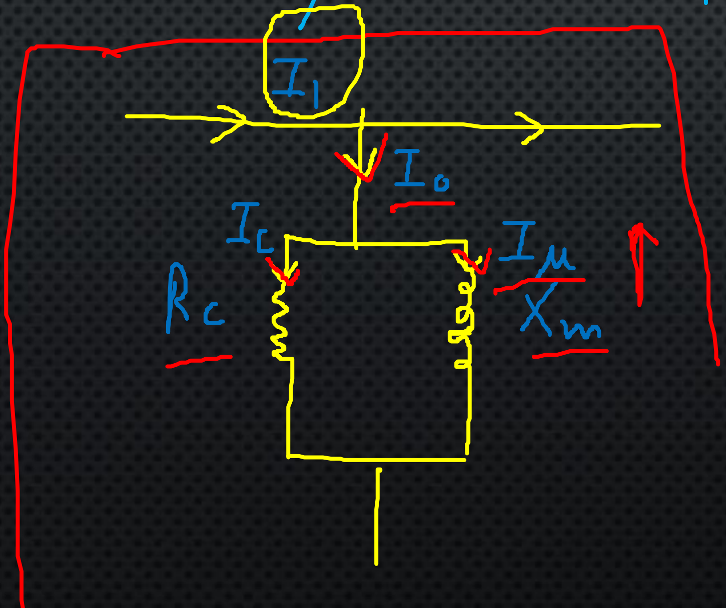
$N_s \downarrow = \frac{120 f}{P}$

$f \downarrow$

$N_r \downarrow = (1 - s) N_s$

Saturation

$\phi \uparrow = \frac{V}{f \downarrow}$ $V \rightarrow$ Constant



$\frac{P_i \uparrow}{pf} \downarrow$

$\phi \uparrow$ $\quad I_\mu \uparrow$ $\quad \frac{I_0 \uparrow}{\phi_0 \uparrow}$ $\quad \frac{I_1 \uparrow}{\phi_1 \uparrow}$

$\cos \phi_0 \downarrow$ $\quad \cos \phi_1 \downarrow$

EFFECT OF DECREASE IN FREQUENCY ON TORQUE

$$T_m \propto \left(\frac{V}{f}\right)^2 \qquad f \downarrow \quad T_m \uparrow$$

$$T_{st} \propto \left(\frac{V}{f}\right)^2 \times \left(\frac{1}{f}\right) \qquad f \downarrow \quad T_{st} \uparrow$$

$$S \propto \frac{1}{f} \qquad f \downarrow \quad S \uparrow$$

DISADVANTAGES

- ANY **REDUCTION IN THE SUPPLY FREQUENCY** WITHOUT A CHANGE IN THE TERMINAL VOLTAGE CAUSE INCREASE IN THE AIR GAP FLUX. INCREASE IN FLUX WILL SATURATE THE MOTOR WHICH WILL
- 1) INCREASE THE MAGNESTISING CURRENT
- 2)DISTORT THE LINE CURRENT AND VOLTAGE pf ↓
- 3)INCREASE THE CORE LOSS I_μ ↑
- 4)INCREASE STATOR COPPER LOSS
- 5)PRODUCE HIGH PITCH ACOUSTIC NOISE

THREE PHASE INDUCTION MOTOR SPEED CONTROL USING STATIC ROTOR RESISTANCE

ROTOR CHOPPER SPEED CONTROL

$R \uparrow \; N_r \downarrow$

- THIS METHOD IS APPLICABLE TO SLIP RING INDUCTION MOTORS.
- SLIP RING INDUCTION MOTORS ARE WIDELY USED FOR HIGH TORQUE AND VARIABLE SPEED APPLICATIONS.
- CONVENTIONAL METHODS OF SPEED CONTROL OF SLIP INDUCTION MOTOR FROM ROTOR SIDE, LEAD TO WASTAGE OF ENERGY, IN EXTERNAL RESISTANCE.
- WITH THE ADVENT OF POWER ELECTRONIC DEVICES POWER LOSS AT ROTOR SIDE COULD BE MINIMIZED AND SMOOTH SPEED CONTROL CAN BE ACHIEVED BY IMPLEMENTING ROTOR CHOPPER CONTROL.

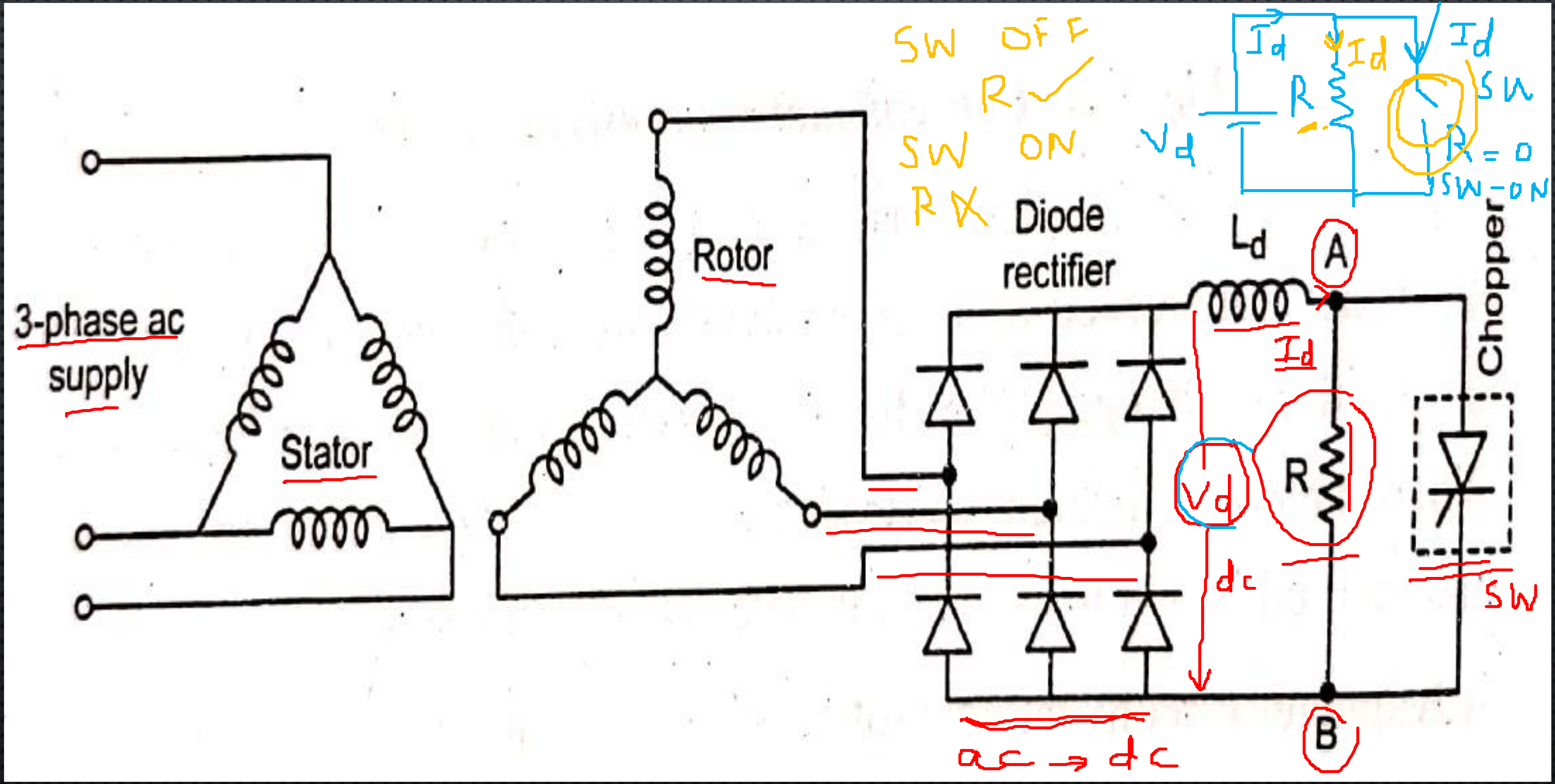
R
Chopper

CHOPPER CONTROLLED SYSTEM

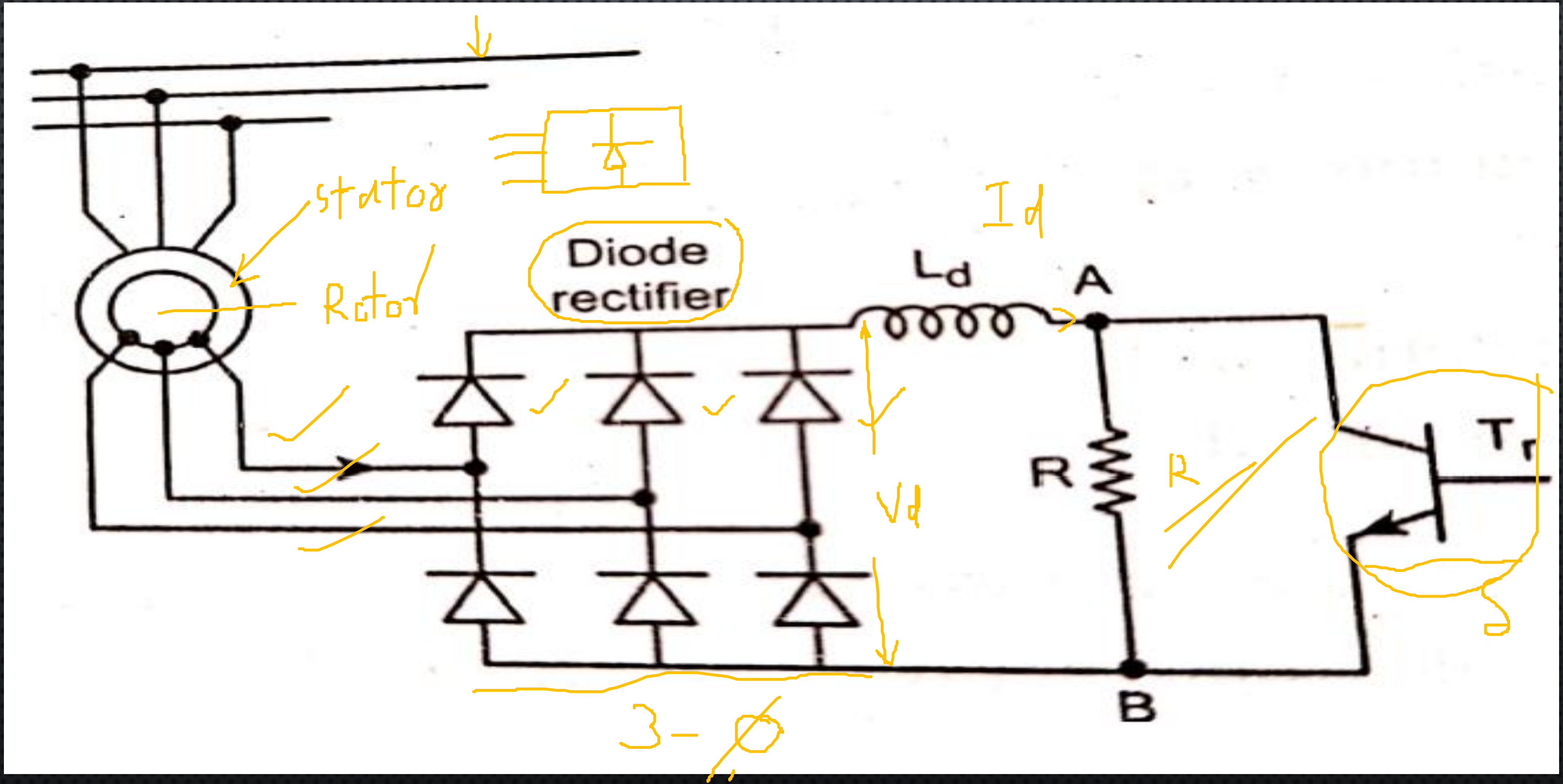
- WITH THE ADVENT OF POWER SEMICONDUCTORS, THE CONVENTIONAL RESISTANCE CONTROL SCHEME CAN BE ELIMINATED BY USING A THREE-PHASE RECTIFIER BRIDGE AND A CHOPPER CONTROLLED EXTERNAL RESISTANCE.

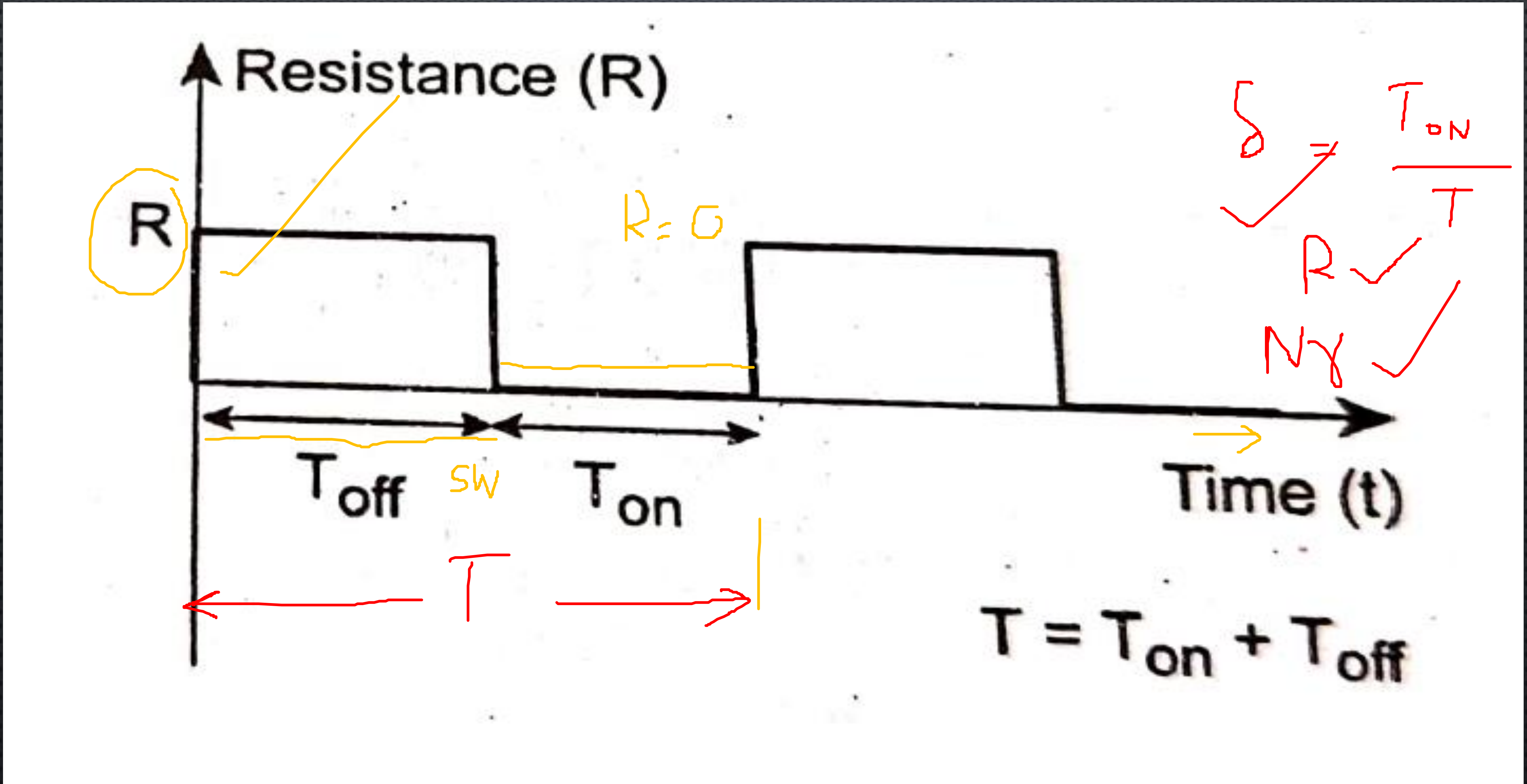
2 ac → dc

CIRCUIT FOR ROTOR CHOPPER SPEED CONTROL



CIRCUIT FOR ROTOR CHOPPER SPEED CONTROL





Resistance (R)
R
R = 0
T_{off}
SW
T_{on}
Time (t)
T
$\delta = \frac{T_{ON}}{T}$
R
Nγ
$T = T_{on} + T_{off}$

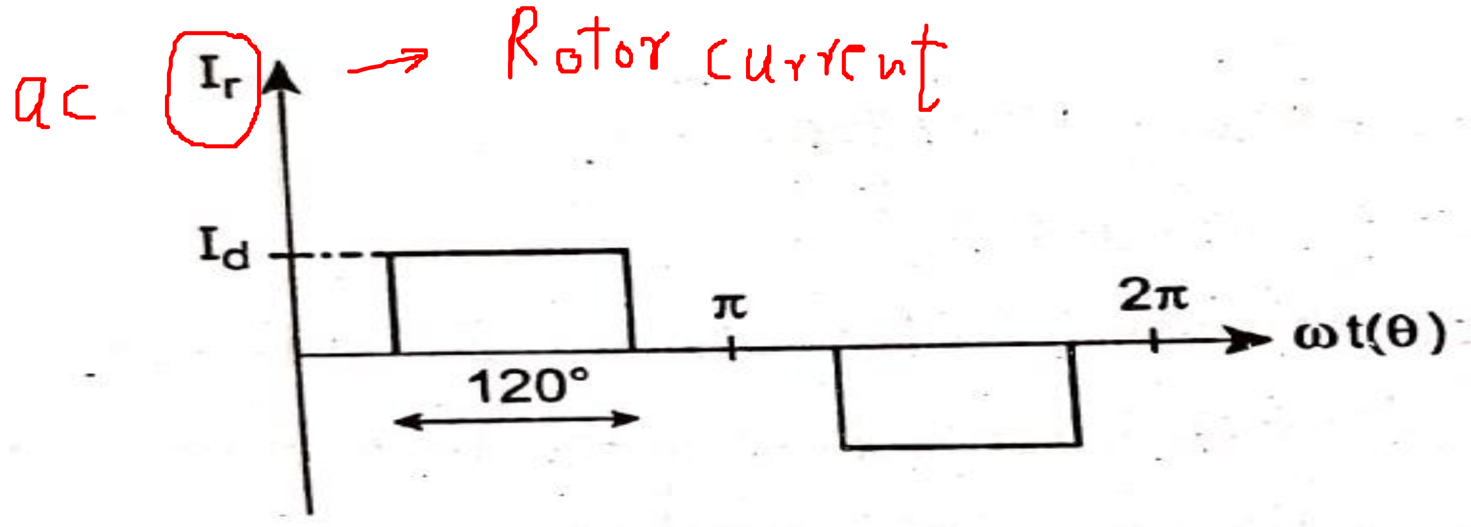
EXPRESSION FOR RESISTANCE ADDED TO ROTOR SIDE

$$R_{AB} = \frac{1}{T}\int_0^{T_{off}} R\,dt \qquad R_{AB} = \frac{1}{T} R\, T_{off}$$

$$R_{AB} = \frac{T_{off}}{T} R = \frac{T - T_{on}}{T} R \qquad R = (1-\delta) R$$

$$R_{AB} = \frac{(1 - T_{on})}{T} R = (1-\delta) R$$

EXPRESSION FOR CURRENT



120

$$I_r = \left(\frac{1}{\pi} \int_0^{2\pi/3} I_d^2 \, d(\omega t) \right)^{1/2}$$

RMS

DC link current

$$I_r = \sqrt{2/3}\, I_d \text{ (or) } I_d = \sqrt{3/2}\, I_r$$

EXPRESSION FOR POWER

$$P_{AB}/\text{phase} = \frac{I_d^2}{3} R(1-\delta)$$

Substituting the value of I_d,

$$P_{AB}/\text{phase} = (\sqrt{3/2})^2 \left(\frac{I_r^2}{3}\right) R(1-\delta)$$

$$P_{AB}/\text{phase} = \left(\frac{I_r^2}{2}\right) R(1-\delta)$$

$$P_{AB}/\text{phase} = 0.5\, I_r^2\, R(1-\delta)$$

EXPRESSION FOR ROTOR RESISTANCE PER PHASE

rotor circuit resistance per phase is increased

Thus, total rotor circuit resistance per phase becomes

$$R_{rt} = R_r + 0.5\,R\,(1 - \delta)$$

where R_r = Rotor resistance / phase, R = External resistance.

PART C

Answer any two full questions, each carries10 marks.

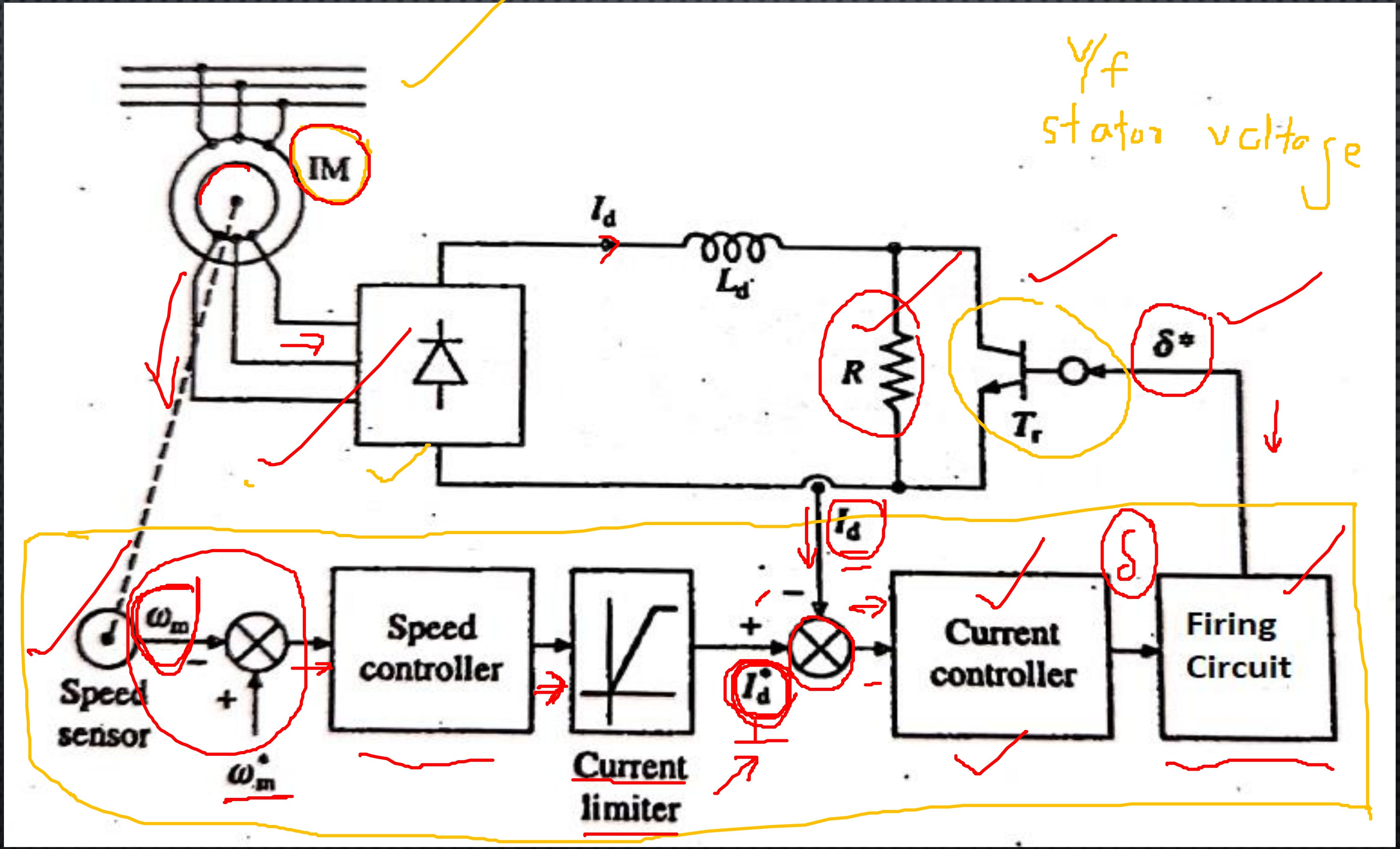
12		Explain the operation of four quadrant chopper fed separately excited DC motor drive with necessary diagrams.	(10)
13		Explain the closed loop static rotor resistance control method for the speed control of a slip ring induction motor. What are the disadvantages of this method?	(10)
14		Explain the static Kramer scheme for the speed control of a slip ring IM. Explain the firing angle control of thyristor bridge with constant motor field.	(10)

PART D

Answer any two full questions, each carries 10 marks.

15	a)	With a neat circuit and waveform explain a thyristor based CSI fed IM drive.	(5)
	b)	Explain how CSI fed IM drive can be used for regenerative braking and multiquadrant operation.	(5)

CLOSED LOOP SPEED CONTROL USING STATIC ROTOR RESISTANCE METHOD



WORKING OF CLOSED LOOP CONTROL

- ✓ This drive is suitable for crane and hoist applications where sustained low-speed running is not required (low speed requires more rotor resistance which leads to more power loss)
- ✓ The rotor slip power is rectified in a diode bridge rectifier and fed through a smoothing inductor L_d to a resistor R. A single thyristor in parallel with the resistor is switched on and off at a frequency of 1 KHZ, by a thyristor chopper circuit.

  The chopper periodically connects and disconnects the resistance R. The ratio of on time to off time, determines the effective value of rotor resistance and thus controls the motor speed by altering its torque-speed characteristics.
- ✓ The speed controller of figure 5.27 sets the reference current proportional to the speed error which is the difference of set speed and actual speed.

  The current controller decides the chopper on and off periods based on the current error signal which is the difference of set reference current from speed controller and actual current through the dc link.
- ✓ The range of speed control can be increased. If a combination of stator voltage control and rotor resistance control is employed. When the load torque is small speed control is obtained by variation of the stator voltage, and rotor resistance control is used in the high torque range.
- ✓ By connecting a capacitor in series with the external resistance, it is possible to obtain a variation in the effective resistance from zero to infinity, thus permitting a wider range of speed control. The rotor resistance control is used in the high torque range.

ADVANTAGES AND DISADVANTAGES

Advantages of static rotor resistance control

1. Stepless speed control is possible.
2. Rotor resistance remain balanced between the 3 - ϕ for all operating points.
3. High starting torque is available at low starting current and improved power factor is possible with wide range of speed control. ıɑɯ
4. Maximum torque capability remains unaltered even at speed.

Disadvantages of rotor resistance control

1. This method of speed control is very inefficient because slip energy is waste in rotor circuit resistance.
2. The rotor current is non sinusoidal. The harmonics of the rotor curre produce torque pulsations. These have a frequency which is six times the sl frequency.
3. More heating is produced in the rotor winding because rotor circuit accompanied with high value of harmonics.