* Two 220V lamps, one of 60W and the other of 75W are connected in series across a 440V supply. Calculate the pd across each lamp, neglecting any variation in resistance. Assuming the candle power to be proportional to the fourth power of the voltage, calculate the candle-power of each lamp under this condition as a percentage of its value under normal operation at 220V.

→ Resistance of 60 watt, 220V lamp.

$$R_1 = \frac{V^2}{W_1} = \frac{(220)^2}{60} = 806.67\,\Omega$$

Resistance of 75 watt, 220V lamp.

$$R_2 = \frac{V^2}{W_2} = \frac{220^2}{75} = 645.33\,\Omega$$

Current flowing through the lamps when connected in series across line

$$I = \frac{440}{806.67 + 645.33} = 0.303A$$

P.D across 60 watt lamp, $V_1 = IR_1$
$= 0.3037 \times 806.67$
$= \cancel{244.42}$
$= 245V$

P.D across 75 watt lamp, $V_2 = IR_2$
$= 0.3037 \times 645.33$
$= 195V$

Normal operating voltage, $V = 220V$

candle power of 60 watt lamp under this condition,

$= \left(\frac{V_1}{V}\right)^4 \times$ normal candle power

$= \left(\frac{245}{220}\right)^4 \times$ 100 per cent of candle power under normal operating at 220V

$= 154\%$ of candle power under normal operation at 220V

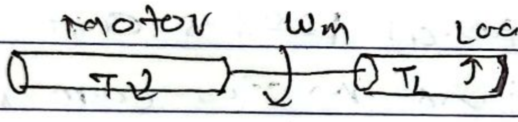
Similarly, candle power of 75 watt lamp under this condition

$= \left(\frac{195}{220}\right)^4 \times 100\%$ of CP under normal operation at 220V

$= 62\%$ of CP under normal operation at 220V.

IMP

Dynamics of Electrical Drives



A motor generally drives a load through some transmission system. While motor always rotates, the load may rotates or may undergo a translation motion. Load speed may be different from that of motor, and if the load has many parts, their speed may be different and while some rotates other may go through translation motion.

where J = polar moment of inertia of motor-load system referred to the motor shaft, $Kg\text{-}m^2$

ω_m = Instantaneous angular Velocity of motor shaft, (rad/sec)

T = Instantaneous value of developed motor torque. (N-m)

T_L = Instantaneous value of load (resisting

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torque, refered to the motor shaft (N-m)

Then,
Load Torque includes friction and windage torque of motor, then fundamental torque-equation.

$$T - T_L = \frac{d}{dt} J\omega_m$$

or $$T - T_L = J\frac{d\omega_m}{dt} + \omega_m\frac{dJ}{dt}$$

It is applicable to variable inertia drives such as mine winder, reel drives, industrial robots. For drive with constant inertia.

$$\frac{dJ}{dt} = 0, \text{ Therefore}$$

$$\boxed{T - T_L = J\frac{d\omega_m}{dt}} \quad \text{--- (i)}$$

Again, $$\boxed{T = T_L + J\frac{d\omega_m}{dt}}$$

where,
$J\frac{d\omega}{dt}$ = dynamic torque.

Drive accelerate or decelerates depending on whether T is greater or less than T_L, During acceleration, motor should supply not only the load torque but in additional torque component $J\frac{d\omega_m}{dt}$ in order to overcome the drive inertia.

Energy associated with dynamic torque $J\frac{d\omega_m}{dt}$ is stored in the form of kinetic energy is given by

$$\boxed{E = \frac{J\omega_m^2}{2}}$$

At steady state condition,

$$\boxed{T = T_L}$$

Load with Rotational Motion

Let us consider a motor driving two loads, one coupled directly to its shaft and other through gear with n and n_1 teeth as shown in figure below. Let the moment of inertia of motor and load directly coupled to its shaft be J_0. Motor speed and torque of the directly coupled load be ω_m and T_{l0} respectively. Let the moment of inertia, speed and torque of the load coupled through a gear be J_1, ω_{m1} and T_{l1} respectively.

Then,

$$\frac{\omega_{m1}}{\omega_m} = \frac{n}{n_1} = a_1 \quad \text{--- (1)}$$

where a_1 is gear tooth ratio.

If the losses in transmission are neglected then, kinetic energy due to equivalent inertia must be the same as kinetic energy of various moving parts thus,

$$\frac{1}{2} J \omega_m^2 = \frac{1}{2} J_0 \omega_m^2 + \frac{1}{2} J_1 \omega_{m1}^2 \quad \text{--- (ii)}$$

From eq^n (i) and (ii) we get,

$$\boxed{J = J_0 + a_1^2 J_1}$$

Power at the load and motor must be the same, if transmission efficiency of the gear be η_1 then,

$$T_t \omega_m = T_{l0} \omega_m + \frac{T_{l1} \omega_{m1}}{\eta_1} \quad \text{--- (iii)}$$

where T_t is total equivalent torque refered to the motor shaft.

From eq^n (i) & (iii) we get,

$$\boxed{T_t = T_{l0} + \frac{a_1 T_{l1}}{\eta_1}}$$

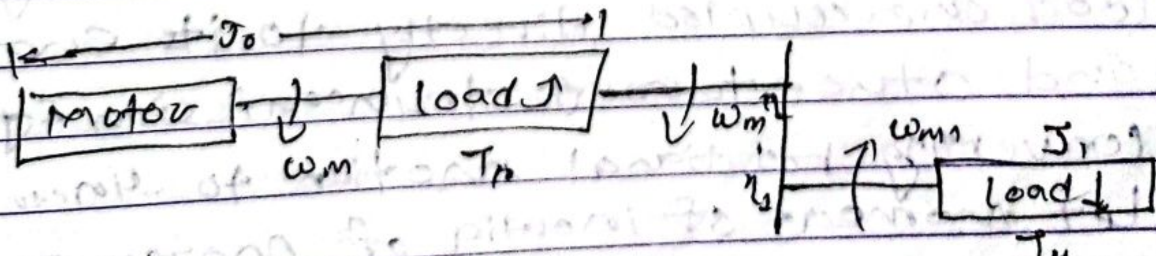

fig: load with rotational motion

In General,

Load is directly coupled to the motor with inertia J_0, there are m other loads with moment of inertia $J_1, J_2 \ldots J_m$ and gear tooth ratio of $a_1, a_2 \ldots a_m$ then

$$\boxed{J = J_0 + a_1^2 J_1 + a_2^2 J_2 + \ldots a_m^2 J_m}$$

If m loads with Torque $T_{l1}, T_{l2}, \ldots T_{lm}$ are coupled through gear with teeth ratio $a_1, a_2 \ldots a_m$ and transmission efficiency $\eta_1, \eta \ldots \eta_m$ in addition to one directly coupled

then,

$$\boxed{T_l = T_{l0} + \frac{a_1 T_{l1}}{\eta_1} + \frac{a_2 T_{l2}}{\eta_2} + \ldots \frac{a_m T_{lm}}{\eta_m}}$$

Load with Translational Motion:-

Let us consider a motor driving two load, one coupled directly to its shaft and other through transmission system converting rotational motion to linear motion. Let moment of inertia of motor and load directly coupled to it be J_0, load torque directly coupled to motor be T_{l0} and the mass, velocity and force of load with translational motion be M_1 (kg) and

V_1 (m/sec) and F_1 (Newton) respectively.

If the transmission losses are neglected the kinetic energy due to equivalent inertia J must be the same as kinetic energy of various moving parts. Thus,

$$\frac{1}{2} J\omega_m^2 = \frac{1}{2} J_0\omega_m^2 + \frac{1}{2} M_1 V_1^2$$

$$J = J_0 + M_1\left(\frac{V_1}{\omega_m}\right)^2 \quad \text{—— (1)}$$

Similarly, power at the motor and load should be same, thus if efficiency of transmission be η_1,

$$T_l\omega_m = T_{l0}\omega_m + \frac{F_1 V_1}{\eta_1}$$

$$T_l = T_{l0} + \frac{F_1}{\eta_1}\left(\frac{V_1}{\omega_m}\right) \quad \text{—— (11)}$$

In General,

If one load directly coupled to motor shaft, there are m other load with translational motion with velocity $V_1, V_2 - V_m$ and masses $M_1, M_2 - M_m$ then,

$$J = J_0 + M_1\left(\frac{V_1}{\omega_m}\right)^2 + M_2\left(\frac{V_2}{\omega_m}\right)^2 + \text{---} + M_m\left(\frac{V_m}{\omega_m}\right)^2$$

And $$T_l = T_{l0} + \frac{F_1}{\eta_1}\left(\frac{V_1}{V_m}\right) + \frac{F_2}{\eta_2}\left(\frac{V_m}{V_m}\right) + \text{---} + \frac{F_m}{\eta_1}\left(\frac{V_m}{\omega_m}\right)$$

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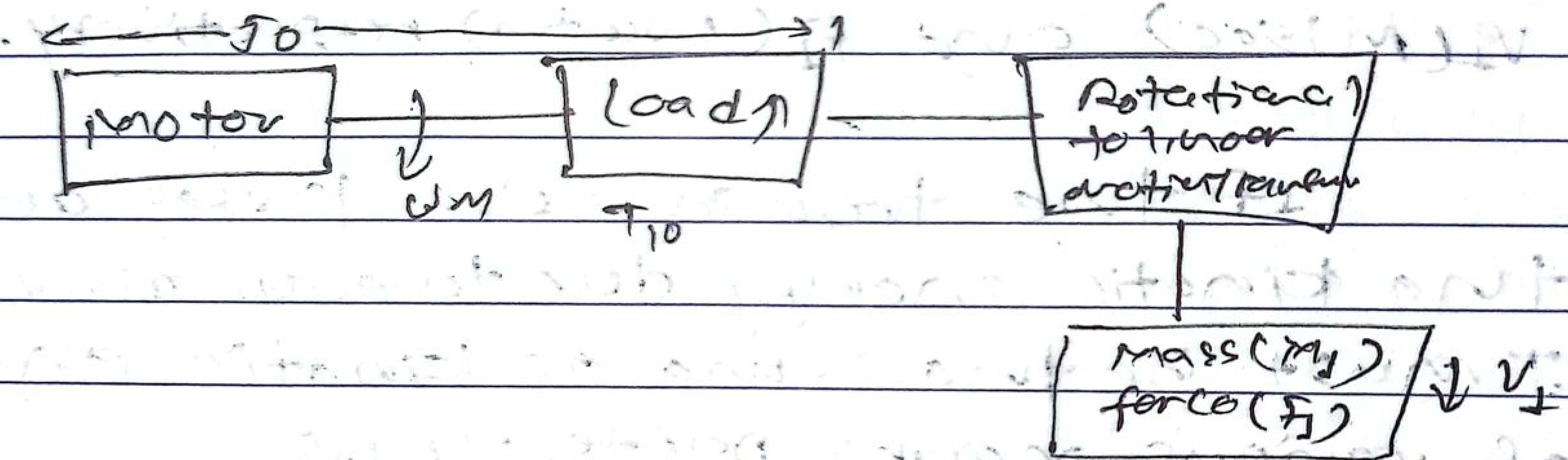
J0
motor
ωM
Load 1
T10
Rotational to linear motion/mechanism
Mass (M1)
force (F1)
V1

→ Overhead electricity
→ compressed or liquified natural gas.
→ Electric batteries/capacitors.
→ Hydraulic accumulater.

Advantage of Hybrid Vehicle

→ Lower emissions and better mileage
→ Reliable and comfortable.
→ Much cleaner cars than normal vehicles.
→ Noise pollution and emission of CO_2 are considerably reduced.
→ Hybrid vehicles uses no energy during idle state, they turn off and use less than petrol engines at low speeds.
→ Reduce energy dependance
→ Improved accelaration
→ Regenerative braking system
→ Financial benefits.

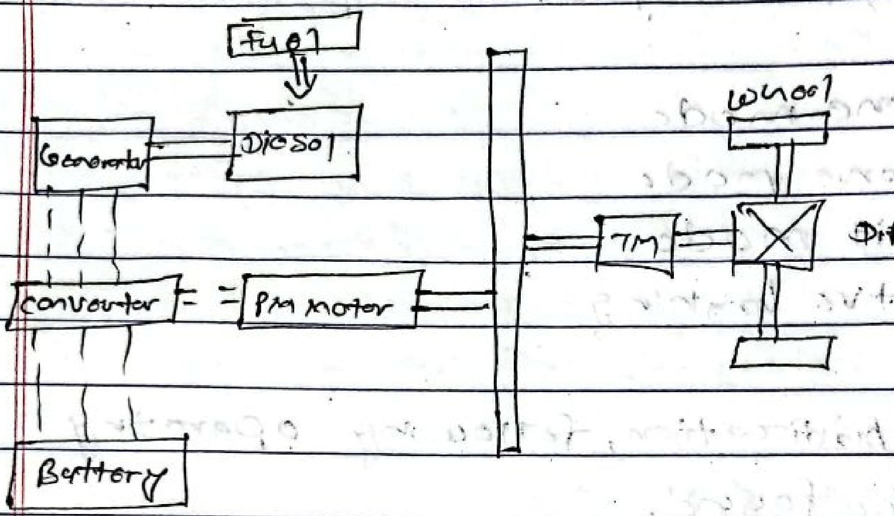

fig:- Series Hybrid vehicle

~~Need of hybrid vehicle~~

1. Fuel efficiency
2. Emission Reduction
3. Improved urban driving
4. Regenerative braking
5. Technical advances
6. Transition to electric vehicle.

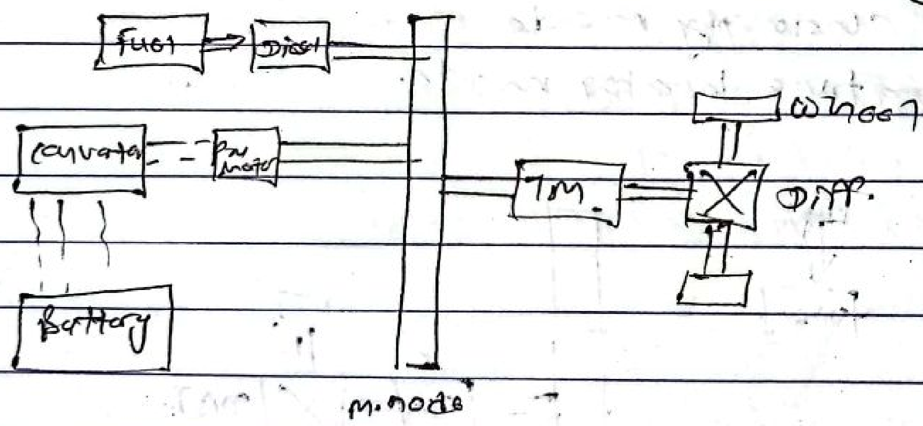

fig:- parallel HEV

→ In parallel HEV, it parallels the mechanical power output from the electric motor and the ICE are utilized to provide total tractive effort.

→ In this situation, the vehicle is powered by the either, engine, electrical motor or both and the coupling are mechanical. In parallel

Hybridization; following operating modes can be found.

→ Motor alone mode

→ Engine alone mode

→ power split mode

→ Regenerative braking

→ In series hybridization, following operating modes can be found.

→ Pure engine mode

→ Power split mode

→ Battery charging mode

→ Regenerative braking mode.

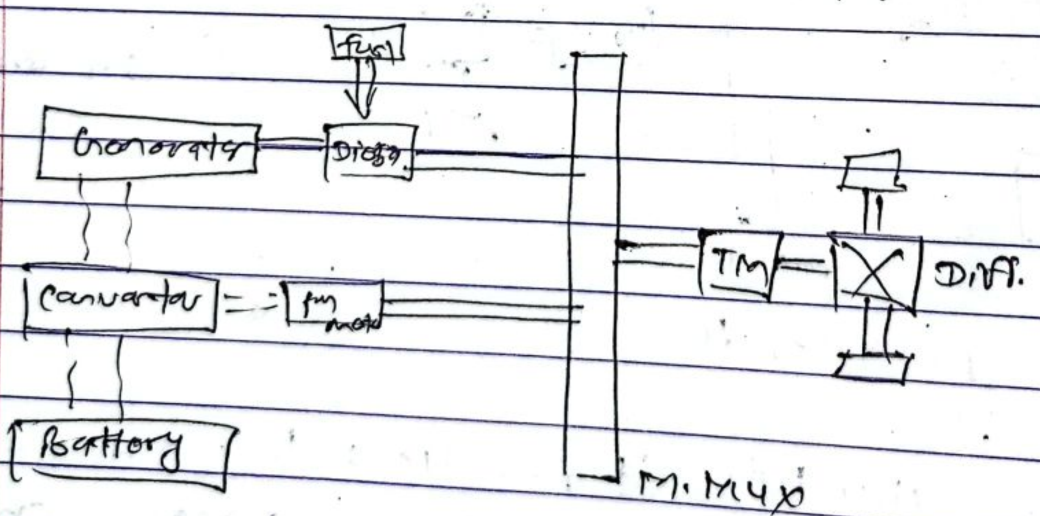

fig:- Mixed hybridization.

Advantages and disadvantages of electric traction system.

Advantages

1. cleanliness
2. cheapness
3. less maintenance cost
4. High starting torque
5. Braking - regenerative braking is used which feeds back 40% of the energy.
6. Saving in ~~by~~ high grade coal.
7. Less noise pollution
8. Lower power loss at higher altitudes
9. Lower running cost of locomotives and multiple units.
10. Higher practical limit of power
11. Higher limit of speed.
12. Higher hauling capability.

Disadvantages

→ (i) High initial expenditure

→ Interference with telegraphs and telephone lines.

→ Failure of supply is a problem.

→ For braking and control, additional equipments required.

→ Electric locomotive can be use only on those routes which have been electrified

→ Upgrading brings significant cost.

Derive the energy loss Expression during starting and plugging for DC shunt motor.

Energy loss during dynamic braking and plugging of dc shunt motor.

we have,
For dc shunt motor,

$$v = R_a i_a + L_a \frac{di_a}{dt} + K_e\phi\omega_m \quad \text{--- (1)}$$

armature inductance drop is small and can be neglected

multiplying eqn (1) by i_a on the both side we get,

$$v i_a = R_a i_a^2 + K_e\phi\omega i_a \quad \text{--- (2)}$$

Also,

$$J\frac{d\omega_m}{dt} = T - T_L \quad \text{--- (3)}$$

For the loss during rheostatic braking $v=0$, and assuming constant load Torque T_L at a steady state speed ω_{m}
From eq (2)

$$R_a i_a^2 = -K_e\phi\omega_m i_a \quad \text{--- (4)}$$

we have.

$$T = K_e\phi i_a \quad \text{--- (5)}$$

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From eqn (3) & (5)

$$J\frac{d\omega_m}{dt} = K_e\phi i_a - T_L$$

or $$K_e\phi i_a = J\frac{d\omega_m}{dt} + T_L \quad -(6)$$

From eq (4) & and (6)

$$R_a i_a^2 = -\left(J\frac{d\omega_m}{dt} + T_L\right)\omega_m$$

$$\int R_a i_a^2 dt = -\int_{\omega_{mL}}^{0} J\omega_m d\omega_m - \int T_L \omega_m dt$$

$$= \frac{1}{2}J\omega_{mL}^2 - \int T_L \omega_m dt \quad (7)$$

i.e. $$\int T_L \omega_m dt = \frac{1}{2}J\omega_{mL}^2 - \int R_a i_a^2 dt \quad (8)$$

This eqn indicates that the load absorbs a part of stored KE and the rest is dissipated as copper loss.

What are the factors that affect the energy consumption of traction?

(a) Distance between stops: → The distance between consecutive stops on the train route directly influences energy consumption. More stops mean more frequent acceleration and braking, which require extra energy to start and stop ~~allow the train to maintain a more consistent~~ the train. Longer ~~dischan~~. distances between stops allow the train to maintain a more consistent speed, reducing the need for frequent acceleration and braking, leading to lower specific energy consumption.

(b) Acceleration: Accelerating a train requires a significant amount of energy. When a train starts from a standstill or increases its speed, it must overcome the initial inertia, and this process consume more energy. Proper control of acceleration rates can help optimize energy efficiency.

(c) Retardation: Retardation refers to the deceleration or braking of the train. Applying brakes to slow down or stop the train dissipates the KE, which is essentially wasted.

Regenerative braking systems, which convert some of the K.E back into electrical energy, can mitigate this loss and improve overall energy efficiency.

(d) Maximum speed: Higher speeds generally result in higher air resistance which requires more power to overcome. As the train reaches higher speeds the power required to maintain that speed increases exponentially, leading to higher energy consumption. Operating the train at an optimal speed that balances travel time and energy consumption is essential for efficiency.

(e) Nature of Route: The topography of the train route, such as gradients, curves, and inclines, affect energy consumption. Climbing steep inclines requires more energy, while descending slopes allows the train to recover some energy through regenerative braking. Curves and twists in the track can also increase friction and energy loss, impacting overall energy efficiency.

(f) The type of train equipment (overall efficiency).
→ The design and efficiency of the train's propulsion system, motors, and electrical systems play a crucial role in determining its specific energy consumption. Modern trains are often equipped with advanced technologies and more energy-efficient components, leading to lower overall energy consumption compared to older, less efficient models.

(g) Train resistance: The resistance encountered by the train while moving, such as aerodynamic resistance (air drag) and rolling resistance (friction between wheels and tracks), affects the energy required to maintain speed. Reducing these resistances through streamlined train design, improved aerodynamics, and better wheel and track materials can significantly enhance energy efficiency

(c) ~~pluggging~~ plugging

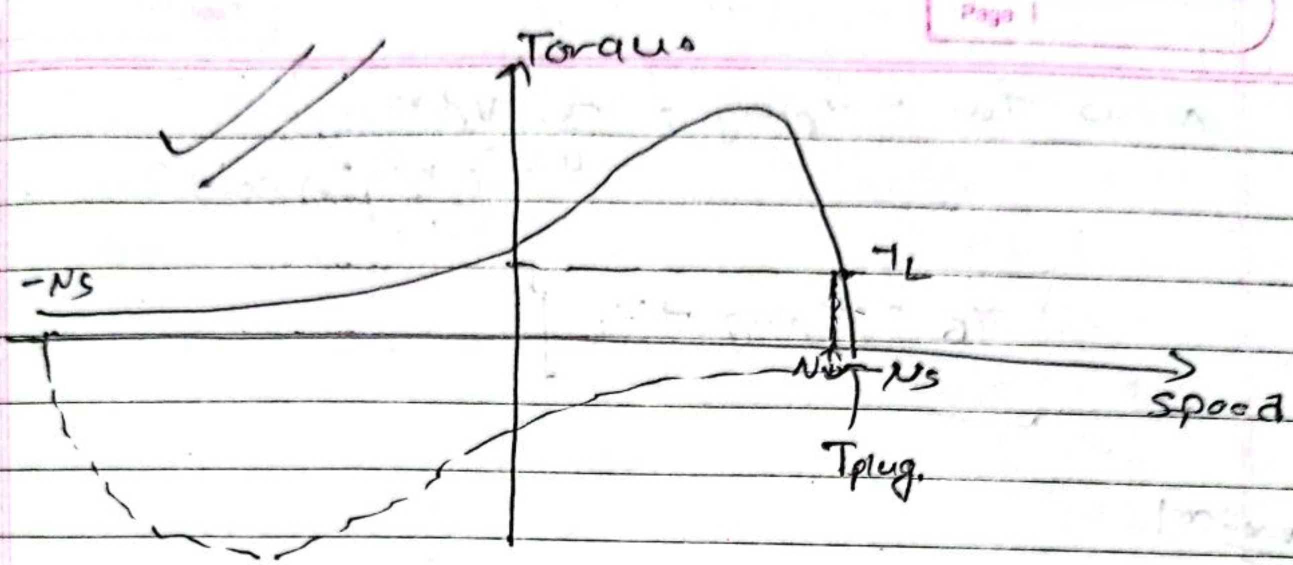
→ In this method, we reverse the phase sequence of the supply voltage connected to the stator.

→ by reversing the phase sequence, the direction of rotation of rotating magnetic field also reverse. So it applies a torque on the rotor in reverse direction.

→ Such a torque opposes the ~~rotating~~ rotation of the rotor.

$$\frac{J d^2\omega}{dt^2} = T_m - T_L$$

By reversing phase



$$J\frac{d^2\omega_m}{dt^2} = T_m - T_L \quad \text{dynamic eqn.}$$

By reversing phase sequence

T_m reverses.

$$J\frac{d^2\omega}{dt^2} = -\underbrace{(T_m + T_L)}_{T_B} \qquad T_m = T_{plug}$$

if rotor rotates at N rpm

$$s = \frac{N_s - N}{N_s} \qquad N = N_s(1-s)$$

Now, direction of RMF is reversed

$$s' = \frac{-N_s - N}{-N_s}$$

$$= \frac{N_s + N_s(1-s)}{N_s}$$

$$\boxed{s' = 2 - s}$$

Initially,

$$\frac{d^2\omega}{dt^2} = 0, \quad T_m = T_L$$

$$T_L = \frac{3}{\omega_s} \frac{V_1^2 \cdot r_2'/s}{\left(\frac{r_2'}{s}\right)^2 + (x_2')^2}$$

V.IMP

* Derive the energy loss expression during starting and plugging for dc shunt motor

→ **Energy loss / consumption during starting of DC shunt motor:**

For a dc motor:

$$V = E + I_a R_a$$

$$= K\omega + I_a R_a$$

or $I_a R_a = V - K\omega$

On no load condition, $V = K\omega_0$ as the drop $I_a R_a$ is negligibly small,

$$\therefore I_a R_a = K(\omega_0 - \omega) \quad \text{--- (i)}$$

Now, on no. load, the eqn. $J\frac{d\omega}{dt} = T_a - T_L$ becomes,

$$J\frac{d\omega}{dt} = T = K I_a \quad \text{--- (ii)}$$

Multiplying eqn (i) by I_a, we have,

$$I_a^2 R_a = K I_a(\omega_0 - \omega) \quad \text{--- (iii)}$$

From eqn (ii) & (iii)

$$I_a^2 R_a = J(\omega_0 - \omega)\cdot\frac{d\omega}{dt}$$

Now, energy loss during starting is,

$$E_s = \int I_a^2 R_a dt = J\int_0^{\omega_0}(\omega_0 - \omega)\frac{d\omega}{dt}\cdot dt$$

$$\boxed{E_s = \frac{1}{2} J\omega_0^2} \quad \text{--- (iv)}$$

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Eqn (iv) shows that the energy consumed by armature of a dc shunt of separately excited motor equals the kinetic energy stored by the armature and is thus independent of the armature resistance.

Whereas, if the motor were started with constant load torque, T_L. The energy consumed in the armature ckt is

$$J\frac{d\omega}{dt} = T_a - T_L$$

or, $T_e = kI_a = J\frac{d\omega}{dt} + T_L$ —— (v)

From eqn (v) & (iii)

$$I_a^2 R_a = (\omega_0 - \omega)\left[J\frac{d\omega}{dt} + T_L\right]$$

$$E_s = \int_0^t I_a^2 R_a \, dt$$

$$= \int_0^{t(\omega)} (\omega_m - \omega)\left[J\frac{d\omega}{dt} + T_L\right] dt$$

$$\boxed{\therefore E_s = J\omega_0 \int_0^{\omega_0} d\omega + \int_0^t \omega_0 T_L \, dt - J\int_0^{\omega_0} \omega \, d\omega - \int_0^t \omega T_L \, dt}$$

Energy loss during plugging for dc shunt Motor :→

Let us suppose that the braking takes place with no load on the motor. The plugging loss during braking is given by.

$$E_{loss} = \int I_a^2 R_a \, dt$$

We have,

$$E_b + I_a R_a = V_t$$

$$\text{or, } I_a R_a = V_t - K\omega \quad [\because E_b = K\omega]$$

Now,

$$T_b = J\frac{d\omega}{dt} = K I_a$$

$$I_a = \frac{J}{K}\frac{d\omega}{dt}$$

Now at no load, $V_t = K\omega_0$

$$\frac{V_t}{K} = \omega_0$$

$$\therefore I_a^2 R_a = (I_a R_a) \cdot I_a = (V_t - K\omega)\left(\frac{-J}{K} \cdot \frac{d\omega}{dt}\right)$$

$$\text{or, } I_a^2 R_a \, dt = \frac{-V_t}{K} J d\omega + J\omega \, d\omega$$

$$= -J\omega_0 \cdot d\omega + J\omega \, d\omega.$$

$$= -J\omega_0 d\omega + J\omega \, d\omega.$$

When, brake is applied at no load, $\omega = 0$

$$\therefore E_{loss} = \int_{\omega_0}^{0} J(\omega_0 - \omega)\, d\omega$$

$$= J\left[\omega_0 \cdot \omega - \frac{\omega^2}{2}\right]_{\omega_0}^{0}$$

$$= J\left[[0+0] - \left[\omega_0^2 - \frac{\omega^2}{2}\right]\right]$$

$$\boxed{E_{loss} = \frac{1}{2} J \omega_0^2}$$

= K.E of the armature at the start of braking.

Now, if rotor reverses its direction of rotation and the speed changes from $+\omega_0$ to $-\omega_0$ the energy loss by armature will be

$$4\left(\frac{J\omega_0^2}{2}\right)$$

$$\boxed{E_{loss} = 2J\omega_0^2}$$

Imp

Prove that during dynamic braking energy dissipated in braking resister is $E = \frac{1}{2} J \omega_0^2$ and during plugging energy dissipated in braking resistor is $E = \frac{3}{2} J \omega_0^2$

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→ let us suppose that the braking takes place with no load on the motor.

We have, eqn. of motor on no load is

$$T_m = K I_a = J \cdot \frac{d\omega}{dt}$$

Multiply above eqn to $I_a R_a = V - K\omega$ by I_a,

$$I_a^2 R_a = V I_a - K \omega I_a$$
$$= \frac{J V}{K} \cdot \frac{d\omega}{dt} - J \omega \frac{d\omega}{dt}$$

On no load, the $I_a R_a$ in the motor will be negligible and hence $V = K\omega_0$.

ω_0 = no load speed of the shunt motor

put $\frac{V}{K} = \omega_0$

Then, $I_a^2 R_a dt = J\omega_0 d\omega - J\omega d\omega$ — ①

The energy dissipated in the armature ckt during rheostatic braking is determined using eq ①. It must be noted that during rheostatic braking $V = 0$ and braking takes place from speed ω_0 to standstill.

Hence,

$$W_{Br(Rho)} = \int_{\omega_0}^{0} -J \cdot \omega \, d\omega$$

$$= \int_0^{\omega_0} \omega \cdot d\omega$$

$$\boxed{W_{Br(Rho)} = J \omega_0^2 / 2}$$

If the motor reverses its direction of rotation and the speed changes from $+\omega_0$ to $-\omega_0$ the energy lost in the armature is $4(J\omega_0^2/2)$

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And,

During reverse current braking / plugging, the applied voltage V is of the opposite polarity and hence, ω_0 in eqn ⑤ will change its sign, while determining the loss in energy.

The speed limits are ω_0 and zero.

$$W_{Br(rev)} = \int_{\omega_0}^{0} (-J\omega_0 d\omega - J\omega d\omega)$$

$$= \int_{\omega_0}^{0} -J(\omega_0 + \omega) d\omega$$

$$= -J\left[\omega_0 \cdot \omega + \frac{\omega^2}{2}\right]_{\omega_0}^{0}$$

$$= -J\left[0 + 0 - \left(\omega_0^2 + \frac{\omega_0^2}{2}\right)\right]$$

$$\boxed{W_{Br(rev)} = \frac{3}{2} J \omega_0^2}$$

2079 (Spring)

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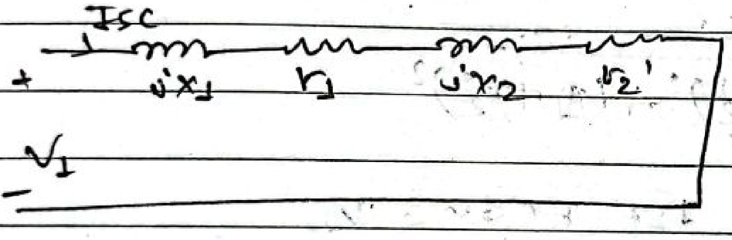
Starting of induction motor

→ At time of starting, $N_r = 0$

slip = 1

→ $R_2'(1/s - 1) = 0$ (short)



Impedance reduces

I_{sc} is high

→ At the time of starting, the current drawn by the motor from the supply is very high which can damage the motor. So starting techniques are studied in order to reduce the starting current but at the same time not reduces the starting torque by large value.

→ For smaller induction motor (less than 5HP), the diameter of the shaft is small. So the motor accelerates faster and hence its speed increases rapidly. Due to which slip decreases and the impedances increases.

$$\boxed{\frac{T_{st}}{T_{FL}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 S_{FL}}$$

2019 (spring)

Starting of SCIM

$$I_{st} = \frac{V_1}{\sqrt{(r_1 + r_2')^2 + (x_1 + x_2')^2}}$$

To reduces Ist reduce V_1

$T \propto V_1^2$

as V_1 reduces, T reduces

→ There are two methods of starting squirrel cage induction motor,

① Direct on-line starting
② Reduces voltage starting

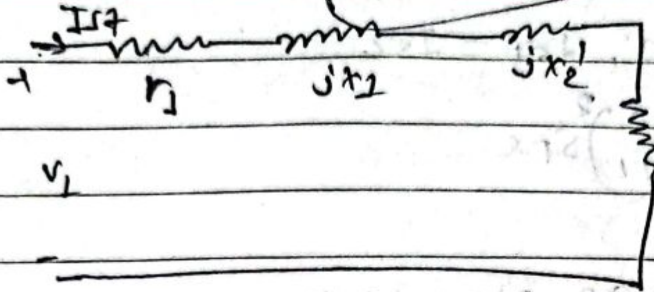
Direct on-line starting (DOL)

→ We apply rated voltage at the time of starting due to which starting current is very high.

→ In the equivalent circuit, we ignore the shunt branch of the circuit

$$I_{fl} = \frac{V}{\sqrt{\left(R_1 + \frac{R_2}{s}\right)^2 + (x_1 + x_2)^2}}$$

$$\boxed{T_{fl} = \frac{3 I_{fl}^2 R_2}{s_{fl}\,\omega_s}}$$



if $v_1 = v_1$ (rated)

$I_{st} = I_{sc}$ = short circuit current

$$I_{sc} = \frac{v_1}{\sqrt{(r_1 + r_2')^2 + (x_1 + x_2')^2}} = \frac{v_1}{Z_{sc}}$$

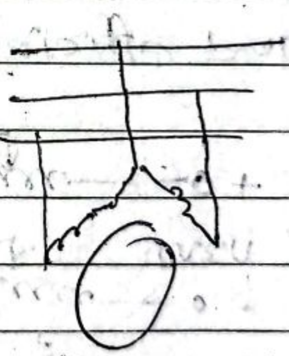
Z_{sc} = short circuit impedance

$$\left[(r_1 + r_2')^2 + (x_1 + x_2')^2\right]^{1/2}$$

$$T = \frac{P_g}{\omega_s}$$

$$= \frac{3 I_2^2\, r_2/s}{\omega_s}$$

$$\boxed{T \propto \frac{I_2^2}{s}}$$



$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_2(st)}{I_2(fl)}\right)^2 s_{fl} \qquad [S_s = 1]$$

$$\boxed{\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 \times \frac{s_{fl}}{s=1}} \qquad \boxed{\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 s_{fl}}$$

I_{st} = stator current at starting.

I_{fl} = stator current at full load.

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DOL Method, $I_{st} = I_{sc}$

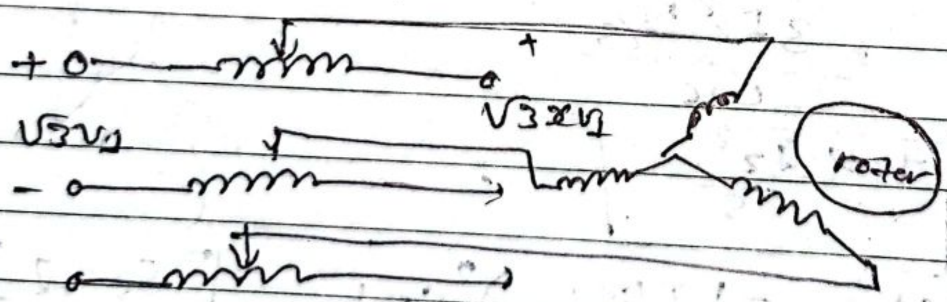
$$\frac{T_{st}}{T_{fL}} = \left(\frac{I_{sc}}{I_{fL}}\right)^2 S_{fL}$$

Reduced voltage starting

Reactor starting

① Stator resistance or reactance

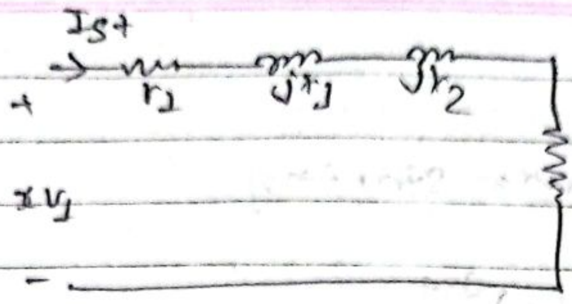
→ In this methods supply is connected to stator by means of potential divider which can be implemented either by the used of resistance or reactance but reactance is prefered because by the use of resistence losses increase and efficiency reduces.



v_1 per phase voltage

α factor due to potential divider
<1

per phase stator voltage $= \alpha V_1$



$$I_{st} = \frac{x V_1}{\sqrt{(r_1 + r_2')^2 + (x_1 + x_2')^2}}$$

$$= \frac{x V_1}{Z_{sc}} = x I_{sc}$$

In this method, the impedance of the circuit remains same but the supply voltage is scaled by the factor of 'x'. So the starting current also scaled by the same factor.

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 s_{fL}$$

$$\boxed{\frac{T_{st}}{T_{fl}} = x^2 \left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fL}}$$

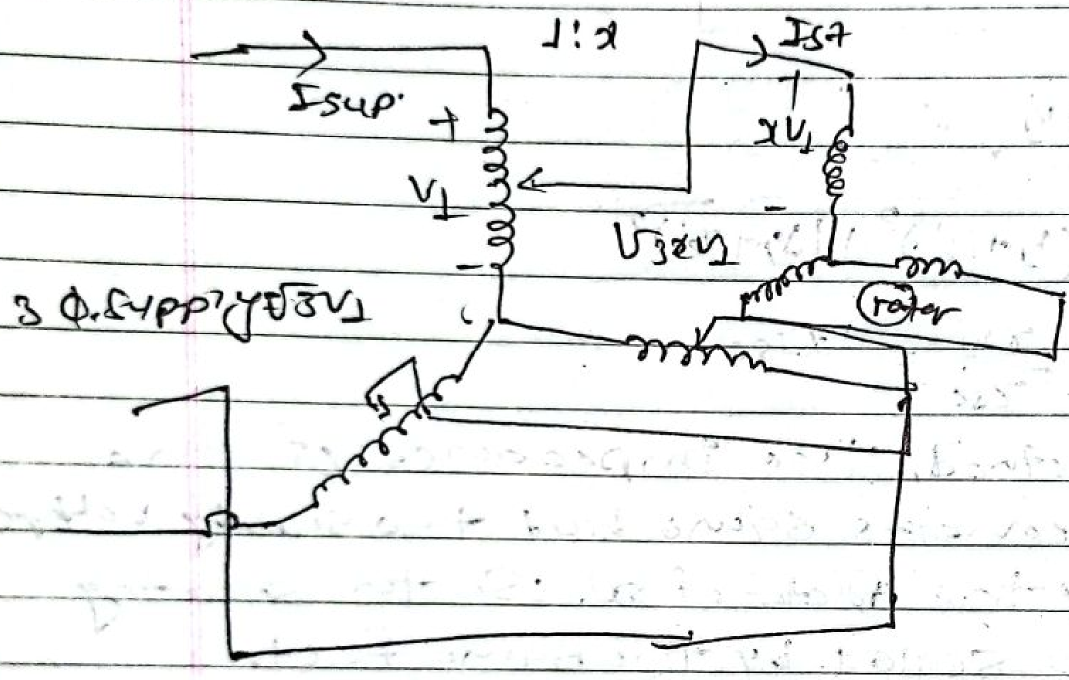
T_{st} is scaled by a factor of x^2.

I_{st} is scaled by a factor of x

→ The ~~current~~ current ~~torque~~ is reduced by lesser amount as compared to torque which is an desirable because of objective of starting method is the reduces the starting current & without sacrificing

Starting torque.

(2) Auto-Transformer Starting



→ In this method, we use a step down auto transformer where supply is connected on the high voltage side and the stator of induction motor is connected on low voltage side.

→ If the transformation ratio is $1:\alpha$, where α is less than 1, then the voltage at the stator of induction motor is αV_1.

$$I_{st} = \frac{x V_1}{z_{sc}} = x I_{sc}$$

$$I_{sup} = \frac{x}{1} \times I_{st}$$

$$\boxed{I_{sup} = x^2 I_{sc}}$$

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 s_{fl}$$

$$\boxed{\frac{T_{st}}{T_{fl}} = x^2 \left(\frac{I_{sL}}{I_{fL}}\right)^2 s_{fL}}$$

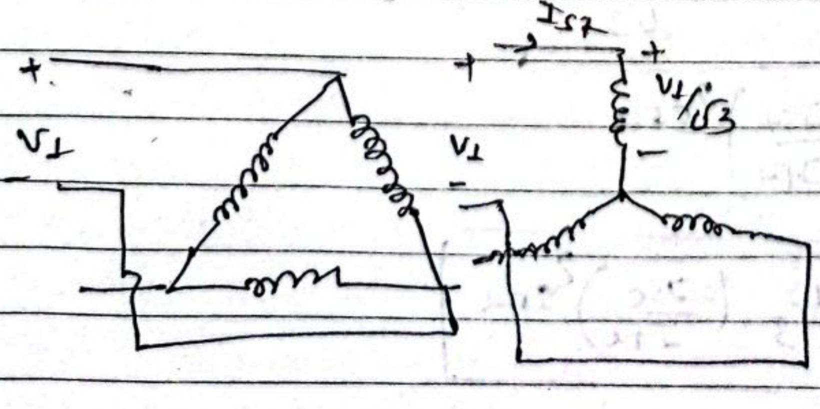
I_{sup} is scaled by a factor of x^2

~~T_{st} is scaled by a factor of x^2~~

In this method, the current drawn by the motor from supply and the torque are both scaled by ~~the same~~ factor of x^2. So the reduction in torque is equal to the reduction in current which better as compared to stator reactor starting.

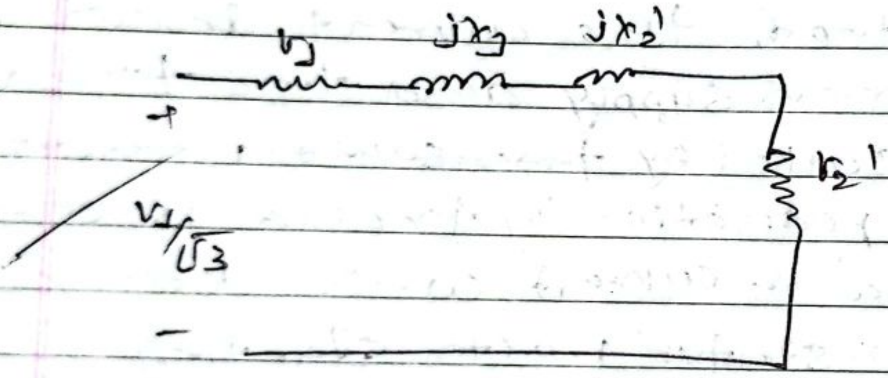
(2) Star-delta starter

→ This method can only be applied to the motor where the stator of the motor is delta connected.



→ If the motor is normally connected in delta, then at the time of starting, the stator winding is connected in star connection.

→ If the line voltage is same for both the cases, then the phase voltage of star connection is $\frac{1}{\sqrt{3}}$ times as compared the phase voltage of delta connection.



$$I_{st} = \frac{V_1/\sqrt{3}}{Z_e} = \frac{I_{sc}}{\sqrt{3}}$$

in Y-connection

$$\boxed{I_{line} = I_{ph} = \frac{I_{sc}}{\sqrt{3}}}$$

$$\frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 s_{fl}$$

$$\boxed{\frac{T_{st}}{T_{fl}} = \frac{1}{3}\left(\frac{I_{sc}}{I_{fl}}\right)^2 s_{fl}}$$

T_{st} is reduced by a factor of $\frac{1}{3}$

If motor is delta connected at the time of starting,

$$I_{st} = \frac{V_L}{Z_{sc}} = I_{sc}$$

$$I_{line} = \sqrt{3} I_{ph}$$

$$\boxed{I_{L\Delta} = \sqrt{3} I_{sc}}$$

$$\boxed{\frac{I_{LY}}{I_{L\Delta}} = \frac{1}{3}}$$

The starting current in star connection from the supply is reduced by the factor of $\frac{1}{3}$ which the same as the factor of reduction for starting torque.

$\boxed{I_{sup} \text{ is reduced by a factor of } \frac{1}{3}.}$

2021 (spring)

3(b) A motor having no load torque T_0 and inertia J_0 is coupled with mechanical load of having of inertia J_1 and torque T_1 via step up gear. Compute inertia and torque referred to motor shaft assuming efficiency of gear is η.

→ Consider motor having no load torque T_0 and inertia J_0 is coupled with a mechanical load having of inertia J_1 and torque T_1 via step up gear. 'g_1'

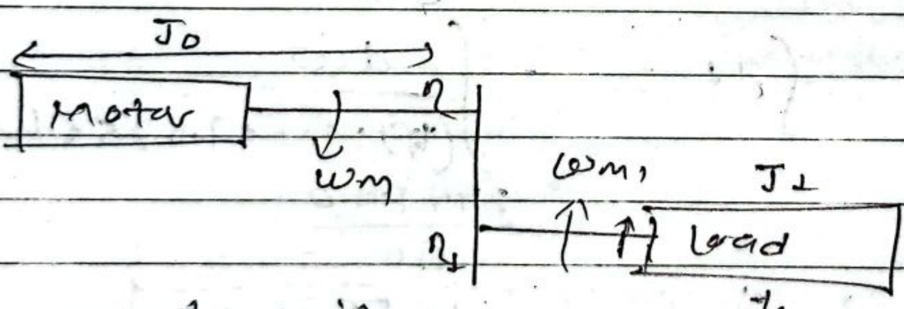


fig: motor with load (Rotational)

We have,

$$\frac{\omega_{m1}}{\omega_m} = \frac{n}{n_1} = g_1 \quad -(1)$$

Where g is gear tooth ratio. If the transmission losses are neglected.

Then, kinetic energy due to equivalent inertia must be the same as kinetic energy of various moving parts.

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Thus,

$$\frac{1}{2}J\omega = \frac{1}{2}J_0\omega_m^2 + \frac{1}{2}J_1\omega_{m1}^2 \quad \text{--- (11)}$$

From eq (1) & (11) we get

$$\boxed{J = J_0 + g_1^2 J_1}$$ ⇒ This is inertia expression refered to Motor shaft

Power at the load and moter must be the same, if transmission efficiency of the gear be 'a' then

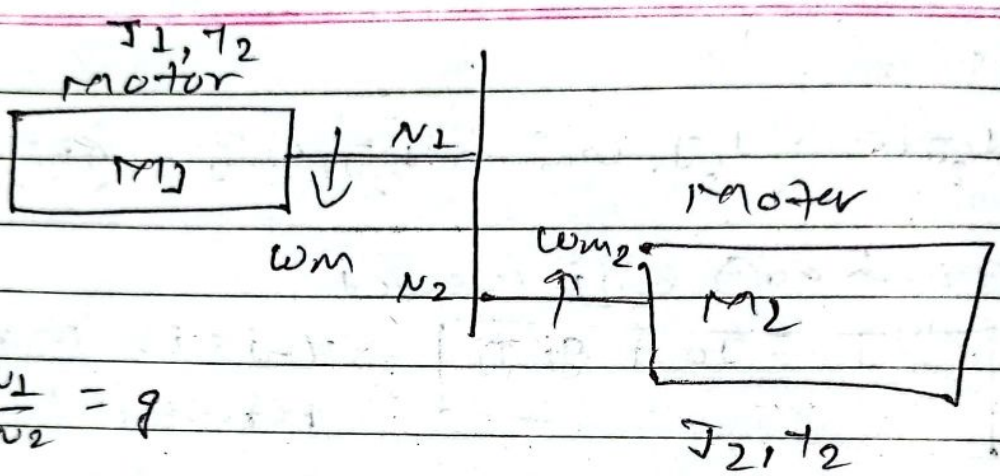
$$T_t\omega_m = \frac{T_1\omega_{m1}}{a} \quad \text{--- (111)}$$

T_t = Total equivalent torque reffered to motor shaft

$$\boxed{T_t = T_0 + \frac{g_1 T_1}{a}}$$ ⇒ This is the torque expression referred to motor shaft

2018 (Spring)

3(b)



$$\frac{\omega_{m_1}}{\omega_m} = \frac{N_1}{N_2} = g$$

$$\therefore \frac{1}{2} J \omega_m = \frac{1}{2} J_1 \omega_m + \frac{1}{2} J_2 \omega_{m_1}$$

$$\boxed{J = J_1 + g^2 J_2}$$

$$T_t \omega_m = T_1 \omega_m + T_2 \omega_{m_1}$$

$$\boxed{T_t = T_1 + \frac{g T_2}{\eta}} \Rightarrow \eta = \text{Transmission efficiency}$$

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2017(Spring)

* Derive the expression for the time required to stop dc shunt motor during dynamic braking. Assume any data if necessary.

→ When the motor is subjected to braking, the following torques need to be considered.

(i) Torque developed in the motor [$-T(\omega)$] is -ve sign is for braking torque.

(ii) Friction torque (T_f) due to brake function, which is constant.

(iii) Load torque (T_{load})

(iv) Inertia torque ($J\frac{d\omega}{dt}$)

→ If the motor is arrested in its motion using the electromagnetic torque proportional to the speed and a form of friction torque we can write, (assuming the load torque on the motor to be independent of speed) as.

or, $-T(\omega) = T_{load} + T_f + J\frac{d\omega}{dt}$

or, $-K\omega = T_{load} + T_f + J\frac{d\omega}{dt}$

where K = constant

$$\therefore dt = \frac{-J\,d\omega}{K\omega + T_{load} + T_f}$$

Now the time required to brake the motor from speed ω_1 to ω_2 is

$$t = -J \int_{\omega_1}^{\omega_2} \frac{d\omega}{k\omega + T_{load} + T_f}$$

$$t = \frac{J}{k} \log_e \left(\frac{k\omega_1 + T_{load} + T_f}{k\omega_2 + T_{load} + T_f} \right)$$

The time (t) required to bring the motor to rest, (i.e. $\omega_2 = 0$) is given by

$$t = \frac{J}{k} \log_e \left(\frac{k\omega_1 + T_{load} + T_f}{T_{load} + T_f} \right) \text{sec.}$$

and

no. of revolutions made by the motor before coming to rest is given by

$$N = \frac{1}{2\pi} \int_0^t \omega_2 \, dt$$

where

$$\omega_2 = \frac{1}{k} \left[(k\omega_1 + T_{load} + T_f) e^{-kt/J} - (T_{load} + T_f) \right]$$

Hence,

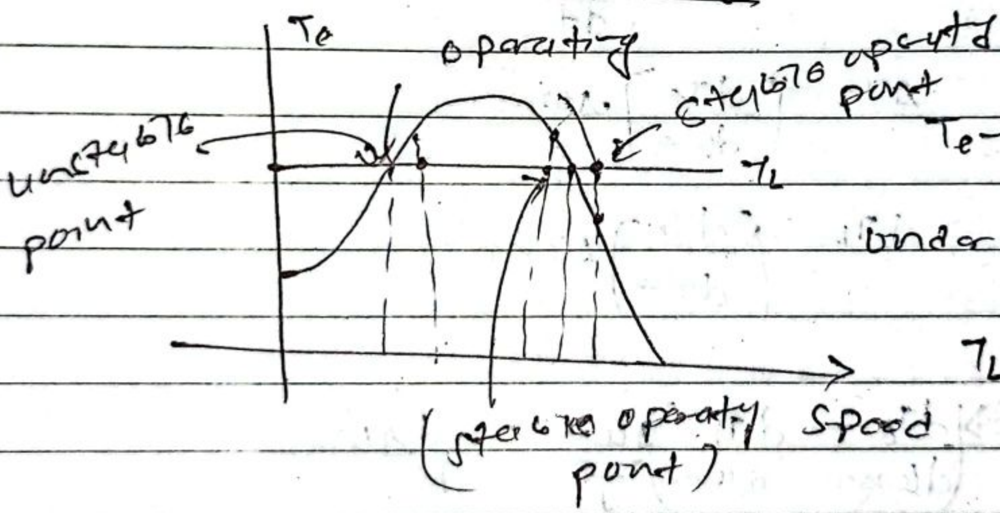
$$N = \frac{1}{2\pi k} \left[\frac{J}{k} (k\omega_1 + T_{load} + T_f)(1 - e^{-kt/J}) - (T_{load} + T_f)t \right]$$

no. of rev. made by motor can be obtained by putting t by t_r in eq^n above.

$$N_r = \frac{1}{2\pi K}\left[\frac{J}{K}\left(K\omega_1 + T_{load} + T_f\right)\left(1 - e^{-Kt/J}\right) - \left(T_{load} + T_f\right)t_r\right]$$

Load Equalization

Steady state stability



$T_e - T_L = J\frac{d\omega_m}{dt}$

under s.s $\frac{d\omega_m}{dt} = 0$

$T_L = T_e$ (operating point)

$\boxed{\frac{dT_L}{d\omega_m} > \frac{dT_e}{d\omega_m}}$ ⇒ stable operating point

$T_e > T_L \Rightarrow \frac{d\omega_m}{dt} = +ve$

$\omega_m \Rightarrow \uparrow$

$T_e < T_L \Rightarrow \frac{d\omega_m}{dt} = -ve$

$\omega_m \rightarrow \downarrow$.

Stable operating point

$T_e = T_L \Rightarrow J\frac{d\omega_m}{dt} = 0$

$\omega_m \rightarrow$ constant

Due to some disturbance

$\omega_m \rightarrow \omega_m + \Delta\omega_m$

$T_e \rightarrow T_e + \Delta T_e$

$T_L \rightarrow T_L + \Delta T_L$

We have,

$$T_e - T_L = J\frac{d\omega_m}{dt}$$

$$T_e + \Delta T_e - [T_L + \Delta T_L] = J\frac{d(\omega_m + \Delta\omega)}{dt}$$

$$\Rightarrow \cancel{T_e - T_L} + \Delta T_e - \Delta T_L = \cancel{J\frac{d\omega_m}{dt}} + J\frac{d\Delta\omega_m}{dt}$$

$$\Rightarrow \Delta T_e - \Delta T_L = J\frac{d\Delta\omega_m}{dt}$$

$$\Delta T_e = \left[\frac{dT_e}{d\omega_m}\right]\cdot\Delta\omega_m$$

$$\Delta T_L = \left(\frac{dT_L}{d\omega_m}\right)\Delta\omega_m$$

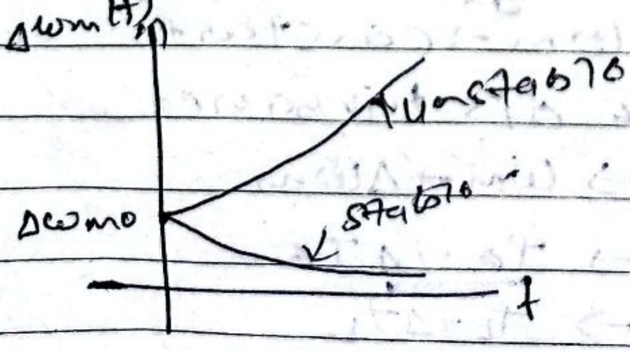
$$\Rightarrow \left(\frac{dT_e}{d\omega_m} - \frac{dT_L}{d\omega_m}\right)\frac{\Delta\omega_m}{J} = \frac{d\Delta\omega_m}{dt}$$

$$\frac{d\Delta\omega_m}{dt} + \frac{\Delta\omega_m}{J}\left[\frac{dT_L}{d\omega_m} - \frac{dT_e}{d\omega_m}\right] = 0$$

first order differential equation

solution,

$$\boxed{\Delta\omega_m(t) = \Delta\omega_{m0}\, e^{-\frac{1}{J}\left[\frac{dT_L}{d\omega_m} - \frac{dT_e}{d\omega_m}\right]t}}$$



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for stable, $\quad$ unstable

$$\frac{dT_L}{d\omega_m} > \frac{dT_e}{d\omega_m} \qquad \frac{dT_L}{d\omega_m} < \frac{dT_e}{d\omega_m}$$

$$\boxed{\therefore \left(\frac{dT_L}{d\omega_m} - \frac{dT_e}{d\omega_m}\right) > 0}$$

proved

Starting of DC series motor

Since a dc series motor cannot be started on no load, let us assume that it is started with constant load torque T_L, the equation of motion will be

$$T_m = K I_a^2 = J \frac{d\omega}{dt} + T_L$$

Therefore, energy consumed in the armature circuit of a dc series motor is given by the expression,

$$W_{st} = \int_0^{t} I_a^2 R_a \, dt = \frac{J R_a}{K} \int_0^{\omega_m} d\omega + \frac{T_L R_a}{K} t_{st}$$

$$\boxed{W_{st} = \frac{J R_a}{K} \omega_m + \frac{T_L R_a}{K} t_{st}}$$

From above eqn. it is obvious that unlike in a dc shunt motor, the energy dissipated in the armature circuit of a dc series motor depends upon the armature circuit resistance

2017 (Fall)

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Starting of 3φ-Induction motor

→ The mechanical torque developed in 3-phase induction motor is given by

$$T_M = \frac{3 I_2^2 R_2}{\omega_s s}$$

and the equation of motor under no-load condition, neglecting friction torque becomes

$$T_M = J\frac{d\omega}{dt} = -J\omega_s\frac{ds}{dt} \quad (\omega = \omega_s(1-s))$$

The total energy loss in the rotor circuit of an induction motor during starting period is given as

$$W_{st} = \int_0^{ts} 3 I_2^2 R_2\, dt$$

$$= \int_0^{ts} s\omega_s T_m\, dt$$

$$= -J\omega_s^2 \int_1^0 s\, ds$$

$$\boxed{W_{st} = \frac{J\omega_s^2}{2} \text{ Joules}}$$

From above eqn, it is showed that the energy lost in the rotor circuit during starting is equal to the kinetic energy stored by the rotor and is independent of rotor circuit resistance

→ Total energy loss (including rotor & stator loss) in the motor during a change in speed can be given as

$$W_m = 3\int_{t_1}^{t_2} I_2^2 (R_1 + R_2)\, dt \quad \because I_2 \approx I_1$$

During starting, the energy lost in the motor will, therefore, be given as

$$\boxed{(W_m)_{st} = \frac{J\omega_s^2}{2}\left(1 + \frac{R_1}{R_2}\right)}$$

where J is the moment of inertia of rotor.

The energy loss during starting of a motor can be reduced by adopting the following methods.

(i) Reduction in moment of inertia of rotor.

(ii) Smooth variation of applied voltage in case of dc shunt motors.

(iii) Smooth variation of supply frequency (v/f control) in case of induction motors

Imp

What are the losses of electrical drive system? Explain methods to reduce it.

165, 1415

→ Energy conservation in electrical drive is achieved by reduction of losses in its various parts, typical losses include the following

(i) Electrical transmission losses:

These losses depends on the drive power factor & harmonics in the line current.

(ii) Electrical losses in conversion process in power modulator:

The semiconductor converter usually has low conversion losses.

(iii) Electric motor losses to convert electrical power into the mechanical power:

These are determined by choice of motor (quality of its design and selection of right rating) & quality of supply (voltage variations, unbalance, frequency variations and harmonics)

(iv) Mechanical losses in the parts of the transmission system such as bearing, gears, clutches and belts.

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(V) Losses on the load:
Load is a machine required to perform a specified task such as fan, pump & train.

(VI) losses caused by throttling or by other means that control material flow by absorbing or by passing excess output.

(VII) Mechanical transmission losses, such as friction losses to move material from one location to another.

Methods to reduce losses in electrical drive:-

(I) Improvement of conventional solutions
→ This can be achieved by means of using new high quality active material in electric machines and by optimization of their power ckt.

(II) Improvement of both the existing solutions and taking into account the combined work of a semiconductor converter and motor.

(III) Systematic approach to designing and taking into account the combined work of all the components of an electric drive.

In this case, improvement ~~des~~ contains development of a new type of electric drives such as switch reluctance machine and others.

~~Starting of DC~~ Motor

2015 F 1/2 f

$T_L = 40\ N\text{-}m$

$N_1 = 500\ rpm$

$\omega_1 = \frac{2\pi \times 500}{60} = 52.33\ rad/sec$

$J = 0.01\ N\text{-}m/rad/sec^2$

$T_m = 100\ N\text{-}m$

$\omega_2 = \frac{2\pi \times 1000}{60}$

$= 104.66\ rad/sec$

Diff. eqn is

$T_m = J \frac{d\omega_m}{dt} + T_L$

Now $dt = \frac{J}{T_m - T_L} d\omega_m$

$t = \int_{\omega_1}^{\omega_2} \frac{0.01}{100-40} d\omega_m$

$t = \frac{0.01}{60}(104.66 - 52.33)$

$\boxed{t = 8.72 \times 10^{-3}\ sec}$

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Flywheel calculations

Let, T_{load} = Load torque (assumed constant during the period). N-m

T_{fw} = Flywheel torque, N-m

T_0 = No-load torque, N-m

T_{motor} = motor torque at any ~~stan~~ instant, N-m

ω_0 = Motor speed on no-load, rad/s.

ω = motor speed at any instant, rad/s,

$s = (\omega_0 - \omega)$ = Motor slip.

J = moment of inertia of flywheel, kg-m², and

t = Time, s

Case I: Load increasing (flywheel decelerating):

→ During the period the flywheel decelerates and gives up a part of stored energy in it. The torque required to be supplied by the motor,

$$T_{motor} = T_{Load} - T_{fw} \quad \text{---} (1)$$

Energy given out by the flywheel when its speed is reduced from ω_0 to ω.

$$= \frac{1}{2} J (\omega_0^2 - \omega^2) = J \left(\frac{\omega_0 + \omega}{2} \right) (\omega_0 - \omega)$$

But, $\frac{\omega_0 + \omega}{2} = \omega$ (mean speed) and $\omega_0 - \omega = s$ (slip)

$\therefore$ Energy given out $= J\omega s$

The power given out by the flywheel

$$= \text{Rate of energy given up}$$

$$= \frac{d}{dt}(J\omega s) = J\omega \frac{ds}{dt}$$

Flywheel torque,

$$T_{fw} = \frac{\text{Power}}{\omega} = \frac{J\omega \, ds/dt}{\omega} = J\, ds/dt \quad -(2)$$

Eqn. (1) becomes

$$T_{motor} = T_{load} - J\,ds/dt$$

As for value of slip up to 10%, the slip is proportional to the torque, i.e. $\boxed{s = K T_{motor}}$

$$T_{motor} = T_{load} - JK \frac{dT_{motor}}{dt}$$

$$\text{or, } T_{load} - T_{motor} = JK \frac{dT_{motor}}{dt}$$

$$\text{or } \frac{dT_{motor}}{T_{load} - T_{motor}} = \frac{1}{KJ} dt$$

$$\text{or, } -\log_e(T_{load} - T_{motor}) = \frac{t}{KJ} + C_1$$

From initial conditions, when $t = 0$, $T_{motor} = T_0$

$$C_1 = -\log_e(T_{load} - T_0)$$

$$\therefore -\log_e(T_{load} - T_{motor}) = \frac{1}{KJ}t - \log_e(T_{load} - T_0)$$

$$\text{or, } -\frac{t}{KJ} = \log_e\left(\frac{T_{load} - T_{motor}}{T_{load} - T_0}\right)$$

or, $e^{-t/KJ} = \frac{T_{load} - T_{motor}}{T_{load} - T_0}$

$$\boxed{T_{motor} = T_{load} - (T_{load} - T_0)e^{-t/KJ}}$$

<u>Case II</u> Load decreasing (Flywheel accelerating)

→ When load decreases, the motor accelerates the flywheel to its normal speed, slip is therefore decreased and $\frac{ds}{dt}$ is -ve.

$$T_{motor} = T_0 + T_{fw}$$

$$T_{motor} = T_0 - J\frac{ds}{dt} \qquad (\text{since } \frac{ds}{dt} \text{ is -ve})$$

By solving the above expression, we get

$$\boxed{T_{motor} = T_0 + (T'_{motor} - T_0)e^{-t/KJ}}$$

Energy losses During starting of DC shunt Motor:

→ In a D.C shunt motor

$$V = E_b + I_a R_a$$

$$I_a R_a = V - E_b = V - K\omega \quad \text{--- (1)}$$

This expression is also suitable for separately excited motor.

~~$T_{motor} = kI_a$~~

The equation of motor at no load is given by,

$$T_{motor} = kI_a = J\frac{d\omega}{dt} \quad \text{--- (2)}$$

$$\text{or} \left(I_a = \frac{J}{k}\frac{d\omega}{dt} \right)$$

$$I_a^2 R_a = \frac{J}{k}\frac{d\omega}{dt}(V - K\omega) \quad \text{--- (3)}$$

As $I_a R_a$ is negligible at no load, $V = K\omega_0$ at no load (ω_0 is the no-load speed of the motor).

$$\therefore I_a^2 R_a dt = J\omega_0 d\omega - J\omega d\omega$$

The energy absorbed (W) by the armature for a change in speed from ω_1 to ω_2 from time t_1 to t_2 is given by

$$W = \int_{t_1}^{t_2} I_a^2 R_a \, dt$$

$$= J\omega_0 \int_{\omega_1}^{\omega_2} d\omega - J\int_{\omega_1}^{\omega_2} \omega \, d\omega$$

$W = J\omega_0(\omega_2 - \omega_1) - \frac{J}{2}(\omega_2^2 - \omega_1^2)$

Hence, the energy change when the motor changes speed from rest to no load speed ω_0 will be

$W_{start} = J\omega_0^2 - \frac{J}{2}\omega_0^2$

$$\boxed{W_{start} = \frac{J\omega_0^2}{2} \text{ Joules}} \quad (4)$$

Eqn. (4) shows that the energy

Explain the braking mechanism of DC Series Motor with relevant equation an figures.

(i) plugging :→ In this method, the connections of the armature are reversed and a variable resistance R is put in series with the armature as shown in figure below.

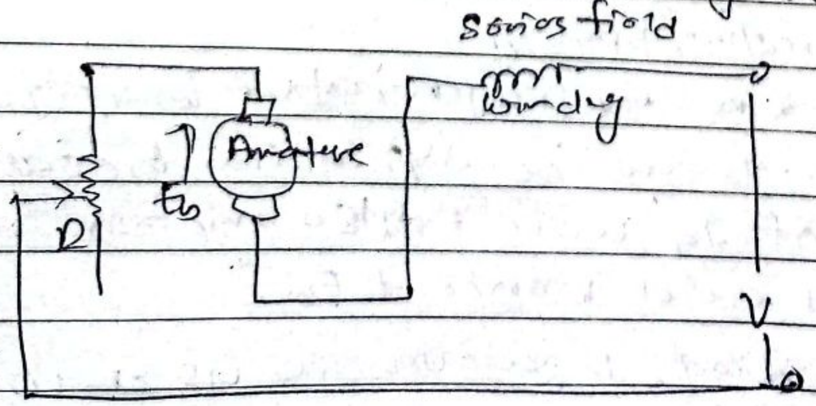
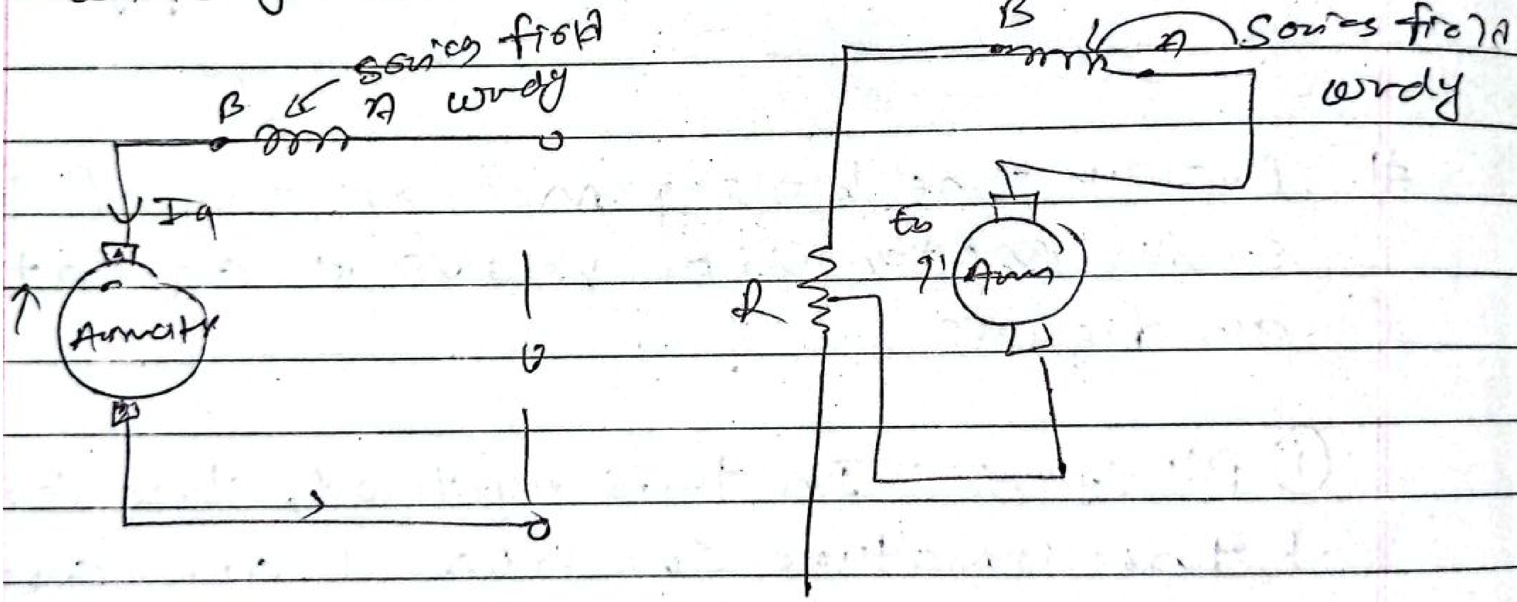


fig: plugging

(ii) Rheostat braking (Dynamic Braking)

→ In this method of braking the motor is disconnected from the supply, the field connections are reversed and motor is connected in series with a variable resistance R as figure below. The machine obviously is now running as a generator. The field connections are reversed to make sure that current through the field winding flows in the same direction



Rheostat Braking.

(iii) Regenerative Braking

In a series motor regenerative braking is not possible without modification because reversal of Ia would also mean reversal of field and hence of Eb.

This method, however is used with special arrangements in traction motors

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2021 (Fall)

Show that for an induction motor having negligible stator resistance and load torque, the acceleration time t_s for standstill to slip s is given by following expression $t_s = \frac{J\omega_s}{T_{max}}\left[\frac{1-s^2}{4s_m} + \frac{s_m}{2}\cdot \ln \frac{1}{s}\right]$

or

starting dynamics of Induction motor

→ Torque developed at any slip is

$$\boxed{T = \frac{2T_{max}}{s/s_m + s_m/s}} \quad \text{---} (i)$$

Assuming the acceleration takes place at no load, the torque developed accelerates the rotor.

$$\boxed{T = J\cdot \frac{d\omega}{dt}} \quad \text{---} (ii) \quad = -J\omega_s \frac{ds}{dt}$$

$$\boxed{\omega = \omega_s(1-s)} \quad \text{---} (iii)$$

Also, we have assume the no-load speed is synchronous speed.

∴ using eq (i) & (ii)

$$\frac{2T_{max}}{s/s_m + s_m/s} = -J\omega_s \frac{ds}{dt} \quad \text{---} (iv)$$

$$\text{or, } dt = \frac{-J\omega_s}{2T_{max}}\left[\frac{s}{s_m} + \frac{s_m}{s}\right] ds \quad \text{---} (v)$$

The motor starts from standstill to slip s. The slip varies from 1 to s.

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Integrating eq (v)

$$\int_0^{t_s} dt = \int_1^{S} \frac{-J\omega_s}{2T_{max}}\left[\frac{S}{S_m} + \frac{S_m}{S}\right] dS.$$

$$= \frac{-J\omega_s}{2T_{max}}\left[\frac{S^2}{2S_m} + S_m \ln S\right]_1^S$$

$$= \frac{-J\omega_s}{T_{max}}\left[\frac{S^2}{2S_m} + S_m \ln S - \frac{1}{2S_m} - \cancel{S_m \ln 1}^{\,\to 0}\right]$$

$$= \frac{J\omega_s}{T_{max}}\left[\frac{1-S^2}{4S_m} - S_m \ln S\right]$$

$$\boxed{t_s = \frac{J\omega_s}{T_{max}}\left[\frac{1-S^2}{4S_m} + \frac{S_m}{2}\ln \frac{1}{S}\right]}$$ proved.

If the final slip is assumed to be $S = 0.05$ the starting time t_s is

$$\boxed{t_s = T_m\left[\frac{1}{4S_m} + 1.5S_m\right]} \qquad \boxed{\because T_m = \frac{J\omega_s}{T_{max}}}$$