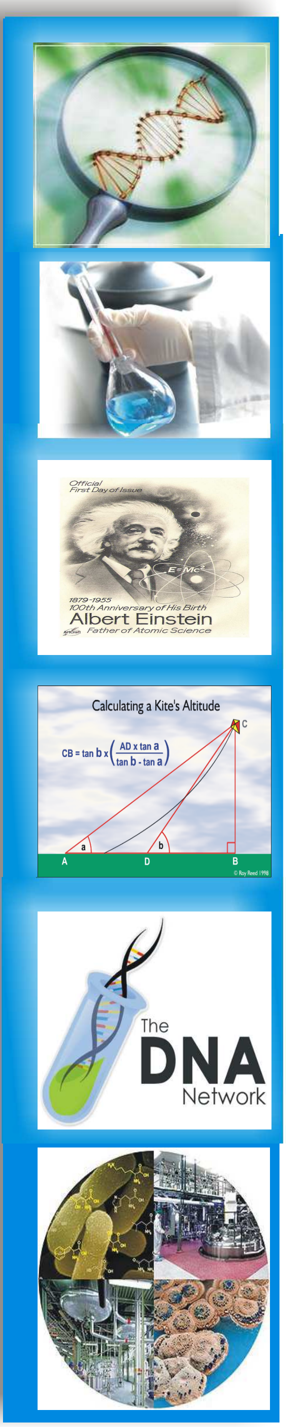

GATE - ELECTRICAL ENGINEERING

SAMPLE THEORY

- 3-PHASE INDUCTION MOTORS
- HVDC TRANSMISSION
- FLEXIBLE A.C. TRANSMISSION SYSTEM

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3 - PHASE INDUCTION MOTORS

- The 3 - phase induction motors are of two types namely (i) squirrel cage and (ii) wound rotor or slip - ring induction motors.
- Both motors operate on the same principle and have the same stator construction but differ in rotor construction. The rotor of the squirrel cage induction motor is of squirrel cage type while slip - ring induction motor employs wound rotor.
- The slip - ring induction motors are less extensively used than squirrel cage type because of their higher initial cost and greater maintenance cost.
- The slip-ring induction motors are employed only when speed control or high starting torque is required.

PERFORMANCE CURVES OF INDUCTION MOTORS

Steady - state operating characteristics of an induction motor, give graphically the variation of speed (or slip), power factor, stator current and efficiency with the variation in power output from no load to full load. The performance curves of a 75kW, 2,200 V, 3 - phase, 50 Hz squirrel cage induction motor are shown in Fig. 5.1

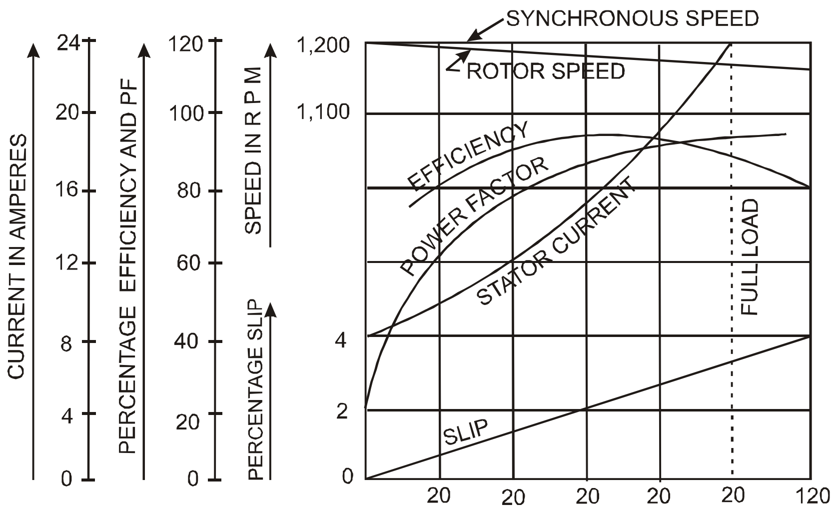

Fig : 1

- Speed Characteristic. The three- phase, squirrel cage induction motor like a dc shunt motor, operates at substantially constant speed from no load to full load. As the rotor cannot attain the speed of the rotating magnetic field (i.e. synchronous speed), it must at all times operate with a certain amount of slip.

Because of the extremely low impedance of the rotor, only a slight decrease in speed is enough to cause a large increase in rotor current to develop the torque necessary to drive the load. The per cent. slip at no load is less than 1 per cent while at full load is usually 2 to 5 per cent. This small percentage change in slip (or speed) from no load to full load likewise indicates why a squirrel cage induction motor is considered a constant speed motor.

- Power Factor characteristic . Because of the air gap between the stator and rotor of an induction motor, the reluctance of the magnetic circuit is high. As a result an induction motor draws a large magnetizing current (Im) to produce the required flux in the air gap.

  The current drawn by an induction motor operating at no load is largely a magnetising current, so no - load current lags behind the applied voltage by a large angle and thus the power factor of an induction motor at no load is quite low (about 0.1 lagging) . As the load is increased , the active or power Consequently , the power factor improves. However, because of the large value of magnetising current, Which is present regardless of load, the power factor of an induction motor, even at full - load, seldom exceeds 90 per cent.

- Efficiency Characteristic. At all loads , there are certain fixed losses (Such as core loss, friction and windage loss) in addition to variable losses that include stator and rotor copper losses varying nearly

  as the square of the load. At light loads, the efficiency is quite low because the fixed losses are a relatively large part of the input. With the increase in load, the efficiency, at first , increases rapidly and attains a maximum value, the fixed and variable losses being equal at this point. Beyond this point, the copper losses (I^2 R losses) become relatively large, causing the efficiency to decrease.

  The maximum efficiency occurs at about 80 to 95% of rated output, the higher values being applicable to larger motors.

- Stator Current Characteristic. The no-load current is about 30 to 40 per cent of the rated current, the higher values being applicable to smaller motors. With increase in load, slip increases in a cause the stator current to increase accordingly.

STARTING OF 3 Φ - INDUCTION MOTOR

Approximate circuit model for starting conditions

Starting conditions :

At s = 1, $R_2'\left(\frac{1}{s}-1\right)=0$

and the condition is short circuited at output.

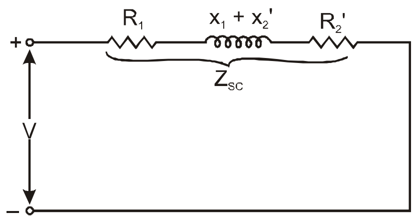

Fig : 2

Therefore at starting, motor current is as large as 5 to 6 times the full - load current.

Now, $T_S = \frac{3}{\omega_s}.I_2^2R_2'$ ....(s = 1)

If $I_\phi \approx 0$ (neglecting magnetizing current), then

$$I_{ft} \approx I_{2ft}' \quad \text{and} \quad T_{ft} = \frac{3}{\omega_s}.I_{ft}^2\frac{R'_2}{s_{ft}}$$

where s_{ft} = full - load slip (2 – 8%)

$$\therefore \quad \frac{T_s}{T_{ft}} = \left(\frac{I_s}{I_{ft}}\right)^2.s_{ft}$$

Assumptions made to drive equation :

(i) Making motor resistance constant which actually varies from few Hz at full - load to 50Hz in starting.

(ii) Neglecting magnetizing current which can be eliminated if motor current instead of stator current is used.

Star Delta startings

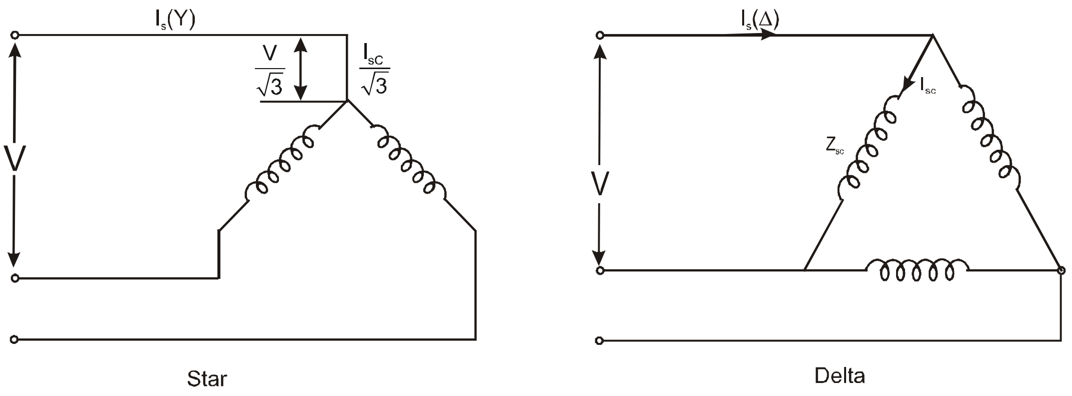

Fig : 3

In direct - Δ startings, $I_{SC} = \frac{V}{Z_{SC}}$

$\therefore$ $I_S(\Delta) = \sqrt{3}I_{SC}$

In Star Starting , $I_S(Y) = I_L = I_P = \frac{V}{\sqrt{3}Z_{SC}} = \frac{I_{SC}}{\sqrt{3}}$

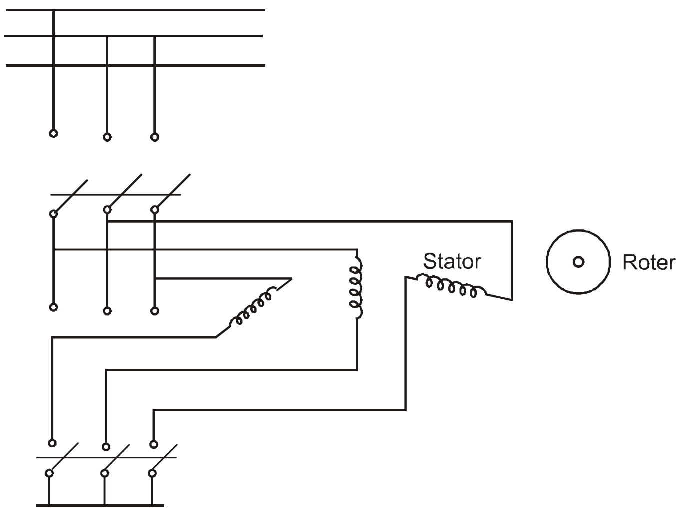

Fig : 4

$\therefore$ $\frac{I_S(Y)}{I_S(\Delta)} = \frac{1}{3}$

Now, $$\frac{T_S(\gamma)}{T_{fl}} = \left(\frac{I_S(Y)}{I_{fl}}\right)^2 .S_{fl} = \frac{1}{3}.\left(\frac{I_{SC}}{I_{fl}}\right)^2 .S_{fl}$$

Squirrel - cage Motors

(i) **On Direct starting** .

$$I_S = I_{Sc} = \frac{V}{Z_{SC}}, \quad I_{SC} = 5\, I_{ft}, \qquad S_{ft} = 0.04$$

$$\frac{T_s}{T_{ft}} = (5)^2 \times 0.04 = 1$$

With such a large starting current motor would burnt out, if not picks up its normal speed. therefore it should be started with no load or light load.

(ii) **Stator - Impedance Startings.**

By inclusion of induction resistors in the line, a reduced voltage xV si obtained.

$\therefore$ $$IS = XI_{SC}$$

and $$\frac{T_s}{T_{ft}} = \left(\frac{I_s}{I_{ft}}\right).S_{ft} = x^2\left(\frac{I_{SC}}{I_{ft}}\right)^2 .s_{ft}$$

This method is used for driving centrifugal pumps, how (Y – Δ) starting in cheaper.

(C) **Auto - transfer startings.**

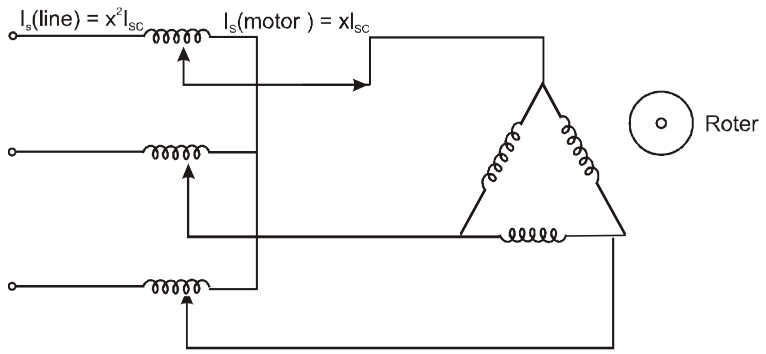

Fig : 5

$I_S(\text{line}) = xI_S(\text{motor})$ and $I_S(\text{Motor}) = xI_{SC}$

$\therefore$ $I_S(\text{line}) = x^2 I_{Sc}$

and $$\frac{T_s}{T_{fl}} = \left(\frac{I_s(\text{motor})}{I_{ft}}\right)^2 .s_{ft} = x^2\left(\frac{I_{SC}}{I_{ft}}\right)^2 .S_{ft}$$

Smooth starting and high acceleration are possible by gradually raising the voltage to the full - line value.

HVDC TRANSMISSION

The use of transformer for transmitting power over longer distances and at high voltages justified the use of a.c. especially where the electric energy was to be harmnessed from water power which usually is available for from the load centres. In such a situation HVDC transmission is more preferable than HVaC.

Principle of HVDC system operation

A typical HVDC system consists of one rectifier station at sending end and one inverter station at receiving end. The two stations are interconnected by a D.C. transmission line. The rectifier station converts A.C. to D.C. while the inverter station converts D.C. to A.C. by varying the firing angle of thyristor in the converter, the, DC output voltage magnitude is controlled.

In rectifier, the firing angle is $0° < a < 90°$ and for inverter it is $90° < a <$ | 80°. The output voltage converter is proportional to cosine of firing angle of converter. Hence the converter voltage becomes negative when $90° < a < 180°$. This makes the converter to operate as inverter. In practical HVDC converter stations three phase bridge converters are used both in rectifier and inverter side.

Principles of HVDC control:-

In A.C. transmission systems the power transfer is governed by voltage difference as well as angular difference between the sending end and receiving end where as in DC systems the transmitted power is governed only by the magnitudes of terminal DC voltages between the two ends. Thus the controllability of HVDC power is fast and stable. The current flows from higher voltage to lower voltage by proper setting of the rectifiner and inverter.

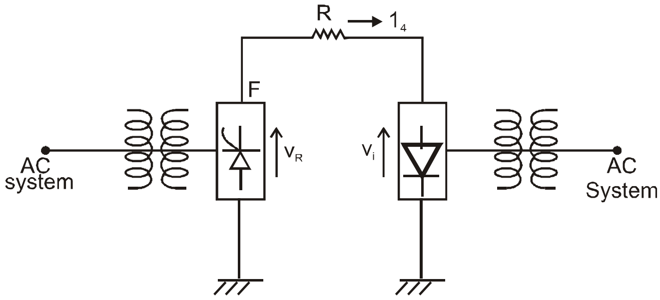

Fig.6

The line current I_d is given by

$$I_d = \frac{V_R - V_1}{R} \qquad ..(1)$$

where, V_R is the DC output voltage at the rectifier end and v_i is the DC input voltage at the inverter end, R is the resistance of the link.

$$V_R = \left[\left(\frac{3\sqrt{2}}{\pi} v_{acr} \cos\alpha\right) - \frac{3x_c}{\pi} I_d\right] \qquad ..(2)$$

$$V_1 = \left[\left(\frac{3\sqrt{2}}{\pi} v_{aci} \cos\upsilon\right) - \frac{3x_c}{\pi} I_d\right] \qquad ..(3)$$

υ is firing angle of the rectifier station.

λ is extination-angle of the inverter station

v_{acr} = AC side line to line RMS voltage at rectifier side.

v_{acl} = AC side line to line RMS voltage at inverter side.

x_c = Commutation reactance

Kinds of D.C, links:-

HVDC links are classified as follows

(i) Monopolar link: - In this configuration, only one conductor is used (usually negative) and uses ground or sea water. Negative polarityis generally utilized as the transmission conductor due to comparatively lesser radio interference.

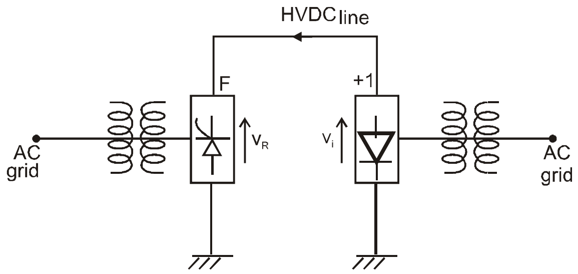

Fig.7

(ii) Eipolar link: This configuration has two conductors, one positive and another negative. In each terminal, two converters of equal rated voltages are connected in series, neutral points being grounded. Two poles can operate independently when both the neutrals are grounded. When the currents in the two conductors are equal, the ground current is zero.

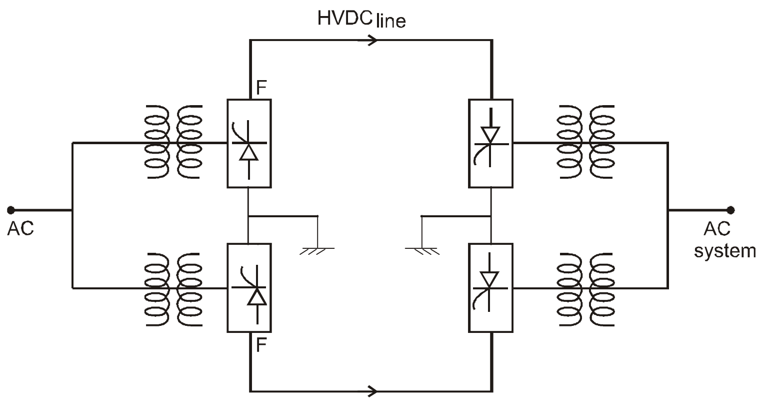

Fig.8

(iii) Homo polar link It has two conductors but have same polarity, usually negative be connected surch that the healthy conductoran the converter can be connected such that the healty conductor can supply power

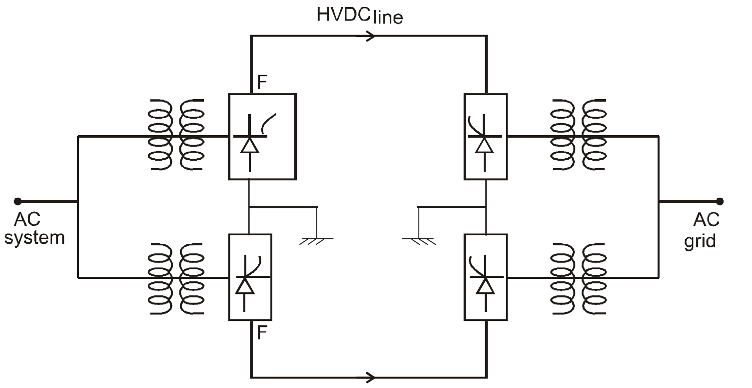

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Fig.9

Flexible A.C. transmission system (FACTS)

The main objective of FACTS devices is to replace the existing slow acting mechanical controls required to react to the changing system conditios by rather fast acting electronic controls. The mechanical controls required power system operators and designers to provide generous margins to assume a stable and reliable operation of the system. As a result the existing systems cannot be made use of their full capacity. However, with the use of fast acting controis, the power system margins could be reduced and power system capability could be more fully utilized while maintaining the present level of quality and reliability. The concept of FACTS is explained as follows. The power transferred between two systems interconnected through a tie-line is given as

$$P = \frac{E_1 E_2}{x} \sin \delta$$

The power flow can be controlled by three parameters, the voltages at two systems, the reactance of the tie-line and the difference between the voltage angles at the two ends. The FACTS devices can be used to control one or more of these parameters. The various devices used are

(i) Static var compensators.

(ii) Controlled series compensation.

(iii) Static condensers.

(iv) Advanced controlled series compensation

(v) Thyristor controlled phase shifting transformer.