Control of AC Motor Drives

Introduction & Basic Principle of Operation

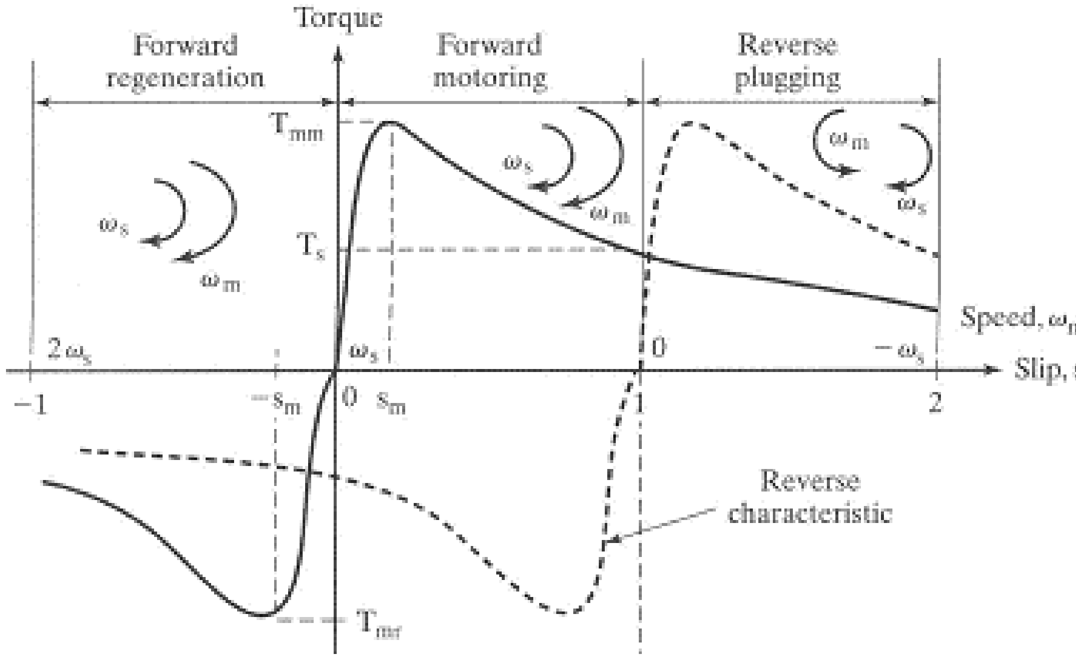
Introduction: AC Motor Drives

- Ac motors exhibit highly coupled, nonlinear, and multivariable structures as opposed to much simpler decoupled structures of separately excited dc motors.
- The control of ac drives generally requires complex control algorithms that can be performed by microprocessors or microcomputers along with fast-switching power converters.
- The ac motors have a number of advantages; they are lightweight (20 to 40% lighter than equivalent dc motors), are inexpensive, and have low maintenance compared with dc motors.
- They require control of frequency, voltage, and current for variable-speed applications.
- The power converters, inverters, and ac voltage controllers can control the frequency, voltage, or current to meet the drive requirements.

Introduction: AC Motor Drives

- These power controllers, which are relatively complex and more expensive, require advanced feed-back control techniques such as model reference, adaptive control, sliding mode control, and field-oriented control.
- However, the advantages of ac drives outweigh the disadvantages. There are two types of ac drives:
  - Induction motor drives
  - Synchronous motor drives
- Ac drives are replacing dc drives and are used in many industrial and domestic applications.

Induction Motor Drives



- The speed and torque of induction motors can be controlled by
  - Stator voltage control
  - Rotor voltage control
  - Frequency control
  - Stator voltage and frequency control
  - Stator current control
- To meet the torque-speed duty cycle of a drive, the voltage, current, and frequency control are normally used.

AC DRIVES

AC motor Drives are used in many industrial and domestic application, such as in conveyer, lift, mixer, escalator etc.

The AC motor have a number of advantages :

- **Lightweight (20% to 40% lighter than equivalent DC motor)**
- **Inexpensive**
- **Low maintenance**

The Disadvantages AC motor :

*** The power control relatively complex and more expensive**

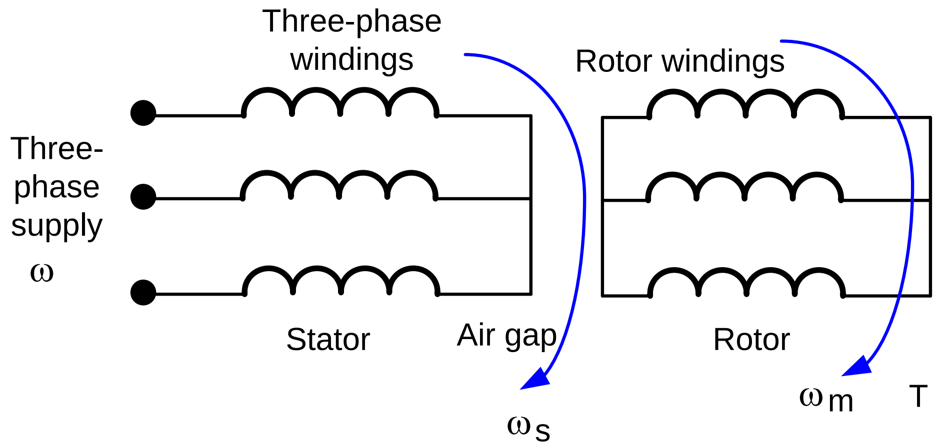
There are two type of AC motor Drives :

1. **Induction Motor Drives**
2. **Synchronous Motor Drives**

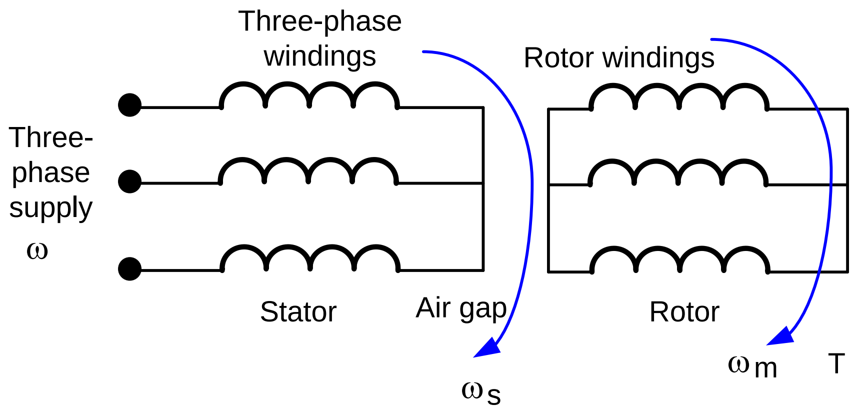
INDUCTION MOTOR DRIVES

Three-phase induction motor are commonly used in adjustable-speed drives (ASD).

Basic part of three-phase induction motor :



- **Stator**
- **Rotor**
- **Air gap**



The stator winding are supplied with balanced three-phase AC voltage, which produce induced voltage in the rotor windings. It is possible to arrange the distribution of stator winding so that there is an effect of multiple poles, producing several cycle of magnetomotive force (mmf) or field around the air gap.

The speed of rotation of field is called the **synchronous speed** ω_s , which is defined by :

$$\omega_s = \frac{2\omega}{p}$$

or

$$N_s = \frac{120\ f}{p}$$

ω_s is syncronous speed [rad/sec]
N_s is syncronous speed [rpm]
p is numbers of poles
ω is the supply frequency [rad/sec]
f is the supply frequency [Hz]
N_m is motor speed

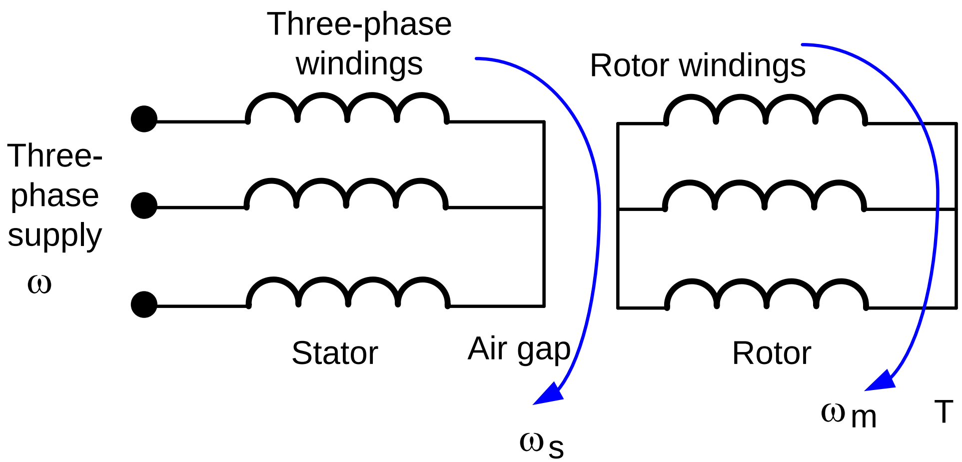
The motor speed

The rotor speed or motor speed is :

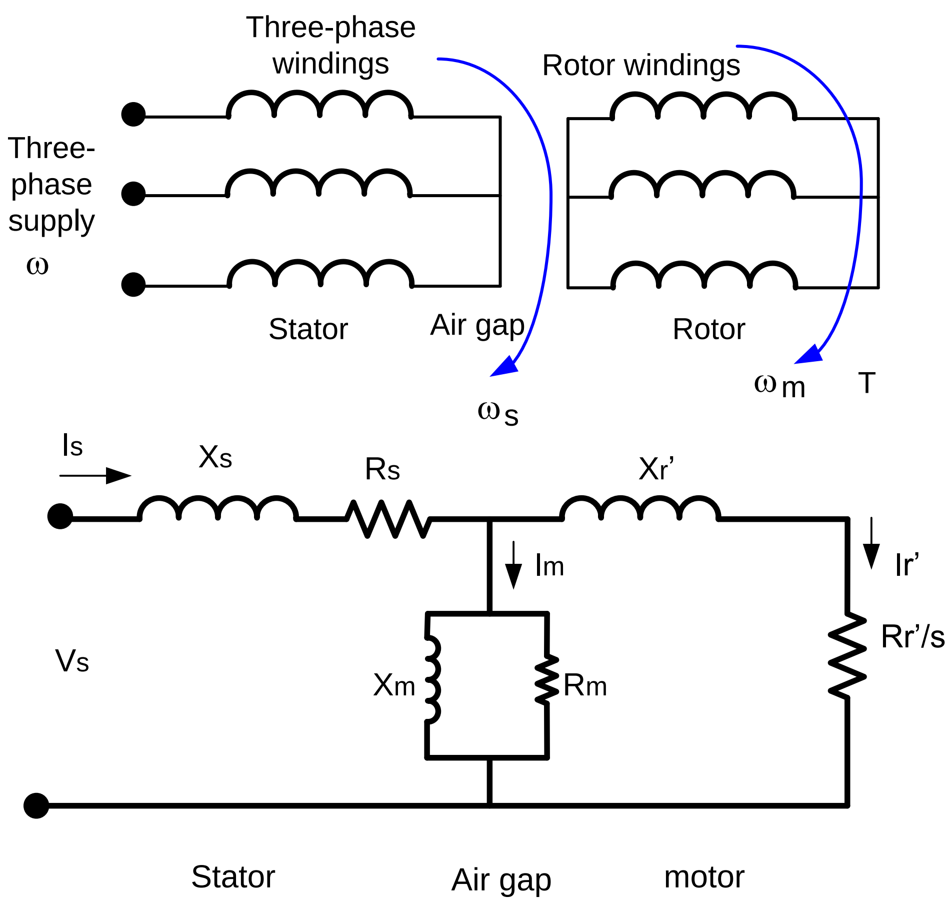
$$\omega_m = \omega_s\,(1 - S)$$

Where S is slip, as defined as :

$$S = \frac{\omega_S - \omega_m}{\omega_S} \quad \text{Or} \quad S = \frac{N_S - N_m}{N_S}$$



Equivalent Circuit Of Induction Motor



Where :

Rs is resistance per-phase of stator winding

Rr is resistance per-phase of rotor winding

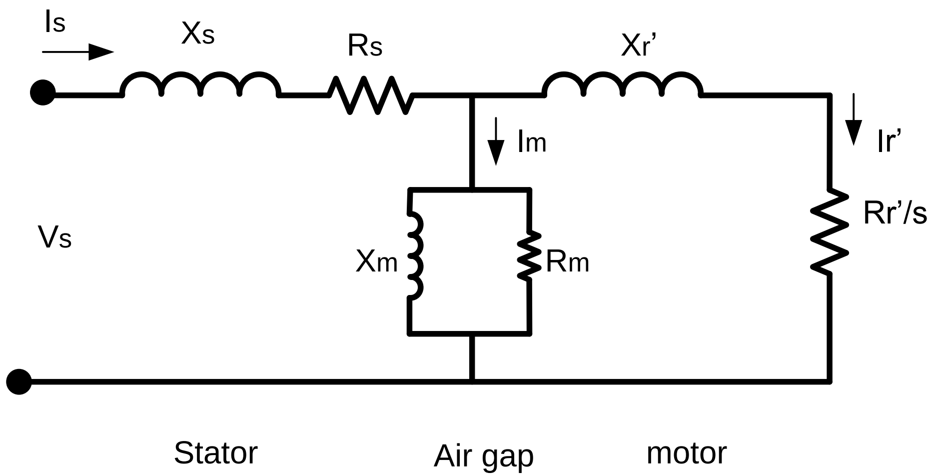
Xs is leakage reactance per-phase of the winding stator

Xs is leakage reactance per-phase of the winding rotor

X_m is magnetizing reactance

$R_{m\ is}$ Core losses as a reactance

Performance Characteristic of Induction Motor



Stator copper loss : $$P_{s\,cu} = 3 I_s^{\,2} R_s$$

Rotor copper loss : $$P_{r\,cu} = 3 (I_r^{\,'})^2 R_r^{\,'}$$

Core losses : $$P_c = 3 \frac{V_m^{\,2}}{R_m} \approx 3 \frac{V_s^{\,2}}{R_m}$$

Performance Characteristic of Induction Motor

- **Power developed on air gap (Power fropm stator to rotor through air gap) :**

$$P_g = 3(I_r^{'})^2 \frac{R_r^{'}}{S}$$

- **Power developed by motor :** $$P_d = P_g - P_{r\,cu} = 3(I_r^{'})^2 \frac{R_r^{'}}{S}(1-S)$$

or $$P_d = P_g(1-S)$$

- **Torque of motor :** $$T_d = \frac{P_d}{\omega_m}$$ **or** $$T_d = \frac{P_d\,60}{2\pi\,N_m}$$

or $$= \frac{P_g(1-S)}{\omega_S(1-S)} = \frac{P_g}{\omega_s}$$

Performance Characteristic of Induction Motor

Input power of motor :

$$P_i = 3V_s I_s \cos\phi_m$$
$$= P_c + P_{scu} + P_g$$

Output power of motor :

$$P_o = P_d - P_{noload}$$

Efficiency :

$$\eta = \frac{P_o}{P_i} = \frac{P_d - P_{noload}}{P_c + P_{scu} + P_g}$$

Performance Characteristic of Induction Motor

If $P_g >> (P_c + P_{scu})$

and $P_d >> P_{noload}$

so, the efficiency can calculated as :

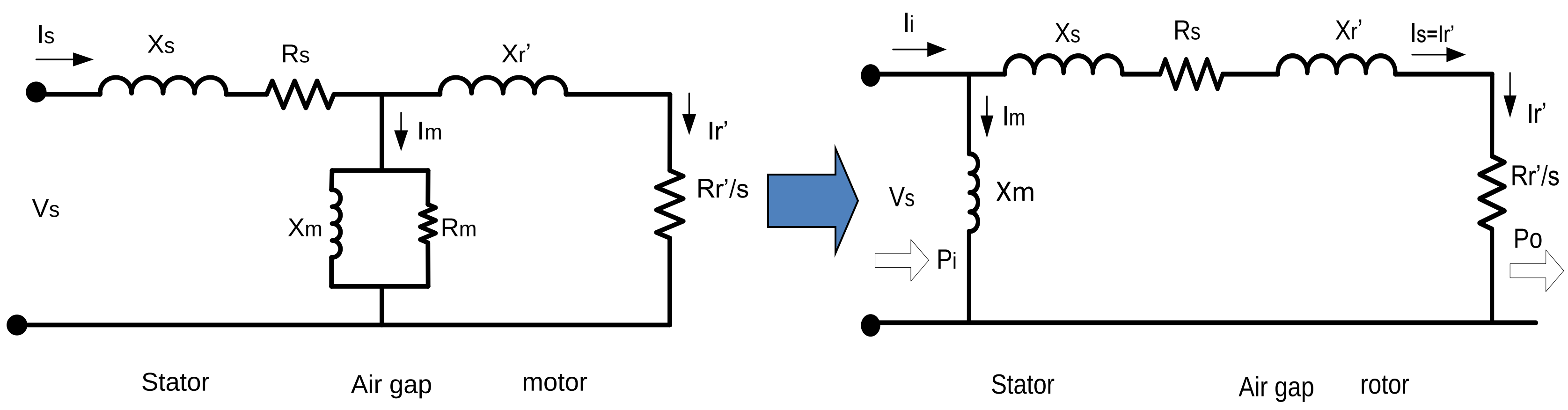
$$\eta \approx \frac{P_d}{P_g} = \frac{P_g\,(1-S)}{P_g} = 1-S$$

Performance Characteristic of Induction Motor

Generally, value of reactance magnetization X_m >> value Rm (core losses) and also $X_m^{\ 2} >> (R_s^{\ 2} + X_s^{\ 2})$

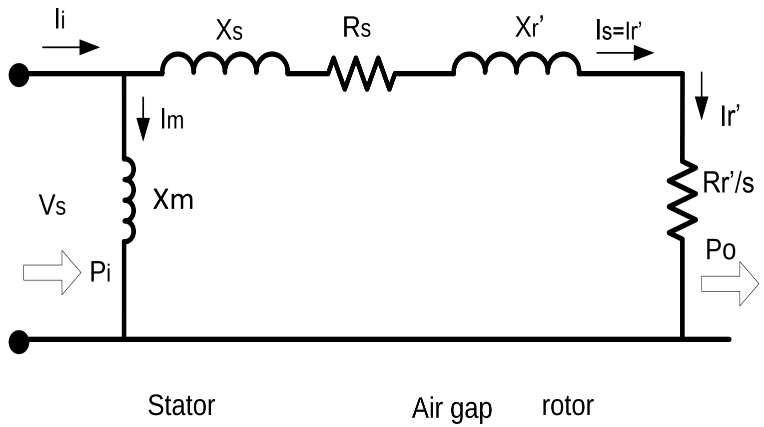
So, the magnetizing voltage same with the input voltage : $V_m \approx V_s$

Therefore, the equivalent circuit is ;



Performance Characteristic of Induction Motor

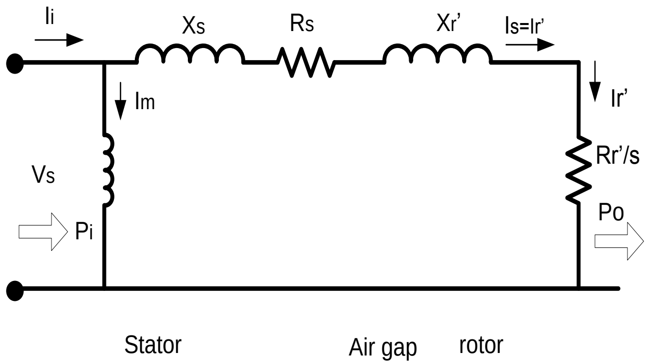
Total Impedance of this circuit is :



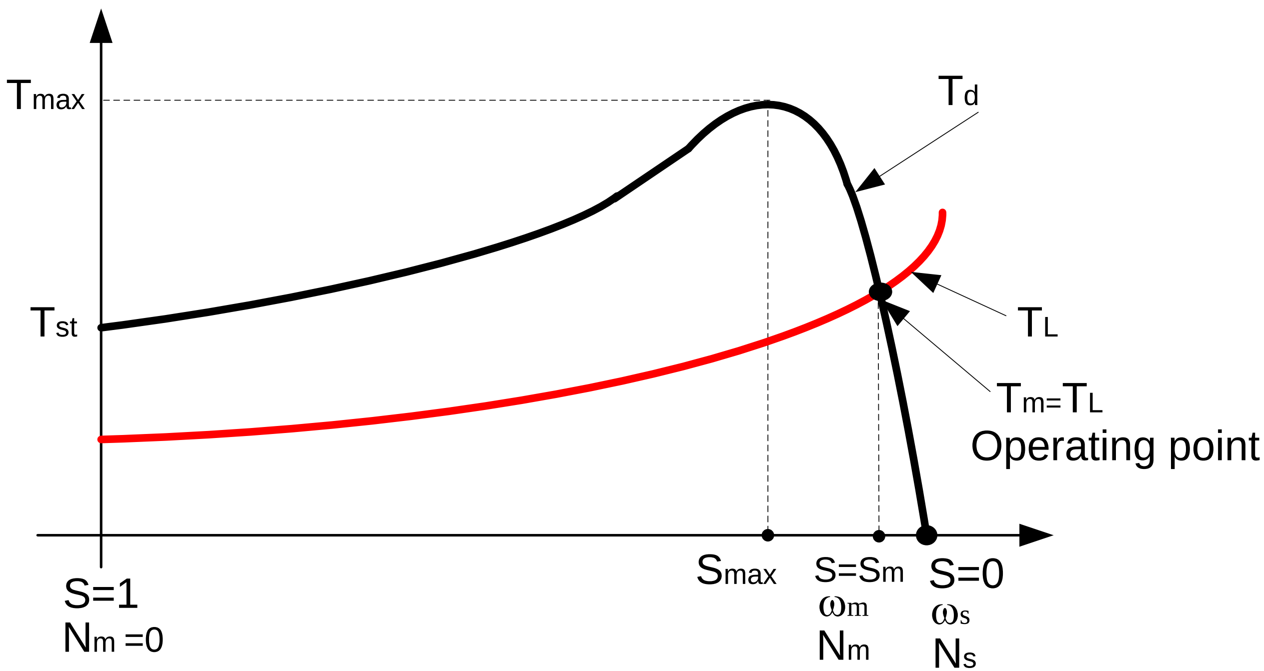
$$Z_i = \frac{-X_m(X_s + X_r^{'}) + jX_m(R_s + \frac{R_r^{'}}{S})}{R_s + \frac{R_r^{'}}{S} + j(X_m + X_s + X_r^{'})}$$

The rotor current is :

$$I_r^{'} = \frac{V_s}{\left[\left(R_s + \frac{R_r^{'}}{S}\right)^2 + \left(X_s + X_r^{'}\right)^2\right]^{\frac{1}{2}}}$$



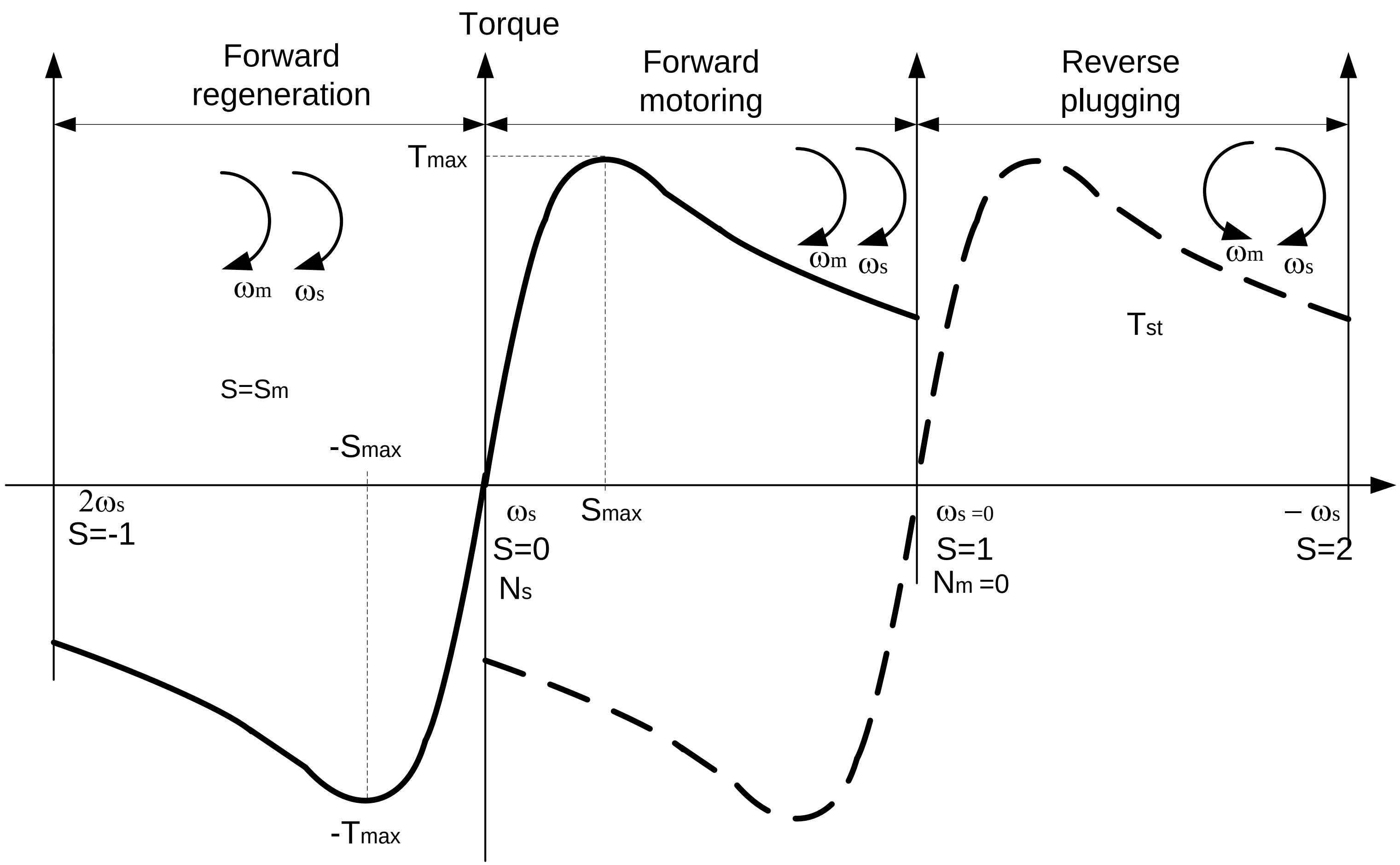
$$T_d = \frac{3 R_r' V_s^2}{S\,\omega_s \left[\left(R_s + \frac{R_r'}{S} \right)^2 + \left(X_s + X_r' \right)^2 \right]}$$



Torque – speed Characteristic

Three region operation :

1. **Motoring :** $0 \leq S \leq 1$
2. **Regenerating :** $S < 0$
3. **Plugging :** $1 \leq S \leq 2$



Performance Characteristic of Induction Motor

Starting speed of motor is $\omega_m = 0$ or $S = 1$,

Starting torque of motor is : $$T_{st} = \frac{3R_r^{'}V_s^2}{\omega_s\left[\left(R_s + \frac{R_r^{'}}{S}\right)^2 + \left(X_s + X_r^{'}\right)^2\right]}$$

Slip for the maximum torque S_{max} can be found by setting : $$\frac{dT_d}{dS} = 0$$

So, the slip on maximum torque is : $$S_{max} = \pm \frac{R_r^{'}}{\left[\left(R_s\right)^2 + \left(X_s + X_r^{'}\right)^2\right]^{\frac{1}{2}}}$$

Performance Characteristic of Induction Motor

Torque maximum is :

$$T_{\max} = \frac{3\,V_s^2}{2\omega_s\left[R_s + \sqrt{R_s^{\,2} + \left(X_s + X_r^{'}\right)^2}\right]}$$

And the maximum regenerative torque can be found as :

$$T_{\max} = \frac{3\,V_s^2}{2\omega_s\left[-R_s + \sqrt{R_s^{\,2} + \left(X_s + X_r^{'}\right)^2}\right]}$$

Where the slip of motor $s = -S_m$

Speed-Torque Characteristic :

$$T_d = \frac{3 R_r' V_s^2}{S\,\omega_s\left[\left(R_s + \frac{R_r'}{S}\right)^2 + \left(X_s + X_r'\right)^2\right]}$$

For the high Slip S. (starting)

$$\left(X_s + X_r'\right)^2 >> \left(R_s + \frac{R_r'}{S}\right)^2$$

So, the torque of motor is :

$$T_d = \frac{3 R_r' V_s^2}{S\,\omega_s\left(X_s + X_r'\right)^2}$$

And starting torque (slip S=1) is :

$$\boxed{T_{st} = \frac{3 R_r' V_s^2}{\omega_s\left(X_s + X_r'\right)^2}}$$

For low slip S region, the motor speed near unity or synchronous speed, in this region the impedance motor is :

$$\left(X_s + X_r^{'}\right)^2 << \frac{R'_r}{S} >> R_s$$

So, the motor torque is :

$$\boxed{T_d = \frac{3V_s^2\, S}{\omega_s\, R'_r}}$$

And the slip at maximum torque is :

$$S_{\max} = \pm \frac{R_r^{'}}{\left[(R_s)^2 + \left(X_s + X_r^{'}\right)^2\right]^{\frac{1}{2}}}$$

The maximum motor torque is :

$$\boxed{T_d = \frac{3R_r^{'}V_s^2}{S\,\omega_s\left[\left(R_s + \frac{R_r^{'}}{S}\right)^2 + \left(X_s + X_r^{'}\right)^2\right]}}$$