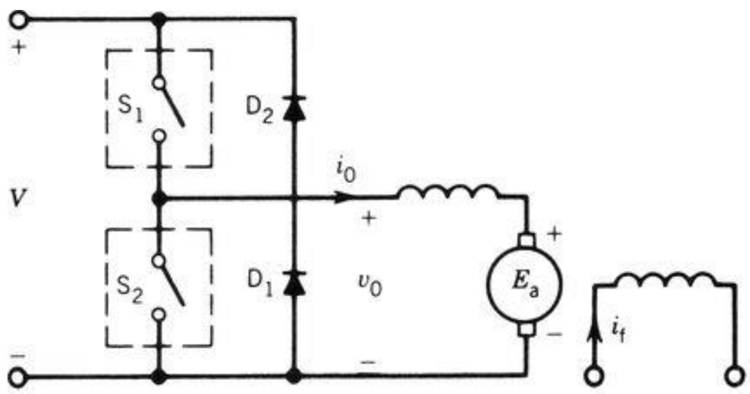
Q 1: A 2-quadrant chopper as shown in the figure below is used to control the speed of the DC motor and is also used for Regenerative braking of the motor. The motor constant $K_a\varphi = 0.1$ V/rpm. The chopping frequency is 250 Hz and the motor armature resistance is $R_a = 0.2\ \Omega$. The inductance L_a is sufficiently large and the motor current i_0 can be assumed ripple free. The supply voltage is 120 V.

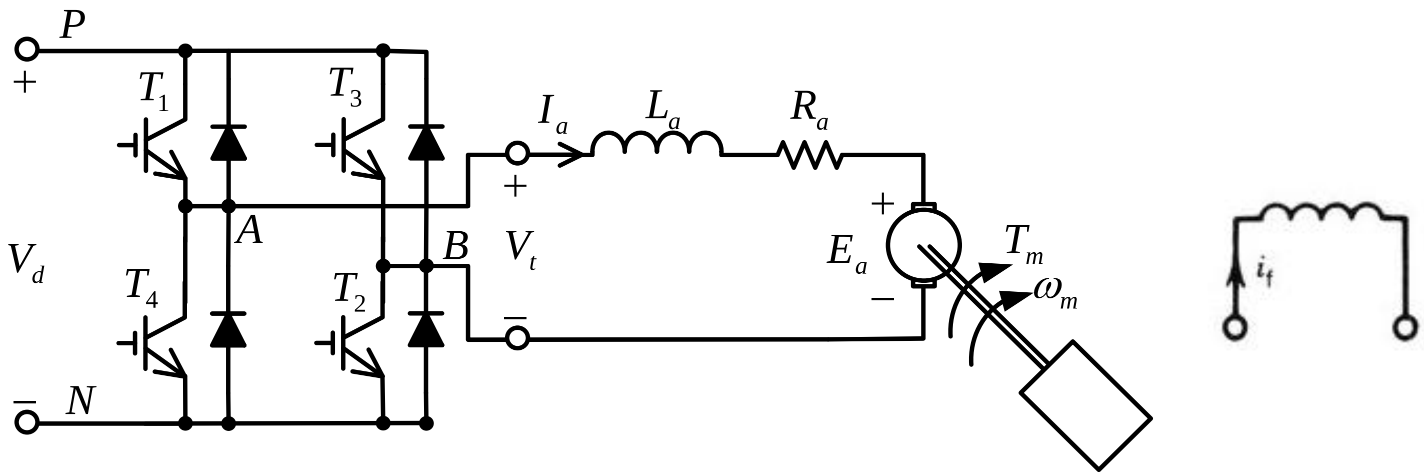
1. Derive an expression for the average output voltage $\mathbf{V_0}$ in terms of the supply voltage **V** and the duty cycle ***d***.

2. Complete the following for the motor operation at N = 400 rpm and i_0 = 100 A (constant ripple free)
    - Draw waveforms for v_0 and i_0
    - Determine the duty cycle ***d*** of the converter circuit
    - Determine the power developed by the motor, power absorbed by R_a, and power supplied by the source
3. Complete the following for Regenerative braking operation of the motor at N = 350 rpm and i_0 = -100 A (constant ripple free)
    - Draw waveforms for v_0 and i_0
    - Determine the duty cycle ***d*** of the converter circuit
    - Determine the power developed by the motor, power absorbed by R_a, and power to the source



2 Quadrant DC to DC converter for separately excited DC Motor

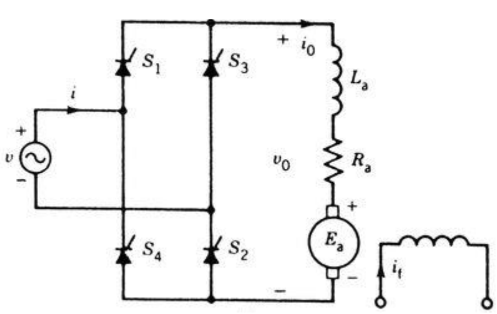
Q 2: A 4-quadrant chopper as shown in the figure below is used to control the speed of the DC motor and is also used for Regenerative braking of the motor.
Derive an expression for the average output voltage $\mathbf{V_0}$ in terms of the supply voltage **V** and the duty cycle ***d***.



4 Quadrant DC to DC converter for separately excited DC Motor

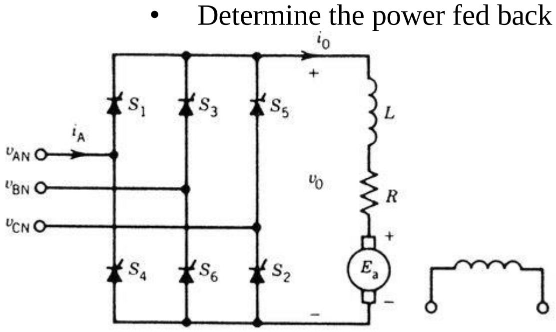
Q 3: A 1-phase full bridge, controlled rectifier is used to control the speed of a 5 hp, 110 V, 1200 rpm, separately excited DC motor. The converter is connected to a 1-phase 120 V, 60 Hz supply. The armature resistance R_a = 0.4 Ω, and armature circuit inductance is L_a = 5 mH. The motor constant $K_a\varphi$ = 0.09 V/rpm.

1. Rectifier (motoring) operation – The DC machine operates as a motor, runs at 1000 rpm, and carries an armature current of 30 A. Assume that motor current is continuous (ripple free)
   - Determine the firing angle
   - Determine the power to the motor
2. Inverter (regenerating) operation – The polarity of the motor back emf E_a is reversed, say by reversing the field excitation.
   - Determine the firing angle to keep the motor current at 30 A when the speed is 1000 rpm
   - Determine the power fed back to the supply at 1000 rpm



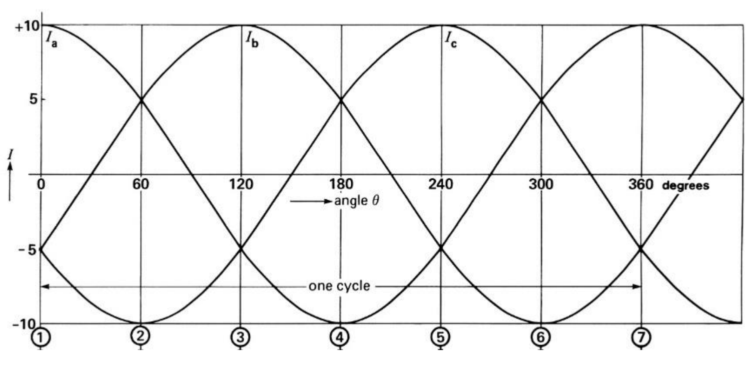
Q 4: A 3-phase full bridge controlled rectifier is used to control the speed of a 100 hp, 600 V, 1800 rpm, separately excited DC motor. The converter is connected to a 3-phase 480 V, 60 Hz supply. The armature resistance R_a = 0.1 Ω, and armature circuit inductance is L_a = 5 mH. The motor constant $K_a\varphi$ = 0.3 V/rpm. The rated armature current is 130 A.

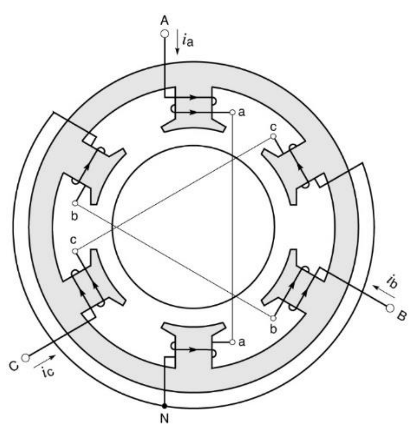
1. Rectifier (motoring) operation – The DC machine operates as a motor, draws rated current, and runs at 1500 rpm. Assume that motor current is continuous (ripple free)
   - Determine the firing angle
   - Determine the power to the motor
2. Inverter (regenerating) operation – The DC machine is operated in regenerative braking mode. At 1000 rpm and the rated motor current,
   - Determine the firing angle
   - Determine the power fed back to the supply



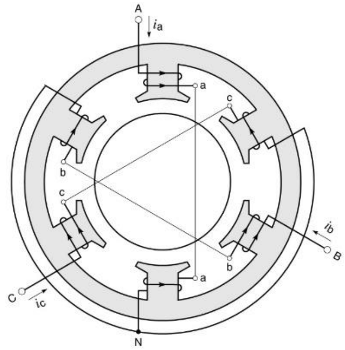
Q 5: Explain the operation of an Induction motor. Clearly and in correct sequence state all steps it takes from standstill to reach rated rotational speed.

Q6: The following diagram shows that the stator of an Induction motor is supplied from 3-phase AC supply of **abc** phase sequence.

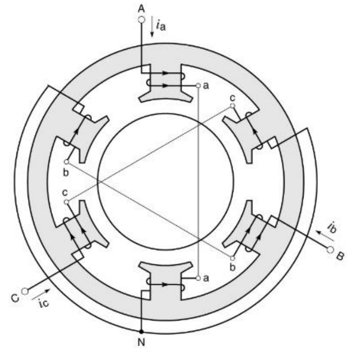




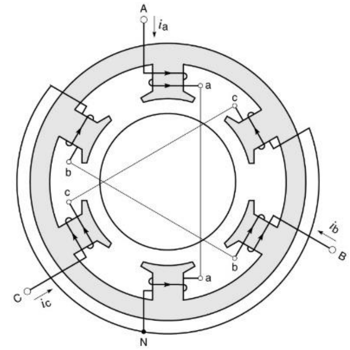
Explain, with the help of the revolving magnetic field concept, what direction (CCW or CW) the motor will start revolving. Consider 7 instants on the power supply at 0^0, 60^0, 120^0, 180^0, 240^0, 300^0, 360^0, and for each instant show the direction of the magnetic field due to currents I_a, I_b and I_c flowing through the coils aN, bN, cN respectively.



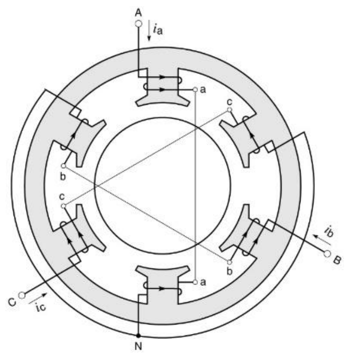
Magnetic Field Instant 1



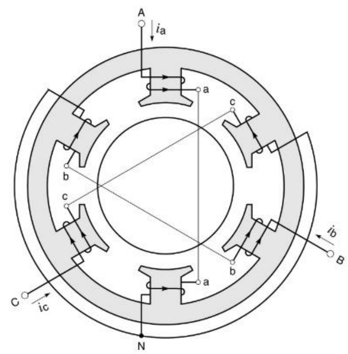
Magnetic Field Instant 2



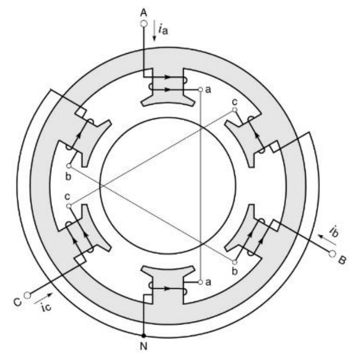
Magnetic Field Instant 3



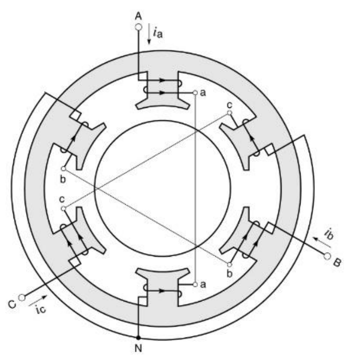
Magnetic Field Instant 4



Magnetic Field Instant 5



Magnetic Field Instant 6



Magnetic Field Instant 7

Q 7: A 480 V, 60 Hz, 50 hp, 3-phase Induction Motor is drawing 60 A at 0.85 pf (lagging). The stator copper losses are 2 kW and the rotor copper losses are 700 W. The friction and windage losses are 600 W, the core losses are 1800 W, and the stray losses are negligible. Calculate the following:

a. The input electrical power to the motor, P_{in}
b. The power converted P_{conv}
c. The output power P_{out}
d. The efficiency of the motor

Q 8: A 50 kw, 440 V, 50 Hz, six pole induction motor has a slip of 6% when operating at full load conditions. At full load conditions, the friction and windage losses are 300 W, and the core losses are 600 W. Calculate the following values for full load conditions:

a. The shaft speed, N
b. The output power in W
c. The load torque in Nm
d. The induced torque in Nm
e. The rotor frequency in Hz

Q 9: A 460 V, 60 Hz, 25 hp, 3-phase, 4-pole, Y connected IM has the following parameters in ohms per phase referred to the stator circuit.

$R_1 = 0.641\ \Omega$; $R_2 = 0.332\ \Omega$; $X_1 = 1.106\ \Omega$; $X_2 = 0.464\ \Omega$; $X_m = 26.3\ \Omega$

The total rotational losses are 1100 W and are assumed to be constant. The core losses are lumped in with the rotational losses. For a rotor slip of 2.2% at the rated voltage and rated frequency,

a. Calculate the following:
b. The motor speed
c. The stator current
d. The power factor
e. P_{conv} and P_{out}
f. τ_{ind} and τ_{load}
g. The efficiency of the motor

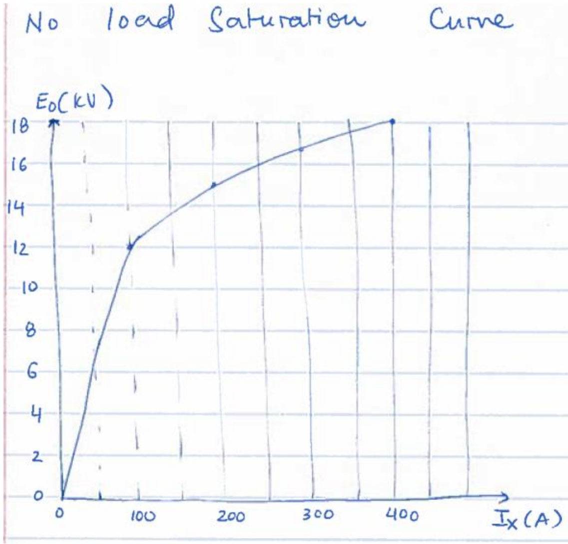
Q 10: Analyze and comment on why synchronous generators are built with stationary armature or rotating field type of construction. Include **four** different and clear points.

Q 11: Explain the operation of a Synchronous Alternator. Clearly and in correct sequence state all steps it takes from standstill to reach rated rotational speed.

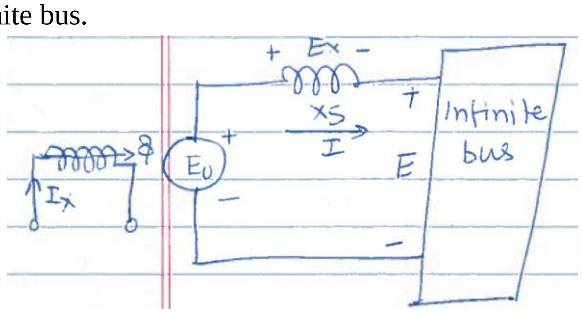
Q 12: Analyze and comment on why synchronous generator's stator winding is connected in WYE. Include **two** different and clear points.

Q 13: A 36 MVA, 20.8 kV, 3-phase alternator has a synchronous reactance of 9 Ω and a nominal current of 1 kA. The no load saturation curve giving the relationship between E_o and I_X is given below. If the excitation is adjusted so that the terminal voltage remains fixed at 21 kV, calculate the exciting current required and draw the phasor diagram for the following condition:

a. No load
b. Resistive load of 36 MW
c. Capacitive load of 12 MVAR



Q 14: Evaluate, with the help of equations and phasor diagram, the impact of change (increase and decrease both) in DC field (excitation) current on the operation of a Synchronous Generator connected to an Infinite bus.



Q 15: Analyze and comment on why synchronous Motors are NOT Self starting

Q 16: A 500 Hp, 720 rpm synchronous motor connected to a 3980 V, 3-phase line generates an excitation voltage E_o of 1790 V (line –to-neutral) when the DC exciting current is 25 A. The synchronous reactance is 22 Ω and the torque angle between E_o and E is 30^0. Calculate:

a. The AC line current Ia
b. The power factor of the motor
c. The approximate hp developed by the motor

Q 17: A 6600 V, 3-phase, Y-connected synchronous motor draws a full-load current of 80 A at 0.8 p.f. (leading). The per phase armature resistance and synchronous reactance are 2.2 Ω and 22 Ω, respectively. If the stray loss of the machine are 3200 W, Calculate:

a. The induced armature voltage (line to line value)
b. The output power
c. The efficiency

Q 18: Assume initially the synchronous motor is operating with a leading power factor load. Explain the effect of load change on the steady state operation of the motor.

Q 19: Assume initially the synchronous motor is operating with a lagging power factor load. Explain the effect of excitation (field) current change on the steady state operation of the motor.

Q 20: A 3-phase, Y-connected synchronous motor rated 800 hp, 2.4 kV, 60 Hz operates at unity power factor. The line voltage suddenly drops to 1.8 kV, but exciting current remains unchanged. Explain how the following quantities are affected:

a. Motor speed and mechanical power output
b. Torque angle, δ
c. Position of the rotor poles
d. Power factor
e. Stator current

Formulas:

Transformers:		
$\frac{v_1}{v_2} = \frac{N_1}{N_2} = \frac{i_2}{i_1}$	$R_2' = a^2 R_2$ $X_2' = a^2 X_2$ A resistance R_2 and reactance X_2 connected to the secondary side, when reflected (transferred) to the primary side, will be R_2' and X_2', respectively.	$R_1' = \frac{1}{a^2} R_1$ $X_1' = \frac{1}{a^2} X_1$ A resistance R_1 and reactance X_1 connected to the primary side, when reflected (transferred) to the secondary side, will be R_1' and X_1', respectively.
$X = 2\pi f L$		
DC Machines:		
$E_a = K_a \varphi \omega_m$	$T = K_a \varphi I_a$	$P = T\omega_m$
$\omega_m = \frac{N_m}{9.55}$	$\eta = \frac{P_{out}}{P_{in}} \times 100\%$	$\omega_m = \frac{V_t}{K_a \varphi} - \frac{R_a}{(K_a \varphi)^2} T$
Electromechanical Energy Conversion:	Force on a current carrying conductor, when placed inside the magnetic field: $\bar{F} = I(\bar{l} \times \bar{B})$	The emf (voltage) induced on a conductor moving inside the magnetic field is: $e = l(\bar{u} \times \bar{B})$
Induction Machines:	$N_s = \frac{120f}{P}$	$s = \frac{N_s - N}{N_s}$
$P_{in} = \sqrt{3} V_L I_L cos\theta$	$P_{conv} = P_{in} - P_{SCL} - P_{RCL}$	$P_{out} = P_{conv} - P_{Rot}$
Synchronous Machines:	Internally generated (induced) voltage in a synchronous alternator: $E_o = E_A = k\varphi\omega$	
Speed Control of Electrical Machines:	2 quadrant DC to DC converter: $v_{o,avg} = dV$	4 quadrant DC to DC converter: $v_{o,avg} = (2d-1)V$
	1-phase full bridge AC to DC converter: $v_{o,avg} = \frac{2\sqrt{2}}{\pi} V_{rms} cos\alpha$	3-phase full bridge AC to DC converter: $v_{o,avg} = \frac{3\sqrt{2}}{\pi} V_{line,rms} cos\alpha$